OPERATION OF GAS WORKS

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Dedicated
To My Wife

PREFACE

The author has endeavored to present the facts and details of gas works management, in concise and readable form. The main reason for undertaking this work was the lack of available information in book form, on the details of coal and water gas manufacture from the standpoint of American practice. There are, it is true, some books covering English and other foreign practice, and a wealth of material in the gas journals and association proceedings of this country, but with the exception of the well-known "Catechism" of the American Gas Light Association, there is, so far as the author knows, no modern book adapted to the needs of the American operator.

This book is intended to supply the needs of the foreman, superintendent, engineer or cadet who is connected with a small or medium-sized gas works and who desires to increase and widen his knowledge of the principles and practice of gas making. No extended description of machinery or apparatus is attempted but rather the aim has been to give as simply and clearly as possible, instructions for operating the standard types of apparatus usually found in gas works together with some discussion of the principles involved. Where particular apparatus is described in detail the author in nowise specially recommends such apparatus but it was necessary to select from the great variety of types in use, certain examples which might reasonably be supposed to typically represent that class. Obviously a description of all the types would be beyond the scope of the book.

For the benefit of those who may wish to employ some of the methods in their own plant, let it be said that everything which appears in the following pages has been tried out on a commercial scale and has been successful. Where results are quoted they have been taken from actual practice. It is hoped that the material which has been gathered together in this work will aid the manager in a better understanding of his manufacturing problems, the superintendent in acquiring a knowledge of what others are doing under conditions similar to those under which he is laboring and the student in gaining an insight into the details of operation of the industry that is engaging his attention.

It has been the endeavor to render the book practical rather than theoretical and to utilize scientific or technical nomenclature as sparingly as possible. At the same time no sacrifice to completeness or accuracy has been made. No attempt has been made to cover the recent developments in mass carbonization or mechanical operation as it is thought that these can best be covered separately. Likewise some of the very recent developments in water-gas operation have been omitted.

The author here wishes to acknowledge his indebtedness to the columns of the *Gas Age* and the *Gas Record* for much valuable material and to the many friends and associates who have given freely of their data and information, rendering valuable aid in the compilation of these pages.

W. M. Russell.

Emporia,
December, 1916.

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OPERATION OF GAS WORKS

CHAPTER I

ORGANIZATION AND MANAGEMENT

OPERATING SYSTEMS

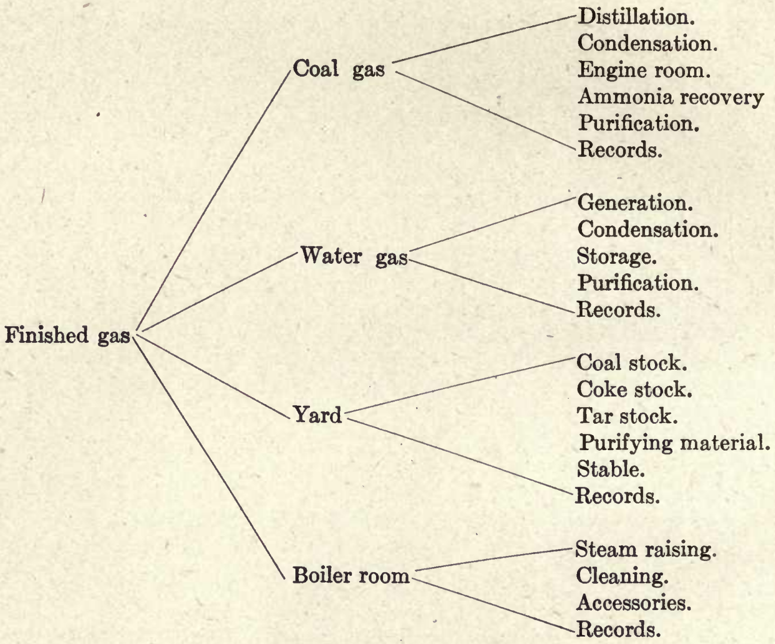
The successful and smooth working of a gas-works organization depends in great part upon the system that underlies the operation. The possession of a system implies a plan that must be developed beforehand and tried out in practice before being accepted as final and satisfactory.

Developing an Organization.—The first essential move is to group the various activities of the plant into general divisions bounded by their natural characteristics. Thus we have first: coal gas, water gas, boiler plant, yard, etc., these in turn yielding subdivisions, such as the retort house, condenser room, engine room; the subdivisions being further carried out for instance, in the case of the retort house, into bench control, charging and drawing, scurfing, etc.

Having gone thus far in assembling the divisions of plant work, it is well to put down on paper an outline of what this effort has suggested. For example, it would look something like the chart on page 2 which is for a combination plant.

A consideration of the foregoing will bring up at once the question of the organization of employees and the placing of responsibility.

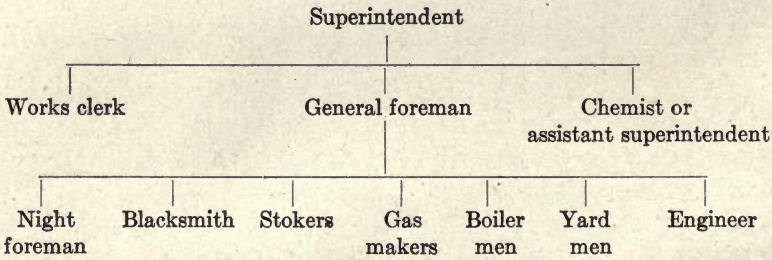
The various divisions and subdivisions must be grouped so as to fall into line when considered from the standpoint of super-



vision. At the head of the whole operation of the production of finished gas is the superintendent. There should be no routine or confining duties attached to his position and he should be free at any time to concentrate on any particular phase of work.

Having in mind the activities of the plant as a whole, a prime organization chart something like the following may be made.

ORGANIZATION



There are, for instance, three possible divisions of the work, *i.e.*, that of the works clerk—records, general foreman—supervision, assistant superintendent or chemist—chemical control. The general foreman should have control over the night foreman, blacksmith, stokers, gas makers, boiler room and yard men and the engineer. The supervisory work of the chemist may touch

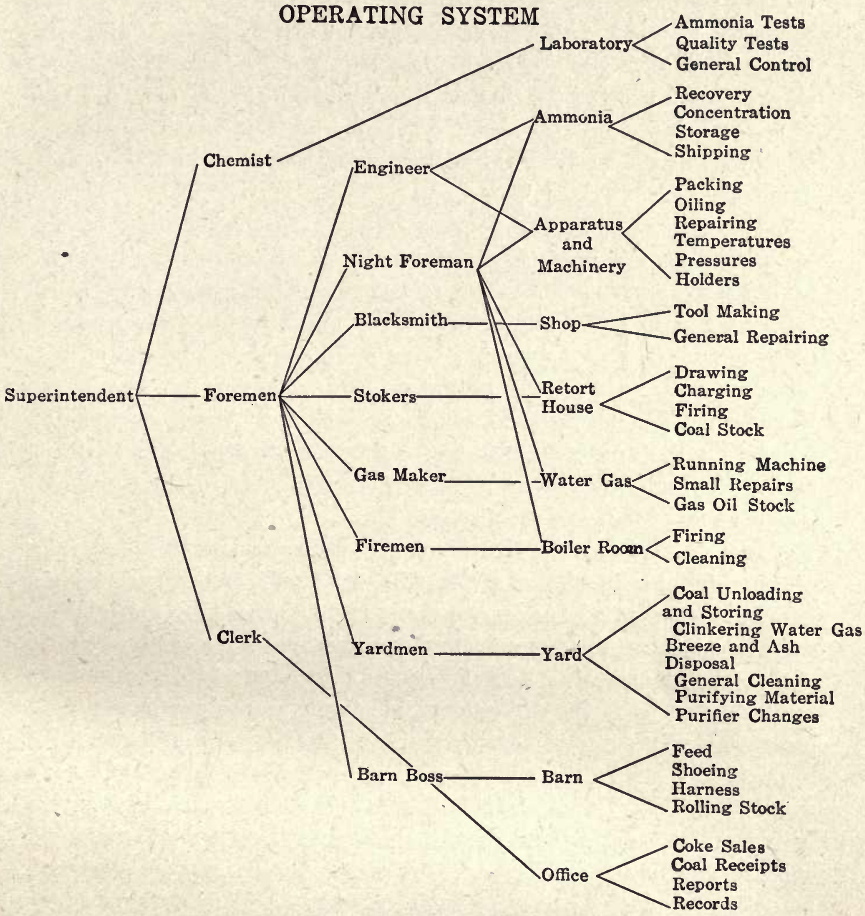


FIG. 1.—Chart of operating system.

that of the foreman through the engineer; the engineer having charge of the machinery of the plant and usually operating the ammonia recovery. The chemist is naturally concerned with the recovery of ammonia and should exercise supervision over the engineer in that portion of his duties.

Operating System.—Having fixed the divisions of work and supervision it is unwise to attempt to outline the operating system until the work has been carefully studied. After having given the matter some attention a conference should be called with the three heads of the divisions and a preliminary working system outlined and agreed upon. This should be placed on paper and tried out. Modifications will constantly suggest themselves and should be incorporated. The superintendent should keep in close touch with the progress of the work. The final system will be dependent on local conditions and peculiarities but will be something like the chart found on the opposite page (see Fig. 1).

Understudies.—The indispensability of any one man must be carefully avoided. There should be no employee with such an exclusive hold on his job, that the smoothness of operation is interfered with by his defection, illness or removal, temporarily or permanently. All gas men have suffered at the hands of an employee who carried everything in his head and without whom they were told they would be helpless. There are many ways of combating this condition but in connection with the standardizing and recording of each man's work, the method of understudying seems to have most to recommend it.

Under this plan every employee, in so far as possible, has an understudy; a man who is learning his work and who is progressing toward the point where he can carry on his immediate superior's work acceptably for a short time, at a moment's notice. For instance, the blacksmith's helper ought to be able to do the shop work for a day or two; the night foreman ought to be in line for the foreman's job; some of the stokers ought to be competing for the opportunity of landing a head stoker's or night foreman's place; some of the yard men should be ready for the next vacancy in the retort house and there should be acceptable water-gas makers around the plant. If there are no understudies like the above, take time and make some. Some day they will be needed and badly needed.

Schedules.—The last step in completing a works system is the laying down of standard practice for the different operations and men's work. This should be done only after careful study and repeated trials and when once agreed upon each schedule should be typewritten and posted on the bulletin board. It is a good idea to have a bulletin board with the whole operating system on it. This not only puts every man's work up to him but also makes clear to the other employees what each is expected to do or not do and it will be found that they will be eager to see that each carries out his program. The different schedules should cover the work of individuals and also different routine jobs. Two schedules follow which illustrate how this is done.

OPERATING SYSTEM

Night Foreman

1. Night foreman will be on duty from 6 p.m. to 6 a.m.
2. All employees at the works at night are under his control.
3. Attend to the following details in the retort house:
    A. See each round and check the coal carefully.
    B. See that the benches are fired at proper times.
4. Read station meter and holders at specified times.
5. Pump holder drip at midnight and 5.30 a.m.
6. Run ammonia still.
7. Read works temperatures and pressures at specified times.
8. Make out full bench report.
9. Leave report in writing of any unusual occurrence, needed tools, repairs or changes.
10. Once each night make complete trip around plant and grounds.

Retort House

Drawing and Charging

1. Open the lids right on time.
2. Ream out the standpipes.
3. Scrape off mouthpieces with a pitch hoe.
4. Clean off the inside of the lid with a chisel bar.
5. Draw the retorts clean.
6. Shut the lids when the retorts are empty.
7. Charge the retorts quickly.
8. Shut the lids and mud them if required.

A schedule should be made up for each operation and for each employee whose duties require it. These should be posted on the board and a copy kept in the office book. Before approving them they should be thoroughly gone over with the men concerned and then adopted and strictly adhered to.

EMPLOYEE'S RELATIONS AND DISCIPLINE

In times past there has been a notable lack of discipline around gas plants. Retort-house men particularly have been a lawless crew and the term "gas-house gang" has long been one of reproach. Now that public utilities have come to realize how potent an advertising value lies in each of their employees they look with less tolerant eye on the shortcomings of their "terriers."

Necessity for Discipline.—Aside from the influence of employees while off duty, discipline is needed while they are at work. Whereever slack discipline exists, dirty retort houses and buildings, low heats, poor general results, etc., are found; but where the discipline is good, nine times out of ten the results will be as good as the equipment and the technical skill of the superintendent will permit.

Discipline in the retort house should be especially strict. The drawing and charging should be done according to schedule and the schedule should be rigidly adhered to. Stokers should not be allowed to clean fires at any other than the regular time and retorts should never be "off" for burning out pipes or scurfing without the knowledge and consent of the man in charge. Emergencies are very prone to occur around gas plants that demand quick decision and effective action. Such emergencies can be met successfully only when the discipline is good. Many serious crises have been averted only because the employees were trained to jump at the word and give instant and unhesitating obedience to an order.

Hiring and Firing.—It is a good plan to allow the foreman to hire all the men who report to him. If it is necessary to replace the night foreman or engineer or some other very important man the matter ought to be taken up between the foreman and superintendent; but for the rank and file the foreman should be the man to decide. In order to build up a desirable class of workmen the foreman should be encouraged to use great care in selecting the men. In taking hold of a plant that is badly run down it will probably be necessary to replace a good many of the men right away and the men who come in may not be the ones who will permanently fill the positions with satisfaction. No man should be allowed to feel that his job is permanent until he has made good over a period of some months. By adopting a policy of selection and inspiring foremen to a high standard of excellence, gradually a high class of men will be acquired. A year is none too long to devote to this work and one would hardly expect to get results in less time.

When it comes to the discharge of a man, this is a totally different matter. The foreman's latitude should be very much narrower. Extra men taken on for unusual work or common labor may be layed off without question when the work is done; but it ought to be an inflexible rule that no man be discharged by the foreman without the privilege of an interview with the superintendent if he feels that he is being unfairly treated. If a man is to be fired for cause he is entitled to a hearing and if his cause is unjust he will not be very likely to be troublesome. On the other hand, the knowledge that every employee has a right to a hearing will deter foremen from exercising personal ill will or petty spite. The night foreman should not be allowed to fire anybody but he must have the right to send home any man who, in his opinion, is not doing his work faithfully or well. The case should then be taken up the next morning.

Foremen should be backed up to the limit by the superintendent. If they are right back them up and do not let anything apparently weaken their authority or they will "lay down on you." They should be made to feel that they must never be unjust and should be trained to a policy of fair dealing and upheld in all dealings with the men. Volumes have been written about the hiring of men but too often the opportunity for selection is limited and they have to be taken as they come along, at least temporarily, without much regard to the science of selection. The following rules, however, should be unbreakable or regrets will follow.

Do not hire old men. If the company is not pensioning now it may soon have to and pensions are a heavy charge on operating.

Do not hire a man because of sympathy or just because he needs a job and can tell a moving hard luck story.

Do not hire a relative or a friend.

Do not hire men whose character or habits are known to be questionable.

Enforcing Discipline.—A great executive once said, "So live your life each day that you can look every man in the eye and tell him to go to H—." We may deprecate the profanity but we feel the force and justice of his principle. Interpreted for the gas-works superintendent it should mean that he should have absolutely no favorites about his plant; that he should give every man a square deal; and that his discipline must never relax. A martinet, however, does not make a good superintendent. Military discipline is not demanded. But your daily life and relations with the men must be such as to command their respect. It is a splendid thing when men admire the boss and regard him with affection as well as respect but the affection is not essential to success and the respect is. It is fine to have popularity but it is fatal to sacrifice respect to gain it. A few good rules are needed. They should be typed and framed and hung in a conspicuous place where they will also be kept clean. A poor rule ought to be rescinded and replaced at once but a good rule partly enforced is an evil and an abomination. A man should never be called down where others can hear it. He should be called aside and spoken to and then the matter should be dropped. Never parley or argue with a man for a minute. If he has an excuse, listen to it but do not argue.

A little praise once in a while does a wonderful lot of good and does not cost anything. The superintendent should be pleasant all the time. He is constantly in the eye of his men and his policies and intentions are all the time being discussed and freely criticized. The men may be untruthful or morally bad in everyway but it will be found that they have the greatest respect for good qualities in their boss and they will expect much from him. As a general thing no drinking on the job should be allowed. The only possible exception to this rule is in the retort house. Many superintendents make it a rule that stokers who leave the works for a drink will be discharged but permit them to send for beer at stated times during the shift. This is a pretty good plan as it brings the matter out in the open where it can be regulated to a fair degree. When a man says that he allows no drinking among stokers it will pretty generally be found that a lot of drinking is going on on the quiet, which is the worst form for it to take.

A good safe rule is that no stoker, whose work is suffering on account of his drinking, can stay. At the same time, it should be well understood that drinking is not regarded with favor and that non-drinkers will always have the preference. The superintendent's feelings should be put up to the men and then there should be no nagging.

Welfare Work.—Only the large companies can go in extensively for welfare work but the small companies should do all that is possible. Every man should have a locker to keep his clothes in, toilet facilities and shower baths should be provided and there should also be plenty of ice water in warm weather and a comfortable place to eat at all times. All these things will be greatly appreciated and will return the investment many times by making the plant a desirable place to work. The plant should have a high standard and the men should be well paid. Therein lies true economy. If the men are moved around once in a while it will keep them from going stale on the job or getting to think that they own it. Somebody should be ready to step into any job there is. The men should feel that an interest is felt in them and they will return it. It should be remembered that one's own job depends on the results of the efforts of the men and that one will stand or fall by what they do. Without them one can do nothing but with them one can do all that is planned.

Committees.—A committee of men from various departments of work should be selected, including for instance, the foremen, a stoker, yard man and water gas man. Let them meet frequently and talk over matters pertaining to the operation of the plant and the general conditions. Encourage them to bring up matters which have a bearing on the relations with the men. Properly encouraged these committees often bring to light a whole lot of things one ought to know.

Safety.—"Safety first" should be the guiding principle. The superintendent and foreman should make periodical trips all over the plant looking for possible hazards. Ways of getting hurt and then ways of preventing those accidents should be foreseen. The works committee may well be on the lookout for hazards and if one is reported it should be gotten after right away and the man who called attention to it should be thanked.

Warning signs should be put up wherever there is danger and never allowed to get dirty or defaced. All elevators should be very carefully safeguarded and stairways should be provided with hand rails. Whenever an accident occurs it must be investigated carefully and attention called to the way it occurred and how it might have been prevented.

METHODS OF CONTROL

There are three natural divisions of the methods of control, namely, mechanical instruments, regular reports and personal inspections.

Instruments.—The most important instruments used are the recording gages. There are several excellent types on the market of which the Bristol is perhaps the best known. Recording pressure gages should be set up at the following places: (1) Foul main; (2) exhauster inlet and outlet; (3) inlet purifiers; (4) outlet holders to record street pressure.

There should also be a gage showing the pressure somewhere uptown on the distribution system. There are several long-distance indicating gages on the market. A nice way to arrange the gage board is to have it in the valve house, office, governor house or booster room. The recording gage showing the pressure at the outlet of the holders may be mounted in the center of a board setting up on the right-hand side an 8-in. U-gage showing the same pressure as a check and on the left-hand side a similar gage showing the inlet to the holder pressure. Directly above, the recording gage may be the indicating long-distance gage. These operate on an electrical principle and the first cost is rather high and the instruments delicate but they have proven themselves of great value in some instances.

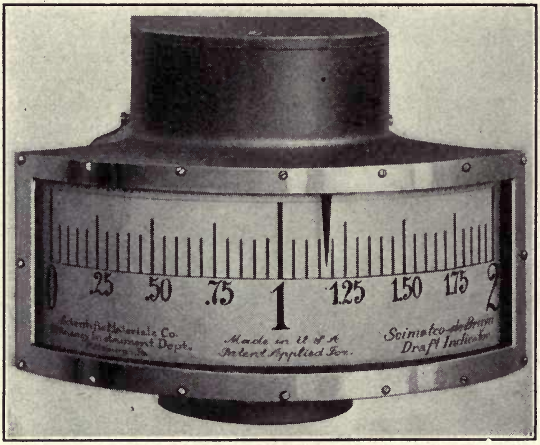


Fig. 2.—Draft gage or foul main gage.

If the ordinary holder pressure is inadequate to meet peak-load demands and a booster system is used, these gages are of the greatest value in maintaining a uniform pressure in the mains.

The gages at the inlet of the exhauster and the foul main are vacuum gages and should have large dials and the charts should be graduated in inches and tenths of an inch of water column.

They should have a very wide scale so that a slight change in pressure or vacuum is readily apparent. This requires a very sensitive working movement and to protect it from injury the line leading to it should be throttled down so as to allow a slow movement of the arm during sharp fluctuations. It is a good idea to assemble all the gages showing works pressures on one board if possible. The line from the inlet to the exhauster and foul main to the gages should be of ¾-in. pipe and provided with drip tees at proper places and should have steam connections for blowing out.

The pressure on the gages on the outlet to the exhauster, on the inlet to the purifiers and on the outlet to the holders should allow for a pressure 50 per cent. greater than the average maximum to prevent injury in case of emergency. For instance, if there is a maximum average of 14 in. at the outlet of the exhauster the gage should have a 20-in. scale.

On the same board with the gas pressure gages there should be a gage showing the boiler pressure in pounds. This gage is connected to the main steam header. The line for this should be of ⅜-in. pipe and should be protected against freezing. The usual gas-works boiler pressure is not above 110 lb. and a scale up to 125 lb. should be sample. It is better to have this gage on the board with the others, than in the boiler room. The firemen will be likely to keep a closer watch on the pressure as they will never know just when one is observing the boiler pressure and they will not have any record nearby to refer to and tell how poorly the other fireman on the opposite shift did. The tendency will be to keep up to the right point all the time.

Special conditions will call for special gages. If high-pressure distribution is used, gages will be needed to show the high and low pressure conditions, etc.

Temperature gages or recording thermometers should be placed at the following points: (1) Outlet P. & A. tar extractor; (2) outlet scrubbers; (3) pyrometer on water-gas machine; (4) outlet purifiers; (5) ammonia still—outlet-vapor pipe; (6) feed-water heater.

The range for Nos. 1, 2, and 4, should be about 0° to 128°F. The pyrometer recording gage should be placed in the office or on the main gage board and connected up in series with the indicating gauge on the machine. The range should be up to 2,000°F. The indicating gage should be mounted in such a way as to be constantly before the gas-maker's eye. The connecting wires should be run in iron pipes. The indications of this instrument are of great importance and should be studied with care every day.

The gage on the ammonia still should be arranged to indicate the temperature of the vapors leaving the still. A good way to mount this is described under the notes on operating the still in the section on ammonia. The range should be up to 220° and the bulb should be lead with a lead-covered tube.

Fig. 3.—Recording thermometer.

An exactly similar gage can be used to show the temperature of the feed water leaving the heater except that the bulb may be brass and the tube incased in metallic hose.

Motion gages may be employed with success on the water-gas machine, ammonia still and station meter. On the water-gas machine the gage should combine pressure and motion recording. The length of blows and runs will be indicated as well as the blast and run pressure. This checks up the gas maker on the number of runs, length of blows and runs and on the relative pressures during the 24 hr.

Any recording gage can be rigged up to show the registration of the station meter. An electric contact on the meter index may be fixed to make a contact for every 1,000 or 10,000 cu. ft. of gas according to the output. The wires should be led to a Bristol gage mounted in the office and a magnet arranged to attract an armature when the circuit is closed. A cord from this spring armature goes to the hand on the gage. Suppose this gage is connected with the city mains. Whenever the circuit is closed, the pen will be moved in toward the center of the chart ¼ in. or so, thus drawing a short ink line. Thus every 1,000 or 10,000 ft. of gas will be recorded.

There are many plants, both large and small, where systematic misreading of the station meter during the night occurs and the above is a sure check on this practice. A superintendent who is not inclined to believe that this is needed in his plant should try it. He may learn something to his advantage.

Some ammonia stills have to be limed at intervals or given attention of some kind. It is a good plan to have the men register when they visit the still for these purposes. A similar electric contact to that used on the meter can be set up and attached to the temperature recorder so that closing a switch by the lime box will register; or just a little cord coming out through the case can be pulled, thus making an identifying mark at the time of his visit. If the gage is properly locked, it will not be easy to fake these marks.

All gages should be securely mounted on heavy boards cleated on the back and varnished or painted. The gages should all be kept locked and the charts changed and the clocks wound by the same man at the same time every day. The charts may be marked and dated and filed on spindles in the office.

Several portable gages, either the U or the straight type should be on hand for pressure surveys over the plant and there should be an inlet and outlet pressure-testing connection for every piece of apparatus. Also there should be one portable

DAY BENCH REPORT

FOR__________________19______

Bench No.		Bench No.		Bench No.		Bench No.		Bench No.		Bench No.	
Coal	Charges	Coal	Charges	Coal	Charges	Coal	Charges	Coal	Charges	Coal	Charges
Scurfed ____ Coal ____ Coke ____		Scurfed ____ Coal ____ Coke ____		Scurfed ____ Coal ____ Coke ____		Scurfed ____ Coal ____ Coke ____		Scurfed ____ Coal ____ Coke ____		Scurfed ____ Coal ____ Coke ____	

Signed____________________Foreman

FIG. 4.—Form for Bench Report.

recording pressure gage with a range higher than the maximum works pressure. Of course the amount of equipment in gages is limited by the size and requirements of the plant and in small plants very few gages are absolutely essential but in the larger plants too much information can not be secured.

For pressures over 18 in. a mercury gage made up like a draught gage, of small and large glass tubing, is handy. The small tube extends out on a long slant and the scale follows it, graduated in inches and tenths of inches. The length of the graduations must be calculated taking into account the relative weights of mercury and water.

Reports.—Adequate reports are a great help to efficient management. They should be brief and easy to make out as good workmen are usually poor clerks and it is hard to put before them the necessity for careful and complete records in such a way that they will appreciate it. There should be some kind of record of every result obtained daily in the plant. The reports which you wish to keep on file for reference ought to be made on paper of ordinary business letter size to fit the usual loose-leaf books. One or two of the largest may be 9½ by 12 in. which will require a little larger book, but with the same marginal punchings as the smaller sheets. The reports which are used for the day only and to make up records may be on very cheap paper and of any convenient size. Some of the reports should be permanent records in book form. A few typical reports are illustrated to show what has been used successfully and to serve as a guide. The few shown do not by any means constitute all that may be used to advantage but are representative.

The Day and Night Bench Report, as illustrated in Fig. 4, may be made of any size or shape to accommodate the number of benches in use but should contain at least all the information shown. In a bench of sixes there are six rounds of three retorts each to a shift with (4-hr. charges) and six lines are therefore provided for the weights of coal per round. If any retorts are scurfed during the period, the number should be shown, as 1 or 2. The amount of coal or coke as fuel should be closely estimated and put down. This report can be on white paper for the day and yellow paper for the night shift. Both can be made on a very cheap grade of paper.

The Water-gas Report should be made out by the gas makers as they run the machine. The oil meter need be read only two or three times during a shift, including starting and stopping. The estimated amount of coke used can be entered on the bottom of the sheet. The dimensions of this report should be about 9 by 14 in. and cheap paper may be used.

The Works Foreman's Report is an important one and should be tastefully gotten up with colored lines and inks and on good paper preferably bond paper. The form illustrated has been used with success but can be modified to suit conditions. The size is 8½ by 11 in. The statement of the holders should be in sheets and rivets. The temperatures should be taken at times specified and checked by the recording gages. These figures can of course be faked up but the more checks placed on the man who reads them, the easier it is for him to do the right thing. The men using this report should keep it clean and make it a matter of pride to turn in a clean sheet every morning. The ammonia liquor test should be made at least every 3 hr. and this is easily checked by the regular chemist's tests. The oil report should show the car number of cars unloaded, and their capacity and the feet and inches of oil in the various tanks. The clerk should use this report for making up his records and then the superintendent should file it for reference.

The Manufacturing Report ought to be the first work of the clerk every morning and should be on the superintendent's desk early every morning together with the charts of the day before the Chemist's Reports and the Works Foreman's Report. The form shown requires very little explanation. The paper should be good quality and the size 8½ by 11 in. or if more information is needed, 9½ by 12 in.

The Weekly Manufacturing Statement consists of totals and averages for the week. The same form is to be used for the monthly report. The paper should be of excellent quality and the size 8½ by 11 in.

A simple report may be needed for the boiler room to show boilers in use, fuel used, boilers cleaned, etc., although this is not essential.

There should be a Bench Record Book ruled as below having two opposite pages for each bench; the first page being devoted to construction and results data.

The opposite page should have detailed information about operation.

BENCH NO.—

Built	Started up	Let down	Days in use	Retorts reset	Rebuilt ash pan up	Builders or resetters

BENCH NO.—

Retorts scurfed	Date	Days run	Carbon removed	Fire drawn for clinkers	Remarks

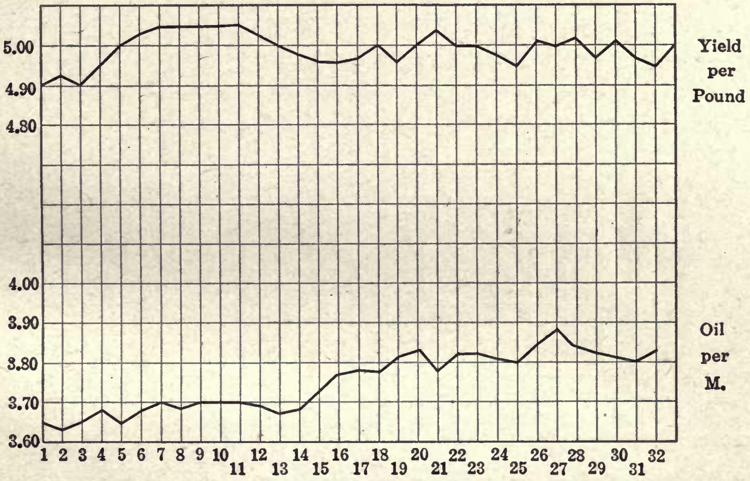


FIG. 5.—Chart illustrating the results over period of one month, daily.

The book should be substantially bound and carefully preserved as it will have great value in time to come. The Manufacturing Reports as made out should be entered in a large, well-bound book with one page or set of pages, for each month. There should be 31 lines, one for each day, with a space below for totals.

The nicest way for the superintendent to keep track of his daily and monthly operation is to supplement the figures submitted each day by graphic charts. These charts should be made on squared paper, 8½ by 11 in. printed in centimeter squares with millimeter subdivisions. There are 24 squares one way and 15 the other. This paper can be obtained from A. D. Maclachan, Boylston St., Boston, or elsewhere. A chart is illustrated for the yield per pound and oil per 1,000 cu. ft., daily and another for a years' results compared.

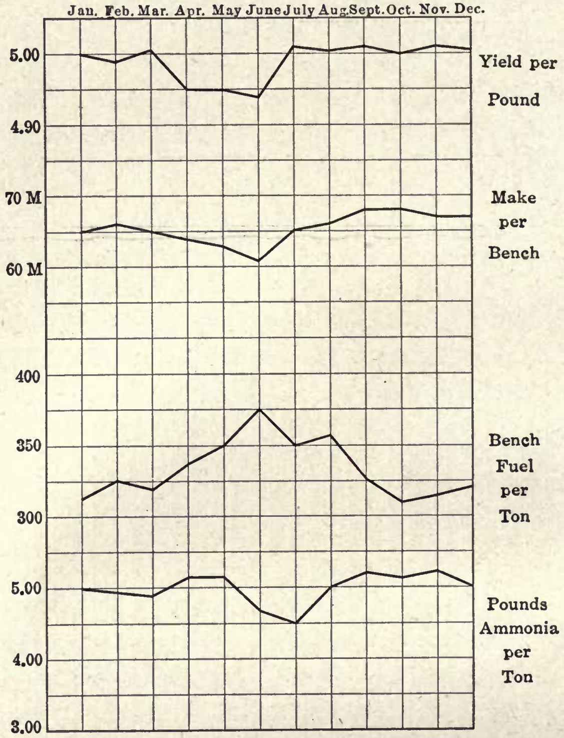


Fig. 6.—Chart illustrating coal gas results over period of one year by months. Previous year may be shown in red or dotted line for comparison.

Cost reports are rarely made up at the plant and superintendents usually have little to do in making them. The results as received should be tabulated and charted each month. The charts are very easy to make, the printing being done mostly on the typewriter and the lines drawn with colored ink by drawing pens.

WORKS FOREMAN'S DAILY REPORT

For ————————covering 24 hr. ending 7 a.m.———————————19—.

Statement and Registration of Meters

	Statement station meter	Total gas registered	Statement water-gas meter	Water gas registered	Coal gas registered
7 a. m.					
9 a. m.					
11 a. m.					
1 p. m.					
3 p. m.					
5 p. m.					
7 p. m.					
9 p. m.					
11 p. m.					
1 a. m.					
3 a. m.					
5 a. m.					
7 a. m.					
Total					

Statement of Storage Holders

Holder No.	7 a.m.	5 p.m.	7 p.m.	7 a.m.	Least on hand
1					
2					
3					

Temperatures in Degrees Fahrenheit

	Atmosphere	Inlet primary condenser	Inlet exhauster	Outlet P. & A.	Outlet condenser	Outlet No. 2 scrubber	Inlet purifier	Station meter	Water-gas meter and cond.
8 a. m.									
12 noon									
5 p. m.									
8 p. m.									
12 night									
5 a. m.									

Ammonia

Oil

	Temperature still liquor test	Cars off capacity test	Tanks
7 a. m.			7 a. m
10 a. m.			1
1 p. m.			2
4 p. m.			3
7 p. m.			4
10 p. m.			
1 a. m.			
4 a. m.			

MANUFACTURING REPORT

Date————————19—

Gas Registered

Statement station meter 7 a.m.......——
Statement station meter 7 a.m.......——
Total gas registered................——
Corrected registration..............——
Statement water-gas meter 7 a.m.....——
Statement water-gas meter 7 a.m.....——
Water gas registered................——
Corrected water-gas registration.....——
Corrected coal-gas registration......——

Gas Sent Out and on Hand

In holders 7 a.m...................——
Loss or gain from yesterday.........——
Corrected registration..............——
Gas sent out........................——

Heating Value

Average B.t.u.......................——

Coal-gas Manufacture

Benches in use	Coal carb., pounds	Number charges	Coke fuel	Coal fuel
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Total				

Total Bench Fuel, pounds

Data and Averages

Yield of gas per pound of coal.......——
Average charge per retort...........——
Gas made per bench..................——
Coke made...........................——
Bench fuel, pounds per ton..........——

Water-gas Manufacture

Water gas in relief holder...........——
Loss or gain last report.............——
Corrected registration...............——
Water gas made.......................——

Data and Averages

Coke used in generator...............——
Coke per 1,000 cu. ft. of gas........——
Oil used, gallons....................——
Oil used per 1,000 cu. ft. of gas......——
Number runs made.....................——
Make per run.........................——
Minutes blow.........................——
Minutes run..........................——
Hours run............................——

Steam Report

Fuel used	Pounds
Coal used..............................	——
Breeze used............................	——
Total..................................	——
Pounds per 1,000 cu. ft. of gas......	——

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Report made by ————————————

Certified as correct by ————————————

Supt.

WEEKLY MANUFACTURING STATEMENT FOR—DAYS ENDING—19-

COAL GAS

Yield per pound................——
Average number retorts in use....——
Charge per retort..............——
Make per man...................——
Make per bench.................——
Bench fuel per ton.............——
Ammonia per ton................——

WATER GAS

Coke per 1,000 cu. ft. of gas......——
Oil per 1,000 cu. ft. of gas.......——
Hours run per day..............——
Make per run...................——

MIXED GAS

Coal gas made..................——
Water gas made.................——
Total made.....................——
Per cent. coal gas.............——
Maximum send out...............——
Minimum send out...............——
Average send out...............——
Boiler fuel per 1,000 cu. ft. of gas..——
Average candlepower............——
Average B.t.u..................——

COAL

Unloaded.......................——
Cost...........................——
Cost per ton...................——

COKE

Made...........................——
Sold...........................——
To storage.....................——
To water gas...................——
To bench.......................——

REMARKS

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Superintendent.

Inspecting.—A thorough daily inspection of the condition of the plant and the manufacturing processes is conducive to efficiency and good practice. While it is desirable that the superintendent have no confining duties, nevertheless he should systematize his own work and make up a daily schedule to be followed as closely as possible. When coming on in the morning he should receive the verbal report of the foreman regarding the general conditions during the night previous and look over the charts from the recording gages with him. Provided there is nothing of importance to occupy time in these, he should next consider the reports of the day previous. Following this a thorough and complete round of the plant should be made noting carefully all conditions that need attention or the progress of any work under way. A note of anything special should be made and at the earliest opportunity the attention of the foreman should be called to it. Quite frequently it is a good idea to take the foreman to the spot where you wish his attention to be directed and thoroughly discuss what is required. If the matter is of considerable importance, written instructions should be given. In fact, it is an excellent idea to write down instructions whenever possible, keeping a carbon copy. A habit of this kind saves a world of dispute and the fact that one is known to do this will act as a deterrent on carelessness about instructions among the men.

This daily inspection trip should be searching and comprehensive and if the conditions found which need attention are taken care of promptly, will be of immense benefit. The chemist or assistant superintendent may well be present during these trips and in any case, should have a trip or schedule of his own. Below is such a schedule taken from practice which can be modified to suit local conditions.

Inspections should cover every foot of the plant and following points be especially noted:

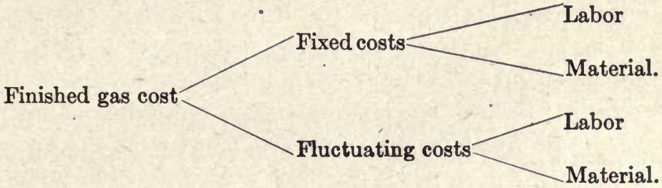
1. Heats on benches.
2. Draughts and fire conditions.
3. Temperatures and pressures.
4. Fire and safety hazards.
5. Water-gas machine conditions.
6. Needed repairs.
7. Leaks of all kinds.
8. Conditions of holders.
9. Condition of purifying house.

Brief written report on unusual conditions.

Conferences.—The superintendent should have frequent conferences to thoroughly discuss reports and operating conditions. There should be included the foreman, chemist and such other men as are needed at various times. These meetings should preferably be the last working hour of the day and should be "strictly business." All changes in methods or proposed construction should be thoroughly thrashed out, or planned, at these times.

Chemical Control.—This will be treated in a later chapter, as while it properly comes under the head of methods of control it is worthy of a chapter by itself.

Controlling Costs.—Almost all gas works of medium size and larger have an accounting system affording detailed costs on the different operations. For coal-gas making there should be about 13 or 14 different accounts and about the same number for water-gas. These may be divided up into fixed and fluctuating costs and again in each case to labor and material.



Such expenses as coal carbonized per 1,000 cu. ft. are almost a fixed amount. The expense will vary somewhat with the make per bench, etc., but these changes are slight and are in the nature of physical results and in considering the cost control we assume that the plant has been brought into a condition of operating efficiently and that the opportunities for large savings have been taken advantage of. Having obtained what appear to be maximum results in carbonization, ammonia recovery, water-gas generation, oil consumption, etc., a consideration of the irregular and fluctuating expense is in order. The fixed expenses will be closely limited by the results from materials and may be readily figured for any given output.

The fluctuating expense falls under two heads, labor and material. Supervision, clerical work, retort house labor, generator house labor, are all pretty well standardized and fixed. When they are properly adjusted to conditions there will be only slight changes from time to time. Miscellaneous labor, however, is another thing. To this account is generally charged all labor for cleaning yards and buildings, washing windows, handling snow, removing ashes and miscellaneous small repairs and alterations not otherwise provided for. Now, at first thought there would seem to be little difficulty in keeping this account down to a minimum. We take on extra men to change a box, tear out an old bench, excavate a sewer trench or what not. Their time is taken care of by accounts that run quite uniformly through the year or are construction expenses and just as soon as the job is done they are dispensed with. But just there is the trouble. Too seldom that close line of demarcation between needful labor and that kept over so as to be on hand when needed, is not drawn. It is not so easy to lay off a man the moment he is through with any of the fixed jobs. We think of so many things for which we could use him and so we keep him in reserve a day or two and pretty soon we have two or three men who stay on the payroll and keep out of the way. This is one of the most difficult and insidious troubles the superintendent has to deal with. A highly organized operating system will help here. From schedules and the printed system the least possible number of men required to keep the holders up can easily be determined. Then every additional man is "miscellaneous labor" and every day the list of men at work the day before may be inspected and any extra men eliminated. Some judicious planning on the part of the superintendent and the foreman in regard to the extra jobs will assist in making possible a minimum labor account. Just because it is known that Sunday a box is to be cleaned a gang need not be held over from Tuesday so as to be sure and have men enough. One can pretty generally get them when needed and even if, when the time comes, the job has to wait a day to collect them again, it will rarely cause any real inconvenience.

The other great source of unnecessary expense is in the purchase of material. It should not be possible for any one at the plant to purchase materials without a signed order from the superintendent and many companies require a requisition from the superintendent to the central office for every purchase. But even these safeguards do not prevent unnecessary expenditures for usually the superintendent has little difficulty in getting any requisition O.K'd and the final choice of material is in all cases up to him. Before purchasing supplies of any kind be sure that they are absolutely needed. Time taken to see that the stock is exhausted or that nothing else will serve the purpose of the material asked for, is well spent. Nothing that can be bought cheaper in quantities should be bought singly or in small lots.

The action of all supplies in service should be carefully studied and recorded and poor service remembered when ordering a new supply. There is always a great deal of pipe work going on around a gas plant and there is room for a good deal of saving by installing a comprehensive stock of pipe, fittings and valves, rather than buying piecemeal from a local house. Paint is another item which affords opportunity for material saving. Suit the quality of paint to the character of job. A coal tar and cement paint can be made that will go a long way toward covering all iron work and cost scarcely anything. When using mixed paint it is often possible to get it as cheaply in small cans as large and there will be far less chance of having a spoiled bucket every now and then from being half used and set aside. Lubricating oils offer another fruitful opportunity. Very low grades of greases and oils are available for many gas-plant uses. All bills should be checked very closely to see that exactly what is received is paid for and that the prices are right.

There should be an inventory of all goods which are in stock and this ought to be kept up to date every day so that one can tell at all times just what is on hand. Very often supplies are purchased when there is plenty of the article on hand but covered up or laid away out of sight in the storeroom.

An excellent way to control plant costs as a whole is through the budget. Figure out beforehand as closely as possible the amounts that must be expended each month and apportion them among the different accounts. It is impossible beforehand to predict exactly how much gas is going to be made but this will have less effect than might be imagined. The amounts can be arrived at as follows. Suppose it is expected to make gas for a certain number of cents per thousand; multiply this figure by the predicted number of cubic feet of gas to be made. This gives the total expense. Now set down all the fixed expenses which are comparatively stable and figure them in cents per thousand also. Add these up and deduct from the total. The amount that is left is what may be spent for casual labor, miscellaneous work, repairs and accidents or contingencies. Every day figure up approximately the amount spent in money and cents per thousand, and deduct the amount of money spent from the total available. Thus every day just where the plant stands in cost per thousand and available money is readily seen. To elaborate this somewhat, a book, ruled as follows, may be kept:

Fixed expense				Fluctuating expense				Total	
Labor		Material		Labor		Material		Cents	
Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual
1									
2									
3, etc.									

One line is provided for each day in the month. If an unexpected increase in send out occurs necessitating greater expense for materials, estimates must be rearranged on the new basis. This book will show every day whether the budget is being exceeded and will give a line on how the plant is coming out at the end of the month.

CHAPTER II

CHEMICAL CONTROL

The chemical control of gas works is covered principally by the making of rather simple tests and analyses during the continuance of the various processes.

COAL AND WATER GAS GENERATION

Under the above heading will be considered the equipment used to produce coal and water gas in the raw state.

Benches.—The principal use of chemical control in the retort house is in maintaining high heats on the benches with an economical consumption of fuel. The percentage of CO_2 in the flue gases is an indication of the character of the combustion. The higher the CO_2 percentage can be raised, the greater will be the fuel economy. One of the greatest advantages of the analysis method of regulating benches is that one is able to reduce the secondary air to a minimum, which is not always possible otherwise. Without knowing beyond a doubt that in the stack gases there is a slight excess of oxygen, it is not safe to reduce the secondary air. There is too much chance of leaving unburned CO in the gas. It is possible to have as high as 18 per cent. carbon dioxide in the flue gases when using coke for fuel. With coal a lower percentage is possible owing to the fact that a good deal of hydrogen and hydrocarbon is distilled off in the fuel bed, some of which is unconsumed in the setting and some forms water vapor, etc., which would reduce the possible maximum CO_2.

The most important part of the analysis is the taking of the sample. This may be taken from various places. Many chemists prefer the lowest recuperator. Others drill a hole into the stack at the rear of the bench just opposite the recuperator openings and some just below the stack slides. The nearer the fire the sample is taken, the less chance there is for contamination from air leaks but at the same time care must be taken not to get samples at a part of the bench where the combustion has not had time to be complete. The lower recuperator is a good place to draw the sample and generally it is the easiest place to work.

Below a red heat an iron pipe can be used to draw the samples through. One end of a piece of ¼-in. gas pipe 4 ft. long should be threaded and a hose cock attached. Two aspirator bottles with tubulatures at the bottom should be connected with a piece of rubber tube about 4 ft. long, with a pinch-cock near one end. The bottles should be stoppered with rubber corks fixed with glass tubes, one about 2 in. long. (See Fig. 7.)

One of the tubes should be connected to a heavy glass tee with a piece of rubber tube about a foot long. From the other end of the tee a tube should run to the hose cock and the third limb of the tee connected to the Orsat apparatus. The water used in the bottles must be saturated with the flue gas by shaking together in large bottles.

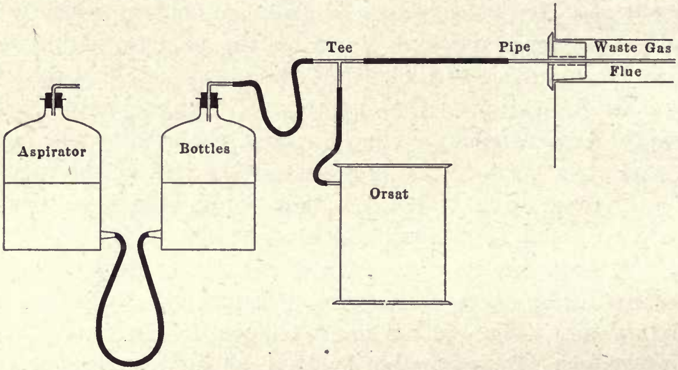


FIG. 7.—Method of connecting Orsat and sampling apparatus to waste gas flue.

The sampling pipe should be inserted in the sight hole of a recuperator as far as it will go and all leakage prevented by plastering with mud. With the hose cock open and the three-way cock on the Orsat shut, raise the aspirator bottle, causing the water to fill the one attached to the sampling tube. Fill the bottle right up to the top and into the tube a little. Now lower the bottle, thus drawing out the water into the empty bottle and sucking the flue gas in to take its place. Fill the bottle with gas, then expel by raising the bottle. Allow some of the gas to flow through the blow off on the Orsat. The above procedure will purge all connections of air and fill them with furnace gas. Now fill the aspirator bottle with flue gas again, shut the hose cock and by raising the bottle put pressure on the tube to the Orsat. Take a sample with the Orsat in the usual way and proceed with the test, allowing 3 min. for the CO_2 absorption; and two absorptions of 5 min. each for the oxygen, if taken. If necessary determine the CO.

If the CO_2 is low and the oxygen high then there is an excess of secondary air and the slides should be closed to reduce this. The test for CO should finally be made and sufficient secondary always admitted to keep the flue gas free from it. Tests on any bench should always be made at a time midway between firing the furnace and on any particular bench at the same time each day. Both sides of the bench should be tested and adjusted to equal conditions.

A **2 Inch Cap**
B **2 Inch Pipe 8 Inch Long**
C **Plaster Paris**
D **Glass Tubes Set in Plaster**

FIG. 8.—A. H. White's sampling tube.

If a number of benches are in operation it is well to try to make all the analyses in the retort house. A rack should be made to hold about a dozen 250-c.c. sampling tubes or cans and the tubes filled with saturated water, drawing samples into these and numbering them according to the bench from which they are taken. The tests may be made in the laboratory with an Orsat or Hempel apparatus. Below are some possible conditions indicated by the analyses:

TABLE I.

Condition	Percentage	Specific heat	Temperature	Efficiency, per cent.
Complete combustion	20.0 CO_2	0.42		
	80.0 N	0.31	4,730	61.7
10 per cent. too little air	17.4 CO_2	0.42		
	4.4 CO	0.31		
	78.2 N	0.31	3,578	49.3
10 per cent. too much air	18.2 CO_2	0.42		
	1.8 O	0.31		
	80.0 N	0.31	4,344	58.2
18 per cent. CO_2, excess air	18.0 CO_2	0.42		
	2.0 O	0.31		
	80.0 N	0.31	4,290	57.8
18 per cent. CO_2, not enough air	18.0 CO_2	0.42		
	3.3 CO	0.31		
	78.7 N	0.31	4,064	55.4

In the last case the efficiency keeps up well but 16 per cent. additional fuel is required.

Water Gas.—It is often desired to test the proportion of blue gas in the finished gas. To do this a test should be made on the blue gas first. Tap the generator lid for ½-in. pipe and put on a blow-off cock and a ⅜-in. hose cock. Connect this up to the Orsat with a heavy rubber tube. The sample should be taken at different intervals of the blow or run; that is, take the first sample after the first minute of run, the second after the second minute, and so on. If there are not enough Orsats or sampling tubes to do this take the first sample after the first minute of run, and the next sample after the second minute of the *next* run, and so on. Always blow off the gas for a minute before taking the samples. Draw the sample right on time, remove to a convenient place and make the absorptions. Be careful not to let the Orsat get too hot. With two Orsats fairly good time can be made.

The amount of blue gas in the finished gas should be about 74 per cent. Analyze the blue gas for several runs, then test the gas in the relief and calculate as follows:

Per cent. CO in blue gas; per cent. CO in relief : : 100 : x

x = per cent. of blue gas in the finished gas.

The tests ordinarily made on purified water gas are for candle-power, which is treated elsewhere, and for CO_2. The percentage of carbon dioxide is an important factor. The Orsat should be used about the plant but the Hempel apparatus is more accurate and should be used in the laboratory whenever possible.

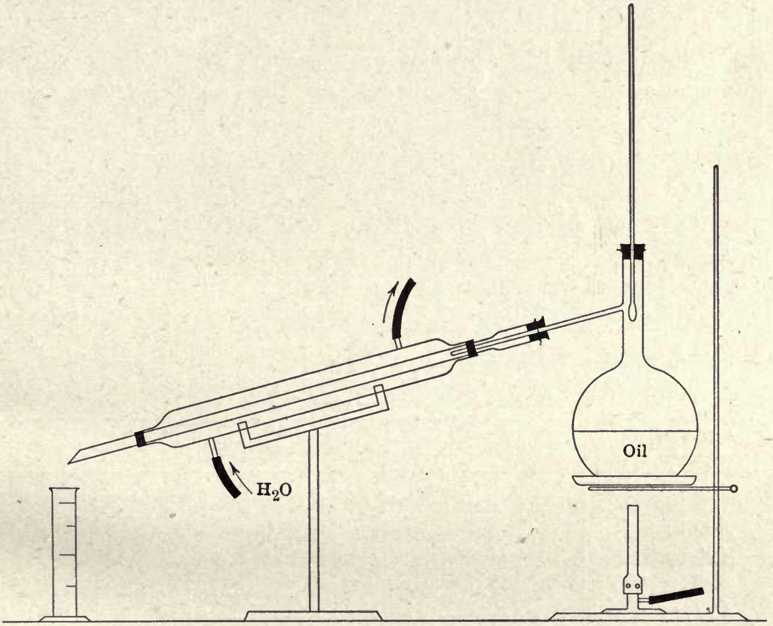


Fig. 9.—Apparatus set up for oil distillation.

Oil Analysis.—A distillation test on gas oil will give a good deal of information as to what to expect when using it. The specific gravity should be taken by a picnometer or Baumé hydrometer. The correction for temperature is as follows:

For each degree above 60° add 0.00036 to specific gravity.
For each degree below, subtract 0.00036 from specific gravity.
For Baumé hydrometer use the following corrections:
From 10° to 20° add or subtract 0.065 per 1°F.
From 20 to 35 add or subtract 0.070 per 1°F.
From 35 to 45 add or subtract 0.075 per 1°F.
From 45 to 55 add or subtract 0.080 per 1°F.

For the distillation test a 500-c.c. side-outlet, round-bottom flask should be used, heated over a sand bath. The condenser may be glass but should have rubber connections between the inner and outer tubes, or it will break from expansion. Two hundred c.c. of oil should be used for the test. Fit a cork to the flask, carrying a thermometer so placed as to have the bulb opposite the side outlet. Provide 20-c.c. graduates for collecting the fractions and one 5-c.c. graduate with wide graduations for the very small fractions. The thermometer should read from 60° to 700°F. and should have a nitrogen-filled stem. Heat the oil slowly until the temperature reaches 300°. Remove the flame, allowing the mercury to fall 20°, then heat the flask again and as the mercury crosses the 300° mark, cut off the fraction. Repeat for every 50° or 100°, allowing the temperature to fall each time. Mark the fractions and test each for specific gravity, also recording the amount of each. (See Fig. 9.)

Above 700°F. the residue is heavy tar, asphaltum and coke. Distillations of gas oil are often stopped at 600°F. The percentage by weight is figured from the number of cubic centimeters and the specific gravity.

The figures obtained may be arranged as follows:

Fraction, ° F.	Percentage by weight	Specific gravity	Degrees Baumé
0 to 300	5.5	0.737	60.0
300 to 400	8.7	0.784	48.5
400 to 500	24.0	0.820	39.7
500 to 600	49.1	0.850	35.0
600 and above	12.7		

The specific gravity of the sample is 0.860–33.5°Bé.

The sulphur in oil may be determined as follows: Take 10 c.c. of oil, mix it with 10 grams magnesium oxide and 5 grams of anhydrous sodium carbonate in a small dish. Stir well with a glass rod, pour into a 75-c.c. crucible, having a layer of the mixture on the bottom and cover it with a layer ¼ in. thick. Heat the crucible gently for 2 hr., then raise to a white heat with a blast lamp. Allow it to cool, boil the residue with 50 c.c. of water, add 2 c.c. of bromine water and boil 5 min. Pour off the liquid and repeat the treatment with 30 c.c. of water. Mix the solutions, filter, add 1.5 c.c. strong HCl, boil and slowly add 10 c.c. of hot barium chloride solution. Allow it to stand for

12 hr., decant, wash, filter, wash clean from chlorides, dry, ignite and weigh as $BaSO_4$. Then calculate the per cent. by weight in the usual way.

BOILER ROOM

Where coal gas plants utilize breeze for boiler fuel, and breeze is regarded as a sort of waste product, it does not pay to spend very much to secure high efficiency in the boiler room. Where any market for breeze exists or where considerable boiler coal is used and it is comparatively costly, it is worth while to reduce the boiler fuel through careful study.

Flue-gas Analysis.—A satisfactory method of controlling boiler operation is to analyze the flue gases and determine the percentage of CO_2. The sample should be taken below the stack damper and all cracks about the setting should be very carefully stopped up so as to reduce air leakage to a minimum. Several pipes of different lengths ought to be put into the stack, fastened together on a common header, so as to get an average sample. Beside the boiler set up a Richards jet pump and run a suction tube with a Y in it to the stack sampling tube. Connect the other leg of the Y to a sample bottle or Orsat apparatus. The pump will cause a flow of gas through the tube and for quick analyses an Orsat apparatus may be used on the spot. For taking an average sample, use a gallon aspirating bottle, arranged so that the water will flow out at such a rate as to nearly fill it in the desired time.

It is good practice to pass the gas from the stack through a wash bottle to clean it of dust and cinders before taking off samples at the Y. All water used in flue-gas tests should be saturated with the gas used. The percentage of CO_2 in the flue gas is a direct indication of the efficiency of the combustion. It should be around 11 per cent. on an average over long periods but will vary greatly, of course, before and after firing. Elsewhere will be found a discussion of the interpretation of flue-gas results.

COAL AND COKE ANALYSIS

The taking of the sample of coal or coke is perhaps the hardest part and the most important feature of the entire process of analysis. The method of sampling must be governed largely by the particular conditions of shipment. In case coal is being unloaded from cars or barges it is comparatively easy to obtain an average sample but when it is stored in a bin of several thousand tons capacity, the operation is much more difficult. In general one may say that the aim must always be to obtain, as nearly as possible, a sample which will absolutely represent every portion of the coal to be tested. The sample should not be confined to lumps or slack but must contain an average amount of both. The sampler can not rely on his judgment in securing this average but must have recourse to a method which is impartial and allows a minimum of opportunity for deviation.

Nearly all gas coal contains some slate and where the pieces of slate do not exceed 1 lb. in weight a sample of coal to weigh not less than 4,000 lb. is required. As the coal is unloaded, at regular intervals a scoopful of coal should be thrown aside in a pile with such frequency that by the time the shipment has been unloaded, about 2 tons have been secured. In very large shipments two or three such piles will be needed. If the coal is piled in heaps, channels may be cut through in various directions, always bearing in mind that no part of the pile must be slighted and that coal tends to segregate.

The original sample of 2 tons is removed to a clear floor of iron plates or if this is not available, a very hard concrete floor, and broken with sledges to not greater than 1½-in. cubes. Shovel these into a cone and then spread out flat, throwing the coal to the edge of the circle with a kind of circular mixing motion. Divide the circle into quarters, setting aside one quarter and rejecting the rest. This will give a sample of 1,000 lb. Pile this and spread it in the same way, saving two opposite quarters and rejecting the rest. The sample will now weigh 500 lb. and before proceeding further must be crushed into ¾-in. cubes. Pile and quarter until the sample is reduced to 5 lb. Crush the sample until no piece is larger than a ⅛-in. cube and place it in a tight can, covering the joint with the cover with adhesive tape.

Moisture.—Weigh the whole sample as accurately as possible, then heat it in an oven for 24 hr. at 100°F. and weigh again. The loss in weight represents moisture and the dried coal is reported as "air-dry." The air-dry coal is used for the rest of the work and after completing the test the analysis is calculated back to the coal as received and also on a dry basis and ash and moisture-free basis.

The air-dry sample is ground in a coffee-mill to pass a 10-mesh sieve, then piled and quartered, reducing to about 60 grams.

1-Sample of coal spread out and crushed with tamper.

2-Mixing: Form cone shaped pile by pouring coal from corner of shovel each time.

3-Quartering: Divide pile into four equal parts.

4- Quartered.

5-Diagonally opposite quarters eliminated with shovel and remaining fine coal swept out.

6-Remaining two quarters spread out and crushed.

7- Mixing: (Same as No 2).

8-Quartering.

9-Quartered.

10-Diagonally opposite quarters eliminated. (Same as No. 5).

11-Remaining two quarters spread out and crushed.

12-Mixing: (Same as No. 2).

13-Quartering.

14-Quartered.

15 Diagonally opposite quarters eliminated (Same as No. 5).

16-Remaining two quarters spread out and crushed.

17- Mixing. (Same as No. 2).

18-Quartering.

19-Quartered.

20-Diagonally opposite quarters eliminated. (Same as No. 5).


21-Remaining two quarters spread out and crushed.


22-Mixing: (Same as No. 2).


23-Quartering.


24-Quartered.


25-Diagonally opposite quarters eliminated. (Same as No. 5).


26-Remaing two quarters spread out and crushed.


27-Mixing: (Same as No. 2).


28-Quartering.


29-Quartered.


30-Diagonally opposite quarters eliminated. (Same as No. 5).

Gathering a sample of coal is very important. It must truly represent the entire lot to be sampled.

The floor upon which the sample is prepared should be either a large boiler plate, absolutely clean, at least 6 x 6 feet in size, or a cool concrete floor.

The reason for crushing the coal fine is to insure an even distribution of the good coal and impurities through the sample.


31-Remaining two quarters swept into shovel.


32-Placing final sample into air-tight container.

When mixing, the coal should be poured from the corner of the shovel so that it will naturally pile up in the shape of a cone or pyramid. This helps to scatter it evenly throughout the pile.

The shovel will not pick up all of the fine coal, so a broom should follow in the same direction in which the shovel is used. After shoveling the sample into a pile for mixing, the fine coal should be swept in. When eliminating the two quarters, the fine coal should be swept out.

(*By permission of the Commercial Testing & Engineering Company, Chicago, Ill.*)

PROPER METHOD OF PREPARING COAL SAMPLE

This sample is ground in a ball mill to pass 60-mesh screen. If a ball mill is not available, an iron mortar may be used, finishing on an agate mortar (Fig. 10). Disc grinders heat the coal too much and are not to be recommended. This 50-gram sample is preserved in a carefully labeled, rubber-stoppered bottle, large enough to be only half filled by the coal, so that it may be well shaken before taking out samples for the tests.

Moisture.—The amount of moisture in the air-dry coal must now be determined and this test must be made much more delicately than the test on the air-drying of the coal as received. Ignite, cool and weigh a crucible and cover, weigh into it exactly 1 gram of the finely powdered coal and place it in a drying oven and heat at 220°F. for 1 hr. (Fig 11). This oven should have a double wall containing a glycerine and water mixture of specific gravity 1.19, the boiling point of which should be close to the desired temperature. A condenser must be attached to the oven

FIG. 10.—Agate mortar and pestle for finely pulverizing coal.

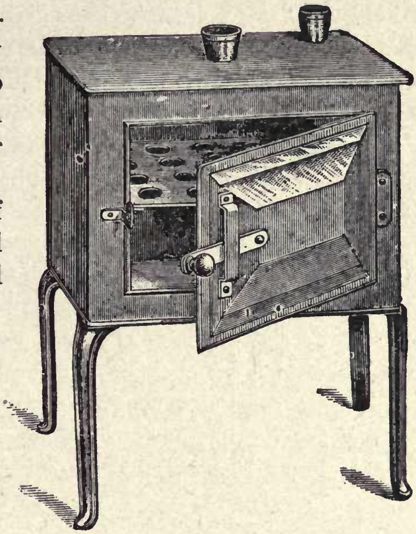


FIG. 11.—Drying oven for moisture determination.

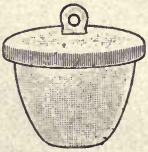


FIG. 12.—Crucible for ignitions.

FIG. 13.—Desiccator.

or the specific gravity will change owing to loss of water from evaporation. After heating the crucible for 1 hr. remove it to a desiccator containing sulphuric acid and allow it to cool, and then weigh it with the cover on (Fig 12).

Ash.—Heat the residue from the moisture determination very slowly until the volatile matter is driven off but avoid coking the coal if possible. Continue this ignition, stirring occasionally with a platinum wire until carbon particles have disappeared, finally carrying the ignition to the highest heat possible with the Bunsen burner. Cool in a desiccator and weigh. Heat ½ hr., cool and weigh again. The weights should agree within 0.0005 gram; but if not, repeat the operation.

Volatile Matter.—Weigh a 1-gram sample into a weighed 30-c.c. platinum crucible with a close-fitting cover. Heat for 7 min. over a Bunsen flame 20 cm. high, with the crucible placed so that its bottom is 6 to 8 cm. above the burner which should be protected by a sheet-iron chimney and adjusted so that the green cone does not touch the bottom of the crucible. After heating for 7 min., cool in a desiccator and weigh. The loss in weight, less the weight of moisture, is the amount of volatile matter.

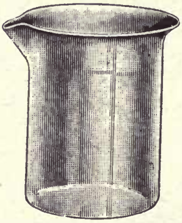


FIG. 14.—Beaker.

FIG. 15.—Wash bottle.

Sulphur.—Prepare an Eschka mixture of 2 parts light calcined magnesium oxide and 1 part anhydrous sodium carbonate. Mix a 1-gram sample of coal with 2 grams of this mixture. Mix in a 30-c.c. platinum crucible and spread over the top ½ gram of the mixture. Place in a slanting position and ignite very slowly so that there shall be no loss of sulphur in the form of sulphur dioxide. After heating slowly for 30 min., increase the heat and after it is thoroughly hot, stir occasionally with a platinum wire until all black particles have been burned out.

Allow it to cool, transfer the contents to a 200-c.c. beaker, boil with 75 c.c. of hot water for ½ hr., filter into a 300-c.c. beaker and wash with hot water until the volume of the solution is about 200 c.c. Add 4 c.c. bromine water and acidify slightly with concentrated hydrochloric acid, boil and add slowly 20 c.c. of hot 5 per cent. solution of barium chloride; keep hot for about 2 hr., filter out, wash, dry, ignite, cool and weigh.

The weight of barium sulphate times 13.74 equals the percentage of sulphur in the sample.

The foregoing methods were developed by the Bureau of Mines and outlined in *Technical Paper* No. 8.

Table II.—Calculation of Results

Air-Dry Test

	Before drying	After drying
Weight of coal and can	7.97	7.72
Weight of can	2.96	2.96
Weight of coal	5.01 lb.	4.76
Loss in weight	.25 lb.	
Percentage of moisture	$\frac{0.25 \times 100}{5.01} =$	4.99 per cent.

Complete Analysis

	Before drying	After drying
Moisture		
Weight of coal and crucible	31.0123	30.9910
Weight of crucible	30.0123	30.0123
Weight of coal	1.0000	0.9787
Loss in weight	0.0213 gram	
Percentage of moisture		2.13 per cent.
Ash		
Weight of crucible and ash	30.1248	
Weight of crucible	30.0123	
Weight of ash	0.1125	
Percentage of ash		11.25 per cent.
Volatile matter, 1 gram		
Weight of crucible and residue	30.6909	
Weight of crucible	30.0123	
Weight of ash and coke	0.6786	
Loss	0.3214	
Less moisture	0.0213	
Volatile matter	0.3001	
Percentage of volatile matter		30.01 per cent.

Fixed carbon

Coal............................100.00 per cent.
Volatile matter, ash, moisture...... 43.39

Fixed carbon..................... 56.61 per cent.

The percentage of fixed carbon is found by subtracting from 100 the sum of the volatile matter, ash and moisture.

Sulphur, 1 gram coal

Weight of crucible, $BaSO_4$......... 18.3196
Weight of crucible................ 18.2431

Weight of $BaSO_4$.................. 0.0765 gram
$BaSO_4 \times 13.74$ .... 1.05 per cent.

TABLE III.—REPORT OF COAL ANALYSIS

Proximate analysis	Air-dry, per cent.	As recorded, per cent.	Moisture-free, per cent.	Moisture- and ash-free, per cent.
Moisture	2.13	6.78		
Volatile matter	30.01	28.58	30.66	34.64
Fixed carbon	56.61	53.92	57.85	65.36
Ash	11.25	10.72	11.49	
Total	1.00	1.00	1.00	1.00
Sulphur	1.05	1.00	1.07	1.21

The coal as received loses 4.99 per cent. moisture on air-drying, therefore each 100 lb. of air-dry coal represents 104.99 lb. of coal as received. Add the 2.13 and 4.99 together and divide by 104.99 to get the percentage of a moisture in coal as received. Divide 30.01 by 104.99 to get percentage of volatile matter and so on. To calculate to a moisture-free basis proceed as follows: $100 - 2.13 = 97.87$. Divide each constituent per cent. by 97.87 to reduce to a moisture-free basis. To calculate to an ash- and moisture-free basis add the moisture and ash percentages together and subtract from 100; $100 - (2.13 + 11.25) = 86.62$. Divide the percentages of the air-dry analysis by this factor.

AMMONIA TESTS

Solution Required.—For determining the ammonia in crude liquor and concentrated liquor a solution of double normal sulphuric acid, 1 c.c. of which is equivalent to 0.034 gram of ammonia, is required. This solution can be purchased ready standardized and by means of pipettes and graduated flasks may be diluted to any desired strength.

Concentrated caustic soda solution is added to the liquor when distilling, instead of the lime used in practice to break up the fixed ammonia. It should be made up of the pure stick caustic dissolved in distilled water.

Methyl orange is used as an indicator, about $\frac{1}{10}$ gram being dissolved in 50 c.c. of hot water and the solution filtered when cold.

Double normal caustic soda should be provided for use in titrating back against an excess of acid.

Sampling.—The concentrated liquor in the tanks may be sampled by lowering into the tank or a 2-in. iron pipe about 2 ft. long, capped on one end and attached to a rope with a wire. By dropping this, open end down, a sample can be obtained from near the bottom of the tank, which should be mixed with one from near the top and middle and poured into a glass-stoppered bottle. The crude liquor may be sampled in the same manner, not, however, using the same tube, or if the still is running the crued liquor may be sampled as it runs into the still. When the concentrated liquor made from day to day varies in gravity, there is a tendency toward stratifications in the storage tanks.

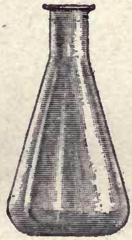


FIG. 16.—Erlenmeyer flask.

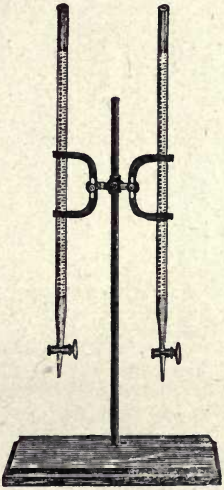


FIG. 17.—Acid and alkali burette for NH_3 determination.

Crude Liquor.—The sample of crude liquor should be poured into a hydrometer jar and the gravity obtained with a Twaddle hydrometer, from the reading of which the specific gravity may be had by referring to the table on weights and gravities of liquor on page 45. The gravity may be also easily calculated by the following formula:

$$\frac{\text{Twaddle degrees} \times 5}{1{,}000} + 1.000, \text{ as for example,}$$

$$\frac{2.5^\circ \times 5}{1{,}000} = 0.0125\ (+\ 1.000) = 1.0125.$$

Now take 50 c.c. of the liquor, measured carefully in a graduate and pour it into a 500-c.c. Erlenmeyer flask. Fill the acid burette with the 2N acid, add a drop of methyl orange to the liquor and run it in the acid until the pink color just appears. Multiply the number of cubic centimeters of acid used by 0.034, giving the number of grams NH_3 present and the number of cubic centimeters of crude liquor by the specific gravity to get the weight of the liquor.

Fig. 18.—Graduate.

Fig. 19.—Glass condenser.

Fig. 20.—Round-bottom flask for distillations.

Example.—

Specific gravity	1.0125
Acid used	16.0 c.c.

$$\frac{16 \times 0.034 \times 100}{1.0125 \times 50} = 1.07 \text{ per cent. } NH_3$$

The above method will give the free ammonia only. To obtain the total ammonia, proceed as follows: Set up on a ring stand, a 500-c.c. round flask having a side neck, and insert a rubber stopper carrying a thistle tube which will reach clear to the bottom of the flask. Connect the side tube with a condenser allowing the side tube to slide down several inches into the inner tube of the condenser. The lower end of the condenser tube should be provided with an adaptor, resting in a 300-c.c. flat porcelain dish. Place 50 c.c. crude liquor in the flask, add 50 c.c. water and 1 c.c. of the concentrated caustic solution. Run into the evaporating dish from the burette, 20 c.c. of the double normal acid. Start a small stream of water running through the condenser and boil the flask until only about 20 c.c. remain. A piece of coke breeze will prevent bumping.

Add a drop of the indicator to the solution in the flask and titrate back with the 2N alkali, until the pink color just turns to yellow. Arrange the figures obtained as below:

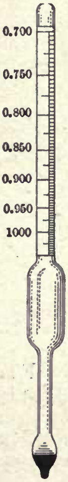


Fig. 21.—Hydrometer for specific-gravity scale.

Crude liquor	50.0 c.c.
Specific gravity 3°Tw.	1.015
Acid used	20.0 c.c.
Alkali used	3.0 c.c.
	17.0 c.c.

$$\frac{17 \times 0.034 \times 100}{50 \times 1.015} = 1.14 \text{ per cent. } NH_3.$$

The calculation of the pounds of ammonia in the crude liquor is very simple. Suppose we have 18,000 gal. of 1.07 per cent. crude liquor testing 2½°Tw. Referring to our table we note that this liquor should weigh 8.44 lb. per gallon.* Then,

$$18{,}000 \times 8.44 \times 0.0107 = 1{,}625 \text{ lb. } NH_3.$$

The amount of fixed ammonia is the difference between the total and the free ammonia. Suppose a liquor tests 1.20 per cent. total ammonia and 1.00 per cent. free, then 0.2 per cent. is fixed ammonia which is two-twelfths of the total amount, or about 17 per cent. This percentage will vary a great deal with different coals and should be frequently determined, as it is an important relation, as shown elsewhere in this work.

Concentrated Liquor.—For accuracy concentrated liquors should always be tested at the same temperature as the liquor in the tank when measured. For titration, 10 c.c. should be taken with a pipette, after determining the Twaddle degree of the

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*Table IV, page 45.

liquor in the usual way. The specific gravity could also be determined by weighing the 10 c.c., when a very accurate test is desired. The liquor may be distilled or titrated; the results being calculated in a similar manner to the crude liquor analyses.

Control of Shipments.—When a car for ammonia shipment is received it should be carefully inspected and then weighed empty. The car should be rapidly filled and then allowed to stand an hour. It should now be sampled by lowering into the liquor a pipe with a loose cork in the end, attached to a string. When the pipe is close to the bottom, the string is pulled, closing the pipe and it is then withdrawn and the liquor poured into a 5-pint glass-stoppered bottle. Shake the bottle, to rinse well and pour the liquor back into the tank. Now fill the sample pipe and empty it into this bottle, repeating until it is full. Take the temperature of the liquor at about the middle of the car, seal it and weigh over the track scales.

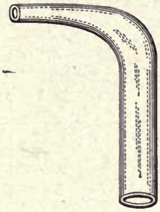

FIG. 22.—Adapter to seal in evaporating dish preventing escape of NH_3.

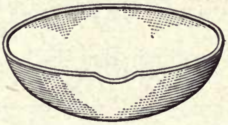

FIG. 23.—Evaporating dish containing acid solution to neutralize NH_3.

FIG. 24.—Thistle tube inserted in stopper of distilling flask.

The liquor should be poured out into as many small bottles as there are samples required and these should be carefully labeled and sealed. The sample for test, is brought to the car temperature when measuring and analyzed for total NH_3 by distillation. The test should be conducted with great care, at least two samples being tested, the results of which should agree within 0.1 per cent. For a very accurate analysis the sample should be weighed on delicate scales and not measured by a pipette.

The capacity of the car should be ascertained and the weight of liquor calculated from the volume and specific gravity. Results may be reported as follows:

Date	
Car No.	
Shipped to	
Weight of car full	104,500
Weight empty	32,000
Weight liquor	72,500 lb.
Capacity of car	8,000 gal.

Test		
Liquor used	10.0 c.c.	10.0 c.c.
Specific gravity	1.09	1.09
Acid used	50.0 c.c.	50.0 c.c.
Alkali used	8.1 c.c.	7.9 c.c.
	41.9 c.c.	42.1 c.c.
Average acid required		42.0 c.c.

$$\frac{42 \times 0.034 \times 100}{10 \times 1.09} = 13.1 \text{ per cent. } NH_3$$

Weight of 1 gal. of liquor	9.086 lb.
Total weight of liquor	72,688 lb.

Ammonia in car $(8{,}000 \times 9.086 \times 0.131 = 9{,}522$ lb.

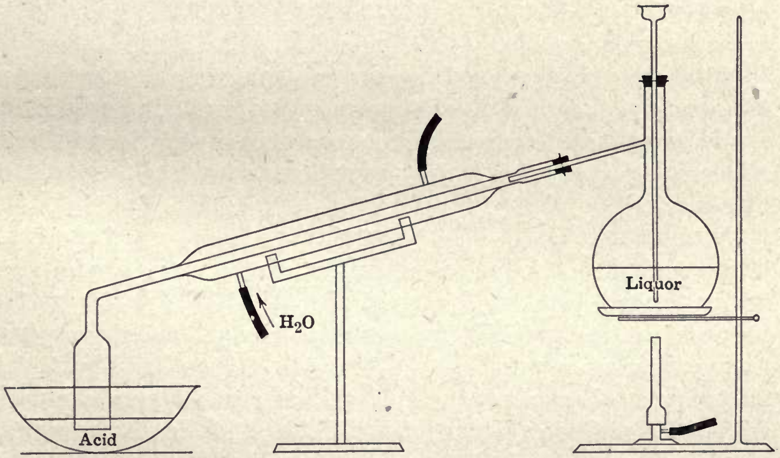

Fig. 25.—Apparatus for ammonia distillation test set up.

This shipment would be billed as 9,522 lb. The agreement between the calculated weight and car scale weight should be quite close.

Waste Liquors.—The waste liquor from the still should always be tested by distilling the sample into a measured amount of standard acid. One hundred cubic centimeters should be the mininum amount used. To determine the amount of free ammonia present, the distillation should be made without adding any caustic soda. After titrating the acid solution and determining the amount of free ammonia, a fresh acid solution should be prepared, water added to the contents of the flask, with a little caustic soda and the test repeated. On this second test any fixed ammonia salts present in the waste liquor will be broken up and the ammonia set free. If the titration shows that fixed ammonia was present, it is evidence that insufficient lime is being used in the still.

Example.—

100 c.c. waste liquor used.

Acid	Alkali
10.0 c.c.	9.0 c.c.

$$10.0 - 9.0 = \frac{1\text{ c.c.} \times 0.034 \times 100}{100} = 0.034 \text{ per cent. } NH_3$$

The above test would indicate a considerable loss, due to low temperatures on the still, or excess lime water, or very weak crude liquor. Now note the test using the caustic: Acid 10.0; alkali 9.0.

In this case there is no difference when using caustic, showing that the loss is all caused by low temperature and not from a deficiency of lime. If the loss were greater with the caustic, it would mean that not enough lime was used. Sometimes when a still is being overloaded it will suggest that considerable loss is to be expected.

Calculation of Loss.—The waste liquor is made up of portions of the crude liquor fed in, condensation of steam, lime water and water formed from reactions in the still. The best way to measure the amount of it is to catch a few gallons at intervals noting the time required to collect 1 gal. It is often about 100 gal. of waste liquor for each 60 gal. of crude liquor although with some makes of stills it should be much less. Now if a still is using 1,200 gal. of 1 per cent. crude a day and one finds a waste of 2,000 gal. and it tests; 0.01 per cent. total NH_3, the loss will be:

$$2{,}000 \times 8.33 \times 0.0001 = 1.66 \text{ pounds per day.}$$

1,200 gal. of 1 per cent. crude will contain about 101 lb. NH_3. Thus the loss is:

$$\frac{1.66 \times 100}{101} = 1.64 \text{ per cent.}$$

Waste liquors should never be allowed to run over 0.01 per cent. NH_3.

TABLE IV

Lime Tables

Degrees Twaddle	Specific gravity	Pounds CaO per gallon	Pounds $Ca(OH)_2$ per gallon
0	1.0	0.0	0.0
2	1.01	0.11	0.145
4	1.02	0.22	0.29
6	1.03	0.33	0.435
8	1.04	0.44	0.595
10	1.05	0.56	0.74
12	1.06	0.67	0.885
14	1.07	0.78	1.03
16	1.08	0.89	1.17
18	1.09	0.91	1.40
20	1.10	1.14	1.51
22	1.11	1.26	1.66
24	1.12	1.37	1.81

From the above, for instance, to have 0.67 lb. CaO per gallon, 0.885 lb. of the hydrated oxide must be used.

Liquor Tables

Degrees Twaddle	Specific gravity	Pounds per gallon
0.0	1.0000	8.336
0.5	1.0025	8.356
1.0	1.005	8.377
1.5	1.0075	8.398
2.0	1.01	8.419
2.5	1.0125	8.44
3.0	1.015	8.461
3.5	1.0175	8.482
4.0	1.02	8.502
16.0	1.08	9.002
16.5	1.0825	9.023
17.0	1.085	9.047
17.5	1.0875	9.065
18.0	1.09	9.086
18.5	1.0925	9.106
19.0	1.095	9.128
20.0	1.100	9.169

Correction for temperature, add or subtract 1°Tw. for each change of 20°F.

Capacity of Stills

48 in.	150 tons coal daily
36 in.	100 tons coal daily
24 in.	50 tons coal daily

Crude liquor to be 1 per cent. and 60 gal. per ton. Recent improvements have greatly increased the capacity of ammonia stills over the above.

PURIFICATION TESTS

Raw Gas.—The most important test on the raw gas is the determination of the number of grains of hydrogen sulphide present at different stages. The determination is very simple and is best effected by using the Tutweiler apparatus which can be obtained from any dealer. This instrument is attractively put up in a very convenient form and can hardly be improved upon. It depends for its usefulness on the action of H_2S on iodine solution and is so arranged that 1 c.c. of the iodine solution is equivalent to 100 grains of H_2S per 100 cu. ft. when used in the apparatus. (Fig. 26.)

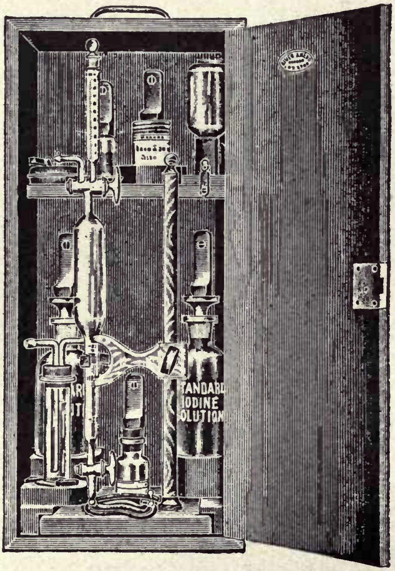

Fig. 26.—Tutweiler test apparatus for raw gas.

The use of the apparatus is fully described in the directions accompanying it and needs no further comment. Tests may be made with it on the raw gas in all stages of purification and valuable information gained, as will be discussed in the sections of this book devoted to the purifying house.

Spent Oxide.—A rough method of estimating sulphur in spent oxide is given below. This test will show tar and sulphur together and is rendered inaccurate in proportion to the amount of tar present. For most purposes where comparative results only are desired, it is sufficiently accurate.

To make this ground-glass test, set up a Soxhlet apparatus, after well greasing the ground-glass joints. Now fill the apparatus with enough carbon tetrachloride to secure good operation. Weigh out a dry capsule, fill it with oxide and weigh again. Transfer it to the Soxhlet apparatus and heat the flask with a small flame over wire gauze. Carry the distillation along until the liquor comes over perfectly clear. Then remove the capsule and dry at 212°F. Meanwhile, distil off the liquor in the flask but do not carry the distillation too far as that will make it almost impossible to clean the flask without breaking it. Weigh the dried oxide and capsule and calculate the loss in weight of the oxide, which will represent the tar and sulphur, which should be reported as a percentage. Fig. 27]

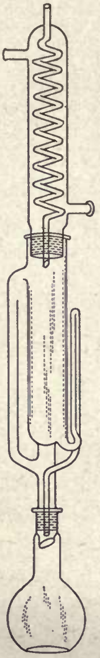

Fig. 27.—Soxhlet apparatus for extraction of sulphur.

The following method is recommended where great accuracy is required, such as, for instance the analysis of material offered for sale for its available sulphur content. One gram of finely ground oxide is dried at 212° for 1 hr. and transferred to a 250 c.c. flask. One and one-half grams of sodium cyanide and 50 c.c. absolute alcohol are added and the whole boiled under a reflux condenser for 3 hr. (Fig. 28). Distil off the alcohol, add 100 c.c. of hot water and wash in a 250-c.c. flask. Make up to the mark. To 25 c.c. of this solution is added 75 c.c. of water and 5 c.c. of saturated iron alum solution. Heat with constant stirring to 200° and filter into a 75-c.c. beaker and wash free from thiocyanate. When cool add 5 c.c. of strong nitric acid and put it into a 500-c.c. flask and make up to the mark. Empty out into a large beaker and run in N/20 silver nitrate solution until the red color of ferric thiocyanate disappears. Or add an excess of the silver and run back with N/20 thiocyanate. 1 c.c. N/20 $AgNO_3$ = 0.0008 gram of sulphur.

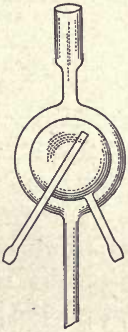

Fig. 28.—Reflex condenser.

Cyanogen.—The residue from the extraction of tar and sulphur may be used for the test. Slightly warm it with a dilute solution of caustic soda, cool and make up to 500 c.c. Take 50 c.c., make it slightly acid with HCl, warm and add dilute ferric chloride to precipitate cyanide. Wash the precipitate by decantation and finally filter and wash free from chlorides. Dry, ignite and weigh as Fe_2O_3. The weight of the iron oxide equals the Prussian blue present. The iron present in the Prussian blue is permanently incapable of sulphur removal and the Prussian blue also acts as a coating over the rest of the oxide.

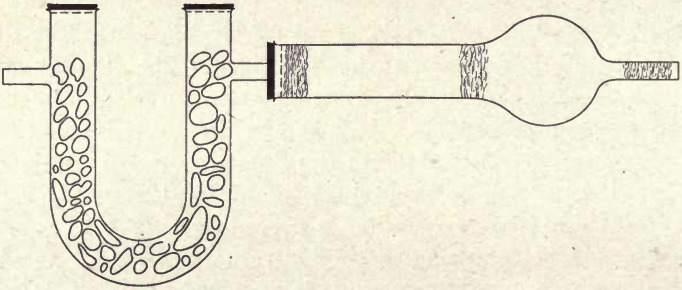

Fig. 29.—Apparatus for Kunberger test.

Efficiency of New Oxide.—The following method is original with A. F. Kunberger. The principle of the method is to determine the increase in weight when a current of H_2S is passed over oxide in a tube. The water formed is absorbed in $CaCl_2$ in a bulb on the same tube (Fig. 29). Fill the bulb of a tube with a calcium chloride and put a plug of cotton at the opening of the large tube into the bulb. Weigh accurately 5 grams of the pure iron oxide and mix with 2 grams of coarse sifted sawdust. Fill this into the large tube and plug the end with cotton. Plug the end of the little tube with cotton. Now quickly weigh the whole. Fill a U-tube with $CaCl_2$ and connect one limb to the raw gas supply and the other to the large tube of the $CaCl_2$ outfit. Now pass raw gas for an hour. The U-tube will remove all moisture from the gas and the H_2S will be decomposed by the oxide forming water which will be caught by the $CaCl_2$ in the bulb. The flow of gas should be reduced by a capillary to a small amount. The weight of moisture formed is equal to the H_2S decomposed. Thus by weighing the tube and subtracting the first weight the amount of H_2S decomposed by the 5 grams of oxide will be known.

In case it is desired to test the efficiency after revivification the oxide and $CaCl_2$ should be placed in separate tubes (to be weighed together). After fouling and weighing, the oxide tube is disconnected and revivified by a current of air, saturated with moisture by bubbling through water, to prevent heating. Repeat as often as it will become active.

GAS ANALYSIS

For ordinary simple tests about the plant some one of the modifications of the Orsat apparatus may well be used (Fig. 30). For accurate work in the laboratory, however, no apparatus has yet displaced that of Hempel, although the excellent systems of Elliott, Morehead and others are much used. The Hempel system is easy to operate and in practised hands will give an accurate complete analysis in an hour's time (Fig. 31).

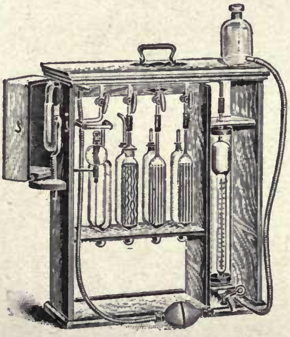

FIG. 30.—Orsat-Muencke apparatus.

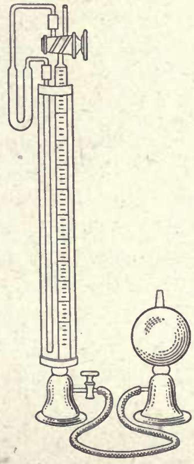

FIG. 31.—Hempel burette.

Hempel Apparatus.—This apparatus consists of a 100-c.c. burette, graduated into 1/5 c.c., inclosed in a water jacket, also inclosing an equalizing tube connected by the two-way cock to the burette. In addition to the burette single pipettes for carbon dioxide and illuminants are required, also double pipettes for carbon monoxide and oxygen and an explosion pipette for methane and hydrogen. A wooden stand should be made to hold the pipettes at a convenient height to connect with the burette. With the explosion pipette an induction coil capable of giving a 1/4-in. spark is used, operated by a dry battery, to produce the explosion. Wires are run from the secondary terminals to the little platinum wires set in the neck of the bulb;

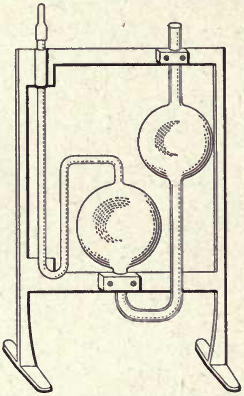

Fig. 32.—Single Hempel pipette.

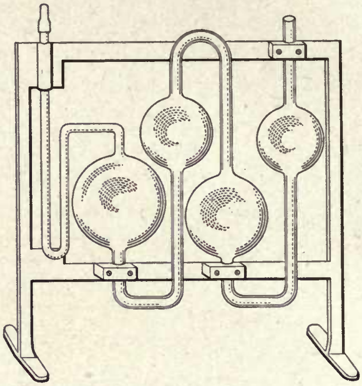

Fig. 33.—Double Hempel pipette.

and closing the primary circuit causes a stream of sparks to pass the gap between the wires. Glass containers of 250-c.c. capacity are used to collect and keep samples of the various gases.

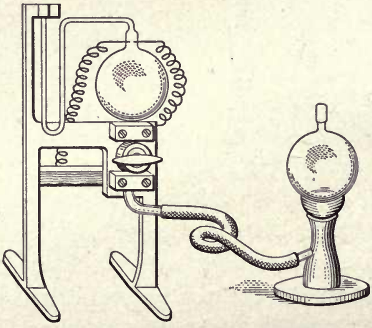

Fig. 34.—Explosion pipette.

Solutions Required.—For absorption of carbon dioxide, dissolve 150 grams of KOH (not purified by alcohol) in 500 c.c. of water; 1 c.c. of this absorbs 40 c.c. of CO_2.

A saturated solution of bromine in water is used to absorb illuminants. Bromine must be handled with the most scrupulous care. The smallest drop falling on the skin will cause a painful ulcer. It should always be handled out of doors when making up solutions on account of the poisonous fumes.

For oxygen a solution of 150 grams KOH and 25 grams potassium pyrogallate in 500 c.c. of water is used; 1 c.c. of this absorbs 2 c.c. of oxygen.

The cuprous chloride solution used to absorb CO is difficult to make and capricious in use. The author has found the following method, the simplest way of making the solution and when taken in connection with the method of using the CO pipette it will give good results. Make up a solution of equal parts concentrated HCl and water and slowly dissolve with constant stirring all the pure dry cuprous chloride it will take. Place a bundle of copper wires in a bottle so as to reach clear to the top and pour the brown liquid into the bottle until it is completely full, then crowd the stopper in tightly on the wires and set away in a dark place. The solution must not be used until the brown color clears up and it is a clear white or straw color. This always takes some time and frequently it will not take place.

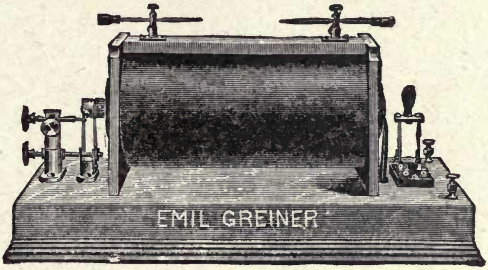

Fig. 35.—Induction coil for producing spark.

The pipette in which this solution is used must have about 200 little copper coils in the bulbs, which are easily made by winding No. 22 wire around a stirring rod and then cutting the coil into ¼-in. pieces and working them around into the bulbs. The clear solution should be introduced into the pipettes by a funnel attached to the large glass tube on the end bulb. It is not easy to fill these pipettes with the liquid and get it evenly distributed to the first and second sets of bulbs but it can be done with care. If desired, the second set of bulbs can be filled with water, dilute acid or old copper solution. Its purpose is simply to exclude oxygen. The solution may turn brown when filling the bulbs but it will clear again in a short time. Two of these pipettes are always used, the first containing used solution and the second, one which is very nearly new, to absorb the last traces; 1 c.c. absorbs 4 c.c. CO.

A record of the absorptions for each pipette ought to be kept so that one will know just how old each of them is and have new ones made in time to avoid errors from weak solutions.

Filling the Burette.—To obtain a sample for a test, proceed as follows: If the gas to be tested is piped into the laboratory, connect a rubber hose to the gas jet, turn it on and let it blow for a minute to get rid of air, then connect it to the burette, open the cock and lower the bottle, allowing the water to return to the bottle and the gas to take its place. Allow about 110 c.c. to run in, then shut off the gas and remove the tube. Raise the bottle and put pressure on the gas, then close a pinch-cock on the rubber tube. Now open the burette cock and by gently pressing the pinch-cock let the water flow into the burette displacing the gas until the bottom of the meniscus just touches the 100-c.c. mark. Shut the cock and there will be 100 c.c. of gas measured at atmospheric pressure. If using the equalizing tube, one must make communication with it through the burette cock and adjust the volume of gas to 100 c.c. when balanced against the pressure in the tube. This equalizing tube is for the purpose of having a standard of comparison for pressure that will not change during the test. The temperature will not change much if the water jacket is filled. The use of the equalizing tube is limited to very accurate work and for ordinary laboratory tests is not needed.

In transferring samples from gas containers they should be connected to aspirator bottles and forced into the burette under a slight pressure. In taking samples into the burette take great pains to have all capillaries filled with water to exclude air. The absorptions are carried out as follows:

Carbon Dioxide.—Attach the caustic soda pipette and pass the gas into it. Detach the pipette from the burette, closing the pinch-cock and shake gently for 3 min. Return the gas to the burette, taking great precautions against admission of air when connecting to the burette and after letting the burette drain for 30 sec., bring the level of the water in the bottle up to the level of the water in the burette and read. The absorption should be complete in the 3 min. and the shrinkage be credited to carbon dioxide.

Illuminants.—Attach the bromine water pipette to the burette and pass the gas into it and shake for 10 min., then return to the burette. Pass into the caustic soda pipette and without detaching shake gently to remove fumes. Now return to the burette and measure, then absorb in the bromine water again and after 5 min. make a final absorption of the fumes in the caustic soda pipette and a final measurement. The two readings should agree within ⅕ c.c. but two absorptions are often required to get all the illuminants. The shrinkage is credited to illuminants which are often assumed to be 20 per cent. benzine and 80 per cent. ethylene in coal gas.

Oxygen.—Next pass the gas into the pipette containing the potassium pyrogallate solution and shake for 10 min. Measure and credit the shrinkage to oxygen.

Carbon Monoxide.—The oldest cuprous chloride solution should first be used for an absorption of about 10 min. followed by a 5 min. absorption with a perfectly fresh solution, to remove the last traces of CO. Some writers advise reabsorption in the caustic pipette to remove vapors of HCl. The absorption of CO is never quite complete but if carefully carried out with clear solutions it will give results of practical value.

Methane.—Pass the gas remaining from the last absorption, called the "residue," into the CO pipette, then withdraw about 12 to 15 c.c. of it into the burette, measure accurately and after detaching the pipette draw in enough air to make the total volume about 100 c.c. Raise the aspirator bulb on mercury explosion pipette and fill the bulb full of mercury including the capillary and rubber tube. Connect up to the burette and pass the mixture of gas and air into the bulb, allowing the water to enter the capillary on the bulb as a seal. Wire on to the rubber connection, then shut the screw pinch-cock, equalize the level of the mercury in the two bulbs and pass the spark. There will be a flash and a chugging sound. Quickly transfer to the burette and allow it to cool 3 min. Measure, transfer to the caustic pipette and absorb the CO_2 formed, then remeasure. The calculation may be made as in the following example:

Residue from absorption	82.0 c.c.
Gas used for explosion	13.2 c.c.
Volume of air introduced	86.4 c.c.
Total volume	99.6 c.c.
Residue after explosion	78.0 c.c.
Residue after CO_2 absorption	73.2 c.c.
Carbon dioxide formed	4.8 c.c.
Contraction 99.6 − 78.0 =	21.6 c.c.

The carbon dioxide formed is equal to the methane present in the 13.2 c.c. of gas, thus there were 4.8 c.c. of methane. Then:

$$13.2 :: : 82 :: 4.8 : x$$

$$x = 29.8 \text{ per cent. methane}$$

Hydrogen $= \frac{2}{3}(C - 2C_1)$

C = contraction from explosion

C_1 = contraction from CO_2.

Then:

$$H = \frac{[2 \times 21.6 - (2 \times 4.8)]}{3} = \frac{24}{3} = 8.$$

Therefore:

$$\frac{8 \times 78 \times 100}{13.2} = 47.3 \text{ per cent. hydrogen.}$$

Nitrogen is always estimated by difference. The percentages of the other gases are added up and subtracted from 100, the amount remaining being credited to nitrogen, as for example:

	Per cent.
Carbon dioxide	2.9
Illuminants	7.8
Oxygen	0.5
Carbon monoxide	6.0
Hydrogen	47.3
Methane	29.8
	94.3
Nitrogen	5.7
	100.0

Calorific Values.—Calorific values may be calculated from analyses, the following values being used by several authorities for the various constituents:

	B.t.u. per cubic foot at 60°F. and 30 in. pressure
Carbon monoxide	325
Hydrogen	328
Benzine	3,732
Methane	1,016
Ethylene	1,621
Ethane	1,772
Acetylene	1,502
Illuminants	
28-cp. water gas	2,550
24-cp. water gas	2,412
20-cp. mixed gas	2,370
16-cp. coal gas	2,308

The following example of a heating value calculation uses the figures of the foregoing gas analysis. The illuminants are assumed to be 20 per cent. benzine and 80 per cent. ethylene.

7.8 × 0.20 = 1.56 per cent. benzine.
7.8 × 0.80 = 6.24 per cent. ethylene
Ill. 0.0156 × 3,732 = 58.11
0.0624 × 1,621 = 101.15
CO 0.06 × 325 = 19.50
H 0.473 × 328 = 155.14
CH_4 0.298 × 1,016 = 302.76

Total B.t.u. per cu. ft..........636.66

Ammonia in City Gas.—Tests should be made on the finished gas to check the results of city or commission inspection. In a well-operated plant, no more than the merest traces of ammonia should be allowed to escape the scrubbers. The method used depends on the absorption of the ammonia from the gas by an acid solution. This acid solution is made up by adding 1.25 to 1.50 c.c. of pure concentrated sulphuric acid to some distilled water and making up to 2,000 c.c. in a graduated flask. Measure out in a pipette 50 c.c. of this solution, dilute to 250 c.c. with distilled water and add 10 per cent. barium chloride solution to the boiling acid with the usual precautions for a barium sulphate precipitation (see page 57). The weight of $BaSO_4$ in grams times 2.25 divided by the number of cubic centimeters of acid taken, gives the grains of ammonia equivalent to 1 c.c. of the acid.

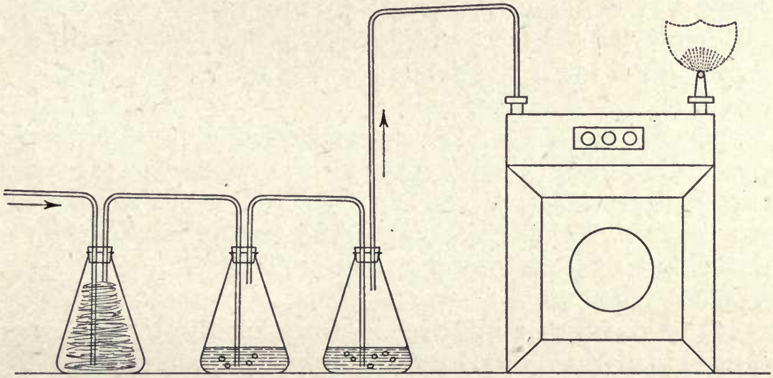

FIG. 36.—Apparatus for testing ammonia in gas from scrubbers. May be used on city gas.

A solution of 1.8 grams of sodium hydrate in 2 liters of water should be made up and checked against the acid to determine its strength and acid equivalent.

Cochineal is used for the indicator, made up by grinding 3 grams with 250 c.c., 25 per cent. alcohol and filtering. This solution changed from brownish rose to lilac and the end point is sharp.

Set up a train of two wash bottles with ground-glass joints and put 25 c.c. of the acid solution in each (Fig. 36). Pass the gas through them, followed by a test meter such as is used on a photometer or calorimeter. The gas should pass at the rate of about 0.6 to 0.7 ft. per hour for 5 hr. At the end of this time disconnect, add the indicator and titrate back with the alkali solution, determining the number of cubic centimeters of acid used up by the ammonia. Multiply this by the factor for the solution giving the number of grains NH_3 in the amount of gas tested, from which the grains per 100 cu. ft. may easily be found.

Total Sulphur.—The Referees' apparatus is most commonly used for this test. The trumpet tube and tubulure on the tower must be connected by a cork only and not by rubber in any way, as the latter will introduce error. The small glass outlet tube in the bottom of the tower should project up into the vessel about ¼ in. to cause a layer of liquid to protect the stopper. A coil of glass rod should replace any kind of metal screen or plate in the bottom of the tower, to support the marbles.

Before making a test, purge out the meter and all connections up to the burner, by burning at least 5 ft., of gas through an ordinary bunsen burner, replacing the regular lava-tip burner. When all connections are purged and the water in the meter saturated with the gas, set up the tower, etc., connect and light the burner, surrounding the stem with as much crystallized ammonium carbonate as it will carry and wet the marbles in the tower with distilled water. Now read the meter and at the same moment slip the burner into place. The gas should be burned 10 hr., replacing the ammonium carbonate once. Close check on the meter readings at the start and end of the test should be made and for extreme accuracy, a correction made for temperature and barometer readings.

After the apparatus is cool, flush out the trumpet tube with 50 c.c. of water and the tower with four portions of 50 c.c. water each combining the whole in one 500-c.c. beaker. Add a couple of drops of methyl orange and add 1:1 hydrochloric acid until the last drop just neutralizes the solution, finally adding 2 c.c. of the acid in excess. Heat to boiling and add 10 c.c. of 10 per cent. barium chloride, boil 5 min., allow to stand on a steam bath 1 hr., filter, wash free from chlorides, dry, ignite and weigh as $BaSO_4$. Multiply the weight of $BaSO_4$ by 0.1374 giving weight of the sulphur. A simple proportion will give the grams per 100 ft. Multiply by 15.43 to convert into grains.

Hydrogen Sulphide.—It is worth while to make a test every day on the city gas for traces of hydrogen sulphide. Two tests may be used, the official and the continuous. The Bureau of Standards recommends exposing the moist lead paper to the flow of gas for 1 min., the gas flowing at the rate of 5 ft. per hour.

The continuous test is very delicate. The paper is exposed for 24 hr. to a flow of ½ cu. ft. of gas per hour. Both tests can be made in very simple apparatus. Take a 4-in. length of ¾-in. glass tube and insert a rubber stopper in one end bored to fit an ordinary burner pillar. Fix a stopper in the other end carrying a glass tube with a constricted opening and on the inside a pin bent into a hook on which to hang the moist paper. The lead paper is ordinary filter paper cut into strips and dipped in 10 per cent. lead acetate solution, held over strong ammonia for a moment and then dried and kept in a glass-stoppered bottle. Just before use it is moistened with distilled water.

Naphthalene.—The test for naphthalene is important for several reasons. Its presence in water gas is an indication of too high a heat in the machine and in coal gas it indicates too high heat in the retorts also irregular or under charging. Make up a saturated solution of picric acid in distilled water and fill a test-tube half full of the solution. Connect to the gas supply a rubber tube terminating in a glass tube about 6 in. long. Insert the glass tube in the solution and bubble the gas through it. Gas containing naphthalene will produce yellow crystals which are like long yellow needles. Some idea of the relative amount of naphthalene may be had by noting the rapidity with which the crystals form. If there is a large amount present, the crystals form instantly. Numerous tests should be made throughout the 24 hr.

CHAPTER III

COAL GAS

The following pages are devoted to the operation problems peculiar to coal-gas production.

GAS COALS

Typical Gas Coals.—The following table illustrates what may be considered as typical gas coals.

TABLE V.

State	Pennsylvania	West Virginia	Kentucky	Ohio	Oklahoma
Coal	Pittsburgh	Fairmont	Straight Creek	Hocking Valley	Hartshorn
Moisture	1.07	1.35	1.92	6.72	3.87
Volatile matter	39.24	36.92	36.56	37.13	35.73
Fixed carbon	50.92	55.36	57.08	50.32	50.05
Ash	8.77	6.37	4.44	5.83	10.35
Carbon	82.47	78.31	78.31	69.42	69.85
Hydrogen	6.01	5.26	5.36	5.35	5.14
Oxygen	6.81	7.61	8.80	16.27	11.38
Nitrogen	1.88	1.55	1.85	1.46	1.29
Sulphur	2.83	0.90	1.24	1.67	1.99
Heating value	15,353	14,164	14,319	12,388	12,620
Column	B	C	C	A	C

A-LORD and HAAS.
B-HALE and WILLIAMS.
C-Report Fuel Testing Plant U.S.A.

Results to be Expected.—The coal from the Pittsburgh bed has been regarded by many as the standard of gas coals, and a representation of results obtained by careful tests is of value in comparing individual works results. A. H. White in his *Bulletin on Coals for Illuminating Gas*, reported a test on Pittsburgh coal and the results of this test are instructive. This coal was obtained from the Ocean Mine No. 2, at Scott Haven, Pa. and was run over a ¾-in. bar screen*.

AVERAGE OF TESTS OF PITTSBURGH COAL

	Per cent.
Coke, per cent. of coal charged	67.07
Gas, per pound of coal charged	5.04 cu. ft.
Candlepower, approximate average	15.50
Candle feet per pound coal	79.50
Heating value per cubic feet	641.00 B. t. u.
Heating value per pound of coal	3,280.00 B. t. u.

Gas analysis	Per cent.
Carbon dioxide	1.30
Illuminants	3.70
Oxygen	0.80
Carbon monxoide	6.50
Methane	34.40
Hydrogen	48.20
Nitrogen	5.00
Ammonia (NH_3) per ton of coal charged	5.43 lb.
Tar per ton of coal charged (pounds)	155.80

The average results obtained in regular practice at the works of the Ann Arbor Gas Co., with a coal from the same general district were:

Coke	67.8 per cent. (8.6 per cent. breeze)
Gas per pound	4.95 cu. ft.
Candlepower	16.9
B.t.u.	617

The following results are taken from test No. 19 in the *Bulletin*, on this coal.

COAL AS RECEIVED

Moisture	2.18
Volatile matter	32.96
Fixed carbon	57.33
Ash	7.53
Sulphur	1.43

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*Bulletin. No. 6, U. S. Bureau of Mines.

In a 4.8-hr. burn, a 400-lb. charge of this coal worked off with results as below,

Yield of gas	4.90
B.t.u. of gas	649.0
Candlepower	15.2
Carbon dioxide	1.2 per cent.
Illuminants	4.4 per cent.
Oxygen	1.1
Carbon monoxide	6.6
Methane	37.9
Hydrogen	42.2
Nitrogen	6.6
Tar per ton	10.7 gal.
Ammonia per ton	5.8 lb.
Coke per ton	67.5 per cent.

Another test on this coal showed 830 grains of hydrogen sulphide per 100 cu. ft. at the outlet of the scrubbers. For further information on these tests the reader is refered to *Bulletin No.* 6, *U. S. Bureau of Mines.*

It is not unreasonable to accept the foregoing figures as being a fair representation of results possible with ordinary benches using a grade of coal equal to that of the tests. With the exception of the yield of ammonia there is nothing unusual in the results as compared with good practice in gas works. Some very remarkable results have been obtained in the modern types of machine operated and chamber oven plants, but these are outside the scope of this description.

Selection of Gas Coal.—The superintendent has, as a rule, very little choice in the purchase of gas coal but he should insist on the right to test each car of coal which is new to the plant before any certain grade is finally accepted. Even where local conditions govern absolutely the kind of coal to be used, considerable testing ought to be expected before accepting the coal for contract. It is hardly possible to get tests on less than a 24-hr. run of coal. The coal should be unloaded by itself and kept separate until used up.

Testing.—In making a test of a new coal have the coal carefully sampled and analyzed as described under coal analysis. Start the test early in the morning charging the new coal until all benches have been charged with it and none of the old coal is still in the retorts. Now allow 4 hr. to elapse and then read the station meter. From now on check the weight of coal into the retorts with great care. If possible have enough coal for a run of 24 hr. from this point. At the end of 24 hr. or soon after charging the last of the coal, read the meter again, the difference being the uncorrected gas made by the weight of coal burned off in that period.

The coke from several of the retorts at intervals throughout the time, should be drawn into a tared buggy and just enough water thrown on to barely quench the fire so the buggy can be handled and drawn over the scales. Weigh up the coke from at least ten charges and average the amount made per ton. Note carefully how well burned the charges are and their effect on the heats. After weighing completely quench the fire in the coke, then dump at one side and after it has air-dried, fork or screen it to get the amount of breeze it contains. After all the retorts have been working on the new coal for 4 hr. start drawing an average sample of the purified gas into a little holder such as is used in the laboratory for getting samples for the calorimeter. Have a complete analysis made of the gas drawn from the main during a period of several hours. If enough gas is collected a B.t.u. test should be run on it also and by all means several B.t.u. and candlepower tests should be made during the run with the coal.

Several tests should be made with a Tutweiler apparatus for hydrogen sulphide on the gas entering the secondary condenser and also entering the purifiers. If the H_2S is high it might be well to run a test on the fixed sulphur in the finished gas. The ammonia in the gas is rather hard to determine. Samples can be aspirated from the standpipes or the foul main, through measured volumes of acid and the grains per 100 cu. ft. calculated to pounds per ton. Of course, samples from the foul main will omit the ammonia removed by the hydraulic main. Likewise, the samples from the standpipes will represent individual charges only and would need to be made continuously through the carbonizing period to get average results. Another method of checking the ammonia is to shut down the still, measure the liquor wells and analyze a sample, calculating the pounds on hand. After the test is stopped measure the wells again, sample and calculate the pounds on hand. The gain will represent that made by the coal. If the bulk of crude in storage is large compared with the amount made in 24 hr. there is a good deal of chance for error. The tar made is found by measuring the wells before and after the test run of coal.

Following is given a standard form for reporting tests on gas coals:

TEST OF ——————GAS COAL

Received from———————————— Date of Test————————————

Coal carbonized in tons..
Average charge per retort..
Gas made, corrected..
Gas yield per pound..
Make per bench, 24 hr..
B.t.u. of gas, avg..
Candlepower, avg..
H_2S inlet condenser..
H_2S inlet purifiers..
Tar made per ton, gallons..
Ammonia made per ton, pounds..
Coke made per ton, pounds..
Breeze, per cent. of coke..
Action in retorts..

Coke, general considerations.

Gas analysis:
    Carbon dioxide..
    Illuminants..
    Oxygen..
    Carbon monoxide..
    Methane..
    Hydrogen..
    Nitrogen..

BENCH OPERATION

Theory of Furnace.—To properly understand and operate gas benches it is necessary to have some idea of the chemical action that takes place in the furnace. This action varies somewhat according to whether coal or coke is used but the fundamental principle is the same, namely the gasification of the fuel. In the process the fuel bed is divided into zones. Care must be taken that the fuel bed is deep enough with active fire to cause the reactions to take place (Fig. 37).

Starting at the grate bars, is the zone of ash and clinker. There is no combustion in this zone as the material is mostly red hot clinker and dead ashes. The hot clinker serves to heat the primary air and steam as they rise through it. Hot coals dropping from this zone are quenched in the water of the ash pan, forming steam which rises through the fire. The depth of this zone will vary wide the length of time since clinkering.

Directly above the ash is the combustion zone. There is a complete combustion of coke here, as the air comes into contact with the red-hot coke. The carbon burns to carbon dioxide according to the simple formula:

$$C + O_2 = CO_2$$

The combustion is practically complete as the air is present in excess but not absolutely so as the air passes rapidly over the coke and incomplete combustion takes place to a small extent.

$$2C + O_2 = 2CO$$

The third zone is the gas-producing or reduction zone. The CO_2 formed in the first zone passes over an excess of red hot carbon and is reduced to a combustible gas, as below:

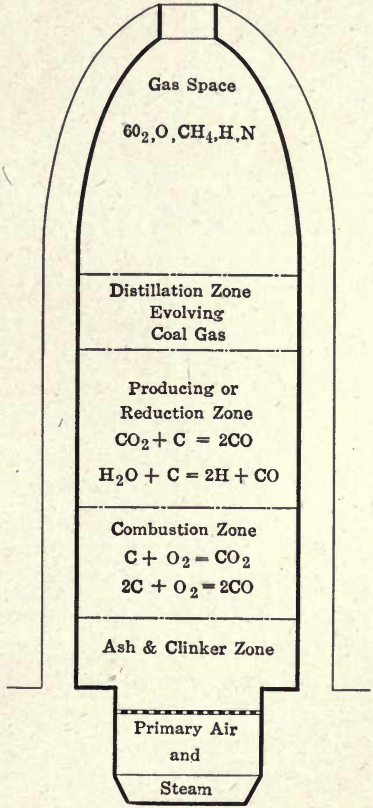


FIG. 37.—Diagrammatic representation of zones in a bench producer.

$$CO_2 + C = 2CO$$

The combustion in the second zone produces great heat which causes the reduction zone to acquire a temperature great enough for active reduction. This reduction is a reaction requiring time as well as contact, which means that this zone must not be too shallow, or the flow of gases through the fire too rapid. The steam produced by the evaporation from the drip and ash pans, or blown under the grate is very highly heated in passing through the first two zones and on reaching the reduction zone it reacts as follows:

$$H_2O + C = H_2 + CO$$

There must be a considerable excess of carbon for the above reaction to take place and its temperature must not be below 1,800°F., that is, a clear red color. Decomposing the steam takes heat from the fire and therefore it must be carefully limited. Under no circumstances will the use of steam cause a gain in heat; the steam will always chill the fire. It softens the clinkers and protects the grates and also adds hydrogen to the producer gas which makes a better and hotter producer gas. While the use of steam produces no additional heat it serves as a way of getting more heat up into the setting around the retorts where it is wanted.

On top of the production zone there is usually some green fuel which gives to it the name of distillation zone, as the heat of the fire distils any moisture or gas that may be present in the fuel. As the time approaches for a fresh fire this zone disappears and merges with the reduction zone.

Composition of Producer Gas.—The composition of the gas issuing from the nostrils of the producer furnace naturally varies a great deal according to the condition of the fire, amount of steam and character of the fuel. If soft coal is used to heat the bench the gas will have a composition approximately as follows, at a time midway between firings:

	Per cent.
Carbon dioxide	4.0
Oxygen	0.5
Methane	3.0
Carbon monoxide	27.0
Hydrogen	10.0
Nitrogen	55.5

The percentage of carbon dioxide is an indication of the condition of the fire. If an excess of steam is used the fuel bed is unduly cooled and the following action takes place:

$$2H_2O + C = CO_2 + 2H_2$$

An excess of carbon dioxide will then be produced. Likewise if the producing zone of the producer is too shallow the following takes place:

$$C + O_2 = CO_2$$

That is, carbon burns directly to carbon dioxide. This reaction takes place in a small degree but still enough to affect the composition. However, if the reducing zone is too shallow a more serious action is the failure to properly reduce the carbon dioxide produced in the combustion zone with the result that a large percentage of CO_2 leaves the zone and passes out to the setting.

The oxygen is always a small percentage and is simply the amount that passes the fuel bed without entering into any reaction. The methane is distilled from the coal in the distillation zone and is present in the greatest amount shortly after firing and is reduced to little or nothing before the time for the second firing. The hydrogen comes in part from the distillation zone but mostly from the decomposition of the steam.

With coke for fuel the analysis is a little different being represented by the following:

	Per cent.
Carbon dioxide	3.5
Oxygen	0.5
Methane	0.0
Carbon monoxide	29.0
Hydrogen	9.0
Nitrogen	58.0

As the coal gas has been already removed from the coke, very little hydrogen and no methane are distilled in the upper part of the fire.

Depth of Bench.—A bench may be rated as a quarter, half, three-quarter of full-depth bench. Different manufacturers attach different meanings to these terms and have never agreed on standard definitions. Generally speaking the depth of a bench is regulated by the depth of active fire but the recuperation may be more or less. In some benches three-quarter depth furnaces are built with half-depth recuperators, etc. In buying benches, therefore, it is never safe to accept any bid on a bench without full knowledge as to the relation of the recuperative surface to the size and capacity of the furnace.

Recuperators.—In the recuperators the air for combustion is heated before entering the fire or combustion chamber. The air passes in ducts over and around the waste gas flues and before entering the combustion chamber at the arch is supposed to have acquired very nearly, the temperature of the waste gases but practically it rarely reaches this point. The secondary air alone may be heated in the recuperators or both primary and secondary. The latter arrangement is not usual (Fig. 38).

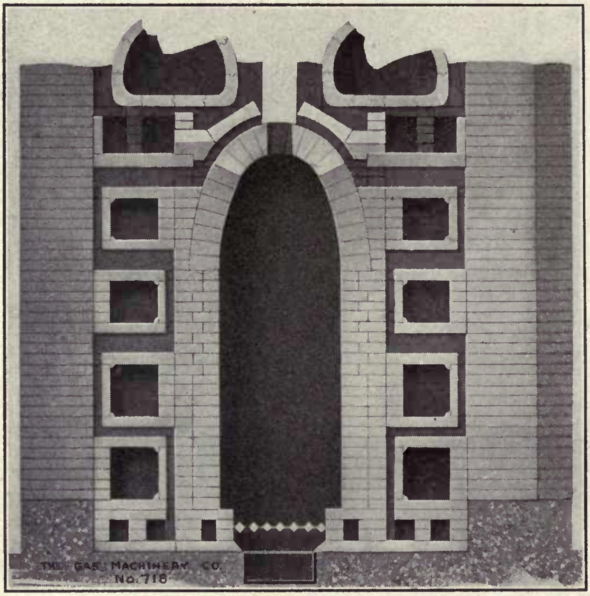


FIG. 38.—Square recuperator flues in half-depth bench.

Primary Air.—The air supplied below the fuel bed is called the primary air. The air enters a flue and is discharged from several ports in the ash pit, on both sides of the bench. This air mixed with the water vapor or steam rises through the fire and from it, and the coke the producer gas is formed.

Secondary Air.—The producer gas issuing from the fire and entering the bench through the nostrils requires a certain amount of air to complete its combustion to CO_2. This air enters a duct at the bottom of the recuperators and rising flows around and over the waste gas flues, becoming highly heated in so doing and carrying back to the furnace a large part of the heat of the waste gases. Issuing from the secondary air ports, each one opposite a gas nostril, it unites with the producer gas in vigorous combustion. Only just enough secondary air should be admitted to insure complete combustion. Too much air cools the bench. When a bench is old and beginning to break down, the secondary air often short-circuits into the waste-gas flues and therefore never gets into the setting, causing incomplete combustion with consequent poor results. This is a condition hard to cope with. Sometimes by shutting down the bench, it can be patched up and the leak stopped. If there are many small cracks that can be seen, they can be stopped with a wash of thick fire clay.

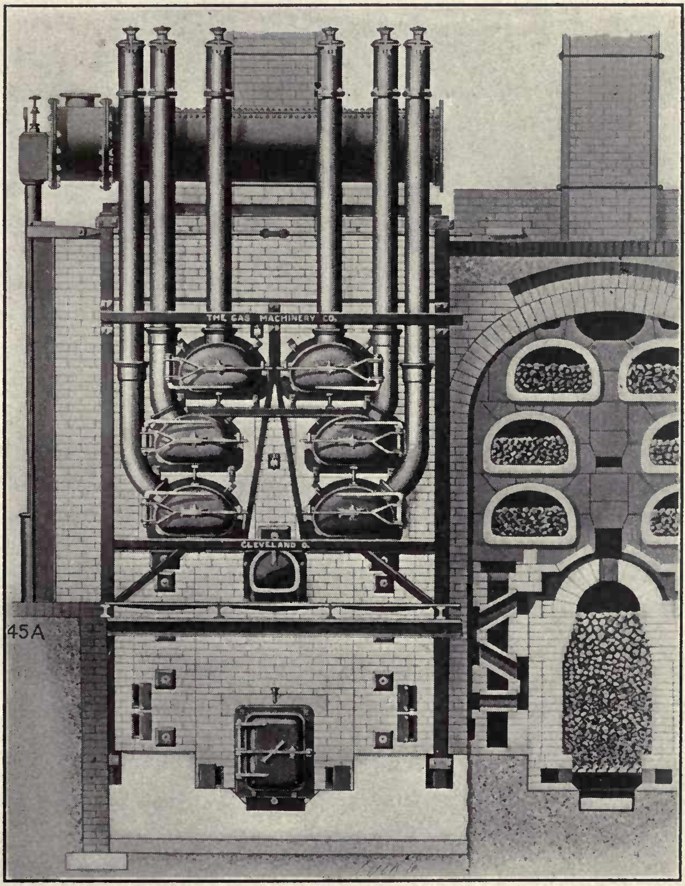


Fig. 39.—Elevation of half-depth bench showing flues and recuperators.

Setting Air Slides—Practical Rules.—First, the flue damper should be adjusted so that there is neither a pressure or a vacuum in the combustion chamber and only a very slight vacuum when the firing door is opened. The ideal condition is such that when a handful of coal is thrown in the firing door the resulting flame will be sucked back and forth. At a time midway between firings there should be a slight pressure at the sight hole in the middle of the bench. If one side of the bench is hotter than the other, the stack damper on the hot side should be pushed in.

The primary air registers should be opened far enough to insure a good active production of producer gas. The color of the fire should be bright but never a white heat. On opening the firing door when ready to fire up, each piece of coke should be visible on top of the fire and not obscured by a dazzling white heat, which would be an indication of overheating and probably too much CO_2 in the producer gas. The secondary air should be adjusted to afford enough oxygen to afford complete combustion at a time midway between firing. Just after firing the production of gas will be in excess of what the secondary air can take care of. This condition will soon pass away and combustion will be complete until a short time before firing. At this time there will be an excess of secondary air for a short period. To get the right adjustment the bench should be observed at a time halfway between firing.

Next the secondary air registers should be closed and after a few moments opened a little. In a short time a sight plug should be removed from a waste gas flue and note whether there is any flame in the top flue, putting a piece of glass over the hole. The secondary should be increased until the blue flame just disappears. There should be a little flame licking down into the top recuperator.

In half-depth benches there must always be a little color even in the bottom flues but in three-quarter or full-depth the bottom flues should be black. When the adjustment seems to be about right the slides should be wedged tight and the combustion chamber looked into. It should be slightly hazy in appearance, not clear. With an excess of secondary the inside of the chamber will appear clear and the air ports will show a darkening at the edges, where they open to the nostrils. There should always be considerable flame action at this point.

Setting by Flue-gas Analyses.—The tests should be made as described under chemical control. When one first begins to make analyses of bench-flue gases, a good deal of disappointment is experienced. The results may not seem to be consistent, in fact, have very little meaning at all. A little practice, however, soon eliminates the feeling of uncertainty and the real value of the tests becomes apparent. The first consistent tests on a bench which seems to be in pretty good shape will probably be something like this:

CO_2 10 per cent.
O 10 per cent.

That is, the tendency is always to have too much secondary air. The first step, then will be to reduce it.

The register should be closed ⅛ in. and after 5 min. the gas tested again. This should be repeated until as close to 18 per cent. CO_2 as possible is obtained, without having a deficiency of oxygen. The surest way to settle the question as to whether the rule of thumb methods will give as good results as chemical tests, is to try it. Adjust the benches to the best possible efficiency and run for a week or so, keeping careful account of heats, coal carbonized and fuel used. Then reset the benches after making analyses and run for another period of a week. Nine times out of ten there will be an inprovement in results.

Firing the Furnace.—The furnaces should be fired with regularity. There is nothing that hurts a bench more than firing it in a haphazard fashion. About 200 lb. of fuel is all that ought to be fired at any one time. If using coal, a scoop with an extra long blade to shoot the coal back to the rear of the bench is advisable. Coke can generally be pushed back easily. It is not good practice to let the fuel pile up in front too much. If using coke arrange a chute so that the hot coke falling out of the retorts will slide right into the furnace and avoid quenching it. It is sometimes good practice to break up the fire from above every time fresh fuel is fired. This makes a very active fire and the draught must be kept down or the excess of fuel will be used. After the fuel is charged the door should be blocked up with lumps and a shovel full of wet slack thrown in to close the opening completely. This will protect the door and assist in keeping any draught from going in over the fire.

Clinkering.—Clinkering once in 12 hr. is often enough for any fuel but none too often even with good coke. With coke fires false bars are generally run in above the clinker to hold up the fire and then the clinkers cut out from below. With coal these bars are not always required. For cutting off side clinkers a heavy and sharp chisel bar is used and a two-pronged hook should be used to hook out the lumps. Clinker on the back wall is often very troublesome. Once in a while say, every 2 months all the fire should be pulled out of the bench, the grates removed and a thorough cleaning secured. Every bit of side and back-wall clinker should be chiseled off as rapidly as possible and the ash pan cleaned out. The stoker who is running the bench should do the work and not an extra man. When clean have the grates replaced and pull hot coke into the furnace until it is nearly filled, then finish filling with some cold coke.

Stack-draft slides, whether in the stack or built into the bench below, should be shut during clinkering to prevent a rush of cold air chilling the bench. The slides should be marked so as always to have just the same opening, before and after clinkering. The stokers should be firmly impressed with the necessity of getting off all side clinker every time they work on the fire and not allow them to get even a good start. Clinkering is a hard dirty, hot job and unless closely supervised will be slighted every once in a while with disastrous results.

Drawing and Charging.—Retorts should be opened for drawing the coke at exactly the scheduled time. When the lid is slacked off a piece of lighted paper or a red hot pipe should be held at the opening as the lid is lifted so as to ignite quietly the escaping gases and prevent any explosion. If the lid is swung quickly open the air rushes in and mixes with the gas and on lighting a loud bang results. This is likely to jar the setting and the noise is also somewhat demoralizing. Usually benches of sixes are handled so that three retorts at a time are drawn, from one side of the bench. Immediately after opening the lid the standpipes must be very thoroughly reamed out. A short handled augur, about 1 in. smaller in diameter then the standpipe should be used. After this has been made to work freely a ring or bell reamer of the same size, should be passed up as far as it will reach. No small reamers should ever be allowed on the floor. The big augurs should be passed every time the retorts are opened for charging and the men will then not be obliged to open the retorts during the coking time, with the consequent loss of gas and furthermore will not be able to take time off on a retort while having it burned out.

After reaming a pipe there is generally a mass of sticky tar and pitch on the mouthpiece. If one is particular about the appearance of the coke, this mass should be scraped off into a small wheelbarrow before drawing the coke. The retorts should then be drawn as rapidly as possible, pulling the hot coke into barrows or chutes. Only enough water should be thrown on to just quench the fire in the coke. It is very bad practice to drown the coke in an excess of water. As soon as every bit of the coke has been withdrawn from the retort the lid should be closed to hold the heat. If the coke barrow is large enough to hold two retorts of coke, the top and middle should be pulled into it and then it should be moved out of the way and the bottom retort pulled onto the floor or into the furnace as the case may be. When ready to charge the retorts the coal buggy, holding three charges of coal is pulled into position and the retorts rapidly charged, closing each lid as soon as the retort is full.

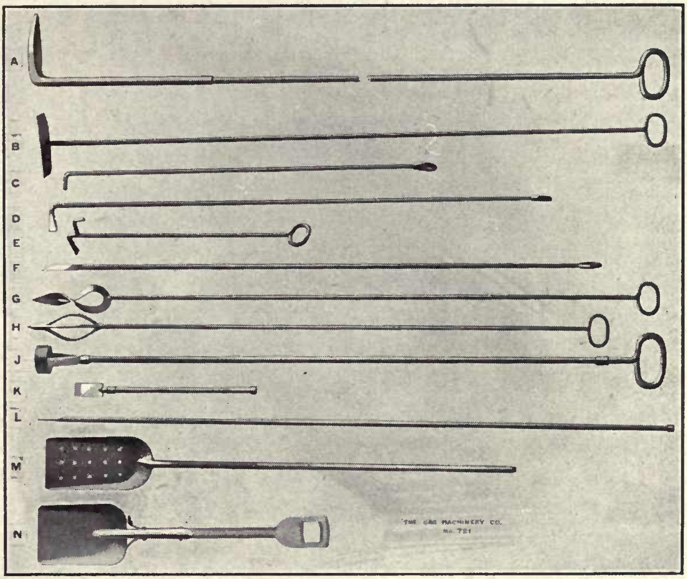


Fig. 40.—Retort house tools.

A, Coke rake, 15 ft. long. B, Hoe for coke or coal, 10 ft. long. C, Hook for coal stopper of inclined retorts. D, Clinker hook, 8 ft. long. E, Mouthpiece hook, 4 ft. long. F, Clinker bar, 9 ft. long. G, Bit auger, 10 ft. long. H, Basket auger, 9 ft. 6 in. long. J, Standpipe reamer, 10 ft. long, rod of 1 in. pipe. K, Mouthpiece Scraper, 3 or 6 ft. long. L, Coke tickler, 14 ft. long rod of ¾-in. pipe. M, Ash-pan scoop. N, Coal-charging scoop.

Sometimes, when the system accommodates such an arrangement two stokers draw and charge together, one drawing the top while the other draws the bottom. They charge together. This saves some time and is advocated by many operators. The charge of coal should be all that can be worked off in the carbonizing time and must be laid level from front to back, keeping the coal off the mouthpiece, where it will only cook into a sticky mess and not coke.

A well-burned charge will have very little flame or gas left in it and after the lid has been open for a minute it should be possible to see clear to the back end of the retort. The gas left in a well-burned charge is mostly hydrogen and this burns with a blue flame. Coal charged unevenly will leave large lumps of soft coke and consequently the yield per pound will be less. The coke on the thin spots will get overheated and the gas in traveling across it, will be deteriorated, the hydrocarbons forming lampblack and naphthalene. The stokers should be trained to get the coal well into the back end of the retort and also to pull the coke out absolutely clean. The stokers should be drilled until they have these details thoroughly perfected and then checked up frequently. A favorite trick of stokers is to weigh up the right amount of coal and then leave 20 to 50 lb. of coal in the buggy which cuts down the output of the bench and gives apparently low yields of gas and ammonia. This should be an offence and watched for closely. When the coal is dirty and flames pretty bad some stokers will throw a couple of pails of water over it, to kill the flame. This is a ruinous on heats and bad for the benches and should never be allowed. A good stoker should be able to draw and charge 1,100 lb. of coal into three retorts, in 10 elapsed min., where the coke is pulled into buggies or onto the floor. If a good stoker fails to do this he is either loafing, wasting effort or has not the right tools. Drawing rakes should be studied and the individual needs and requirements of the men catered to. Charging shovels for each man ought to be selected after repeated trials. There is not a very great range to select from but stokers are particular and one should see to it that they have the most efficient tools, if a high standard of performance is set.

To determine whether there is wasted effort in drawing and charging, a time study of the operation is very valuable. Two such time studies are illustrated on the charts (Figs. 41 and 42). The number of seconds required by each operation is shown by the vertical columns in each case. The first chart shows that 14.8 min. were used in drawing and charging the three retorts. The second chart shows the results after changes were made in the method of doing the work and the total time is cut to slightly over 10 min. Twenty seconds were cut off the

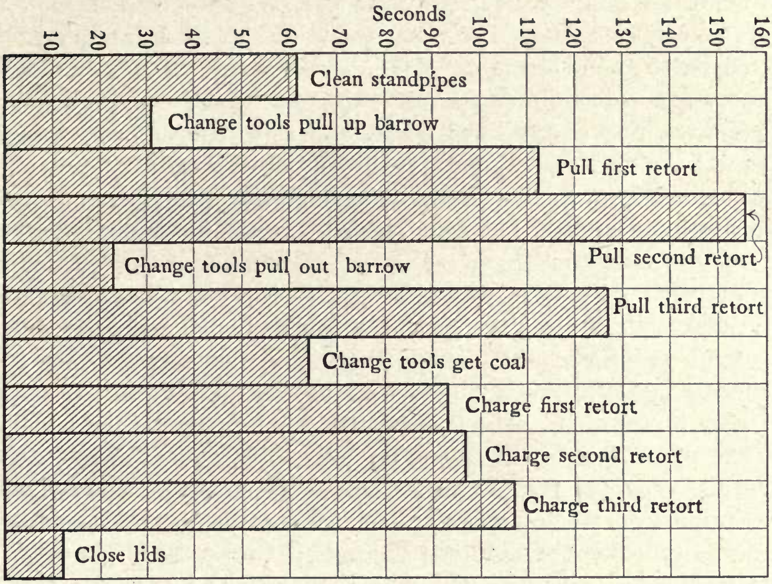


FIG. 41.—Chart illustrating time study on draw-and-charge operation.

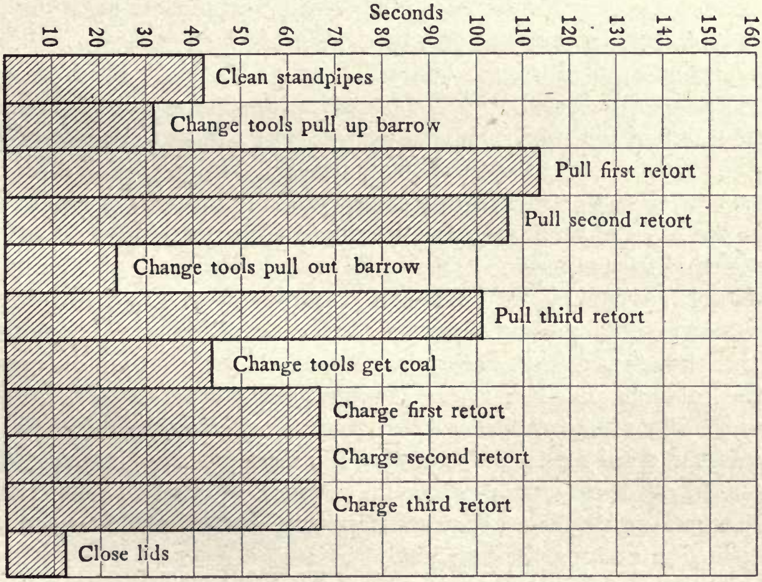


FIG. 42.—Chart illustrating time study on draw-and-charge operation.

time of cleaning standpipes by the use of better reamers and a systematic cleaning. The chart shows 30 sec. used in pulling up coke barrows and changing tools. This was known to be too high and was cut down in two ways. The men had to change reamers while reaming and walked 20 ft. and return after exchanging. Under the new scheme both reamers were brought up and one laid down next to the bench while the other was used.

The stoker pulled his coke buggy up to the bench leaving the handles *toward* the bench. Then when he was ready to pull the coke, with the retorts open, he went to it, *turned it around* and pushed it in against the bench. This was changed so that he turned the buggy around and placed it nearly in position *before* slacking off the lids. Then when he was ready for the coke buggy it was near, with the handles pointing in the right way. This cut off 20 sec. Too much time was taken in pulling the middle or second retort. This was because the stoker pulled his rake clear out from the top retort and let it fall to the floor and then had to raise it back to the middle. The practice was stopped, the stoker being taught to drop his handle and slide the rake out so that it did not fall down but entered the middle retort instead. This cut off 20 sec. and better methods of handling the rake 30 more. The third retort was pulled in the same time as the first, as it should be, cutting off about 28 sec. In the first case the stoker had pulled the coke in such a way as to block the front of the mouthpiece and he killed time and lost effort pushing this coke out of his way. He was shown how to keep clear of this. Allowing 30 sec. to cool off in the doorway in each case, 20 sec. was cut from the time used to change tools. The stoker had been in the habit of pulling his hot rake out of the way, hitting it with a sledge to straighten it then pulling up coke buggy, getting his shovel, getting his lid hook and returning to the bench. This was changed to pulling away the rake, and pulling up coal buggy. The shovel and hook were placed on the buggy before opening the retorts. An idle stoker straightened out the rake if necessary. By studying the stokers motions, an average of 35 sec. was cut off of the time of charging the three retorts, making 105 sec. in all, this being possible on account of wasted motion in charging and useless effort spent on trying to shut lids without carefully latching the bar first.

All these changes seem small and the saving in seconds pretty trifling but the final result is considerable. Suppose six benches of sixes are in use carbonizing 4 hr., there will then be made 72 rounds per day and a saving of 4 min. to the round will make 4 hr. and 48 min. every day added to the gas-making period.

In starting to make a study of the draw and charge operation, a good hot bench and your best stoker should be selected and he should be told just what is trying to be done and his interest enlisted. The studies should be made on all the benches after finishing with the first one and then all the results averaged. Individual tests are misleading as no two rounds can be exactly alike and some will necessarily take more time than others. After careful study take some number of minutes total time, as a standard, and require the stokers to come up to it. Heats should be closely watched and charges adjusted accordingly. If one bench is found to be extra hot, a little more coal should be charged or if the heat is down a little the stoker should be helped out with a little lighter charge and his fire cleaning supervised and the yield per pound will undoubtedly be improved.

For each bench should be reported exactly the coal carbonized by it. Stokers should never be permitted to cut charges or raise them without authority. They will do it enough, in any case, so it should be kept to a minimum. If charging slack coal it will be necessary to have the highest possible heats, with big charges, burned 6 hr. The charge ought to be at least 500 lb. unless the coal is wet, or the bench incapable of carrying a high heat.

Scurfing.—Retorts should be decarbonized whenever the carbon deposit begins to interfere with the working off of the charge. As a general thing once in 50 days is about right. This operation should be according to a system. For example if there are 48 retorts, one should be scurfed every day; if 96, two every day and so on. Many operators burn off the carbon with air under natural draft but this is slow and wasteful. For rapid work, a 4-in. pipe should be shoved into the empty retort about 5 ft. A 3/8-in. steam pipe is placed inside the larger pipe extending in about 1 ft. By turning on the steam a blast of air will be forced into the retort. In a short time the carbon will begin to crack and loosen and the chisel bars may be used to loosen the obstinate pieces. After breaking up the carbon is drawn out with a rake and carried to the stock pile. The work should be completed in 4 to 6 hr. A record should be kept of the time taken to decarbonize each retort and the amount of carbon removed. Standpipes should always be burnt out while the retort is being decarbonized. A wood fire is built on the mouthpiece and long strips of wood pointed up the pipe. As the top cap is always off a strong draft will pull the flame up the pipe and in a short time it will be red hot and the pitch will rapidly burn off. Good practice requires the bagging off of all idle dip pipes during this operation.

Patching.—Patching holes and cracks is quite an art in itself and not one which can be easily described. Fire clay is usually used but the different brands of retort cements are very satisfactory. Many ingenious ways are devised for patching big holes or building up new back ends. Cracks and holes should be patched the moment they appear. A lump of coke will support a bottom patch pretty well, giving the cement time to harden before burning away. A section of a retort, on the bottom, may be replaced by carefully trimmed pieces of shield tile and fireclay balls.

Temperatures.—The temperature of the retorts and settings is a matter of much argument among operators. The following figures are offered for what they are worth:

TABLE III.

Above fire	1,950–2,050°F.
Two feet above arch	2,440
Four feet above arch	2,470
Top recuperator	1,475
Bottom recuperator	750

The above is for a full depth bench of sixes.

Temperature Table—Liddell

	Cent.	Fahr.
Incipient red heat	525°	977°
Dull red heat	700°	1,292°
Incipient cherry red	800°	1,472°
Cherry red	900°	1,652°
Clear cherry red	1,000°	1,832°
Deep orange	1,100°	2,021°
Clear orange	1,200°	2,192°
White	1,300°	2,372°

Loss of Heat.—A bench may lose its heat from a great many causes. Excessive clinker in the firebox is perhaps the most frequent and most easily remedied. All the fire should be pulled out of the furnace and the clinker removed from the side and back walls. Immediately after cleaning fill the furnace full of hot coke drawn direct from the retorts.

Heavy charging may pull the heat down in the retorts somewhat but this is a temporary condition and will right itself if the charges are reduced a little. The primary air ports often choke up from cinders and fine ash, which causes a low production of gas and consequently loss of heat. They are easily cleaned and in fact this should be a part of the regular work when clinkering.

When the heat on a bench gradually fails and no change that is made in the setting of the draughts helps it materially it is likely that the whole bench needs cleaning. Open the bench in front between the retorts and with a steam jet blow all the loose dirt and accumulations down onto the arch or the flue next to the walls. Then clean out all the nostrils and secondary air ports with a sharp-sided hook. Open the flues at the sides and under the bottoms of the retorts and clean out all the accumulations here. Replace all stoppers and brickwork and go down below and clean the waste-gas flues in the same way. The stack should receive attention also although it is rare to find any stoppage there. This thorough cleaning should be a matter of routine and not be put off until absolutely imperative.

Sometimes air leaks occur between the secondary-air flues and the waste-gas flues. The result of this would be that the secondary air would short-circuit into the waste-gas flues and never be drawn into the furnace at all. Thus the producer gas that was formed would pass through the setting largely unconsumed and meeting the secondary air in the waste-gas flues would burn there, bringing the flues to an intense heat which would be evident clear up the stack. To search for these leaks, close the primary air ports nearly shut and open the secondaries wide and open the stack draft to get a strong pull on the bench. Now remove one flue stopper after another placing a sheet of glass over the opening to prevent an inrush of air. Wherever a dark spot or streak in the flues is seen in contrast to the red hot brick it is probable that there is air leakage. To close these leaks a mush of fire clay and salt may be made just thick enough to be handled with a whitewash pump and the liquid pumped through a 3/8-in. pipe having a street ell on the end whereby the stream of liquid may be directed at the point desired.

If it is found necessary to increase the draught on the bench to pull enough air through the fire to produce the ordinary amount of gas and that opening or closing the secondaries has little effect on the flames seen in the top recuperator it is almost certain that there is an air leakage into the waste-gas flues and it should be diligently sought for. A study of the relative draughts using a draught gage may prove helpful in tracing out trouble to find the leaky flue. A gage such as is used to measure chimney draughts is recommended and should be applied to the plug holes with a stopper and rubber tube. Never attempt to look for trouble soon after firing. Always wait until shortly before firing when the flues will be clear, and, if anything, hotter. If a bench is otherwise in good shape but loses its heat, it will pay to spend a good deal of time studying it before giving it up and renewing it. With the bench running as usual, just before firing, soak a wet rag or piece of waste in oil and burn just inside the secondary air port. If a dense smoke is produced and there is a considerable leakage into the flues, it may be possible to see the smoke and get an idea into which flue it is coming. If the leakage is to the stack, direct from the back of the bench, it is very nearly hopeless to try to stop it, without renewing.

Renewing Benches.—It rarely pays to run a bench with less than its full number of retorts. If one retort has failed so badly that it can not be repaired if at all, it will usually pay to renew the six retorts. To determine this a calculation should be made on the cost of the loss in efficiency and the cost of renewing. For instance, it might be something like this:

Cost of renewing	$500.00
Life of retorts (minimum)	20 months.
Renewed cost per month	$25.00
Labor cost on bench per day	$5.00
Labor, cost per month	$150.00
Loss in efficiency of running five retorts	1/6
Loss per month	$25.00

In the above case it is an even thing whether to run or renew but usually it is in favor of renewal as there are other reasons which affect the matter. Sometimes it is possible to shut down the bench and renew only the broken retort but this is very seldom true.

Hydraulic-main Overflows.—With a main having a tar tower acting on the displacement system, no tar-seal overflow is required, nor is one used where the tar is allowed to collect in the main and drawn down at intervals. With a circulating system, however, it is customary to have both tar and liquor overflows, connected to seals. The tar pipe should come out of the bottom of the main and then a seal should be constructed which will place the height of the tar overflow pipe about ½ in. lower than the level it is intended to carry the liquor in the main. This overflow pipe should be adjustable and an equalizing pipe should be connected to the space above the liquor in the overflows, running to the main so that the pressure will be equalized. The drain from the overflow should run to a seal pot and then to the tar well (Fig. 43).

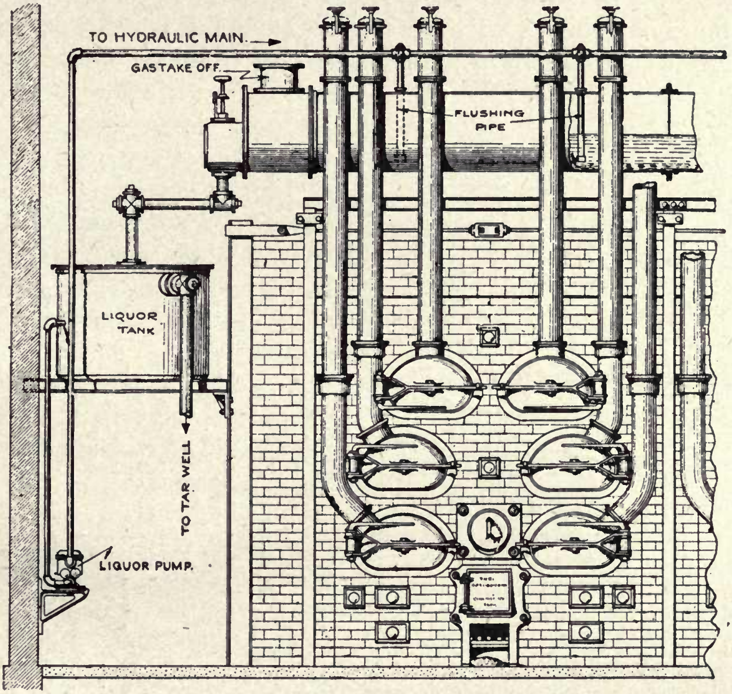


Fig. 43.—Hydraulic main overflow and circulation system.

The liquor overflow is made up in a similar manner but of smaller pipe. In starting the arrangement, allow the tar to accumulate to a depth of several inches in the main. Adjust the liquor overflow to carry exactly the seal you desire to carry on the dip pipes. In times past a ¾-in. seal was regarded as fairly low but nowadays most retort houses run on ¼-in. seals and many on 1/10-in., not to speak of those which use a dry main. The low seals are certainly better practice than high seals. Assuming that the seal has been set at the desired point and that the liquor is overflowing normally into its seal pot or U-seal and draining away, the valve on the tar line leading to the overflow from the bottom of the main should be opened. There will probably be a rush of tar from the main up through the overflow and down through the seal pot to the tar drain. After a few moments this will cease and the main may be filled up with fresh water until it overflows normally from the liquor seal.

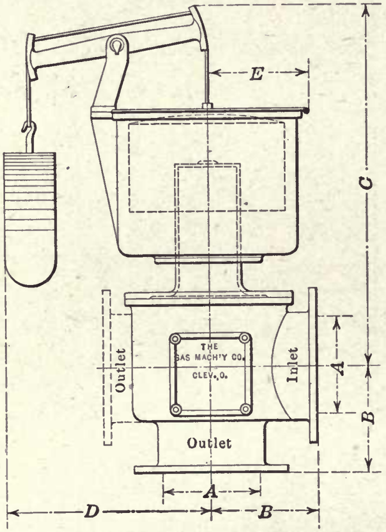


Fig. 44.—Retort house governor.

If the tar overflow has been set at the proper height below the liquor overflow, as fast as the tar forms it will run out and drain away. That is to say, the column of tar in the outer leg of the seal is heavy enough to balance the greater column of liquor in the main. As soon as tar accumulates the level in the main is slightly raised, this in turn increases the weight of tar and liquor balanced against the column of tar in the seal and a little tar runs out to restore the balance. In practice the flow is nearly constant. It will take a little experiment to find just the right difference in height between the liquor seal and the tar seal but it will not be far from ½-in. Both overflows may easily be made up out of ordinary fittings.

Setting the Seal.—A hosecock should be installed on each standpipe arranged so that it may easily be kept clear and a connection also placed on the hydraulic or foul main. A gage should be placed on the hydraulic and another on the standpipe, throttling the cocks so that the fluctuation will be slight. The speed of the exhauster should be adjusted so as to pull a perfect level gage on the standpipe. The reading of the gage on the main will show the depth of seal, that is, if the gage shows a vacuum of ½ in. then there is a ½-in. seal, if the standpipe gage is level. If the seal is too high the adjustment should be changed to lower it a little and in a few minutes the gage may be read again. Each bench should be tested for depth of seal as in many cases the hydraulic main has settled out of line making one portion lower than another with a deeper seal for the low portions. If this is found to be the case the main should be leveled off and the dip pipes altered if necessary so that they will all seal the same amount.

RULES FOR OPERATION

The following remarks are abstracted from an article by Mr. W. A. Baehr, published in *Progressive Age.*

Time required to bring various kinds of recuperative bench installations to operating heat after being shut down or when new.

Entire New Stack of Benches.—Time required for drying—15 to 20 days, depending on size, atmosphere and general conditions. Time required after drying to bring benches to operating heat—5 to 10 days.

Entire Old Stack of Benches.—After being shut down for some time. Time required for drying—5 to 10 days. Time required after drying to bring benches to operating conditions—3 to 5 days.

Single New Benches in Old Arches.—Time required for drying—10 to 15 days. Time required after drying to bring bench to operating conditions—3 to 5 days.

Single Old Benches in Old Arches.—Time required for drying—2 to 3 days. Time required after drying to bring bench to operating conditions—2 to 5 days.

Precautions to be Observed Before Starting Drying-out Fire.—Brick up mouthpieces leaving hole about 2 in. square to allow escape of moisture. Close all dampers and sight holes except main-flue damper. Leave small air openings to underneath grate bars.

Drying-out Fire.—This may be started with wood kindling or hot coke. After starting keep it up as a low (1 ft.) fire at dull heat at first, gradually increasing air opening day after day, until at the end of drying-out period, a low, say 2 ft. deep, but fairly bright fire exists. Feed this fire at intervals with small quantities of fuel not varying the heat any more than can be helped.

General Instructions During Drying-out Period.—Watch expansion of brickwork very carefully and carefully loosen buck stays and tie rods from time to time. Keep damper in ash door open to burn up any carbon monoxide that may be formed, or if this is not above floor, the fuel-feeding door can be left open. Be sure to have the main-flue damper wide open, so that all gases, moisture, etc., can escape. At the end of the drying out period, the furnace portion of the bench should be at a dull red heat.

To Bring Heat to Operating Conditions.—Clean and clinker fire thoroughly and then add coke until a fuel depth of 2 to 2½ ft. is secured. Keep an ample amount of air going under the grate bars so that the fire will gradually brighten. Still keep firing door open but do not allow flames to come out of it. This can be regulated by main-flue damper. Keep dampers in the ash door open. Start water slowly dripping into the ash pan. See that primary air dampers are open. Gradually increase depth of fire until it is not less than 3 ft. deep just before firing. When the combustion chamber begins to get hot the secondary air slides should be opened about ¾ in. each. Close fuel feeding door. When certain that carbon monoxide is burning at the nostrils and the furnace is at a bright heat, fill the producer with fuel, open secondary air slides to an ample amount and increase the water running to the drip pans and ash pans to the full amount. Conduct the heating up process gradually keeping up an excess of secondary air. If the bench heats too rapidly cut down primary air. About 1 to 2 days before coming to full heat, remove brickwork from mouthpieces and charge retorts with small amount of slack coal, leaving caps on ascension pipes open at first, until ready to put hydraulic main into operation. The charge of coal in the retorts prior to regular charges should be one large charge of slack coal, left in at least 12 hr., to fill cracks in retorts, etc.

Regulation of Furnace During Operation.—Have the works superintendent or chemist set primary and secondary air slides after sufficient flue-gas analyses have been made. After that no one but the superintendent or chemist should be allowed to touch these slides. Since instructions for such analyses have been written and rewritten so many times they will not be repeated here. Secure the most intimate mixture of air and water vapor that is possible with the construction under consideration. If steam is used under the fire, run in one or more pipes, cap up at ends, drill a hole in each cap of proper size to admit the correct amount of steam per hour with the average boiler pressure carried at plant. The superintendent should determine proper size of holes. Keep fires clean, deep and level throughout. When firing, keep firing door open a minimum amount of time. The same rule applies to clinkering or cleaning. It is advisable to have stack dampers closed during these periods. The main-flue damper should be open only so far that there is a very slight pressure on the setting. Any slight crack or opening around a sight hole should, therefore, show a slight flame. Usually when clinkering it is advisabale to use false bars.

General.—See that all cracks in brickwork are promptly patched, that sight hole plugs fit tightly, that feeding doors into furnace (as well as other doors) are tight; and do not permit air leakage into benches. Keep top of stack clean and free from tar, dust, etc. Clean out the recuperators frequently, with scrapers steam jet, or still better, compressed air. This should be done every 2 or 3 weeks. If leaks develop in the recuperators try to get them tight again by washing with a thin grouting.

Letting Down Settings or Benches.—This is virtually the reverse process from starting up but is simpler. Put last charges into retorts about 1 hr. before closing down. Have fire in producer not over 3 ft. deep. One hour after last charge, close primary and secondary air slides, lute all openings, shut off water supply, shut all dampers and allow bench or setting to cool down slowly. When cool, pull coke, clean out fire and leave things clean and neat, inside and outside the bench.

Retorts.—Keep well patched. Keep well scurfed. Scurf a little too often rather than not quite often enough. Scurfing is probably best accomplished with compressed air, but steam jets up the ascension pipe, or the ordinary D-tile will do where compressed air is not available. Coal charges must be put in properly. Get coal well into back end of retort and have top practically uniform throughout. The shape of the top of the coal should be such as to best receive the radiated heat owing to the shape of top of retort. Have superintendent determine this point. When charging or drawing, keep mouthpieces open as short a time as possible. Keep mouthpiece bolts properly tightened and keep eccentrics on self-sealing lids in good order. Do not allow stokers to tighten eccentric levers by hammering with shovels, bars, etc. Do such work by hand.

Ascension, Bridge Pipes, Hydraulic Main.—These should be kept thoroughly and regularly clean. Have stokers push a gouge up ascension pipes after each draw. Thick tar should not be allowed to accumulate in hydraulic main. See to this every day. Keep every hand hole or cleaning hole in working order as well as overflows. Inspect every operating device about the bridge pipes and hydraulic main every day and if ammoniacal liquor circulation is used, see that all jets are clear, pumps in working order, etc.

General.—Keep all air, steam, water and other pipes tight. Keep whatever machinery is used, in good order and well-oiled. Keep none but good first-class tools for the men and keep them properly repaired. Last, by all means one of the most important instructions is in regard to cleanliness. Keep your house clean, thoroughly in repair all the time, have floors swept regularly, provide receptacles for rubbish, proper lockers, toilet and wash facilities for the men; keep tar off all bench and ironwork, keep all dust off top of stacks, provide neat racks for tools and endeavor to apply all the useful little devices for promoting ventilation you can. Remember that cleanliness is the greatest simple factor tending to insure your success and the appreciation of your superior officers.

RETORT-HOUSE METHODS

The following is abstracted from an article by A. S. B. Little, published in *The Gas Age*.

Next in importance to a well-regulated, properly placed coal store is a correct weighing machine. Even in the smallest plant a means of checking weights is a necessity. I am not calling into question anybody's honesty, but coal has a way of disappearing between delivery from the mine to the retorts, and it is well to know if you are suffering loss. Most companies can not afford a car scale, but if each car is unloaded in a separate place and you then weigh coal into the retort house you can tell soon if there is any shortage. The idea is not so much to detect short weights as it is to check daily results. No company can tell what it is doing if it does not note daily results. It is the easiest thing in the world to fool oneself and most people do it unconsciously.

What has to be guarded against in the retort house are: Irregular time of charging, variation in weights, uneven distribution, coke left in retorts, irregular furnace firing, bad stoking of furnace, too low coke bed, ash on grates, clinker on walls, heavy hydraulic seals, accumulation of carbon in pipes, incorrect vacuum in foul main, leaky retort lids, cracks in retorts, carbon in retorts, leaks around pier walls, low heats, high heats, the open furnace door, and the choked primary flues.

There are other things, but here we have a list of the principal causes of trouble. Cure those and others will be found at once if not automatically cured.

Irregular Charging.—By this we mean drawing a little late and firing a little early; also the missing of charges altogether during the night shift. This is done more frequently than most of us admit and it is the starting point for most of the trouble in a gas plant. If you try to segregate each car of coal, then weigh each charge and note the total amount of coal used each shift compared with the gas produced, you will have a pretty accurate idea of your stokers' work. The trouble with missed charges is serious in many ways: it upsets the heats, ruins the benches, puts the cleaning machinery out of gear and disturbs the purifiers as well as the exhauster.

Variation in Weights.—This is also a common fault and even though the charges may be correctly weighed, variation in the retorts frequently occurs because the men measure out coal for three retorts in each wagon and, starting with the top retort, fire lightly at the back end, where the charge should be heaviest. Then when they get to the bottom retort the coal left over is all charged therein. The bottom retorts are always coolest, especially at the front end and yet we can notice in many plants that they are usually overloaded.

Uneven Distribution.—A good stoker is not so frequently found as one would like. One bad charger will upset a whole gang, because although there are many first-class shovel men, none of them like to have extra work thrust upon them. When on the last charge of a shift the men load the retorts unevenly, then the new operators who come on find, when the time to draw the retorts arrives, that at the very beginning of a day's work they have to haul and hack and kick and cuss to make up for the bad firing of the poor charges. Even distribution must be insisted on and the manager must see for himself that his orders are carried out.

Coke Left in the Retorts.—This is a common fault and it cuts down the capacity of a bench, results in overheating and burning out the back ends of retorts and generally reduces the efficiency of a plant. There are very few plants where this fault is not found, at least at times. The stokers do surely hate to draw retorts and the worst part of their work is the removal of the pocket of coke which lodges up against the back end of the retort. Once let the trouble start and you can never cure it, because the overheated back walls of the setting will give way, let the retort sink or distort and make a difficult place for the rake to get into or out of.

Irregular Furnace Firing.—This is a most common fault in a gas works and causes lots of trouble. There is only one way to run a furnace. It must be kept as full as possible, be fired regularly with not more than 200 lb. of coke or 100 lb. of coal at one time. After every draw the stoker should shake down all soft ash (say every 2 hr.) and at least once in every 12 hr. (whether it needs it or not) all loose clinker should be removed. Once every 24 hr. all hard clinker that has fused into the side walls must be chipped off, as if it is once allowed to grow it means trouble continually and a mighty hard job for the man who removes it. Let your men thoroughly understand that it has to be removed and that they are only laying up trouble for themselves if they neglect this duty. Of course no general rule can be laid down for the time a furnace can go without clinkering. Some fuels high in ash with fusible elements will make it necessary to use the slice bar every 12 hr. Others will run 48 hr. or more. Let the men understand that a shallow fire means a hot fire, causing plenty of flinty clinker that fuses and sticks closer than a brother. The use of water properly distributed is a necessity on all cleaning out doors and it is a first-class plan to use also a steam supply. Run an exhaust steam pipe through one of the recuperator flues and deliver the steam along with the primary air underneath the grate bars. This is a common practice in Europe and gives good results. Have your ash pan made of concrete. Cast-iron pans are an abnomination. When charging furnaces adopt the plan advocated by T. J. Weber at the 1912 Michigan Gas Association meeting. Spread a layer of breeze over the top of the charge. This evens up the resistance to travel of air and gases causing a more regular supply of combustible gases to the setting and it also uses up some excess breeze. Further it serves to protect the charging door. It may be said that these suggestions are all old; no doubt they are but even if you believe they are all being carried out in your plant, just make a habit of finding out regularly that this is so and I will venture to say that the improved operating conditions and results will surprise you.

RETORT-HOUSE SYSTEMS

The following charging schedules illustrate different ways of laying out retort-house work. Where there is a large number of benches they can be split up into units of the number best suited to conditions. In all cases given below the retorts are handled in tiers of three.

Three Benches of Sixes.—Two stokers and one helper may operate three benches of sixes. Each stoker draws and charges 27 retorts per shift and helps to haul in gas and fuel coal. Every other day one stoker handles two fires and the alternate day, one fire. The helper quenches the coke as it is drawn onto the floor, loads coke into buggies and takes it to storage pile. He loads and helps to haul in all gas and fuel coal. The helper is paid 10 per cent. less than the stoker.

Four Benches of Sixes.—Two stokers and two helpers may operate four benches of sixes. Each stoker puts in 36 charges and draws 18; he handles two fires and helps bring in coal. Two helpers each draw 18 retorts, remove coke for two benches and load all coal.

Seven Benches of Nines.—Five stokers put in 36 charges and help to haul in coal. They handle all fires. One stoker puts in 27 charges and helps to load coal and take up coke. One coke man hauls out all coke with the help of the extra stoker. One coal man loads all gas and fuel coal.

Four Benches of Nines.—Two pairs of benches are worked with one stoker and one helper to each pair. The stoker makes 54 charges and 27 draws and fires one bench. The helper fires one bench, draws 27 charges, takes up coke and loads all coal.

Fourteen Benches of Sixes.—With double deck floors, seven stokers, one man to each two benches may work fourteen benches of sixes. Draw charge, ream pipes, draw coke into furnace; one coke cellar man, handles all coke to yard or cars. Two coal men bring up coal, help on fires, remove ashes, trim and unload all coal. One clinker man clinkers and takes out ashes, cleans and repairs below the floor. One head stoker attends to hydraulic main, draws tar, reams pipes from above each day and patches all leaks. This system was used at Chattanooga, Tenn.

The following is a further illustration of the three-bench system. The chart shows the time that retorts are to be charged. Such a schedule should be made out and posted in the retort house.

Number 1		Number 2		Number 3	
Left	Right	Left	Right	Left	Right
6 10 2	7 11 3	8 12 4	6 10 2	7 11 3	8 12 4

Two benches are open at one time, one helper serving water for two stokers.

Rates and Hours for Stokers.—Various systems for paying stokers are used. Straight time for so many hours per day is the general rule. In some plants certain benches are allowed a few cents a day more than others and head stokers generally draw 10 per cent. more than regular stokers and the helpers 10 per cent. less. The bonus system has been tried out and works well in plants that are large enough to allow of some money being spent to check up. Under this system the stoker is paid a certain fixed sum per day and the bench must carbonize a certain amount of coal. For all coal carbonized above this minimum amount, a bonus is paid so that the stoker divides the saving with the company. That is for every 1 per cent. cut off the retort house labor, the stoker gets ½ per cent. or some other arrangement.

Unless there can be only one man at the plant it is not necessary that stokers put in a 12-hr. day and if such hours exist in a plant it would be a good idea to change them voluntarily as if this is not done it will surely be forced in the near future, perhaps resulting in three shifts and greatly increased expense.

In the retort-house systems referred to above the stokers are on the job from 6 o'clock until 4.15 o'clock. At 4.15 p. m. the last charge is in and they are at liberty to clean up and dress. Just before leaving the plant however they are required to look at the furnace and if necessary fire it with a little coal. If coke is used for firing this will never be necessary as the coke will be drawn into the furnace on the last or 4 o'clock round. While this is by no means a short day, it cuts a good deal off the 12 hr. that used to be customary and the plant will not suffer in any way, as there will always be someone about to keep an eye on the house until the next shift comes on at 6. Whatever system is being used, it should be studied to see if the stokers' hours can not be shortened and if it is found that it can be done no time should be lost in making the change. Reducing hours of labor without decreasing the amount of work done by no means replaces an increase in wages but it will go a long ways toward heading off an impending demand for more money if brought up at the right time.

There are a great many ways in which this may be brought about but the conditions in every retort house must govern the method used and details can not be given to cover them all. It is a matter which will repay very earnest consideration, however, and ought not to be dismissed casually.

Cleaning Hydraulic Main and Standpipes.—In most plants it would pay to clean the hydraulic main every Monday. Too often this job is neglected until it just has to be done, which means an unnecessarily dirty and disagreeable piece of work. If cleaned every week it will not take long and will not be nearly as disagreeable. The standpipes ought to be reamed clear through from the top at least every other day, unless the house is unusually free from standpipe trouble. The tar and liquor overflows should be daily inspected by the foreman and cleaned or adjusted if necessary. If a circulation system is used in the hydraulic main very little cleaning needs to be done. Spraying liquor into the standpipe and also allowing water to trickle down are sure cures for standpipe trouble. The former is the better but has been made the subject of patent protection.

Tar Removal.—The removal of the tar from the raw gas is accomplished in a number of ways. In the hydraulic main, the gas is forced to bubble through a water seal and a great proportion of the tar is removed here. This is the heavier tar and it sinks quickly to the bottom of the main from which it flows intermittently or continuously as the case may be. The line from the tar tower should run to the separator.

The first condenser removes considerable of the lighter tar not left in the hydraulic main and the overflow should be piped

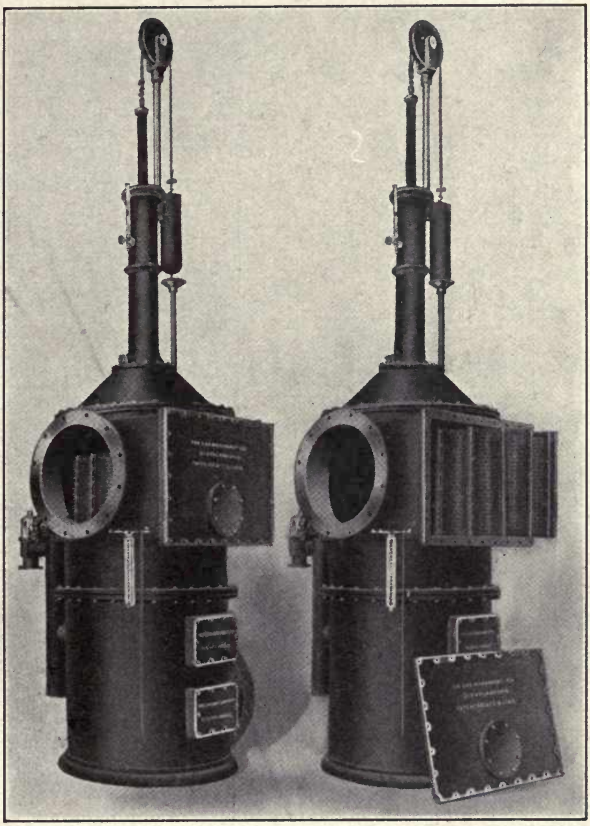


FIG. 45.—P. and A. tar extractor.

to the separator. In many plants the first condenser is followed by the exhauster in which a small amount of tar and some condensation is deposited. It should also be connected to the tar and liquor separator. As the gas leaves the exhauster it will contain tar in the form of bubbles each enclosing a small amount of gas. To break up these bubbles, obtain the tar and free the gas, a very ingenious apparatus is used, familiarly known as the

"P. and A." The initials are derived from the inventors of the appliance, Messrs. Pelouze and Audouin. Briefly, the appliance consists of a cast-iron shell or frame enclosing two or more perforated cylinders, arranged concentrically, with the holes staggered. The passage of the gas is in a zig-zag direction and the bubbles of tar, forced against the sharp edges of the perforations are broken up. The cylinders are arranged so as to be movable and are sealed in the tar. By means of a chain and weights the cylinders are balanced and increasing the flow of gas through the P. and A. causes the cylinders to rise exposing more surface to the action of the gas (Fig. 45).

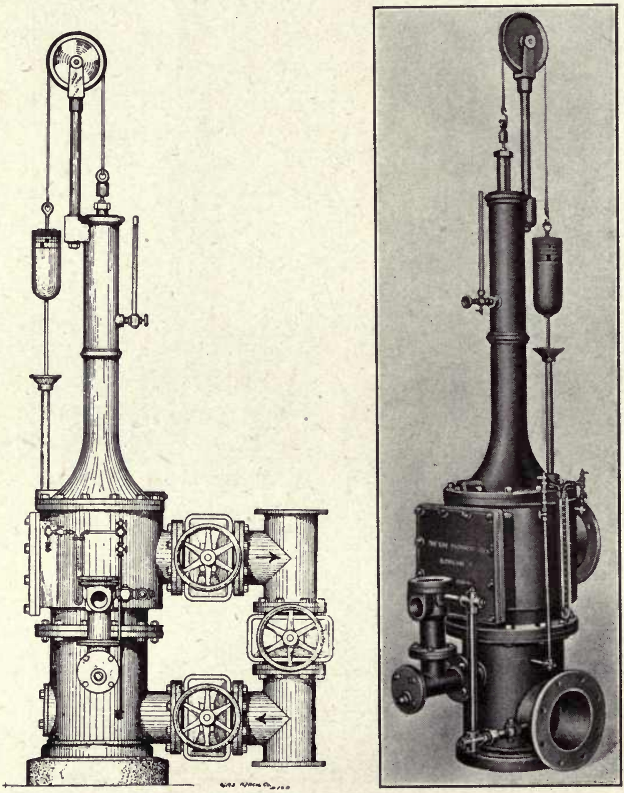


Fig. 46.—P and A. tar extractor.

By this means the appliance can take care of a wide range of flow. The differential is controlled by adding or removing weights so that the bells rise or fall in the seal, giving greater or less surface. After the desired differential is determined the appliance will automatically preserve it, as with a greater flow of gas, a larger number of holes will be open for the gas to travel through and *vice versa* (Fig. 46).

The tar that is not removed by the P. and A. is in the form of very fine fog or mist and a tar washer as shown in the diagram of ammonia recovery apparatus is used to remove it. The gas is broken up into fine streams and intimately mixed with water which efficiently removes the last traces of tar. Little or no tar is recovered in the scrubbers when the washer is working properly. The seal on the washer should be adjusted so as to obtain the desired degree of efficiency, a deeper seal of course securing more complete removal. The overflow of all the condenser room apparatus goes to a common separator where the tar settles out of the liquor and is removed to the tar storage wells.

AMMONIA RECOVERY

Production.—The ammonia is derived primarily from the nitrogen in the coal and in the process of distillation the nitrogen unites with hydrogen to form NH_3. After charging the coal the ammonia begins to appear in the crude gas very soon and quickly reaches a maximum, then declining as rapidly as it appeared. High heats are not favorable to high yields of ammonia as under the influence of high temperature the following reactions take place:

$$\begin{aligned} 2NH_3 &= 2CN + 3H_2 \\ 2NH_3 &= N_2 + 3H_2. \end{aligned}$$

The decomposition depends almost entirely upon contact with the heated retort walls which helps to explain the high ammonia yields from bulk carbonization and fully loaded retorts. The decomposition occurs at a temperature of 1,900°F. The presence of steam slightly decreases the decomposition. The ammonia as produced by coal distillation exists in two forms, fixed ammonia and volatile ammonia. The fixed compounds are those which do not decompose when their aqueous solution is boiled. Among these compounds are the following:

Ammonium sulphate $(NH_4)_2SO_4$
Ammonium chloride NH_4Cl.

The volatile or free ammonia compounds are those which are broken up by boiling the aqueous solution. Among them are:

Ammonium hydrate NH_4OH
Ammonium acid carbonate NH_3HCO_3
Ammonium carbonate $(NH_4)_2CO_3$
Ammonium sulphide $(NH_4)_2S$
Ammonium sulphocyanide $(NH_4)SCN$
Ammonium polysulphide $(NH_4)_2S_x$.

The fixed and volatile compounds are all present in crude liquor but only the volatile compounds occur in the concentrated as a rule. The recovery of ammonia in the gas is accomplished by condensation, washing and scrubbing.

Hydraulic Main.—In the hydraulic main the crude gas is subjected to a more or less severe washing which cools it to a certain extent and removes nearly all the fixed ammonia compounds. The temperature of this liquor is such that it can retain very little free or volatile ammonia. The liquor produced here is quite strong but very small in amount. Some condensation of water vapor occurs in the main which forms water to carry the ammonia salts. Many plants recirculate crude liquor through the main, which keeps it a little cooler and increases the condensation. With a continuous tar overflow, the tar and liquor should empty into the same pipe, which carries them both to the tar and liquor separating well. If a tar column or displacement system is used, care should be used that no excess of water enters the liquor. When emptying the tar column the valve at the top of the tank, leading to the hydraulic, should be closed, the vent opened, the lower valve opened and the tar run out of the column. The flow should be stopped the moment the tar stops and liquor begins to come. Then the column may be filled with water, the vent closed and the valve to hydraulic opened again.

Foul Main and Primary Condenser.—A strong liquor of small volume will be produced in the first condenser, varying in strength according to the amount of cooling. This liquor is usually yellow from ammonium sulphide.

Exhauster and Secondary Condenser.—Some condensation will take place in the exhauster and connections and a good deal in the secondary condenser which should be carefully piped to the well. This liquor will not contain much fixed ammonia which drops mostly before reaching the exhauster but will be rich in sulphides and carbonates of ammonia. The volume of condensate is considerable.

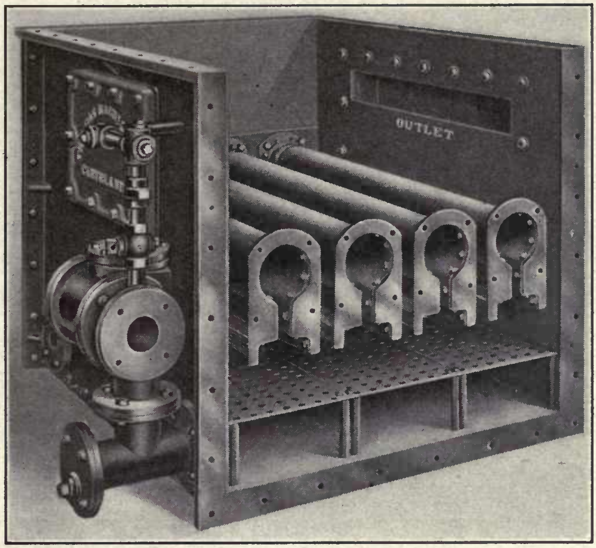


FIG. 47.—Bubbling tar and ammonia washer.

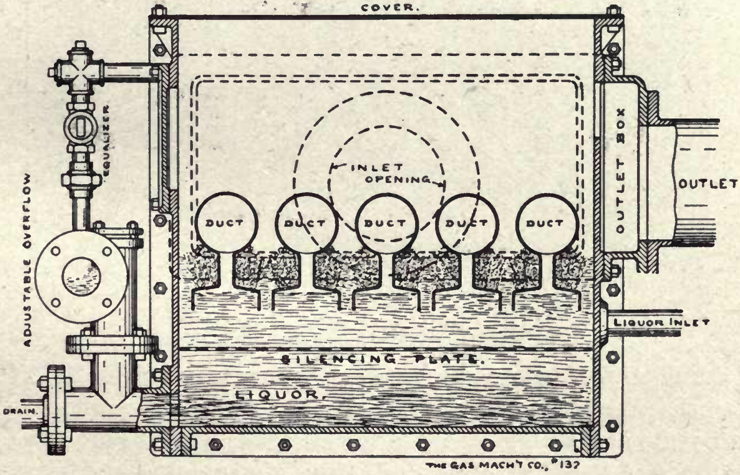


FIG. 48.—Interior diagram bubbling washer.

Washer.—If an old-style, bubbling washer is used in connection with scrubbers, it will be found to remove a considerable portion of the ammonia coming to it. The temperature of the gas coming to the washer should have been reduced to at least 75°. The composition of the liquor entering and leaving the washer will be discussed below (Figs. 47, 48, 49, 50).

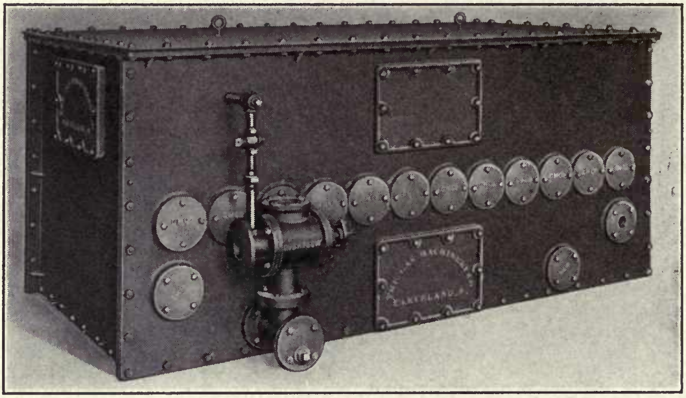


FIG. 49.—Washer showing overflow.

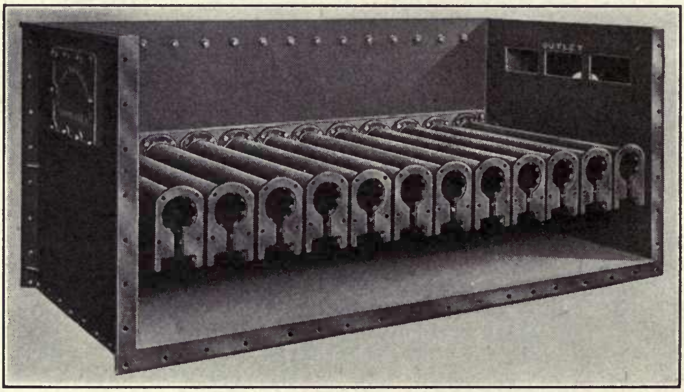


FIG. 50.—Interior view of washer.

Scrubbers.—Two tower scrubbers are usually used for the final traces of ammonia and serve to remove the last of the ammonium carbonate and all but traces of the free NH_3. There are several methods of handling scrubbers. One of the best is as follows: A spray is placed in the top of the secondary scrubber. This may be a 1¼-in. cap drilled with about eight ⅛-in. holes in the sides of the cap. A reversed elbow delivering a jet up against an

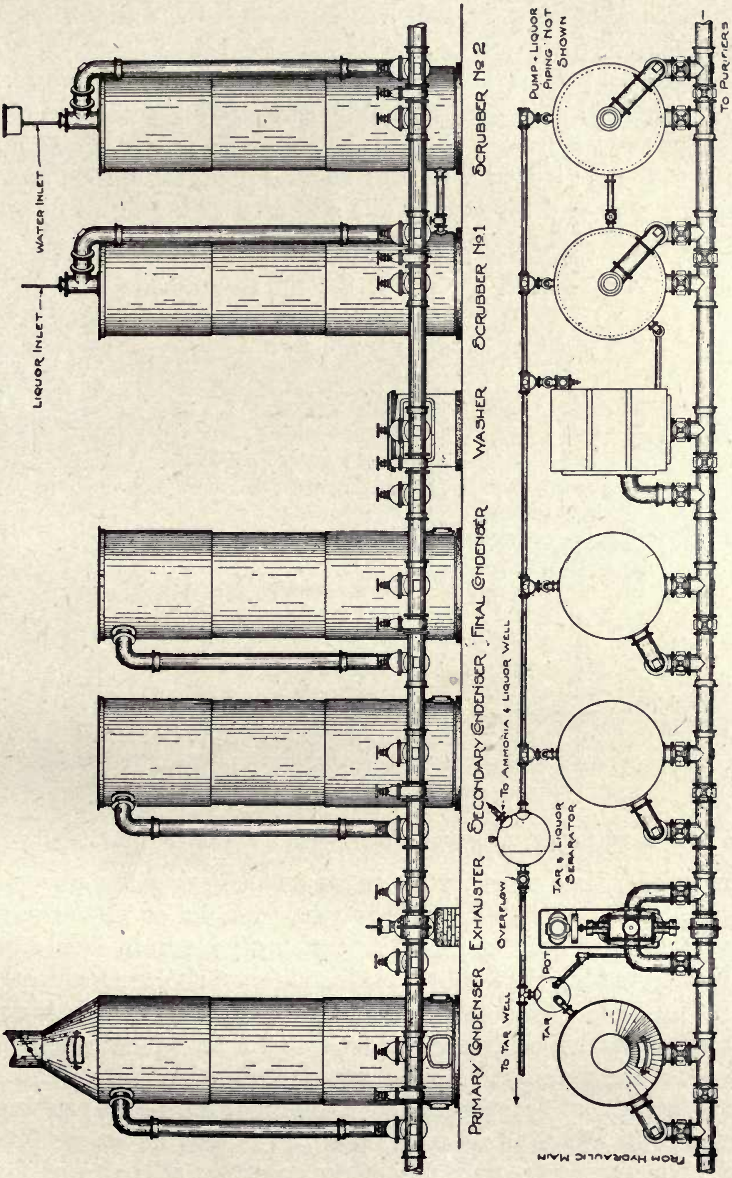


FIG. 51.—Coal gas condensing and scrubbing system.

inverted iron saucer-shaped plate, so as to throw an umbrella-like shower of water is also successful. The spray should be low enough so that no water will be thrown into the scrubber pipe (Fig. 51).

On the wall behind the scrubber an ordinary closet flush tank, with a dumping bucket in it should be arranged so that after the tank flushes, the bucket rises as the water flows into the tank. When the tanks is nearly full the arm carrying the bucket runs against a stop and the bucket fills and after filling drops by its own weight, thus opening the valve and allowing the tank to empty. When the tank is nearly empty the outlet valve closes and the bucket rises again. The outlet of this tank should be connected to the scrubber by a 1¼-in. pipe, which has a seal made up, 6 in. longer than the maximum pressure on the scrubber. The effect of the flushing of this tank will be to deliver a rush of water to the scrubber. As the water first enters the scrubber it will be sprayed clear to the edge of the trays but as the pressure decreases it will tend to come into the center, or as one has said, "the umbrella will close," thus wetting all parts of the tray surface, with a rush of water that will slowly trickle down to the bottom of the scrubber (Fig. 52).

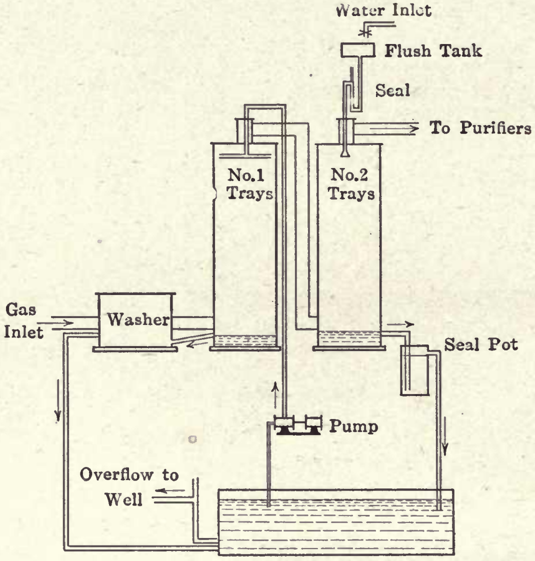


Fig. 52.—Arrangement of liquor piping, etc., for scrubbers and washers.

A meter should be placed on the water line supplying the tank and a cock to regulate the flow of water. The amount of water should be about 4 gal. per 1,000 cu. ft. of gas. From the bottom of the scrubber the weak ammonia runs into the top of a large steel tank. From near the top of this tank, a pump draws the weak liquor and forces it into a spray in the top of the primary scrubber. This spray is drilled so as to shoot the liquor down over the trays in a shower. This weak liquor runs down over the sprays and absorbs free ammonia and salts from the upcoming gas and overflows through a seal to the washer. From the washer it runs back to the bottom of the tank. A pipe runs from the bottom of the tank to the well. As it leaves the bottom of the tank it rises in a seal to a point higher than the suction to the circulating pump by about 6 in. The top of this seal must be open to the air to prevent siphoning. About 50 gal. of liquor per 1,000 ft. should be circulated through the primary scrubber and

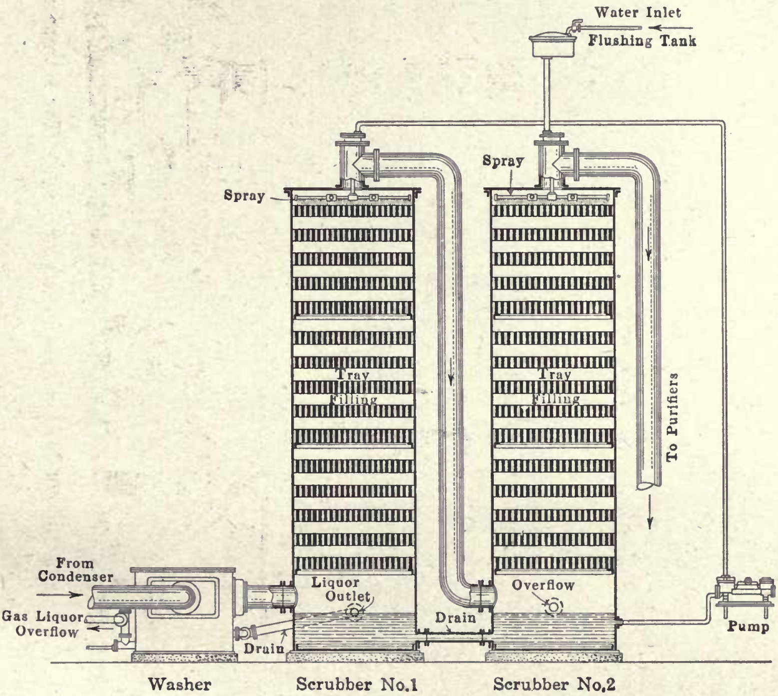


FIG. 53.—Alternative arrangement.

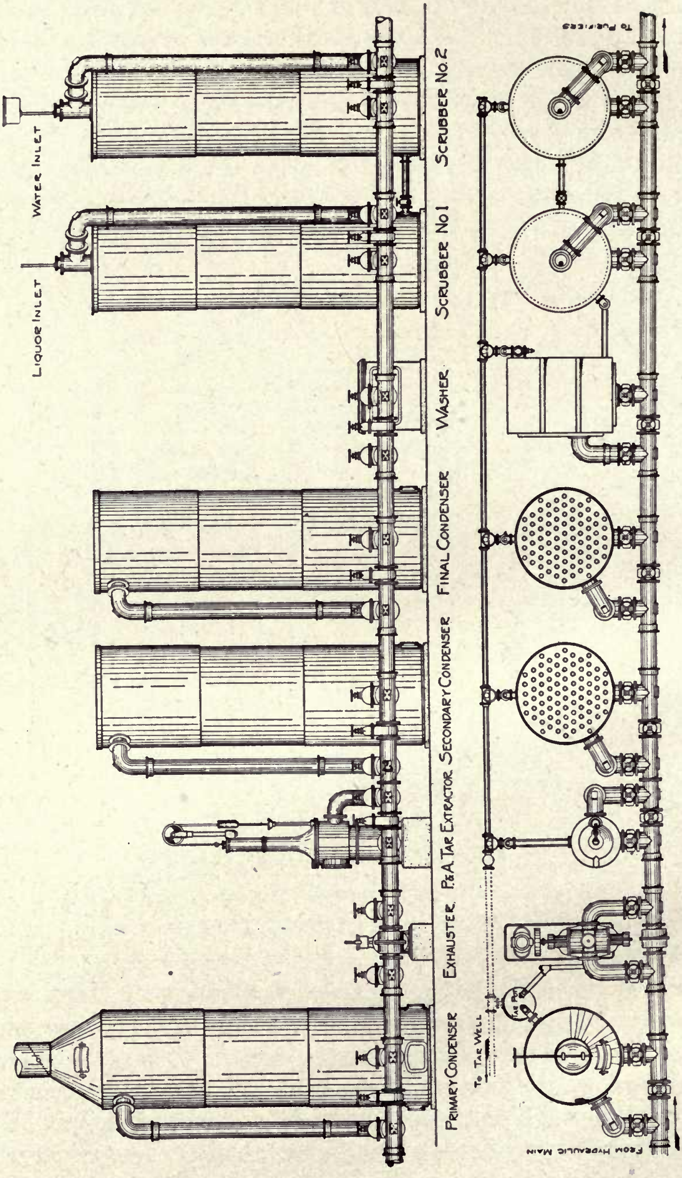


Fig. 54.—Scrubbing and condensing system with P. and A. Tar extractor.

washer. This method produces a rather strong crude liquor which is heavily charged with carbonates and sulphides. The liquors from the hydraulic main, foul main, drainage from exhauster, tar lines, condensers and scrubbers should all run to a common header and thence to the well. From the tar well the liquor overflows to the liquor well (Fig. 53).

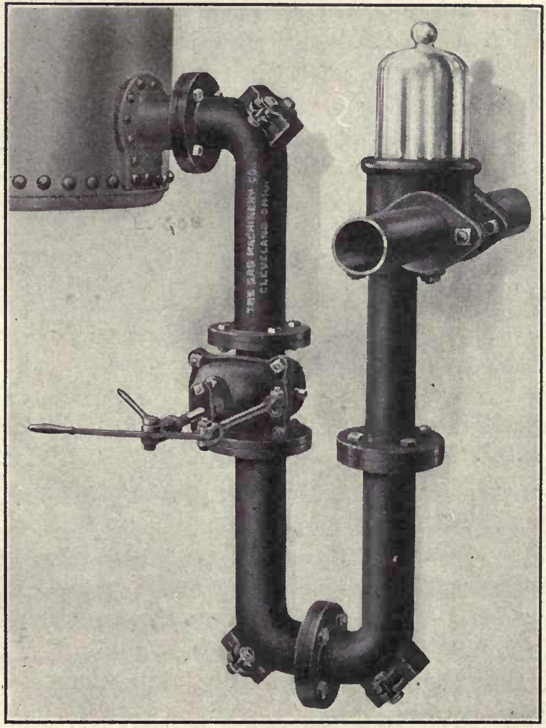


FIG. 55.—Condenser overflow for tar and liquor.

Scrubber Trays.—The scrubbers should be filled with wooden trays built up of slats on end, 1¼ in. thick, 3 in. high and ¼ in. apart, each successive tier placed at right angles to the one below. A comparison of the effective surface of coke and slats is as follows:

One cubic foot space, coke gives 8½ sq. ft.
One cubic foot space, boards give 31 sq. ft.
Coke fills half the space.
Boards fill one-quarter the space.

Tumeric Paper Test.—The amount of fresh water added to the scrubber should be enough to remove all but the last traces of ammonia. To test whether the absorption is complete, the outlet main of the second scrubber should be tapped and a hose cock put on. Some tumeric paper should be prepared in strips and after wetting a strip, held in the stream of gas from the cock. If there is over 2 grains of ammonia per 100 cu. ft. a decided brown stain will appear very quickly. The paper should not be wet in the mouth as there is often enough alkali present in the saliva to color the paper. If the stain is very plain and comes instantly on the paper it is a good plan to make the test for loss of ammonia as described elsewhere in this work.

Temperatures.—If possible control the temperatures to the points given below:

Inlet P. & A.	100°–110°
Inlet primary condenser	85°–100°
Inlet washer	70°–75°
Inlet primary scrubber	70°
Inlet secondary scrubber	60°–70°

The cooler the scrubbers can be kept the more efficient the ammonia extraction will be.

Summary.—The liquor is gathered from many different places and has long distances to travel. Ammonia is a volatile gas and hard to retain. Wherever it must be exposed to the air, the area of exposed surface should be as small as possible and the exposure as brief as possible. The tanks and wells must be tightly covered and opened only when absolutely necessary. The circulating pump must be tightly packed and no liquor or vapor leakage permitted at any point. A frequent inspection of all liquor overflows and lines will keep the loss down to a minimum. The overflows are apt to plug up with naphthalene and should be fitted with steam pipes to blow them out.

There are a good many ways to handle scrubbers and the method given above is only a suggestion. Rotary scrubbers and washer scrubbers are coming into use now but the operation of these is peculiar to each installation.

The very closest attention to the process of recovery will be found worth while. The piping carrying liquor should always be exposed and very frequently inspected. The scrubber trays need cleaning whenever they become dirty with tar or choked with naphthalene. Sometimes simply bypassing and steaming is sufficient.

AMMONIA CONCENTRATION

The Still.—One of the common forms of ammonia stills will be described below with some notes on operating. There are a number of stills on the market differing somewhat in construction but the principle of them is about the same. They generally consist of a fixed still, volatile still, lime leg and absorber with auxiliaries, condenser, etc. In the volatile still the free ammonia and the compounds volatile at steam temperature are driven off. The liquor then mixes with lime in the lime leg and passes over to the fixed still; before reaching here a chemical reaction has taken place, decomposing the fixed ammonia salts and freeing the NH_3. This NH_3 is boiled off in the second or fixed still, the waste liquor running away through a seal pot.

A very intimate mixture of lime and liquor must be obtained and time must be allowed for the reaction to take place. This is provided for by a series of dam sheets in the lime leg which cause the liquor to travel up and down in the leg, taking time for the mixture to react and giving something of a mixing action as well.

Small jets of steam controlled by a ¼-in. valve should be admitted to the various sections of the lime leg to prevent settling out and to keep the liquor hot and prevent throwing too heavy a load on the fixed still. The main steam passes into the fixed still and after driving off the ammonia freed by the lime action it passes through the volatile still and on into the condenser.

This condenser consists of a long coil of extra heavy 2-in. lead pipe, flanged to the top of the still and contained in a steel tank full of water. This water is introduced cold at the bottom of the condenser and rises slowly to the top, absorbing heat from the lead coil until at the top it is nearly boiling hot. This method produces slow and very gradual cooling of the ammonia vapors and helps to prevent salting the coil. It is possible to cool liquors up to 25°Tw. without trouble. The water should be admitted at such a rate as to keep the bottom of the condenser entirely cold and the top quite hot. From the condenser, the condensed ammonia passes through a deep seal in the absorber where uncondensed vapors are caught. A second small absorber is provided with a catch vessel, for small amount of NH_3 passing the first

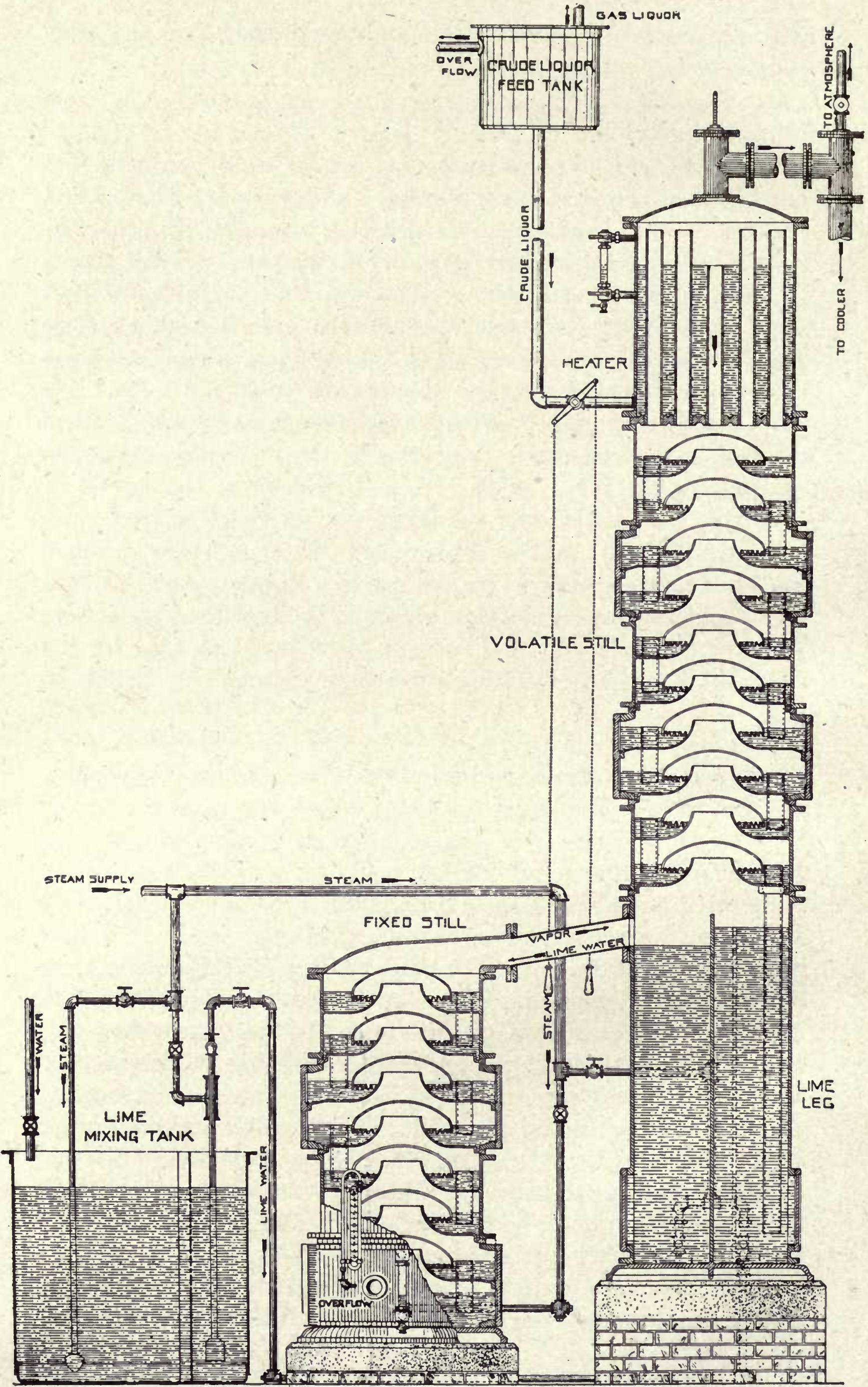


Fig. 56.—Ammonia still showing fixed and free sections.

absorber. From the absorber the liquor flows through a seal to the receiving tank.

The vapors which pass into the receiving or condensing coils contain NH_3 in the form of a gas, also CO_2 and H_2S in gaseous form, along with a considerable amount of water vapor and a few other impurities of minor importance. The white salt that forms on suddenly cooling strong concentrates is ammonia carbonate, a compound of the NH_3 and CO_2. The yellow color of the concentrate is due to ammonium sulphide; small amounts of ferrocyanides are also present, sometimes giving rise to a blue coloration of the salt.

The crude liquor is pumped through a 1-in. lead pipe coil in the absorber to cool the concentrated liquor, thus saving water, then goes to the overhead feed tank, overflowing back to the well. The feed to the still is regulated by a cock, the handle moving over a graduated arc. From a funnel below the cock the liquor runs into a 1-in. lead pipe coil, about 25 ft. long, hung in the very top of the condenser, in its hottest part. This has a strong preheating effect and saves steam in the still as well as helping to make a stronger liquor. The coil connects with a long seal discharging finally into the top of the still. There should be a tee in the line leading from the coil to the seal. From this tee a ¼-in. pipe runs up to the crude liquor tank, sealing about 4 in. The crude liquor heated in the lead coil gives up a good deal of its CO_2 and H_2S but is not heated enough to lose much ammonia. However, sealing the vent pipe in the liquor will allow the cold crude liquor to catch any traces and at the same time the other gases will escape. Freeing the liquor from a part of these gases will render the process of distillation easier as there will not be so much danger from salts. If there is not a vent pipe the gas evolved traps the liquor in the pipe and it backs up.

Not many stills are built nowadays with a lead coil condenser but have condensers a good deal like the sections of the distilling columns in which the vapors are condensed and scrubbed in the condensed liquor, making a combination condenser and scrubber. In such a case the use of the top of the condenser for preheating the liquor is not possible unless a special arrangement is made when setting up the condenser.

Overflow.—A part of the condensed liquor is taken out of the lead pipe just as it enters the absorber, by a tee, having a ½-in. pipe connection, and after passing a long seal, overflows through a special weir, carrying a Twaddle hydrometer, into the receiving tank direct. That is, this liquor does not enter the absorber. Some liquor does enter the absorber and all the vapors pass through the absorber seal. The small stream that flows over the weir is a sort of sampler and shows at a glance just what sort of concentrate is being made at any time (Fig. 57). The waste liquor runs out from the bottom of the fixed still, through a deep seal pot and overflows to the sewer.

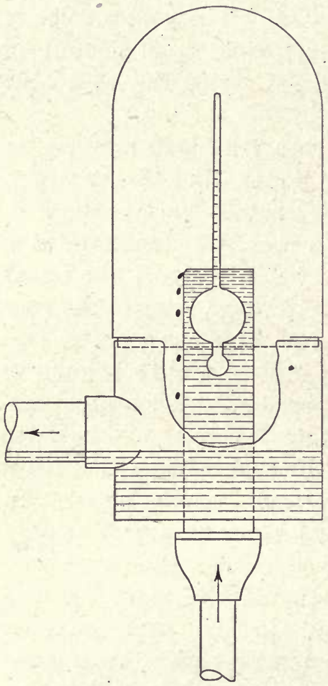


FIG. 57.—Overflow of concentrated liquor.

Lime Feed.—The lime needed may be introduced in various ways. Some very ingenious methods for this have been successfully developed but they are all rather expensive. One very good method, which can be cheaply applied is to build a wooden tank 5 ft. long, 2 ft. wide and 18 in. deep. This is filled with water to the depth of 12 in., giving a volume of about 75 gal. In the bottom of this tank is placed a rectangular frame of ¾-in. pipe, perforated on three sides, with eighth inch holes and connected to the exhaust of the liquor pump. This will boil the water and keep the lime suspended by agitation. An overflow pipe is put in at a depth of 1 ft. Above the tank is mounted a waterwheel. This waterwheel is about 2 ft. in diameter, with cups 3 in. deep and about 3 in. square. These cups are put in so that when a cup is at the extreme outward position on the way down, the bottom is at a small angle from the vertical. The effect being that the cup remains full until it is nearly down. This wheel is mounted on a brass pipe. From this pipe run two ½-in. arms of brass pipe long enough to dip well below the surface and holding two brass cups about 2 in. in diameter and 2 in. deep. As the wheel turns around the cups take up a charge of lime water and turning over these cups discharge it into the arms. These arms project ½ in. into the shaft tube. The lime water runs down the arm to the shaft and thence to a funnel placed under the end of the shaft. While one cup is dumping the other is filling. The water to run this wheel is obtained through a ¼-in. line and after running the wheel, the waste is caught in a pan below the wheel and from there it goes to a barrel. From this barrel it may be diverted to wherever it can be used. One way to use it is on the condenser of the still. About 45 gal. of water for each 60 gal. of crude run through the still will be needed.

The overflow from the lime tank discharges into the same pipe that carries the lime water delivered by the cups. A pipe runs to the lime leg. Enough exhaust steam should be used in the tank to boil the lime vigorously and produce about 10 or 12 gal. an hour of condensed steam.

Now suppose the plant is distilling the liquor from 24 tons of coal per day, the fixed ammonia being 25 per cent. There will be needed 1 lb. of caustic lime for each 10 per cent. of fixed NH_3, per ton of coal, or 2.5 lb. in this case. That is, the liquor from 1 ton of coal per hour is distilled and 2½ lb. of lime required for it. As 10 gal., for instance, of water will be formed from condensation in the lime vat, the strength of the lime water must be such that 10 gal. will contain 2½ lb. of lime. Therefore, add to the lime vat each hour enough lime to keep up this strength. To charge the vat originally we will need 7½ times 2½ or 19 lb. This lime should be carefully slaked in cold water and poured slowly into the tank. Avoid lumps. If one can get hydrated lime in bags it should be by all means used, but it must be remembered that to get the same amount of CaO 1.32 times as much must be used as unslaked CaO.

The lime water should be about 4¼°Tw. when cold and well agitated. It is a good plan to always use a slight excess of lime. In case the wheel picks up a little more lime water than the condensation will take care of, the loss should be made up each hour when adding the lime.

NOTES ON OPERATING STILLS

Rate of Feed.—The liquor should be fed at a constant rate. A graduated cock on the feed into the funnel should permit of close regulation. Ordinarily about 60 gal. of 1 per cent. liquor are produced per ton of coal; about 40 gal. coming from the scrubbers and the remainder from the rest of the recovery plant. It is advisable to shut down the still about once in 10 days for cleaning so the feed should be set to run 10 per cent. faster than liquor is being made from the coal. If the plant is making 1,000 gal. of crude liquor per day there should be distilled about 1,100 gal. each day. Then every 10 days the liquor wells will be nearly empty.

Seal Pot.—The waste from the fixed still goes down into a seal pot, often 10 ft. deep, and then flows to the sewer. This should be watched to make sure that enough lime is getting through the still. The waste liquor should always be slightly milky from excess of lime and it should never be clear. The action of lime is as follows:

$$CaO + (NH_4)_2SO_4 = CaSO_4 + 2NH_3 + H_2O.$$

About all the calcium sulphate goes into solution. If clear waste liquor be tested with caustic potash the following reaction occurs:

$$CaSO_4 + 2KOH = K_2SO_4 + Ca\,(OH)_2.$$

About all the lime comes out as a precipitate. If just exactly enough lime were present to unite with the fixed ammonia salt the resulting waste would be clear, but in practice it is safe to have a slight milkiness at the outlet of the still.

Back Pressure.—This occurs from various causes. The condenser coil may be choked with salt, the absorber pipes may be salted, or if the feed runs over and the still will not take it, the volatile still may need cleaning or the lime leg blowing down. If the salt is in the condenser coils, the condenser water should be tested with steam. The absorber pipes may be steamed directly. Often the seal pot blows from a dirty still or from excessive steam pressure entering the still. The lime leg may build up with settled-out lime and should be blown down every 2 days for a minute or so, to remove it.

Cooling.—The absorber should be fitted with 1-in. lead coil for cooling. If the absorber is run cool, the crude liquor may run through it, on the way to the feed tank, or, the water that runs the lime wheel may be used. The crude liquor is usually the coolest in the summer as the water in the piping reaches very nearly the temperature of the air.

Temperature Control.—At the outlet of the still a thermometer should be placed so that it will show the temperature of the vapors leaving the still. This temperature must be closely watched. With a given strength of crude liquor, a certain temperature is required to give the desired per cent. of NH_3 in the concentrate. What this temperature is must be determined by experiment. Generally speaking, with a crude liquor of 1 per cent. a temperature of 190° F. will give a concentrate of 14 per cent. With weak liquors or with excessive water used with the lime, the temperature must be run lower to get the same result, thus causing danger of loss in the waste from insufficient boiling.

The temperature may be regulated by a Mason reducing valve taking steam at 100 lb. pressure. With a constant flow of liquor and water a certain pressure on the outlet side of the governor, will give the desired temperature. When the valve is adjusted to give the desired pressure, the temperature will be fairly constant. With a Sylphon or Sarco regulator the temperature is controlled automatically. These devices are not expensive and have been known to operate with great exactness. The steam valve is placed on the line leading to the still and the lead bulb which controls the action of the valve may be placed either in the top section of the still or in the outlet pipe to the condenser. It will take some experiment to set these instruments to maintain the right temperature but once set there is very little deviation.

Extra Strong Liquors.—It is usually impossible to concentrate stronger than 15 per cent. without danger of salting. This salting is due to the CO_2 forming ammonium carbonate. By passing the lead vapor pipe down into a solution of milk of lime kept boiling hot, the CO_2 will combine with the lime and form calcium carbonate. The ammonia vapor will pass on to the condenser and liquors as high as 25 to 30 per cent. can be made. On a 50-ton still the washer should be about 50-gal. capacity, hold 25-gal. milk of lime and the vapor pipe should be sealed 12 in. All the lime for the lime leg plus enough to take care of the CO_2 should flow through this tank, running through a seal to the lime leg. With a crude liquor containing 1 per cent. by weight of CO_2 there will be required 14.25 lbs. of hydrated or 10.8 lbs. of caustic lime per 100 gal. of liquor to unite with the CO_2. If there is much H_2S present, more lime will be needed in the proportion of 14 lb. CaO for each 1 per cent. per 100 gal. There are also ingenious methods of preheating the liquor to remove CO_2 and H_2S. The formulæ for the above reactions are as follows:

$$CaO + CO_2 = CaCO_3$$
$$CaO + H_2S = CaS + H_2O.$$

Cost of Operation.—Mr. A. F. Blossey, in a paper read before the Illinois Gas Association, gives the following data in regard to a plant carbonizing 3,000 tons of coal per annum:

Assume an actual recovery and sale of 4.5 lb. of ammonia per ton, selling at 7 cts. per pound. The return will be $945 and the cost of making marketable ammonia would be as follows:

Steam coal necessary for still only	$90.00
Steam coal for pumps, lime, heat, etc. est.	20.00
Interest and depreciation on $3,000 @ 10 per cent.	300.00
Extra labor for cleaning, operating, etc	150.00
Lime, 21 lb. per ton, 30 bbl. @ $1	30.00
Repairs, renewals, contingencies	40.00
Total	630.00
Yearly saving	315.00

In the discussion of the paper some further facts were brought out. Theoretically about 70 lb. of steam per ton of coal carbonized will be required to concentrate liquor from 1½ to 18 per cent. pure NH_3. Allowing a safe efficiency of 75 per cent. for the average still, we would have a consumption of 100 lb. of steam per ton of coal carbonized. The boiler horsepower thus required for a plant with a daily capacity of 50 tons of coal carbonized would be about 7, for a 24-hr. period, and thus about 14 for the same-sized plant for a 12-hr. period.

Chemical Control.—Full details of the chemical work required in connection with ammonia recovery are given in the section on ammonia in Chapter II on chemical control. There are also tables of value in calculating the results and operating methods.

Efficiency Tests.—In addition to the loss of ammonia in the effluent on the still, there are other possible means of escape for the vapor of NH_3 during distillation. Therefore a determination of the waste-liquor loss does not give a complete check on the efficiency of the still. To thoroughly test the operation it is necessary to determine the input and output of the still in pounds NH_3.

To carry out such a test, isolate a well of crude liquor, measure it, then pump out the receiving tank so that it will be entirely empty. Measure and sample the absorber, if of the tank type, and also sample the crude in the well. Make analyses of these samples. After running 24 hours, again measure and sample the absorber, also the receiving tank and measure the crude well. Make analyses of these samples, calculating the amounts of ammonia represented by the different liquors. The figures might be arranged as follows:

Crude well at start	20,000 gal.
Crude well at finish	15,000 gal.
Crude distilled	5,000 gal.
Crude tests, 2.5°	1.00 per cent.

Pounds NH_3 delivered to still

5,000 (gal.) $\times$ 8.44 (lb.) $\times$ 0.01 = 422 lb. NH_3

When the test was started there were 300 gal. of 18°, 14 per cent. liquor in the absorber, that is, 382 lb. NH_3. The receiving tank at the end of the run held 260 gal. of 19°, 15 per cent. liquor and the absorber 300 gal. of 20°, 16 per cent. liquor. The total amount of ammonia in the concentrate figures out 796 lb. Assembling the figures, we have:

Pounds NH_3 delivered to still			422
Pounds on hand, start of test		382	
Pounds on hand, end			
Absorber	440		
Receiving tank	356		
		796	
Pounds made on still			414
Pounds lost			8

Efficiency $\frac{414 \times 100}{422} = 98.1$ per cent.

While the test is being carried on, obtain an average sample of the waste liquor from the still and determine the loss in ammonia at this point, for the 24 hr. It should agree closely with the total loss but if it is much less and the total loss rather high, the still should be very carefully examined for vapor or liquor leaks.

Recovery Balance.—When the amount of ammonia available for sale is unsatisfactorily low, a systematic campaign must be undertaken for the detection of the losses. While in some cases it will be impossible, for reasons of insufficient or improper equipment to obtain the maximum result one should not be satisfied until losses are accounted for and a balance of loss and production obtained. It should be possible as a rule to obtain a delivery to the standpipes, of 5.25 lb. ammonia per ton of coal carbonized. Suppose the maximum possible recovery has been determined at 5.25 lb. Proceeding through the plant, the loss in the gas from the secondary scrubbers has been determined accurately over a period, also the amount lost in regular practice in the effluent from the still. There remain losses from leakage of liquor, evaporation etc., which are not susceptible of accurate determination. The results may be arranged in a table as follows:

Ammonia in crude gas, to be accounted for		5.25 lb.
Pounds NH_3, concentrated	4.98	
Pounds lost, scrubber gas	0.05	
Pounds lost in still effluent	0.15	
Accounted for		5.18
Unaccounted for		0.07

The ammonia accounted for represents loss by leakage of liquor, evaporation of ammonia vapor, leaks on the still, etc. If the amount not accounted for is much over 1/10 lb. per ton, there are probably undiscovered losses that can be corrected and a further search should be instigated.

CHAPTER IV

WATER GAS

THE GENERATOR

Sizes of Machines and Capacity.—In stating that a water-gas machine of given size will produce a given amount of carburetted water gas per day, a good deal of latitude must be assumed. Local conditions, kind of oil, fuel, quality of gas required, etc., will all affect it. The table shown below indicates average results from one make of machine.

Table VI. Water-gas Machine Sizes.

Diameter generator	Daily capacity, cubic feet
3 ft. 9 in.	80,000– 100,000
4 ft. 0 in.	100,000– 125,000
4 ft. 6 in.	150,000– 175,000
5 ft. 0 in.	200,000– 225,000
5 ft. 6 in.	225,000– 275,000
6 ft. 6 in.	350,000– 450,000
7 ft. 6 in.	475,000– 676,000
8 ft. 6 in.	800,000– 950,000
9 ft. 6 in.	1,000,000–1,300,000
10 ft. 6 in.	1,265,000–1,600,000
11 ft. 0 in.	1,500,000–1,850,000
11 ft. 6 in.	1,650,000–2,000,000

Western Gas Construction Co.

Blasting.—Gas makers, as a rule, are in too much of a hurry to get the first run on. They will often excuse themselves by saying that they are afraid to blast longer for fear of overheating the carbureter or superheater. However, it is extremely bad practice to put on a run before the generator is ready for it. If the shells get too hot, open the coaling door and blast out into the room for a while. When the fuel bed is of proper depth, say 6 to 7 ft. deep, the differential through the fire at mid-clinkering time should be about 6 in. Less than 5 in. would indicate that there are blow holes up through the fire. The blast pres-

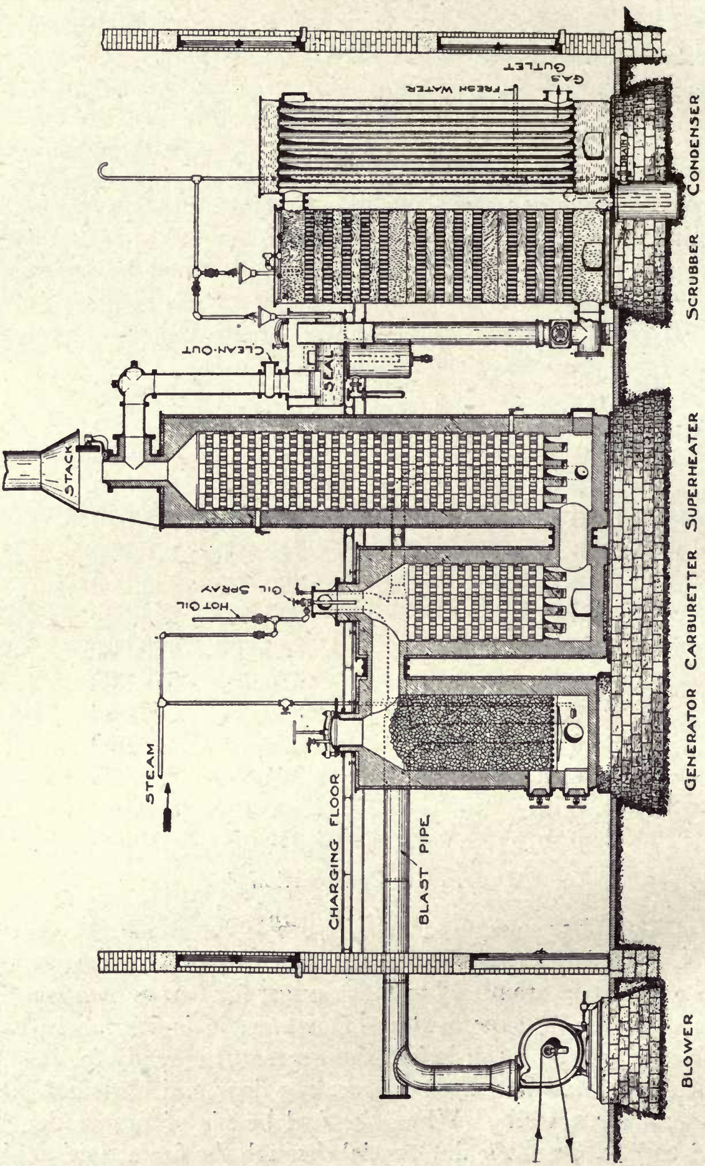


FIG. 58.—Diagram of a carburetted water-gas apparatus.

sure should be about 20 in. in the blast main and between 12 and 20 in. under the grate. Too high a blast through the fire generates excessive heat with the formation of clinker resulting in a waste of fuel. Generally it is not advisable to have a pressure under the grate of more than 18 in. On the other hand, if the blast pressure falls below 12 in., the velocity of the hot gases through the fire falls too low. As a result the CO produced is not altogether swept out of the fuel bed and a good deal of it burns to CO_2 before leaving the fuel bed which seriously interferes with the efficiency of operation. During long blasts there is danger of overheating, burning out linings and grate bars; and to prevent this it is usual to open the steam valve and run in steam with the blast for a few moments, very frequently.

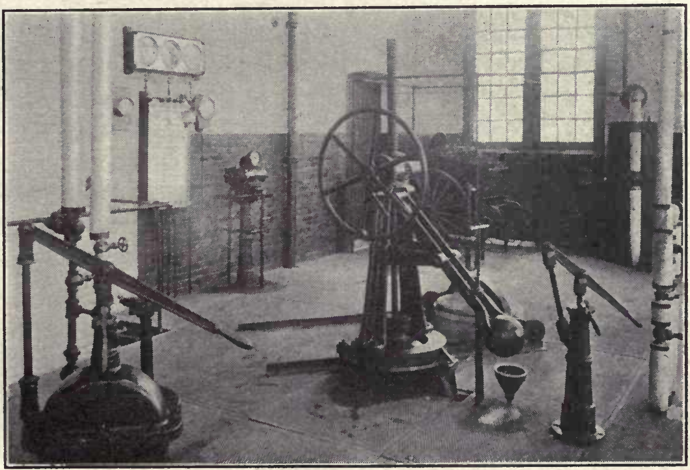


Fig. 59.—Operating floor of set.

Measuring Air for the Blast.—The most satisfactory method of measuring air for the blast is to install a Venturi meter in the line leading to the generator. The differential readings are calculated to correspond to cubic feet per minute and the scale is put on the gage-glass, so that the gas maker can see at all times the exact amount of air he is putting through the fire. With a coke fire of 6½ to 7 ft. deep, about 1,400 cu. ft. of air per minute will be required for each 1,000 cu. ft. of gas produced.

The air should be admitted at such a rate as to supply about 100 cu. ft. of air per square foot of grate area per minute. Thus suppose an 8 ft. 6-in. machine makes 6,300 cu. ft. of gas per run of

4 min. Then 6,300 times 1,400 equals 8,820 cu. ft., the amount of air to be used. The grate area is 33.2 sq. ft., then 100 times 33.2 equals 3,320 cu. ft. of air that should be supplied per minute. To determine the time of blowing, divide 8,820 by 3,320, which is about 2.7 min. The nominal length of blow should then be 3 min. If the set is properly proportioned and the checkerbrick clean and properly spaced, a 3-min. blow under these circumstances, should put the fire in prime condition for making gas; and the resulting CO should, if consumed with the right amount of air, just bring the carbureter and superheater to a good heat for vaporizing and fixing the oil.

Steam for the Generator.—The amount of steam which can be decomposed by any given generator fire falls within quite narrow limits. To use less than the proper amount means a loss of capacity and trouble from excessive clinkering. On the other hand, the use of too much steam deadens the fire and produces carbon dioxide which has a bad effect on the gas by lowering its candlepower. For every per cent. of carbon dioxide in the gas the candlepower is lowered approximately 4 per cent. Theoretically it requires 15.5 lb. of steam to produce 1,000 cu. ft. of gas. To get results however, it is necessary to double the amount of steam admitted to the generator. This steam must be as dry as possible; and all steam lines leading to the generator should be covered and a good steam separator and trap should be installed. The boiler pressure should in all cases be above 90 lb. The bottom steam outlet below the grates should be a T-shaped fitting with a head pointing up, drilled like the head on a watering pot and with an opening pointing downward so as to allow the condensation to drop out and not be thrown up against the grates.

If bottom and top steam are both used the lines should be connected just above the steam valves so that there will not be a long column of pipe on the down-run line to fill up with condensation while making up runs. That is, the main steam line should branch just above the valves. For up-runs about 35 lb. of steam per 1,000 cu. ft. of gas should be allowed and 30 lb. for down-runs. For an 8-ft. 6-in. machine the calculations would be simple. For example, the minimum make per run expected would be 50 cu. ft. per square foot of grate area per minute. Thus, with a grate area of 33.2 sq. ft. at least 1,660 cu. ft. of gas per minute should be made. Then 1.66 times 35 = 58 lb. of steam per minute the amount that would be required on up-runs. About 60 lb. would be used in this case, tapering off a little on the last minute of the run. For the down-run about 10 lb. of steam less would be used.

Measurement of Steam.—It is very important to be able to tell the exact amount of steam being used. If the boiler pressure remains constant, the same number of turns on the steam valves will give the same amount of steam each time but no dependence can be put on the boiler pressure. A rough method of gaging the steam so as to get the same amount in each run is to have a tee below the valve, with a ¼-in. pipe running to a steam gage.

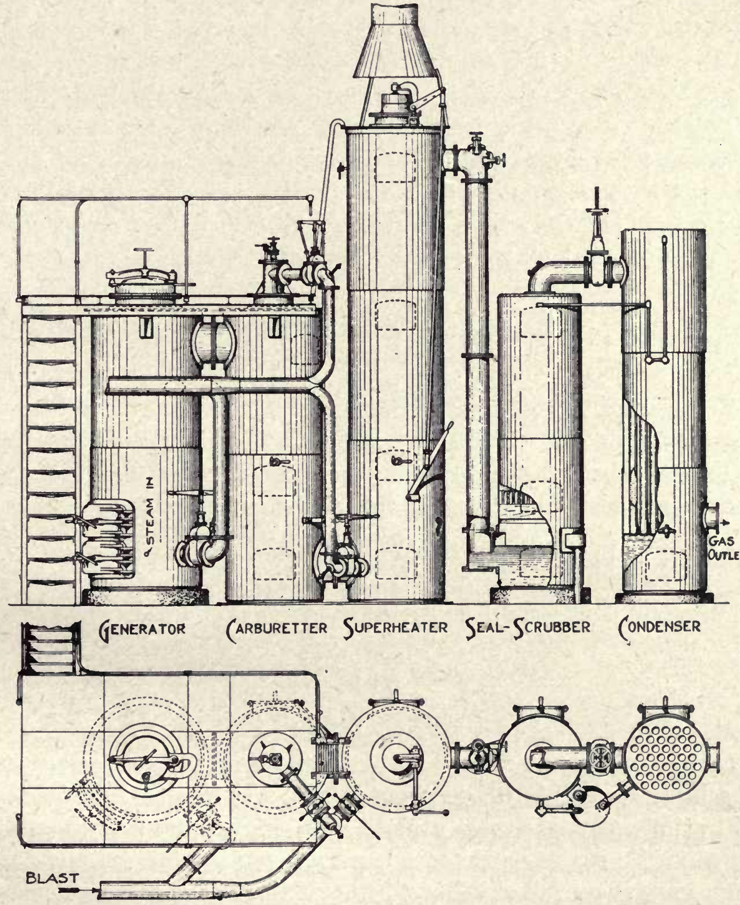


Fig. 60.—Small set with seal scrubber.

Opening the valve each time until the same pressure is registered in the line leading to the generator will insure every nearly uniform delivery. Just how much steam this is per minute may be determined by experiment. This is done by condensing the steam in a barrel of water and weighing before and after condensation. Thus by knowing how many pounds of steam per minute are desired, one may by experiment find what the pressure on the generator line must be in order to deliver it. Another more satisfactory method, is to have an accurately bored disc in a flange union below the valve, with a pressure gage connected above and below the disc. The hole in the disc must be of such a size that the absolute pressure on the low side is not more than 58 per cent. of the pressure on the high side. Then the steam per minute is calculated by the following formula:

$$\text{Steam} = \frac{60 \times \text{area of hole in square inches} \times \text{absolute pressure, high side}}{70}$$

For example, if the boiler pressure is 100 lb. and the pressure just above the disc is 90 lb. or 105 lb. absolute pressure, then the pressure below the disc must not be over about 60 lb. For instance, we wish to deliver 55 lb. of steam per minute. Then, the formula being: $S = \frac{60 \times A \times P}{70}$ we have,

$$55 = \frac{60 \times A \times 105}{70}$$

$$a = \frac{55 \times 70}{60 \times 105}$$

$$= 0.414 \text{ sq. in.}$$

A hole, to have an area of 0.414 sq. in. should have a diameter of a little over 23/32 in. or about 0.7 in. It is good practice to drill a hole of this size in a piece of 1/8-in. steel and try it out. Turn on the steam until the upper gage registers 90 lb. and the lower gage should read below 45 lb. If this is the case an accurate measure of the steam may be assumed. The discs wear rather fast and should be renewed from time to time. They have many other uses such as measuring steam to the pumps, to holders, to benches, etc.; and are handy and accurate.

Of course, the ideal way of measuring the steam is to install a regular indicating steam meter. This shows directly the pounds of steam flowing per minute. One meter should be used for up- and one for down-runs. In the foregoing calculations the lengths of the blow and the run has been stated as 3 and 4 min. respectively. As a matter of fact, the actual time is a little shorter, depending on the amount of time used in changing valves, etc. For very accurate work the operator should determine the time that is taken in mechanical changes with a stop watch and deduct it from the nominal blow and run.

Summary of Calculations.—To make the matter a little clearer especially for small-plant workers, figures are given below for working out results on a 3-ft. 6-in. machine, up-runs only:

Inside diameter of generator		2 ft. 6 in.
Area of grate surface		4.908 sq. ft.
Depth active fuel bed		6.5 ft.
Desired make per square foot of grate area per minute of run		50 cu. ft.
Length of run		4 min.
Air to generator per 1,000 cu. ft. of gas		1,450 cu. ft.
Velocity of air per square foot area per minute		100 cu. ft.
Steam per 1000 cu. ft. of gas made		35 lb.
Make per minute of run	50 × 4.908	= 245.4 cu. ft.
Make per run	245.4 × 4	= 982 cu. ft.
Steam per minute	0.982 × 35	= 8.6 lb.
Air per blow	0.982 × 1,450	= 1,424 cu. ft.
Air per square foot area per blow	1,424 ÷ 4.908	= 290 cu. ft.
Length of blow	290 ÷ 100	= 2.9 min.
Actual length of blow		= 3 min.
Air per minute of blow	1,424 ÷ 3	= 475 cu. ft.

In practice from the foregoing figures, about 9 lbs. of steam would be used and a make per run of 1,000 cu. ft. corrected would be expected. Of course, the amount of oil used to carburet the gas would have an effect on the make per run. Probably a little more air would be needed as the smaller sizes of machines do not run quite in proportion to the larger ones. The machine should be run 4 or 5 days on the above schedule and tried out. If the carbon dioxide is low and the candlepower holds up with a reasonable amount of oil, it is well to try increasing the steam until the maximum production of the machine is reached. With good coke the make per square foot can be crowded up to 55 cu. ft. and even in some cases to 60 cu. ft. The calculations for other sized machines are governed by the same factors.

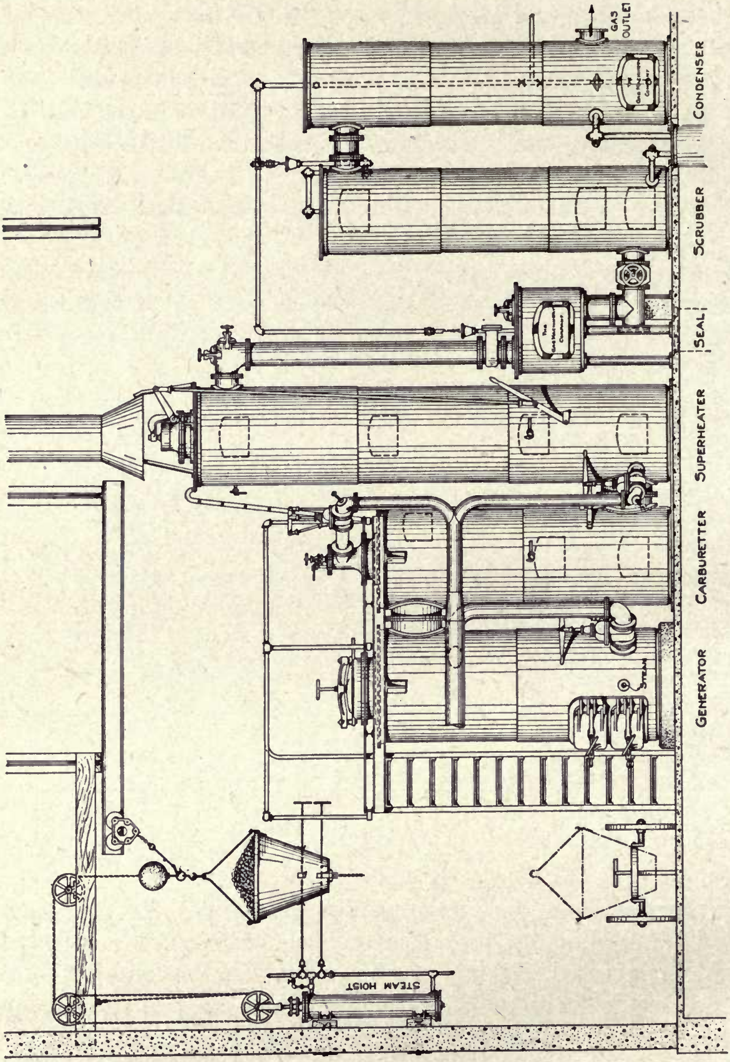


Fig. 61.—Water gas set with steam hoist.

Table VII.—Effect of Carbon Dioxide on the Candlepower of Gas (Nesbit-Latta)

2.5 per cent. CO_2 causes a loss of	9 per cent. in candlepower.
5.0 per cent. CO_2 causes a loss of	20 per cent. in candlepower.
10.0 per cent. CO_2 causes a loss of	40 per cent. in candlepower.
20.0 per cent. CO_2 causes a loss of	75 per cent. in candlepower.
30.0 per cent. CO_2 causes a loss of	90 per cent. in candlepower.
58.0 per cent. CO_2 causes a loss of	100 per cent. in candlepower.

Chemical Control.—In the chapter on chemical control the method of calculating the blue gas in the finished gas is discussed. The most important factor to consider in generator operation is the percentage of CO_2 in the finished gas. Next is the percentage of CO_2 in the products of the blow. The amount of CO_2 in the water gas must be kept as low as possible on account of its effect on the candlepower; and the percentage of CO_2 in the products of the blow should be as high as possible. Every per cent. of CO left unburned means a loss of 1 lb. of generator fuel. When the heats are in proper balance it should be possible to keep the percentage of CO_2 up to 18 per cent. at the stack, during the blow, most of the time. Samples should be taken with the Orsat apparatus and tested from time to time. The percentage of CO_2 in the water gas increases with the length of the run, which is one of the chief arguments for shorter runs. The effect of carbon dioxide on candlepower is given in the table on p. 118.

An excess of CO_2 would indicate either a cold fire, a dirty fire, holes through the fuel bed, an excess of steam, a leaking up-and down-run valve, or shutting the stack too quickly, etc.

Relining.—The generator lining should be renewed frequently. The lining should be double from a point about 5 ft. above the grate down to it. The lining toward the fire when worn through can then be easily renewed. Latta recommends a compound of "salt, sal ammoniac, fire clay and finely powdered brick for patching" and also a compound of "iron filings 100 parts, fire clay 50 parts, common salt 10 parts and quartz sand or powdered firebrick 20 parts." There are several excellent brands of patching cements on the market. When a generator is to be relined the damaged or worn layer is removed for a considerable space and the surfaces of the exposed layer and the joint with the old lining are cleaned. The old work and new blocks are thoroughly wet, then thinly coated with fire-clay mortar mixed thin and the blocks are then rubbed into place in such a way as to bring the surfaces into contact with one another and at the same time leave mud enough to fill the interstices between them. When one section is renewed another section should be cut out around the generator without leaving too great a space unsupported at any one time. The cut surface of a block should never be exposed to the fire. The very highest grade of blocks should always be used in generator work.

Clinkering and Barring Down.—The number of runs that can be made before clinkering depends on the size of the machine, the kind of fuel, the blast rate and the manner of operation. For a 3-ft. 6-in. machine with a high ash coke, it may pay to shut down at the end of every 15 or 16 runs for a 10-min. job of clinkering. With an 8-ft. 6-in. machine with fair coke it may be possible to run 18 hr. without clinkering and with the larger machines using oven coke clinkering once only in the 24 hr. has been practised. A safe rule to follow is to clinker as soon as the deposit begins to make serious inroads on the efficiency of operation. The most thorough work must be done, of course, when getting the machine ready for the day's run.

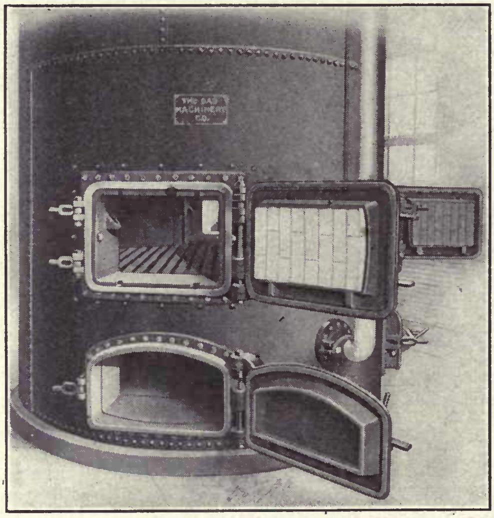


Fig. 62.—Clinkering and ash-pit doors.

If false bars are used they should be driven in above the clinker. To do this open the coaling door and drop stack valve. Then cut out all clinker, going to the sides of the generator so as to thoroughly clean them, using sharp chisel bars and a hoe to remove the side clinkers. If false bars are not used great care must be taken not to drop the fire too soon. Two or three men usually work together on a large machine working from different doors toward each other, cutting out the clinker from the sides and gradually working to the center, leaving a sort of inverted cone supporting the fire, the apex of which is at the center of the grates. Finally this should be cut out, and the lumps should be broken up and raked out as the fire drops. The fire should be left evenly distributed over the grate. All of the ashes should be worked out by running a hook up from below, between the grate bars. About once in 5 days or oftener if needed, it is well to bar down from above to get off all side clinkers that have formed high up, using a very heavy bar. Whenever the clinkers form on the sides and refuse to come off or the bottom clinker is piling up, the fire should be pulled and the generator given a very thorough cleaning. This should never be necessary oftener than once in 30 days.

Oyster or clam shells dumped in with the coke may help to soften a bad lot of clinker. If the time is available it is well to leave the steam valve cracked for about 12 hr. and at the end of that time the clinkers will be found to be rotted and softened; and nine times out of ten the fire will be out also.

Blast Lines.—The cheapest way to prevent damage from explosions in the blast lines is to put on the blast tees some kind of easily ruptured cap. One good way to handle this is to put on these tees sheets of brown cardboard, cut to fit the flanges and with the bolt holes punched to fit the flange holes. A supply of these should be kept on hand. An explosion in the pipe will burst these papers but cause no other damage. If one of the tees is in a particularly inaccessible place double thickness of cardboard should be put on it. If this is done it will rarely have to be renewed. If for any reason these papers cannot be used on a particular machine, a spare section of blast pipe should be kept on hand, to be slipped into place in case of a rupture.

With some machines it is almost impossible to prevent occasional shots and with the paper heads in the tees, no damage and little loss of time will result. Sometimes a tee is placed in the blast line with a leg pointing down into a barrel filled with water. If this is done the seal should be about 26 or 27 in. deep which will hold any ordinary blast pressure and will instantly relieve the pressure of an explosion.

THE CARBURETTER

Recheckering.—Mr. W. I. Battin has described the checkering of a water-gas machine very clearly, as follows:*

"A starting tier is laid in parallel rows on edge, the next tier is at right angles to it, and the third tier is laid in the same direction as the first but the rows of brick are directly above the spaces in the first tier—staggered, we say—and this scheme is followed out all the way up.

* Paper read before Ill. Gas Assn., published in *Progressive Age.*

Instead of staggering the bricks over the spaces the rows may be placed directly over each other, making flues, if it is desired to have the machine blast freer. The idea in checkering should be this: The gas ought to go rapidly through the checkerbrick when the machine is turning out the proper amount of blue gas. In this case, the heats can be high. If with a bad fuel the make of gas is small, by lowering the heats no harm will be done if the gas does travel through the checker brick slower. In extreme cases a great excess of steam can be used to carry the oil gas along. When checkerbrick are spaced close, the speed of the gas through them is increased but the gas is brought into more intimate contact with the brick; there are also more brick for the same amount of gas made, and these bricks will be hotter, and especially so because the increased resistance to the blast makes the speed of the blast through the fire slower. More carbonic oxide is thus made to burn between the bricks.

"Widening out the spaces does just the opposite. For coke, 2½ in. is nice spacing. For coal, on account of the dust carried over from the fire 3 in. is preferable. When naphtha is used, it is sometimes customary to space the brick 4 in. apart. In recheckering don't forget the sight cocks. Always put a rod through them right across to the other side of the machine. The checkerbrick around this will form a flue through which the heats can be watched across the whole machine.

"A machine which runs continuously every 24 hrs., ought to be recheckered every 30 or 40 days and those which run intermittently in proportion. Moreover, if there is any reason to suspect that a machine is not working right there should be no hesitation about taking out the brick and replacing it. If the brick are in good shape they are simply dusted off and replaced and very few new ones are needed. Reject only those that are glazed or slagged. The cost of recheckering is small but a slight reduction in oil efficiency runs the operating cost up very fast. Unfortunately it is not the length of time alone that causes a machine to depreciate in efficiency. A machine just recheckered may be spoiled the day it is put on by wrong handling of it or by trouble with the oil spray or very bad fuel."

Pyrometer Couples and Sight Cocks.—There should be two openings for pyrometer couples in the carbureter. The upper one should be about nine courses down from the top of the checkerwork and the lower one about five courses up from the bottom. There are usually two sight cocks in the carbureter, one at the top and one near the bottom of the machine. If the machine is equipped with a pyrometer their use is not so important but in case the set is not so equipped the upper part of the carbureter and the superheater should be closely observed. During the first blow the sight cock at the top of the carbureter will show whether the secondary air lights the gas or not when the gate is raised a little. Observation through the sight cocks will give a good general idea of the condition of the bricks and when they need to be cleaned.

Oil Sprays.—There are a number of different oil sprays supplied with the various types of machines but they are all likely to clog and cause trouble. They should be removed and examined very often. The disc sprays which throw an umbrella of oil are very likely to spray incorrectly. The wheel valve regulates the spray of the oil and should be adjusted so as to throw the spray evenly nearly to the sides of the brickwork. In order to adjust it, it should be removed from the machine and connected up to a water line, cutting the pressure to that in the spray line when running the oil into the machine. The wheel should then be adjusted until the spray is thrown to a circle slightly smaller than the inside diameter of the carbureter measured at a distance below the spray equal to the distance of the brick when it is in the machine If the spray does not lift out of the carbureter during the blast it should be carefully protected by being wound with asbestos rope.

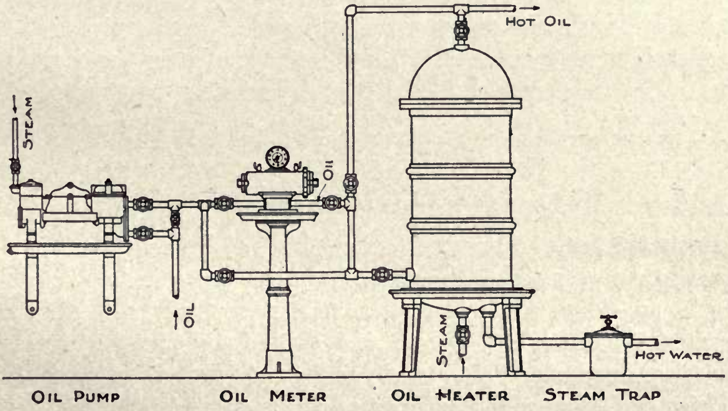


FIG. 63.—Oil-feed heater.

Oil Heating.—Opinions differ about the advantages of preheating the oil. Authorities are about agreed that a series of pipes arranged in the take off pipe is not a good way of heating the oil. A better way is to use exhaust steam from the pumps when the oil has to be pumped long distances (Fig. 63). In cold weather it is frequently sluggish and very difficult to move. In such a case an oil heater may be installed at the tanks so that the oil may be heated by exhaust steam; and it will not lose all its heat in passing underground to the pump room. Such a heater may be made of several lengths of 2-in. pipe, inside a brick or concrete housing into which the steam is exhausted.

Oil Supply.—Fully 3 weeks' and in most cases 1 month's supply of oil should be on hand at all times. It is better not to have all the oil in one tank but to have it in at least two tanks, connected together but with a valve between them. The tanks should be half sunk in the ground and surrounded by a concrete-lined pit capable of holding the contents of both tanks in case of failure. Generally it is the practice to have two pipes entering the tank, an inlet and outlet pipe with a check valve on the inlet pipe so that no oil can be lost through an accident to the inlet lines.

The oil pumps should be single and not duplex; and should have a long stroke, should run slow and should be of a large size for the work they are called upon to do. As these pumps operate continuously it pays to spend a little extra money to get a pump of assured economy of steam consumption. The oil pressure should run around 60 to 70 lb. to get the best results. The pump ought to run at a constant delivery pressure which can be provided for by installing a steam governor and a relief valve in the discharge line. The relief valve should discharge into a bypass so as to circulate the oil when it is not going into the carbureter.

THE SUPERHEATER

Recheckering.—The superheater should be recheckered in the same manner as the carbureter but it will not need to be done nearly as often. The minimum life of the bricks in the carbureter should be 1,000 hr.; and in the superheater three or four times as long. The usual number of bricks in a machine is 250 for each square foot of grate area, that is, 8,250 for an 8-ft. 6-in. machine or 1,250 for a 3-ft. 6-in. set. In common practice one-third of the number of bricks are put in the carbureter and two-thirds in the superheater.

When recheckering the carbureter it is usually the case that all of the bricks that go back into the machine have to be new. With the superheater this is not the case. The new bricks should be placed at the bottom of the superheater and the best of the old bricks should be taken from the carbureter or superheater and put in the rest of the way up. It is usually possible to use two-thirds of the old bricks, which have been used not more than once before; and some bricks will last through several cleanings. These bricks are expensive and every bit of wear possible should be got out of them. When they are no longer of any use for the machine, they are still of value for foundations and concrete work.

Sight Cocks.—There are two or three sight cocks on a superheater. The one on the top is used to get samples of the gas during the run. A jet of gas should be allowed to impinge on glazed paper or on a bright trowel. A characteristic stain of tar or lampblack as the case may be will be obtained. Excess steam will also condense on the trowel and it should be borne in mind that there should be only a slight dew. Tar will be deposited if the heats are low or if the bricks are not fixing the oil; and lampblack will be deposited if the oil is burning up. The odor is also distinctive. Over or underfixed oil has a sour odor but if it is well fixed it will have a pleasant pungent smell. Two pyrometer couples should be provided, one, three or four courses from the top and the other about the same distance from the bottom.

APPLICATION OF PYROMETRY

Judging Heats.—The method of judging heats before the advent of the pyrometer was by means of the eye. It was left to the eye of the gas maker, foreman or superintendent to determine what was a proper temperature and when it had been attained. While there were men, no doubt, who obtained marvelous precision in judging heats, it is still true that enormous losses were sustained by the gas business through not having a method of measuring the temperatures uninfluenced by the personal equation. Blue-glass pyrometers were brought out and when these were set by an experienced operator they were often of value in enabling the gas maker to secure a proper heat; but even then a great deal was left to use personal judgment. Even if a correct heat was maintained in a machine for a period, there was no way of knowing what variations occurred throughout the cycle of running.

The Pyrometer.—It was left for the inventors and developers of the pyrometer, as applied to water-gas machines, to step in and give the gas industry a system whereby the gas maker might be accurately informed about the temperature of the checker-brick at all times and the superintendent provided daily with a means of recording the temperature throughout the entire 24 hr. Additional advantages were developed in operating. For instance, it became possible to check the number of runs made, the length of the blow and the run, the time of clinkering and the general skill of the operator

The three best-known pyrometers are the Brown, the Bristol and the Thwing instruments. Each claims special advantages; and all are known to have given splendid results in practice. In its simplest form, the set consists of a fire end, enclosing the thermocouple, a set of lead wires and a delicate millivoltmeter calibrated to read in degrees of temperature. The fire ends are slipped into iron-pipe sheaths placed where desired and the indicating instrument is placed on the water-gas machine gage board. Going a step farther a recording instrument may be connected in parallel with the indicator and may be put in any convenient place; the superintendent's office or the general works gage board being perhaps the most desirable locations. Distances of 600 ft. between the fire end and the recorder are not uncommon. The recording instrument is also a millivoltmeter which records a line on a smoked chart or a line of dots on a waxed chart, or otherwise. The indications of the recorder and the instrument on the gas-maker's gage board are identical. Hence the superintendent without leaving his office can tell if the machines are running, how long they have been running, whether or not a machine is being clinkered, the length of the blows and runs and the temperatures maintained.

Thermocouples.—The fire ends are usually put up in an iron pipe with a porcelain head and with brass-connecting posts. To further protect the fire ends, they are inserted in sheaths set in the shell of the machine. The sheaths are made of extra heavy 1-in. pipe about 4 ft. long with a plug welded in one end and the other end threaded with 1¼ by 1-in. bushing screwed on backward. The shell is tapped 1¼ in. and the sheath is inserted and then the bushing is screwed tight. If possible it is best to have the sheath rest on the bricks. If the sheaths are renewed as soon as they burn out, the fire ends will last a long time.

One of the fire ends should be placed at the fourth course from the top of the superheater and one about the fourth course from the bottom. Another should be placed four courses up from the bottom of the carbureter and the fourth near the middle of the carbureter or about the ninth course from the top. If there is a full set of instruments and couples it is well to put a fire end in each of the four holes and connect them to the two sets of instruments. Two indicating instruments may be made to show all four temperatures by having a two-pole switch in the case, one contact for the top and one for the bottom of the shell. The most important temperatures are those at the top of the superheater and those near the middle of the carbureter. One recorder may be used to show these two temperatures by having a two-pole switch, as suggested above to record either temperature desired. The least expensive installation which would give really satisfactory results would be to have one indicator connected to the carbureter and superheater and one recorder similarly connected.

The couple in the upper part of the carbureter should be placed at a point where there will be a drop during the run of about 150° with new bricks. This will give a good clear mark on the chart. Generally it is the case that the ninth course from the top will show this variation but it may be found anywhere between the fifth and twelfth courses depending on the size of the machine.

Operating Temperatures.—With ordinary fuels and with a gas oil of 33° to 36°Bé., clear light oil, a temperature varying between 1,300° and 1,350° at the top of the superheater will give maximum results from the oil and no unfixed vapors will pass through and practically no lampblack and naphthalene will be deposited. The temperature should always be 50° to 100° higher at the bottom of the superheater. The temperature at the top of the carbureter, with 1,300° at the top of the superheater, will average 1,400° to 1,600° with a drop during the run of 150° with new bricks and 300° with old bricks. As the bricks get old a little higher temperature may be maintained in the superheater. If the temperature falls below 1,250° there will be unfixed oil in the gas. Above 1,350° to 1,400° most oils produce a good deal of naphthalene and lampblack. The chemical composition of the gas is altered by the difference in temperature in the superheater as is shown by the following figures:

Temperature bottom of superheater	1,250°	1,350°
CO_2	3.5	3.3
Illuminants	13.8	11.7
O	0.5	0.5
CO	32.0	30.7
CH_4	12.5	16.3
H	34.7	34.0
N	3.0	3.0

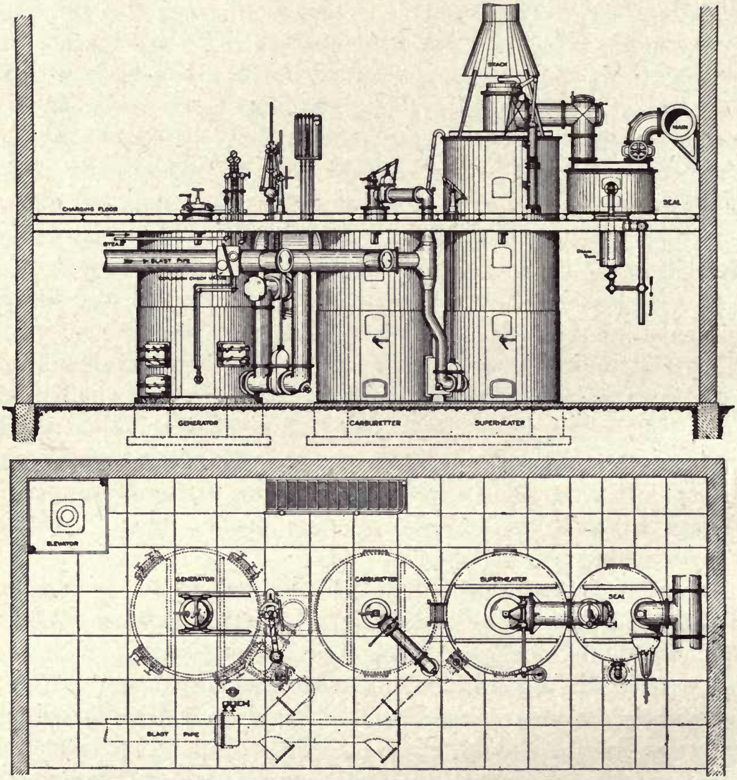


FIG. 64.—Large water-gas set with hydraulically-operated stack valve.

Generator Conditions.—If the fire is not producing carbon monoxide enough to heat the carbureter during the regular blow, not enough primary air is being used. The primary air should be increased until the blue gas shows strongly at the stack, then the secondary air should be increased enough to pull the blue gas down into the machine. The checkerbrick ought to heat up easily in the regular length of blow. If during the regular blow the carbureter gets too hot and the temperature in the superheater begins to go up and at the same time there is a lot of unburned gas at the stack, the fire has got too hot and the primary air should be decreased. Mr. C. I. Heath tells of an interesting incident illustrating the value of the pyrometer. A decided drop in temperature was noted on each down-run and a survey of the machine showed nothing apparently wrong. On examining the hot valve, however, a small quantity of coke breeze was found in the seat of the valve which prevented its seating tight during the down-run with the result that the steam short-circuited into the carbureter causing the excessive drop in temperature. Cleaning it out remedied the trouble. That was a case where the trouble would hardly have been detected without the indications of the pyrometer; and where serious effects on output and efficiency would have resulted ordinarily.

If the fire burns low, as it does toward the end of the day's run especially, the amount of steam regularly supplied may be enough to cause a cooling of the fuel bed. This will be very quickly detected by the pyrometer as there will be a quick and decided drop in the carbureter temperature. If the run is nearly over for the day, the steam can be reduced; but if there are a good many more runs to be made, the fire should be refilled as high as possible. It may even be necessary to pull out some clinker to make room for a fuel bed of sufficient depth. When the temperature of the carbureter is about 1,400° it will be found that the temperature will rise during the first minute of the run about 50°. If the rise is less than this, it would indicate that the fire was not hot enough. A greater rise than this would indicate a fire that was too hot.

Detection of Steam Runs.—Gas makers often through carelessness get in too much oil on one run and then make up for it by using none or not enough on the next run. This a bad practice as it is likely to throw the heats out of balance and make an oily gas on the run where the excess is used and make naphthalene on the later runs where the deficiency in oil occurs. The pyrometer chart will show this every time by the excessive drop in temperature followed on the next run by no drop or even by an increase. It will also show in minutes any runs that exceed the regular time.

Determining Recheckering Time.—With new bricks the drop in temperature near the middle of the carbureter is slight during the 4-min. run. As the life of the brick goes on, the drop will increase until about the time when the brick are ready for changing and cleaning, it will be double what it was at first. This condition, taken in connection with the other usual indications, will tell fairly accurately when the carbureter is "due" for cleaning. If when recheckering the top of the carbureter is found to be badly fused or massed together, it may be that the oil is prematurely admitted for the run. At the very outset of the run the brick edges are likely to be at a very high temperature but if you let the blue gas flow over them a moment or two before starting the oil you will kill this sharp heat and there will be less of this disintegration and fusing effect on the brick.

WASH BOX, CONDENSER AND SCRUBBER

Seal Pot Overflow.—The appearance of the overflow of the wash box is a good indication of what is taking place in the superheater. If a light foamy tar is running over, mixed with oil this is evidence that the oil is not being fixed. On the other hand, overheating the oil will produce lampblack which will appear on the surface of the overflow. A clear brown tar is a good indication of well-fixed oil.

The safest way of supplying water to the wash box is by circulating water from the tar well or separator. This water may be circulated by a pump or steam siphon. The amount of water supplied per hour should be about 10 gal. per 1,000 cu. ft. of gas made. Cold, fresh water should never, under any circumstances, be used in the wash box as it will absorb hydrocarbons. The ideal temperature of the water is about 110°F.

Cleaning the Wash Box.—If there is a valve between the scrubber and wash box or between the seal scrubber and condenser it should always be closed before starting to clean the wash box. If there is a seal scrubber, the scrubber and space above the water in the seal must first be very carefully ventilated before proceeding to the cleaning. The stack valve should be shut to prevent sparks from igniting any gas that may escape when opening the scrubber. The hand hole at the top of the scrubber should be opened and steam should be blown into the upper part of the wash box so as to drive out all of the gas. The hand holes on the take-off-pipe should then be opened and it should be cleaned out thoroughly. Any burning carbon will drop into the water in the seal and will go out. This pipe should be bagged off with a sack of wet shavings and then the wash box should be drawn down, the clean-out door should be opened and with hoes and hooks, a thorough cleaning out should be made. When clean it may be filled up with water.

With a separate wash box, the valve between the wash box and scrubber should be closed and the procedure outlined above followed. For a quick job proceed as follows: Open the stack valve and close the gas valve between the seal and scrubber, then remove the hand hole on the scrubber. Turn on the water and fill the wash box full of water, driving out the gas and after removing the hand-hole plate blow a jet of steam into the take-off pipe. Push a close fitting pail on a chain down into the take-off pipe and chip off the carbon, catching it in the pail. In this way work down near to the bottom of the pipe. There will be a ring of carbon just under the water's edge and to prevent this from falling into the water a dipper with a long handle should be pushed down under the surface and the chunks knocked off into it. Then draw down the tar in the box. Have a large stream of water flowing into the wash box and overflowing from it. Open the draw-off cock and let it run until the overflow stops. Then fill it up with water again and when it is overflowing strongly, draw it down again. Repeating this several times will clear the wash box of tar. Never draw down after the water stops overflowing or there may be an explosion. Be careful not to let any chunks of carbon get down into the box unless it is to be cleaned out immediately as they might choke up the outlet and cause the water to back over into the hot machine.

Condenser.—The scrubber is always placed after the wash box and then the condenser is placed next except in the case of small machines which dispense with the latter. However, the condenser is taken up after the discussion of the wash box, on account of the way the condenser water is usually used. The water on the condenser should be as cold as possible and should be admitted to the bottom of the condenser. The overflow should go to the scrubber if fresh water is used there, or to the feed-water tank in the boiler room if it is not so used. The temperatures should conform as nearly as possible to the following schedule:

Outlet of	Degrees Fahr.
Wash box	220
Scrubber	170–190
Condenser	120
Relief holder	Atmosphere

The best authorities recommend for multitubular condensers 8 to 10 sq. ft. of water-cooled surface for each 100 cu. ft. of maximum capacity per day. With such a condensing capacity the temperatures must be closely watched to prevent too severe cooling.

Scrubber.—The pump serving the wash box with water from the tar separator may also serve the scrubber. Whether fresh water or circulated water is used there it should always be warm. A spray should be installed in the top of the scrubber like the spray described in the section of ammonia recovery for the primary scrubber, the idea being to cover the entire surface of the trays with a spray of water. These trays are often of the same size and construction as those described for the ammonia scrubbers. They will rarely need any further cleaning than an occasional steaming but if necessary they may be easily removed.

METHODS OF OPERATING

The methods of running a water-gas machine are modified by local conditions, by the size of machine, by the make and construction of machine, the kind of fuel, the oil, etc. Consequently only general considerations can be outlined.

Starting a Cold Machine.—In starting up a machine that is perfectly cold, having been shut down for some time, considerable precaution should be exercised. The gas maker should first look the machine over to see that all the attachments are in place and that everything is ready for starting. A good pile of wood made up of broken boxes, old planks, etc., should be stacked up on the grates to a depth of about 1 ft. On top of this about 2 ft. of clean dry coke should be shoveled. Oily waste should be stuffed in and around the wood pile together with some excelsior. All valves on the machines should be closed. The coaling door should be shut, all but an inch, stack valve opened and the fire touched off down below. The reason for leaving the coaling door open is twofold. The air drawn in will burn any gases formed in the fire and prevent shots and the effect of the current of air will be drying due to the large volume of warm air, rather than a small amount of very hot gases from the fire. To further prevent shots it is a good plan to have a hole through the fire all the time during heating up.

As fast as the fire heats up fresh coke can be added. Too much draft must not be allowed and the ash-pit doors should be kept almost closed. If the grate bars get too hot a little steam may be turned on. When the fire has been going some hours and the set is well heated through, the fire should be built up until it is about 7 ft. deep. Now the pilot at the stack may be lighted, the coaling door closed, then the ash-pan doors and the blower started. Turn on a little steam below the grates before raising the blast. Shut off the steam and with the blower running up to full speed, cautiously raise the primary blast gate. Now blow the fire continuously, shooting in a little steam now and then, until a good production of CO is shown by flames at the stack, which may try to strike back into the machine. Try to light the carbureter by raising the secondary a little, but if it does not light drop the air at once as it will only cool down the carbureter. If the carbureter does not light within an hour, the blast should be shut off and fresh coke added. After the carbureter lights the blasting should be continued until the carbureter shows a good red heat. Enough secondary should be used to just burn the CO but never any excess.

By the time the carbureter shows a good red heat, up to 1,400° on the pyrometer couple, there will be heat enough in the superheater for a run. The seal pot should be observed, to see if the water is overflowing all right, then the gas valves may be opened from the machine to the relief holder.

Runs and Blows.—Drop the secondary blast gate, then the primary gate and cautiously turn on bottom steam until there is about half the regular amount of steam on. Lower the stack valve slowly watching the pressure gage for back pressure, then after a moment start the oil in. Make the run the usual length but use half the steam and half the oil. Cut off the oil about a minute before the end of the run. After two or three runs have been made, gradually increasing the oil and steam, the machine should have a good heat all the way through and should be ready for the regular amount of oil and steam.

In going on the run do not drop the stack valve too soon, or there will be too much blast gas going over into the holder and the CO_2 will cut down the candlepower severely. Let the blue gas flow over the checkerwork a few seconds before turning on the oil to take the sharp heat off the bricks. Put the oil in quickly the first couple of minutes and have it all in 1 min. before going off the run, to give the machine a good chance to purge. In going on the blow, raise the primary first, slowly, then after a moment open the secondary making sure that the gas lights in the carbureter, by watching it through the sight cock. The primary air must never be turned on after the machine has been standing idle without first putting a little steam under the grates. Neglect of this will cause an explosion in the ash pit, often communicated to the blast pipe and either bursting it or blowing out the explosion caps, at a time when one can not afford to shut down and renew them. There should be enough secondary air admitted to keep a little flicker of flame at the stack. When this is visible it is known that there is a complete combustion going on in the shells and the most is being gotten out of the CO produced in the generator.

At the end of each hour, coke up and before going back on the blast, steam out under the grate. If the machine is up- and down-run, the first runs should all be up-run, then after everything is hot make one down-run for every three or four up-runs. The down-run must always be changed over to an up-run for the last minute of run to clear the space below the grate, of gas. With badly clinkering coke the following schedule has proven satisfactory, Up, Up, Down, Up, Up, Up, Down, coke up and repeat. The ratio of up- and down-runs is governed by the tendency to clinker. The more down-runs that can be made the more will be gotten out of the machine but the number is limited by the action of the fire. Too many down-runs also puts the heats out of balance in the shells. The matter is one which can only be decided by experiment. Before turning on the down steam the water of condensation in the pipe must be got rid of. In some plants this is a considerable amount. During the blow the water may be worked out by cracking the valve for a minute at a time. If too big a slug of water gets in at once, there will be a tremendous puff in the machine.

The pyrometer should be watched closely all the time. The superheater should show a gradual rise up to 1,320°, where it should remain. The carbureter should go to about 1,450°F. During each run it will drop and during each blow, rise again. The superheater, however, ought to remain stationary.

The coke should be forked into the generator, or screened first if chuted in. Breeze will cause trouble and but very little can be used.

Clinkering.—The frequency of clinkering depends on the kind of fuel used, ratio of down- to up-runs, blast pressure, etc. Many large machines have to be clinkered every 12 hr. and smaller machines as often as every 2 hr. in extreme cases. In getting ready to clinker, as soon as the last run is made and the stack valve raised, it should be left open a moment and then closed. The clinkering doors should be cautiously opened, false bars driven in over the fire and all clinkers thoroughly removed, using chisel bars and hooks. When as clean as possible, the false bars should be pulled dropping the fire onto the grates. The clinker doors may then be closed and clamped tight. A bit of oily waste should then be lighted and laid on the coaling door which may then be cracked open and the escaping gas will quietly ignite, when the door may be swung wide open and the generator filled with coke.

The first blow after clinkering will need to be a little longer than usual. If, in spite of keeping the stack valve down, the superheater temperature has gone up, do not raise the secondary blast but let the gases from the generator go through and burn at the stack. They will cool down the superheater somewhat. If the carbureter goes down too much, of course, the secondary must be raised and the carbureter heated up.

Controlling the Heats.—This is the hardest part of running a machine and all machines have to be regarded as individuals. Certain general principles pertain to them all. The length of blow should be largely determined by the temperature of the carbureter. If during a run the temperature falls only a little, then the blast can be shorter as the generator fire will be brought into a healthy condition by the time the carbureter regains the proper heat. If the temperature of the carbureter comes up and the secondary blast is cut off to keep it from going any higher and the blow is continued the full number of minutes, then a waste of coke will come from this unnecessary blowing. That is, to get the fire into a healthy condition a certain amount of blasting is required. The resultant CO from this blowing is enough to raise the temperature of the carbureter to the right point, in ordinary running, provided its combustion is complete.

The secondary blast should only be opened just enough to complete the combustion and leave a thread of blue flame at the stack. As the blow continues and the CO increases the secondary must be gradually increased.

As this is done the primary must also be raised a little to keep the amount of air going through the fire uniform. If the temperature of the fire is about 1,400° at the commencement of a run, during the first part of the run it should rise about 50°. If this does not happen it is probable that the generator fire is not hot enough. If a greater rise than this is noted, the fire is too hot and excessive clinker will result. Sometimes after clinkering it will be found that the carbureter and superheater are both so hot that the blasting will overheat them. To obviate this, after coking, leave the coaling door open and blast out into the room until a good deal of flame shows. Then shut off the blast, close the door, steam out and blast for a minute or two, then go on the run.

When all else fails to keep the heat down in the superheater, blow steam into it from a separate connection during the run. The bottom of the superheater should run about 1,400° and the top 1,300°. If the top gets overheated, raise the carbureter blast way up. This will burn the CO completely in the carbureter with an excess of air. Then raise the superheater blast, the effect of this being to add a volume of cold air to the hot burned gases from the carbureter which will sweep the heat out of the superheater. For a short time the bottom will be hotter than the top but soon the temperature will have fallen to a uniform condition and after one or two runs will be back in balance.

Shutting Down.—In case the machine stands idle over night or for a number of hours, some precautions are worth considering. If the checkerwork has a tendency to carbon up a little, it can be kept pretty well burned out by leaving a draught of air through the set. Open the coaling door about an inch and the air drawn through the set will burn off all the carbon. If there is much carbon this may cause overheating but if it is done often there is no danger.

Some gas makers leave a little steam on while the set is idle, to soften the clinkers. This is all right if not overdone, but just a little too much will put the fire out by morning and it also has a rotting action on the linings. Be sure that all gas valves on the machine are shut tight. Neglect of this precaution may sometimes cause serious trouble. The blower should be shut down and gone over to see that it is all ready to start up again. The pet cocks on the oil and circulating pumps should be opened and the cylinders and steam lines well drained. If the pumps need packing or adjusting, it should not be left till the next day. Everything should be left so that the machine can be started up right away in the morning.

GENERAL CONSIDERATION

Blower Engines.—High-speed automatic engines, belted to the blowers, were installed on water-gas sets for a good many years and there are many plants still using them. Turbines and electric motors have lately come into use. The engines or turbines run on a bypass while off the blow and then just before starting the blow the throttle is opened and the engine is brought up to speed. If several machines are fed by a set of blowers the speed should be constant, regulated by the steam governor. The turbines are always direct connected and run at high speed. The steam consumption is rather high, at least 75 lb. per horsepower-hour. The average efficiency of a fan blower under operating conditions will be about 40 per cent. With a pressure of 24 in. in the blast line and 2,700 ft. of air per minute, allowing for generator and carbureter, $\frac{4}{10}$ hp. per 1,000 cu. ft. of gas made will be required. The consumption of steam for the engine would be about 40 lb. per b.hp. and 16 lb. per 1,000 cu. ft. of gas. R. N. Davis recommends the use of a positive pressure blower, which he states has an efficiency of 85 per cent. requiring, therefore, 9 lb. of steam instead of 16.

In using a motor to drive a blower it is reasonable to assume a consumption of 1 kw.-hr. per 1,000 cu. ft. of gas made. Suppose the use of electricity is being considered for this purpose and it is desired to know at what price it compares with steam. If using an engine-driven blower, there will be required not less than 16 lb. of steam per 1,000 cu. ft. of gas made. With an evaporation of 5 lb. water per pound of coal, which is rather low, with coal costing $2.50 per ton delivered to the boiler room, the cost per thousand will be:

$$\frac{16 \times 2.50}{2,000} = 0.02, \text{ i.e., } 2 \text{ cts. per } 1,000 \text{ cu. ft. of gas made.}$$

Then current must be purchased for 2 cts. per kw. to compete with steam. With a turbine unit the consumption is nearly twice as great and current at nearly 4 cts. would compete.

Relief-holder Alarm.—It is frequently the case that the gas maker can not see the relief holder from the operating floor. While it is usual to have the exhauster run at such a speed as to take care of the hourly make, keeping the relief stationary, there are a good many times when the gas maker is obliged to use great care not to blow or land the holder. In such a case a high and low alarm is valuable. A red light should be connected in series with a bell placed on the wall by the machine. A contact should be clamped to the relief-holder column and another one to a wheel on the holder so that a contact will be made at a point about one-half sheet from the landing. The bell will ring and the light flash on, warning the gas maker to slow down the exhauster. A green light may be similarly connected to show when the holder is about to blow. By arranging a butterfly valve in the steam line to the exhauster and hanging a weight on it, supported by a lever caught on a trigger, it is possible to make the holder shut off the steam by having the trigger pulled by a magnet acting when the relief holder closes the circuit. The current for these devices may be obtained from the regular lighting circuit.

A seal made up of 4-in. pipe, filled with oil and placed on the top of the relief, near the edge of the crown may save it from being pulled in some time when the electrical device fails to work.

If the relief is near to the generator house a gage board may be set up on the wall showing the sheets and rivets in the holder, the pointer traveling up and down the scale, being connected by a cord and pulleys to the holder. By proper arrangement of the pulleys the gage board may be one-half or one-fourth the height of the holder.

Dry Scrubber.—It is frequently the case that the gas coming from the relief holder carries an excessive amount of tar especially in summer, which gives great trouble from clogging the purifiers and ruining the oxide. To remove this a dry-shavings scrubber may be employed. Almost any old shell may be fitted up for this purpose, putting on hat flanges for the gas connections and arranging two trays inside to carry 3-ft. layers of shavings. Doors should be provided for cleaning out and a manhole at the top, for putting in fresh shavings. This scrubber should be surrounded with a wooden housing, if out of doors, having a space of about 3 in. between the boards and the shell, this space being filled with dry shavings, a layer of tar paper being placed next to the wood to exclude dampness. Great care must be taken to make this housing tight and to prevent the shavings from getting wet.

Properly lagged the drop in temperature through this scrubber should not exceed 10° even in severe weather. If the scrubber is not protected and a considerable drop in temperature takes place, the cold wet shavings, covered with light tar will absorb a large percentage of hydrocarbons, cutting the candlepower severely. In large works this scrubber should be preceded by a water-gas P. and A. tar extractor (Fig. 65). The efficiency of a dry-shavings scrubber will run up as high as 99 per cent. but it must be cleaned often to maintain this high efficiency.

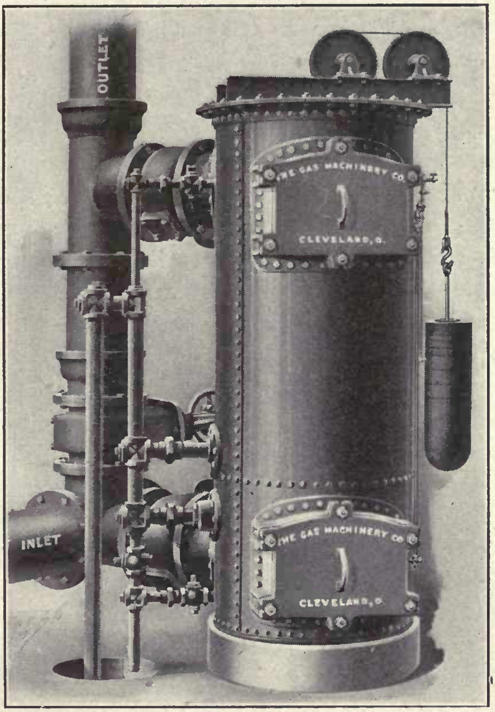


Fig. 65.—Water gas P. and A.

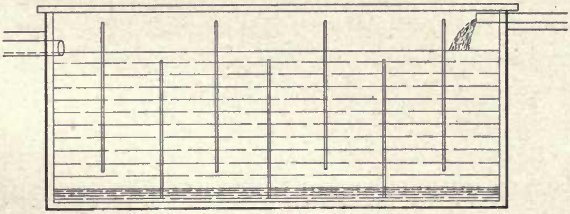


Fig. 66.—Tar and water separator.

Tar Separator.—To receive the condensation and drainage from the water-gas set and recover the tar in usable form, a separator is needed. This may be made of brickwork or concrete and should be amply large. For an 8-ft. 6-in. set run all the time, it might be 16 ft. long, 6 ft. wide and 6 ft. deep. At intervals of 18 in. wooden baffle plates should be run from the top down to within a foot from the bottom. Alternating with these, dam sheets should be put in extending from within 4 in. of the bottom to within 4 in. of the water line. The course of the tar and water will be up and down over the baffles and dam sheets and the tar will settle at the bottom. From here it can be drawn or pumped off to the storage tanks. The effluent should be practically clear. The circulating pump should draw from the last compartment where the water is clear (Fig. 66).

Tar as an Enricher.—A good many experiments have been tried, pumping water-gas tar into the top of the generator during up-runs,with a view to enriching the gas and saving oil. This method has never come into general use although there are operators who have been doing it for some years. About ½ gal. per 1,000 cu. ft. of gas is all that can be used.

A better method is as follows: Place a live steam coil in a small tar storage tank and heat until the water has been largely driven off and the moisture remaining in the tar will not exceed 2 per cent. Then mix this hot tar with the oil in the storage tank, in the proportion of 1 gal. of tar to 3 or 4 gal. of oil. The mixture must be well agitated with the circulating pump and not allowed to settle out. The regular oil pump may be used for this circulation and mixing or the pump used to handle the tar may be employed. If using a good grade of light gas oil possibly one-quarter tar may be used which will be nearly 1 gal. per thousand and as tar rarely sells for a price greater than you buy oil for, it will pay well to do this. It may be possible to use all tar produced in this way, and even to cut into the storage if there is a lot on hand, or tar prices slump. There will be some action on the upper course in the carbureter and it may be necessary to rechecker a little oftener but if the tar is clean and free from excess water the action will not be at all serious. Attempts have also been made to use water-gas tar as a generator fuel by spraying in on down-runs and they have been quite fairly successful but as a rule if the tar can be used as an enricher, that is the better way.

Naphthalene.—Some naphthalene is always present in water gas but if it shows strongly at the outlet of the purifiers it is being formed in excess and the heats and oil spray should be examined. The picric acid test should be used to detect the presence of naphthalene.

CHAPTER V

GENERAL PLANT OPERATION

COAL STOCK

Placing Cars.—In a small plant the cars of coal are usually unloaded right into the retort house or very close to it so that there is no labor charge for delivering the coal to the benches. If the coal is unloaded by day labor something may be saved by holding the car the full length of free time and letting the stokers throw off the coal into the charging buggies finishing the amount they do not move with the coal heavers. Coal unloading is usually let out on contract; 10 cts. per ton being a fair price in most localities.

In a large plant a good deal of care in placing cars should be exercised, to get them as near to the point of use as possible. It will pay in a great many cases to change the location of a switch track to cut down the expense of unloading the coal. The first cost of this may seem considerable but coal moving goes on all the time and a little increase in labor mounts up rapidly.

Storage.—It is possible for most coal companies to ship all their coal in dumping cars and if so, it will pay to erect a coal trestle, so that the coal may be dumped and the cost of unloading greatly minimized. The storage coal may have to be rehandled but once in stock it should be undisturbed and the incoming coal used as much as possible. In former times gas men believed that there was a heavy deterioration of the quality of coal kept in storage but recent exhaustive investigations by the U. S. Bureau of Mines have dispelled this belief. The deterioration is very slight and there is more than a suspicion that the alleged inferiority of stored coal was a cloak to poor management or operation.

Heating.—Coal that is high in sulphur should not be stored over 10 ft. in depth. Where coal is in storage a long time, it is a good idea to drive iron pipes into the pile and drop thermometers into them occasionally to test the temperature. A coal-pile fire is a very serious thing and is to be avoided. The only thing to be done if the coal starts to heat is to dig into the hot spot and scatter it. Coal may be handled to storage by means of a grab bucket, dumping car or locomotive crane. Not less than 30 days' supply of coal should always be on hand, which may be increased prior to strikes or other adverse conditions. The coal should be kept coming in at about the amount used daily.

COKE STOCK

Screening.—Where a plant has a coke trestle it is easy to keep on hand a good supply of screened coke of the various sizes required. The screens should be arranged so that the coke in falling over them travels slowly enough for the fine coke to drop through the screen. A good arrangement is to have the top screen of heavy wire with a mesh of 1½ in., the second set below it of ¾-in. mesh and the third at the bottom of ⅜ in. The first screen will produce lump coke; the second, nut size; the third, pea coke; and the part rejected, falling through the last screen will be dust, breeze, etc., and may be burned under the boilers, if mixed with tar and coal, or made into briquettes. Such a set of screens would have to be about 30 ft. high to

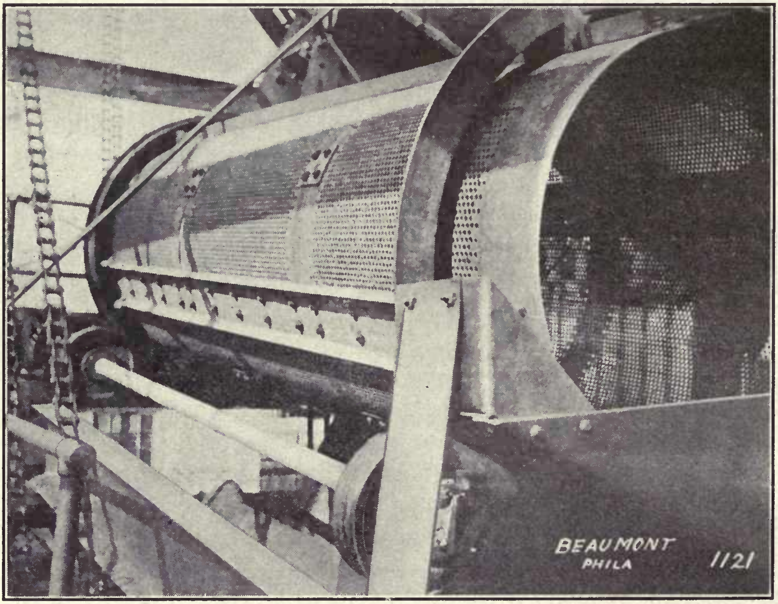


Fig. 67.—Rotary coke screen.

get the best results and from the screens the coke should fall into bins, from which wagons may be loaded. For loading into cars the coke should run over a 3/8-in. screen only and be chuted into the car. Revolving screens are more satisfactory than set screens but are rather more costly to install and the operating cost is something (Fig. 67).

Quenching.—Coke, as drawn from retorts, should be quenched instantly and not allowed to burn at all; but it must never be drenched with water. Bright silvery coke is the result of quick quenching with a minimum amount of water. It may not be any better than dirty black coke, but it certainly sells a lot better.

Where the trade requirements justify it, the domestic coke should be crushed, screened and delivered into pocket chutes under which carts may be driven and quickly loaded. For loading from a pile of coke, some one of the the first class types of conveyor loaders and screeners should be used.

YARD WORK

Cleaning.—In a small plant the work of cleaning up has to be evenly divided among the men and it is not always easy to keep the plant looking its best. Where the conditions warrant it, the cleaning and general caretaking should be given to an old employee who is past doing the hardest work but who can be depended on to keep the works and yards in good shape. All buildings should be swept out every day; a large number of the windows washed every week; and the yard kept picked up and neat all the time.. No superintendent or foreman errs on the side of too much cleanliness; the reverse being the case as a rule. There is nothing that lends an air of prosperity and efficiency to a plant like cleanliness. This can only be obtained by constant vigilance and good discipline.

The caretaker may pump drips and remove ashes from the water-gas room or boiler room in addition to his other duties. Enough odd jobs should be found for him to make a day's work. If there is any bright work in the engine room it should be polished every day. The cleaning should be systematized like all the rest of the work and closely followed up. If a plant is dirty and run down it will take a long time and a lot of work before much of an impression can be made.

All trash should be burned up as fast as it accumulates.

There should be an old lumber pile but nothing should be stored in it except sound lumber and trash of any kind should be disposed of at once. There should be also a stock of old brick neatly piled and not thrown into a heap. The iron that accumulates about a gas works will always bring a good price and should be sold as fast as it accumulates. Spent oxide makes a good filling for low places around the plant and cinders should be used in the same way until the yards are nicely graded.

Flower beds can be put in around the holders very cheaply and add a great deal to the appearance to the plant during warm weather. Wherever there is an opportunity the ground should be softened up and planted to grass and the grass kept short. In the winter time great care should be taken to have all side walks running by the plant kept free from snow if the plant is near the residence or business section.

Painting.—The inside of condenser rooms, purifying houses, shops, engine rooms, etc., should be whitewashed all over and then a band of black, 4 ft. high should be painted around in the nature of a wainscoting. Such machinery as tar extractors, washers, scrubbers and condensers should be painted black using a paint made of boiled tar 16 parts, cement 1 part, and kerosene 1 part; all by measure. This paint can not be kept but must be made up fresh every time it is used. It gives a fine glossy finish. The engines and some of the pumps will look well if painted with some kind of a good high-finish engine paint, red or green with simple black trimmings. The standard finish for wooden buildings, fences, etc., about a gas works is Venetian red. The janitor or caretaker should keep all painting done as needed, giving special attention indoors in winter and outdoors in the spring.

In the retort house it is a waste of money to use paint but a good thick coat of whitewash will help a great deal if you have a dark retort house and it can be sprayed on very cheaply with a whitewash pump. This is especially good in the cellar in front of the benches which is a dark and dismal place at best in most plants. The boiler room is another good place to use whitewash liberally on the walls and ceiling. White cold-water paint is slightly more expensive but the better finish is often worth the difference in cost of buying and putting it on.

Holders.—The holders require periodical care and inspection which should not be slighted. They should be painted when needed with a good quality graphite paint, a contrasting color being used on the guide frames.

The wheels on the frames should be centered if they get slightly out of line and well greased every 2 months with good stiff wagon grease. The tie rods should be frequently inspected and tightened or loosened as the case may be to keep the columns vertical and the strains evenly distributed.

When using steam ejector tees to heat the water in the holder tank, the suction pipe should be run down nearly to the bottom of the tank which will cause a circulation and help to cut down the tendency to form anchor ice. The cups should be heated with ejector tees and short suction pipes and the discharges should all point in the same direction to cause a circulation. A small hole should be drilled in the top of the steam connection to the tees. The little plume of steam will tell when steam is being delivered to the tee without the necessity of climbing up each time. It will also prevent siphoning the water out of the cup when the steam is shut off. The cups should be inspected every day to see if enough water is in them and if they are free from ice. The steam connections are preferably of metal hose, but wire-wound hose or ½-in. iron pipe with swing joints are both good. The steam connections to the holder should be put in commission early in the season to avoid a rush when a sudden cold snap comes. In a water-gas plant steam can be saved by circulating the condenser water from the tank through the condensers and back to the tank.

Engine and Meter Rooms.—If there is a separate room for the exhausters and one for the station meters these two should be the show rooms of the plant. The engine room may be painted light green with a 4-ft. black border. If there is a steam radiator in this room it should be gilded or silvered. If the works gage board is placed in this room it should be kept in scrupulously neat condition.

The engine and exhauster may be painted in gloss finish red and black and kept in spick-and-span condition. The packing on the engine and exhauster should be kept in perfect condition and if the sets are duplicate one should be run each week and the idle set cleaned and tuned up. There ought not to be the slightest escape of steam, oil or tar about the units and no oozing of tar onto the floor from the gear cases, etc.

If there are pumps located in this room, they should likewise be kept in fine condition, tightly packed and no leak or drip should be allowed to run on the floor. All units should be provided with oil pans properly drained. On the wall there should be a tool board painted black, the space beneath the tool being white and all tools used in the engine room should be kept on the board. The engineer should be held strictly to account for the condition of the tools and the engine room. The practice of standing oil cans on top of machinery or cylinders to keep them warm should be forbidden as it always makes a mussy place. Lumps of oily waste should not be left around. A neat cupboard for the oil cans and clean waste and an oily waste can for the dirty waste should be provided. All moving machinery should be enclosed in a neat pipe railing.

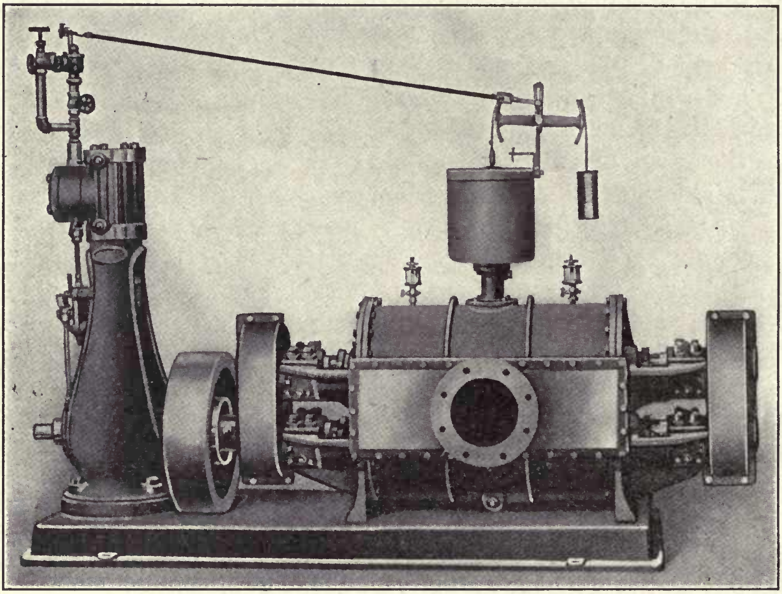


Fig. 68.—Engine and exhauster on same bedplate.

The meter room should be painted light green on the walls and ceiling and the wainscoting a darker green. This room often contains the booster or governor and all this apparatus ought to be in the pink of condition at all times. The meter should have daily attention; and one should screw down the grease cups to lubricate the bearings and listen carefully to the sound of the drum to detect leaks or improper movement. Once each year the meter should be accurately tested.

STEAM LINES

The steam lines of the plant should be laid out in a system such as is used for the water distribution; a main header running through the plant, with an exhaust steam system returning the exhaust to the feed-water heater. The main line should have valves at different points whereby it is possible to cut off the line beyond the valve for the purpose of repairs and each branch should be provided with a steam cock for the same purpose. The steam lines, both live and exhaust, should be well covered with sectional covering including the valve bodies and fittings. In putting on the covering it is a good idea to tear strips of cheese cloth and soak them in the flour paste, and then wind them like a bandage along the length of the covering so as to form a continuous spiral. The exhaust lines should have a good pitch to the main and the main should be well drained toward the feed-water heater. Traps should be put in wherever there is considerable condensation and the drip returned to the feed tank, whenever possible, or to the sewer.

Steam traps should be very frequently inspected to see that they are working right and not blowing steam away unnecessarily. Tilt traps are recommended for many positions and the little traps that operate on a difference in temperature of condensation and live steam are good for some places.

It is advisable in gas works to use extra heavy pipe and fittings. The extra cost will be more than compensated by the increased life as corrosion is severe in many parts of the plant and deteriorations rapid.

Live steam should never be used for any purpose where exhaust steam can be substituted. In a large plant there are even opportunities for the use of low pressure turbines operating on exhause steam. The exhaust steam system in any plant should operate an a back pressure of 5 lb. which will give ample pressure for heating buildings and holders. A back-pressure valve should be installed on the feed-water heater, with a relief valve opening to the air.

WATER SYSTEM

Every plant above medium size should have a well-planned water system. If the plant purchases water it will pay to spend a considerable sum with a view to economy and even if the supply is drawn from wells or a river, there is a good deal to be saved by careful arrangement of the water supply.

Works Pressure Pump.—The works pressure pump should be a large, long-stroke, slow-speed single-pump, selected for its reliability and economy of steam consumption. The pressure on the discharge side should be controlled by a governor set to carry a certain pressure. This pressure is often higher than there is any need for; 25 lb. usually being ample. If this pump draws from the city mains there should be a bypass around it. In case this pump is used to supply a fire line there should be a steam line bypassing the governor so that the pressure can be run up if desired.

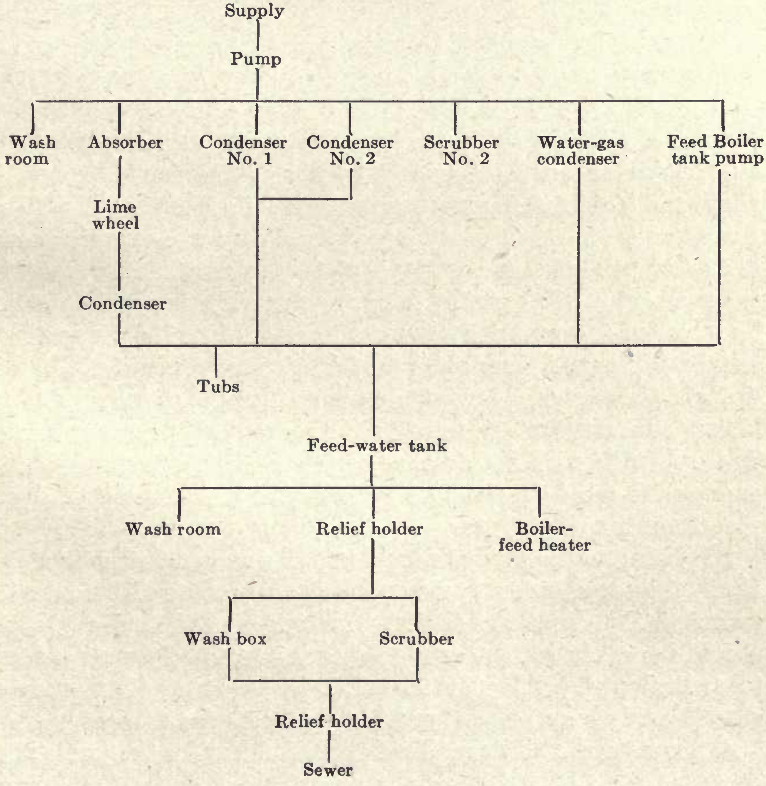
Pipe System.—From the works pump a main water header, amply large for the purpose, should be run through the entire plant with branches to the various apparatus it serves. These branches should have cocks where they leave the main line to facilitate repairs. It is a good idea to paint all water lines blue so that they can be easily traced.

System of Handling Water.—Considerable care and study may profitably be put upon the use of water in a gas works. To illustrate the ways in which the use of water may be conserved the following example is cited. Water is drawn from wells by a works pressure pump maintaining 30 lb. on the discharge side. A main water header serves all parts of the plant. A branch runs to the ammonia plant where the cold water runs through the absorber coils, then to the liming apparatus, where it operates a wheel and from there to the ammonia still condenser. The overflow from this condenser runs to the feed-water tank with an outlet connection to tubs in the retort house which supply water for quenching the hot coke. This water is never too hot to be used here with comfort and is particularly agreeable in winter. A branch runs to the condenser room with individual lines to the secondary scrubber, the secondary and primary condensers. The overflow from the two condensers runs to the feed-water tank through the same header that carries the waste water from the ammonia-still condenser. A branch runs to the condenser on the water-gas machine, the overflow from this returning to the feed-water tank. A branch runs direct to the boiler pumps, cutting in to the boiler feed line between the heater and the pumps. As the pumps have a bypass, if necessary, the works pump can put water into the boilers direct by running up the pressure on the works line. A branch runs to the locker room for toilets and showers.

The feed-water tank in this case is a large steel tank set as high above ground level as possible, after allowing sufficient fall for the lines draining into it. From the bottom of this tank a line runs to the feed-water heater, another carries warm water to the wash room, still another to the water-gas room for quenching clinkers, one to the purifying house and the overflow goes to the relief holder. When more water is needed than is supplied by the waste from the plant a float valve opens on a branch from the main and empties into the feed tank. From the relief a circulating pump sends water to the wash box and scrubber which returns again to the holder.

Such a system as the above might not suit any particular works but serves to illustrate the value of planning the use of

WATER SYSTEM



water for economy suited to local conditions. In the winter time something may be gained by circulating the condenser water through the condensers, from the storage holders.

PUMPS

Selection.—The duplex pump may be ideal for some conditions and classes of service but it should find little favor about a gas works. With the exception of a hydraulic elevator pump there should be no duplex pumps in use. With single pumps the consumption of steam is less, the setting of the valves much simpler and with proper-sized air chambers their tendency to pound is no greater. In buying pumps study the use to which they are to be put. If used once in a while for important service get them oversize. If used constantly on a known load get them just big enough so that they will be run to capacity for the sake of steam economy. Pumps for ammonia or tar must be all iron to resist corrosion.

Setting.—Pumps should be set on a good high concrete foundation well away from the wall. Bear in mind when setting a pump that it will have to be frequently worked on for a good many years and a few minutes extra trouble when installing will help a great deal in time to come. The foundation should extend to about the length of the pump overall and be slightly wider than the foot plates. It is sometimes advisable to set the pump up on blocks of concrete at each end of the foundation to make it easier to get at the rods for packing, etc. The pet cocks should be removed and replaced by cocks threaded for pipe connection, usually ¼ in., and these pipes should be connected and run to the drain in the center of the foundation so that the cylinders can be blown out without scattering oil or water all over the room. There should be a hole in the center of the foundation communicating with a hole in the floor to drain away condensation, dripping from the glands, etc.

All piping to the pumps should be full size and put up in shipshape and symmetrical manner, the steam pipe carefully covered as well as all fittings and valves. The suction and discharge lines should be put in without sharp bends, using 45° elbows or sweep tees and elbows. The valves on all water lines to and from pumps should rarely ever be anything but the best gate valves.

A template should be made of the bolt holes for the pump and long bolts imbedded in the concrete before it sets. The pump must not be set up until the foundation is thoroughly seasoned. When ready to set up the pump, place it on the foundation, tighten all bolts, connect up and run. After running a few days take up on the bolts and go over them periodically to keep them tight. Nothing is worse for a pump than to run on an unsteady foundation.

Care and Operation.—The steam end of the pump should have some attention and the valves reset whenever there is reason to believe that there is something wrong with them but as a rule the steam cylinders should not be meddled with. Nine times out of ten, when a pump goes wrong, the trouble is in the water end and its possibilities should be exhausted before attacking the steam end. A good lubricator should be installed on every pump and a fair quality of cylinder oil fed to it while running in moderate amounts. Oil cups on top of the steam chest should not be used.

If the pump groans, graphite put in the water end and a little mixed with the cylinder oil, will usually cure it. It is a good rule to adopt, that whenever the cylinder or valve chest of a pump is opened, a little oil and graphite is to be rubbed into the working surfaces. Pumps should be packed often and the glands ought never to be very tight. It is usually the case when a pump gland starts to leak, that the first man to see it tightens up on the gland stopping the leak temporarily. Then after a while it breaks out again and along comes another man and he tightens up on the gland and pretty soon that packing is as hard as wood and begins to score the rod. Pumps should never be used in that way.

The packing glands and rods on all the pumps and engines should be calipered and the figures set down in a notebook so that the stock of packing can be made to include all sizes required and can be referred to easily. Some standard brand of packing should be decided on and a full line put in for every machine. The packing should be bought cut in rings to fit the job instead of having it come in long coils and depending on the engineer to cut the rings to fit. Hydraulic packing is usually used for packing the water ends of oil pumps and is satisfactory. A rubber insert packing has given good service on oil pumps, as has also soft hemp. A few pumps require special packings for unusual service but as a rule one can adopt some standard line and stick to it for everything. This is frequently not done and a plant will be buying four or five different brands for no real reason whatever. The same thing is true of oils. There are really only two kinds of oil to find a use about the ordinary plant; a good engine oil and a fair cylinder oil; but there are plants buying five or six different kinds, some of them very expensive. The engineers' department is rather too often neglected in a gas works and it will pay to standardize the oiling, packing and general care of the moving machinery. The amount of oil used is generally excessive and may usually be safely reduced a good deal.

TAR STOCK

Storage Wells.—Coal tar and water-gas tar should be confined in separate wells. Experience has shown that a masonry tank will allow very little coal tar to seep through it but water-gas tar frequently escapes. Whenever possible water-gas tar should be stored in steel tanks of 10,000 gal. capacity. The tar well is used as a tar and liquor separator in many coal-gas plants, the liquor draining to a well of its own. Water-gas tar is usually put through a separator and then siphoned or pumped to storage.

In the bottom of all tar wells or tanks there should be pipe coils for heating with steam. By heating the tar with these coils a tar having a maximum of 2 per cent. water can be obtained while water-gas tar is often sold having as high as 6 per cent. water, which is a detriment in several ways. If the tar is to be used as an enricher or fuel it must be especially dry. Tar wells should be tightly covered and precautions should be taken against fire.

Simple Tests.—A water-gas tar may be tested for water by putting a few drops on glazed paper and blowing it out into a thin film when the water will separate out in drops. To test for lampblack, put a drop of the tar on filter paper where the tar will enter the fibers of the paper and leave the lampblack. A good water-gas tar should all be absorbed by filter paper leaving a clear dark brown stain. Water-gas tar should run between 1.04 and 1.08 specific gravity, weighing about 9 lb. per gallon and coal tar a little heavier, up to 10 lb. per gallon.

Tar Pumps.—Tar pumps should be of all iron construction with ball valves, large openings and should be built strongly. Rotary pumps are much employed for tar and are successful and satisfactory. For transferring tar about the plant small single pumps are best but for loading cars a good-sized rotary will be appreciated as it will fill a 10,000 gal. tank car in a short time. All-iron cocks should be used on tar lines; never brass of any kind. Asbestos-packed cocks are often used, but are a waste of money as a cheap all-iron blow-off cock will serve the purpose equally well.

PURIFICATION

Chemistry.—The chemistry of purification is somewhat complicated. The reaction has a simple result, *i.e.*, the removal of sulphur in the form of H_2S, from the gas. The reaction may be expressed in the following formula:

$$Fe_2O_3.H_2O + 3H_2S = Fe_2S_3 + 4H_2O$$

In addition to this there is another reaction taking place, to a certain extent, as below:

$$Fe_2O_3.H_2O + 3H_2S = 2FeS + S + 4H_2O$$

It is believed that from 17 to 30 per cent. of the H_2S enters into the second reaction. It has been argued from the above equation that anhydrous Fe_2O_3, with no moisture present, can not absorb H_2S. However, no such conditions exist in purification practice and the so-called anhydrous oxide works efficiently.

Making Oxide.—A very simple formula for making oxide is as follows. Fine, clean cast-iron borings are mixed with sal-ammoniac, 1 oz. to 20 lb. borings, and spread over a floor to a depth of 6 in. The borings should be sprinkled with water from a watering pot and thoroughly turned every day for 3 weeks. By that time the borings should be thoroughly oxidized.

Spread out a bed of soft pine shavings 1 ft. deep and measure the sides to get the right number of cubic feet to the batch. Then spread a layer of oxide over the shavings so that there will be 20 lb. of the oxide to each cubic foot of the shavings. Mix by turning until the oxide is well incorporated with the chips, sprinkling well with water meanwhile. Ground corncobs are used as a substitute for shavings. They weigh about 15 lb. per bushel and shavings 5¼ lb.

A standard bale of shavings measures 18 by 20 by 30 in. and weighs 129 lb. Broken up loosely it will swell to 9⅓ bu. Cork has many advantages over shavings and is especially good with a wet gas as it will not become soggy or saturated in the boxes and throws only one-third the back pressure of the other materials.

Prepared Oxide.—In recent years there have come on the market several varieties of prepared oxide, some of them being derived as a byproduct from bauxite treatment and others are preparations of natural oxides. Phenomenal results in the way of long life, high capacity of material per cubic foot and increased capacity per box are claimed. Experience has demonstrated their superiority over any homemade material and it is only in special cases that it pays any longer to oxidize iron borings in the plant. Local conditions will always govern but careful consideration should be given the new oxides before deciding to make oxide in the works.

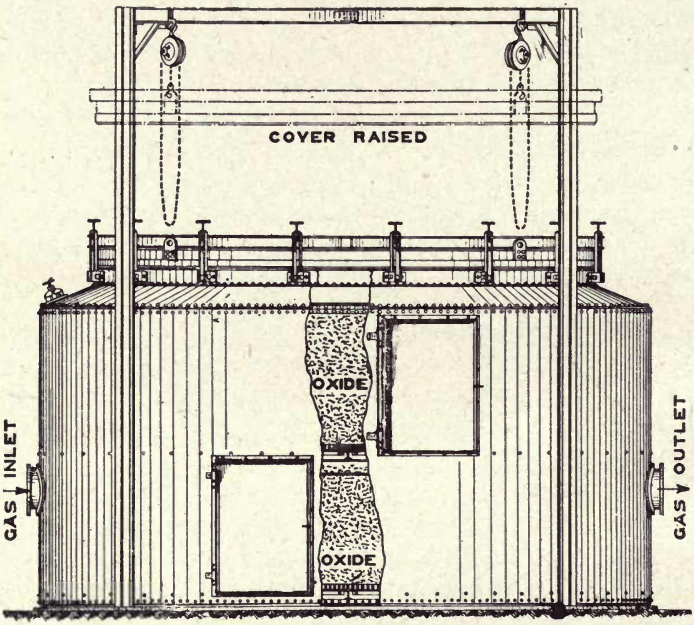


Fig. 69.—Round purifying box.

Dumping Boxes.—After cutting out the box a vent should be opened and the box cover removed and swung to one side. Allow several minutes for ventilation and then send men in with shovels and picks if the oxide is hard. If it is necessary to use wheelbarrows to remove the oxide from the box arrange runways so that the barrow men can be at work all the time and not have to wait for the others to fill or get out of the way. A little study in placing the men will result in saving of time. If the oxide can be thrown out alongside the box quicker time in dumping can be made as the oxide can be moved after filling. In double deck outdoor purifiers the side doors must be opened and the oxide shoveled through and then moved away from the bottom doors so as not to be in the way of the bottom layer coming out.

Great care against fire must be exercised, no smoking being allowed anywhere near the boxes and no flames or open lights of any kind. If the job has to be a quick one, work the men in relays, sending the idle ones clear away from the box to get fresh air. Remarkably quick time may be made by keeping the men fresh and putting up a small bonus for quick work.

When the oxide is all out the trays should be removed and cleaned between the slats and the bottom of the box should be cleaned out. The inlet and outlet pipes should also be cleaned out carefully. If old-fashioned square boxes are in use it will pay to change the outlet pipe to the inlet connection. Then the gas will pass down through the oxide instead of up through it and half the time it will not be necessary to remove the lower half of the oxide at all. This will interfere somewhat with keeping track of the oxide beds but that is more than overcome by the decreased labor expense. It is frequently the case that boxes have to be changed, not because they are foul but because the back pressure has become excessive. Removing the layer which the gas first enters will often relieve this.

Filling Boxes.—After cleaning the trays, chutes and pipes, boxes should be ready for refilling. If possible a fresh gang should do this as they will do the work much quicker. Replace the trays, carefully blocking up any holes with shingles and put in the fresh oxide as fast as possible. Water should be sprayed on the oxide as it is loaded into the box. The layers should be evenly distributed as the barrows are dumped. When all the oxide is in the men should walk in a procession around the outside edge of the box, treading down the oxide, and packing it against the wall of the box so that the gas will not follow the sides of the box and escape purification. Then if there is trouble with tar or condensation in the boxes, put on a layer of 8-in. clean shavings. Of course, if a down-flow box can not be arranged this layer should be on the bottom, or if the box is divided flow, on the bottom of the top layer and top of the bottom layer. Now close the box and secure the lid and doors, then with the vent still open, turn on the gas and do not cap the vent until the gas has blown all the air out of the box. If there are water lutes, replace the vent cap slowly to avoid a sudden excess of pressure. With dry lutes, a good stiff wagon grease should be used on the gasket and the doors should be closed against candle wicking dipped in red lead.

Carefully examine for leaks after putting the boxes back into commission. Many plants are equipped with mechanical means of handling oxide and the saving in labor cost is well worth considering. New oxide that has never been used should never be placed in the last box but always in some box earlier in the series, as it is liable to form iron carbonyl which will be carried to the burners and cause trouble.

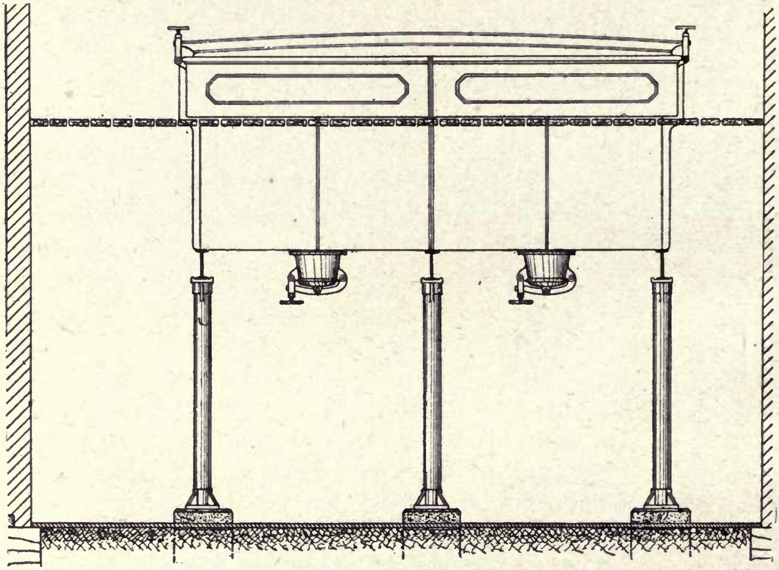


FIG. 70.—Square boxes with bottom cleanouts.

Rotation System.—If a plant is adapted to it there are great advantages to be derived from the use of the rotation system, which is touched on in the chapter on chemical control. By means of reversing the flow, through double flow boxes and rotating the order of the boxes, revivification of the oxide will take place without removal from the box. This reaction can only take place through contact with oxygen in an atmosphere free from H_2S.

The adherents of the forward rotation system seem to have the best of the arguments against the backward rotation adherents. Forward rotation is accomplished by putting the fouled box on last. The fouled box, which goes on last in the series is then cleaned up by the oxygen in the clean gas.

Howard Mann uses a modification of this plan which has many advantages.

Operate 3 days	1–2–3–4
Operate 60 min.	4–1–2–3
Operate 3 days	2–3–4–1
Operate 60 min.	1–2–3–4
Operate 3 days	3–4–1–2
Operate 60 min.	2–3–4–1
Operate 3 days	4–1–2–3
Operate 60 min.	3–4–1–2
Operate 3 days	1–2–3–4
Operate 60 min.	4–1–2–3

His idea in the above system is to work without a catch box and at the same time prevent the slightest escape of unpurified gas. It is obvious that if box one gets dirty and is put on last that the foul gas left in this box will pass over into the holder. While by putting it on second for an hour the foul gas will be swept out by the clean gas coming in from the first box which has just been put on clean and then after an hour it may safely be put on last, to be revivified in turn.

Many operators advocate admission of air to the gas to assist in revivifying the oxide but this is something that must be used with great care as if an excess of air is used above what is needed the candlepower will suffer as shown in the table.

TABLE VIII.—LOSS OF CANDLEPOWER

Percentage of air	Candlepower
1.0	2.0
1.2	2.3
1.4	2.6
1.6	3.0
1.9	3.6
2.1	3.9
2.3	4.3
2.5	4.8

Most coal gas already contains 0.5 per cent. of oxygen which is nearly enough to secure a good reviving action. If it develops that additional oxygen must be used, not over 2 per cent. of air should be introduced. This should be done by connecting a small blower to the exhauster and metering the air through a regular tin meter and piping the air to the inlet of the purifiers where it enters the stream of gas.

It is not advisable to try to foul a box completely before putting it on last in the series as it has a tendency to make the oxide hard. Rotating every 3 or 4 days is in line with present practice. Sometimes a box which develops back pressure can be put on last and the back pressure will disappear. Just why this should be so may not be quite clear but it is vouched for by high authorities.

Revivification.—Oxide is revivified by exposure to air whereby the oxygen of the air unites with the iron driving out the sulphur according to the equation:

$$2Fe_2S_3 + 3O_2 = 2Fe_2O_3 + 3S_2$$
$$12FeS + 9O_2 = 6Fe_2O_3 + 6S_2$$

To start the reaction it is sometimes necessary to raise the temperature of the mass. This will frequently accomplish itself if the oxide is piled up in a heap as the first oxidation will generate some heat which will intensify the oxidation resulting in building up the heat until the whole mass is actively oxidizing. Care must be taken not to let the oxide overheat as it will catch fire and burn. Fouled oxide often starts to burn as soon as the box cover is raised which has resulted in bad explosions.

The revivification plan of Mr. A. F. Kersting is a good one. The oxide is wheeled to the revivifying floor and piled up in a heap, of triangular section, 6 ft. high, with a 12-ft. base and as long as required. After the oxide has heated, say 24 hr., it is raked down into subpiles, each having a base of 6 ft. and being 3 ft. high of triangular section. This will make long rows with the edges touching in the valleys between the tops of the rows. Then after standing until the oxide exposed has revived, the tops of the rows are raked into the valleys and the whole heap leveled off flat, being about 18 in. deep. Then starting at the points where the apex of each hill was, rake into new rows, thus making a new hill where the old valley was. The result of this handling will be to expose nearly every particle of the oxide to the action of the air and produce revived oxide with a minimum of handling.

In winter time, stick a steam pipe into the mass to start the heating. Turning the oxide by shovel takes more time although the result is the same in the end. Oxide beds that have apparently come to the end of their usefulness will "come back" and be active if left spread out, in the open for 6 months or more. Beds should not be discarded until they contain 50 to 60 per cent. of sulphur in addition to the tar absorbed. Mixing lime with the oily or tarry oxide during reviving helps old oxide to become active again for a period.

If a catch box is operated the oldest oxide can be used up in it, by mixing in 15 lb. of lime per cubic foot.

Temperature.—Theoretically oxide works at its best at a temperature of 100°. Practically there is no necessity for keeping the gas entering the purifiers at a temperature greater than 70° as oxide is very active at temperatures as low as 60°. Purifying boxes stand exposed to the severest winter weather without any protection whatever and still the oxide is active and does good work. It is difficult to decide at just what temperature the oxide becomes inefficient.

Records and Results.—Accurate and complete records of purification results are of considerable value. If it can be arranged to keep the different beds of oxide intact, during life, each bed should be given a number and a separate page in a note book. Whenever the boxes are open the beds should be sampled and analyzed for sulphur. A record of the gas passed through the bed while it is on as first in the series should also be kept. The results should be entered in the note book ruled as follows:

Bed No. ———

Kind of Oxide———

Date made	Date cut in	Date cut out	Gas passed	Date removed	Date replaced	Percentage of sulphur

The date cut in and out are the dates that the bed is cut in or out as first in the series. The date removed is the date the bed is taken out for revivification. Each bed should have a separate page in the book.

There should also be a record made of the rotations showing the date, position of beds, after and before rotating, and the number of the bed in each box.

Theoretically a cubic foot of oxide containing 20 lb. of iron should absorb without reviving about 80,000 grains of H_2S but in practice this result will not be secured without one or two revivifications and even then can hardly be expected under ordinary conditions. Such an oxide should purify about 200,000 cu.ft. of coal gas having an average of 400 grains H_2S per cubic foot, during its life. Twenty pounds of iron per cubic foot will call for 32 lb. of oxide per cubic foot.

The average amount of H_2S per cubic foot of the raw gas should be determined and the amount of gas purified by each bed calculated to the amount per cubic foot. The result will be short of 200,000 cu. ft. because the gas passed by the box while on as first taker only is considered and this takes no account of the sulphur removed by the box while in use later in the series. The figure obtained, however, taken in connection with the per cent. sulphur contained by analysis when the bed is ready for discarding, will give an accurate check on the value of oxides undergoing comparison.

Just before rotating the boxes the amount of H_2S in the gas entering and leaving each box should be taken with the Tutweiler apparatus. About an hour after rotating the tests should be repeated. If a bed of oxide has become so fouled that it will allow the gas to pass with scarcely any purifying action at all it is useless to attempt to revive it in the boxes and it should be removed. When the gas tests about the same at the inlet and outlet of a bed, after being on as last taker and then coming on as first in the series, it shows that the bed is temporarily exhausted. If the per cent. of sulphur in the bed is not too high it may be revived in the open air and go back in the series again as first taker. When a bed is active it will absorb 80 to 95 per cent. of the H_2S entering it when first put on as first taker in the series.

BOILER PLANT

Feed Water.—The feed water for the boilers may come from many sources. In smaller plants it is frequently from the city water supply and is fed by injectors into the boilers or by a small boiler-feed pump without a heater. If there is any amount of exhaust steam it will pay to pipe it to the boiler room and install some kind of a feed-water heater. The waste water from condensers in the plant should all be run to a common tank to supply the boiler water.

A home-made water heater is better than none, but it will usually pay to purchase one of the standard types. The water should run to the heater by gravity and the float valve in the line should be frequently examined to see that it is shutting off positively when the heater is full. Sometimes these valves allow the heater to flood with water which cuts down the efficiency. From the heater there should be a slight drop to the boiler-feed pumps which should be designed for handling hot water. Duplex pumps are often used for boiler pumps but are not as good as single pumps. The single pumps should be of ample size with long stroke so that they may be run slowly. The piping from the heater to the pump and from the pump into the boiler should be carefully covered with sectional pipe covering. After the water has become heated from the exhaust steam every bit of heat in the water should be carefully conserved until it enters the boiler. The heater should be provided with a bypass to send the water direct to the pump in case of need and it is a good idea to have a connection supplying water under city pressure to the pumps. Gate valves only should be used in the suction lines of the boiler pumps. If well-made and heavy, globe valves are satisfactory for the discharge lines and should always be used at the entrance to the boilers. Where the pressure is low, a cheap "clip" gate valve is very satisfactory, with an iron body, brass-mounted.

For 2 in. and over it is best to use flange unions on boiler-feed lines. For the smaller sizes, ground-joint box unions give good results. Extra heavy pipe and fittings should be used on the discharge side, with long radius ells and long sweep tees. Duplicate feed pumps should be run on alternate weeks and the idle pump should be given careful attention as soon as it is shut down so that they will always be in the best possible condition.

A recording thermometer should be placed in the feed line leaving the pumps and with good feed-water heater and plenty of exhaust steam a temperature of 210° is attainable. The pumps will not handle water at this temperature unless there is a good fall to them from the heater. A temperature averaging below 190°, should be considered unsatisfactory. For every 11° which the temperature of the feed water is increased, the boiler fuel will be reduced 1 per cent. If the pump works jerkily from the water being very hot, firemen often inject a little cold water into the suction line and forget to turn it off when the trouble stops, which allows the feed-water to get cold, dropping to 150° perhaps, for a considerable time. If the system is so arranged that the pump can not be set low enough to get away from the trouble, the cold water should be taken in from the feed-water tank, through a small pipe constantly, and the amount should be regulated so that the pump will just work and not slam. This may cut the temperature some but a steady temperature of 175° is far better than a temperature fluctuating between 100° and 200°. The recording gage will give a splendid check on these matters. The feed-water heater should be opened periodically and kept clean and painted on the outside.

Firing.—Most gas works use a cheap grade of slack coal for the boilers, mixing in breeze. In this case a fuel bed, 5 to 6 in. in depth, should be used, firing light and often and spreading the fuel. There is usually quite a tendency to clinker when using a mixture of slack and breeze and care must be taken that the depth of fire does not exceed 6 in. If the coal fuses and cakes over, even when thinly fired, this crust should be broken up every fourth or fifth firing by lightly scratching with a two-pronged rake. Do not let the prongs drag up ashes or clinkers into the active part of the fire.

The tendency of a soft coal fire is to burn into hills and valleys leaving thin spots with very little coal on them. The draft is thus increased through the thin spots causing a fierce combustion and high temperature with consequent clinker formation. To avoid this the fire should be kept as level as possible. Before throwing a scoopfull of coal into the fire, pick out a thin spot on which to place the coal. A bright hot flame is an indication of these thin spots. A small quantity of coal should be taken on the scoop and thrown onto the thin spot. It will take several firings to build up a thin spot to the level of the rest of the fire as it is not good practice to throw in a heavy charge of coal at one time in the effort to fill up all at once. The evenness of the fuel bed is of great importance and it will pay to train the firemen to take pains and keep a level fire. If the fuel bed gets very uneven, it is best to go in with a rake and level up this way but that means extra work for the fireman and allows the firing door to be open an undesirably long time.

A good fireman can keep a fire level for hours simply by careful firing, watching for thin spots and keeping them covered. In firing the man should stand 4½ to 5 ft. in front of the furnace and 12 to 18 in. from a line running through the middle of the firing door. The scoop can them move nearly in a straight line to the furnace door. It should be brought to a stop just inside the door by bringing it to rest against the bottom edge of the frame. The coal will then slide off the scoop and may be deposited accurately where desired. With a very deep furnace considerable force is needed to reach the rear. With a boiler steaming up to capacity the frequency of firing can be determined by watching the steam gage. The pressure should be allowed to drop only a very little between firings and firing at least every 5 min. will produce a very even pressure-gage chart as a rule. A heavy charge thrown in every 15 min. will on the other hand make a bad fire, use an excess of coal, and allow a considerable drop in pressure between firings.

When a boiler furnace having several doors, or marine boilers, are used and some special precautions against smoke must be taken, firing alternate doors or furnaces is recommended. Thus the gases driven off from a fresh charge of coal mix with products of combustion from very hot sections of the fire and are readily consumed keeping the smoke down to a minimum. For economy, alternate firing does not equal thin spreading across the fuel bed and is not so conducive to a level fire. If the boiler doors are equipped with adjustable dampers, they should always be opened immediately after firing and remain so for about 2 min. to provide air for the combustion of the gases driven off. When the boiler has rocking grates they should be manipulated about once an hour to break up the clinker and allow any loose ash to fall to the ash pan.

When the amount of breeze is considerable and must be disposed of, it is usually impossible to burn it under the boilers by itself if the load is at all heavy. A tar burner arranged to play down onto the fuel bed, will however, make it possible to burn up a great deal of the breeze without mixture with coal. If the plant is small and can not be arranged for a tar burner, soaking the breeze with tar before firing will help but will lead to the formation of clinker if the fires are pushed.

Cleaning Fires.—By far the best method of cleaning boiler fires is what is called the side method. The frequency of cleaning will depend entirely on the class of service, kind of fuel and rate of combustion. Frequently fires are cleaned at noon, midnight and just before changing shift at six or seven o'clock. When ready to clean, the fireman assures himself of a full head of steam, plenty of water and a bright fire. The damper is nearly closed, the left-hand side of the fire is then scraped and raked over onto the right-hand side leaving the ash and clinker exposed. Now run a slice bar or clinker hook under the clinker, working it all loose and raking it into a pile on the dead plate. Now run the barrow up before the door and quickly pull all ash and clinker into it. Run the barrow to one side, push the fire over onto the clean side and repeat with the right-hand section. If the pressure has dropped off too much, open the damper and allow the fire to burn up brightly for a few minutes before going to work on the right-hand section, giving time for the pressure to rise again. With a big four-door furnace the work should be divided into two cleanings. It is important to greatly decrease the draught during cleanings or the rush of cold air will cool the boiler severely, straining it and dropping the pressure.

Raising Steam.—When a boiler has been idle for cleaning or repairs, considerable care should be exercised when bringing it into service again. The manheads and handhole plates should be looked over and tightened, the blow-off cock and valve closed and the upper gage-cock opened to vent the boiler. Hot water should then be pumped in until it stands at about two gages. As soon as the water appears in the gage-glass the fire may be started. A low fire should be carried until steam issues from the vent, which is then closed. After the water is boiling the fire may be increased and the boiler brought up to pressure quite rapidly.

When the pressure first starts to go up look the boiler over very carefully for signs of leaks and never allow anything to be done to a boiler after the pressure reaches 10 lb. If a leaky gasket can not be stopped by tightening on the nut, while the pressure is at 10 lb., it is pretty sure that it will leak badly at 100 lb. and the fire should be drawn, the boiler emptied and the gasket examined. Tightening bolts or nuts at 100 lb. pressure is criminal carelessness.

When ready to cut a boiler in on line with other boilers, bring the pressure to the identical pressure of the others. Then crack the stop valve and allow any slight difference of pressure to equalize and also drain away quietly any slight condensation. Then very slowly and carefully open the valve wide, the entire operation consuming not less than 2 min. and being at all times ready to whirl the valve shut at the least sign of distress. Marine boilers contain a very large amount of water for their rated horsepower and have to be heated slowly and carefully as the circulation is poor. Return-tubular and water-tube boilers can be brought up to pressure more quickly but it never pays to force a boiler while heating up.

Banking Fires.—Where boilers are carried over night, not under any load, the fires are banked to hold the fire and keep the pressure from dropping too much. Before banking, clean the fire thoroughly and carefully, then with a good bright fire, rake it all into a windrow across the front of the grates just inside the door and cover well with a bank of wet fine coal. Close the damper and the ash-pit doors and crack the fire doors or open the dampers in them, the idea being to cause a slight draft over the fire and none through it.

Dampers and Draught.—Some means should be provided for readily regulating the draught. It should never be done with the ash-pit doors. A simple way to handle the damper is to hang a weight on one end of the damper arm and attach a light chain to the other, leading down over pulleys to the side of the boiler, terminating in a 3-in. ring which can be hooked over a series of bolts or pegs so arranged that with the ring on the lowest peg the damper will be shut and open when on the top peg. The rate of combustion can then be regulated entirely by the stack draft as it should be. If it is convenient to do so a little better job will result in connecting to the damper arm with ¾-in. gas pipe, with swinging joints where needed, the pipe ending in a wooden handled lever set at the side of the boiler. By moving this lever between pegs any desired opening of the damper may be had (Figs. 71 and 72).

The closing of the damper should be insisted on during cleaning and partial closing during light loads. It may work well in some cases to remove the ash-pit doors. It is a frequent trick of firemen, when they see that the boiler is going to pop off, to close the ash-pit doors and open the firing doors, cooling off the boiler with a rush of cold air. Nothing worse could be imagined. Instead of doing this the damper should be shut tight and if the water is not too high the boiler pump should be speeded up a little for a few minutes. It is really better to let the boiler pop, wasteful as that may seem, than to prevent it by a method that racks and strains the tubes and sheets. If the boiler inspector will permit it, it is a good idea to set the boiler to pop off 25 lb. higher than the usual working pressure, that is, if you carry 100 lb. while running, have the pop set at 125 lb. Thus there is a good leeway and there should be no excuse for careless popping.

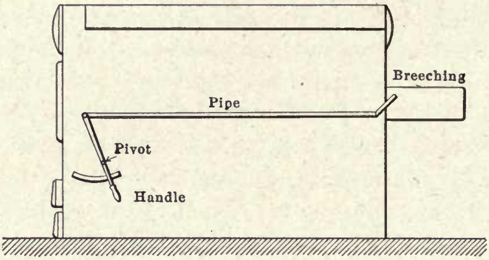


FIG. 71.—Simple method of controlling damper.

A draught gage is not an expensive instrument and will give a great deal of information about the fire. There are two kinds, the better being an inclined gage filled with oil giving readings to 1/100 in. If this can not be afforded, get an ordinary U-gage and have it graduated to 1/16 in. and fill it with water. Small copper tube of 1/4-in bore makes a good connection to the furnace as it can be bent easily and requires no fittings. Connect the gage

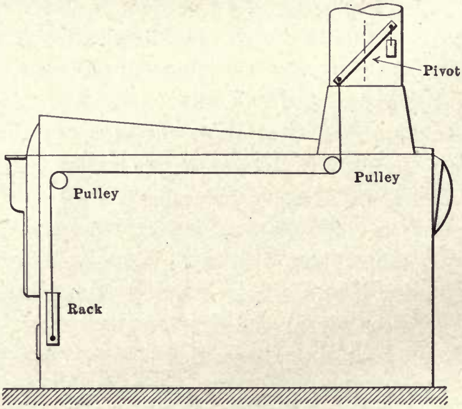


FIG. 72.—Better method of damper control.

to the tube with a piece of seamless pure gum rubber tube and run the copper tube along the wall of the setting and insert it through a small hole into the furnace above the fire and about halfway back. The tube should project into the furnace only about an inch and the end should be at right angles to the flow of gases. The tube should be cemented in place, filling up the hole. If possible have two gages, one connected as above and the other below the grates in the ash pit. If only one can be had, make a little header of ¼-in. pipe with two cocks so that the same gage can show the draft in either place. If the draft over the fire is low with the full opening of the damper, there are thin spots in the fire and perhaps holes as well. The differential through the fire will be very low. If the draft is high and the differential great it is likely that too thick a fuel bed is carried or there is heavy clinker on the grate. By studying these two gages much may be learned about the efficient handling of the fire.

Cleaning Marine or Fire-tube Boilers.—When ready to clean, allow the fire to go out and as soon as the pressure has fallen to 20 lb. the boiler may be blown down. After it is nearly cool, open the manheads and handhole plates and wash out with a stream of water under as heavy pressure as you can get, using the jet of water at all the openings you can and washing the tops of the tubes as well as the bottoms and sides. Follow this by entering the boiler and scraping off the tubes and sheets with sharp chisel scrapers, removing all scale possible and paying special attention to the back sheet. Finally repeat the washing. The frequency of cleaning will depend on many local conditions but should always be done at once as soon as the efficiency of the boiler begins to fall from the accumulation of scale. Before closing a boiler that has been cleaned pass a light through it to make sure that all tools, etc., have been removed. In replacing manheads always give the gaskets a good coating of graphite and have the surface of the iron perfectly clean.

Daily Routine.—The boilers should not be allowed to pop off at frequent intervals, but once each day the pressure should be raised and the boiler popped, noting carefully the pressure at which the valve releases and also the loss in pressure before closing. The valve should open exactly at the pressure for which it is set and the drop ought not to exceed 3 to 5 lb.

Once on each shift the boiler should be blown down. If possible two men should be in the fire room when this is done. The boiler is pumped up until the water stands at nearly three gages, the blow-off cock is then opened and the blow-off valve cracked. After a moment slowly open the blow-off valve wide. When about a gage or more of water has been blown down the valve should be slowly closed and then the cock should be closed. Blowing down should not be done while the boiler is under a heavy load but should be done after the boiler has been standing by for a time, say during the noon hour, as the mud and sediment will have had a chance to settle. One man should watch the gage-glass while the other handles the valves.

The water column should be blown down at frequent intervals or the glass will register a false level. If the water recovers slowly in the glass the pipes connecting to the boiler should be opened and cleaned out at the very first chance.

Flues should be scraped out or blown off once on each shift. A combination flue brush and scraper works well for fire-tube boilers. Water-tube flues should be blown off with a steam jet. This may be done while the boiler is under load but fire-tube boilers have to be cleaned while the load is very light. The pressure is apt to drop in any case and the work should be done rapidly. If the flues are scraped out twice a day, they should be easy to clean. Whenever the boiler is let down, the flues should be given an extra good cleaning.

Cleaning Water-tube Boilers.—After letting down the boiler, all manhole plates in steam and mud drums and handhole plates should be removed and the boiler washed out with a hose using as high pressure as possible. The inside of the drums should be scraped free from scale. The water-column connections should be rodded out to make sure that all the pipes are clear.

After removing all tube caps on the bottom four or five rows the tubes should be cleaned with an air- or water-driven cleaner. The cleaner should be fed through the tubes slowly, taking 3 or 4 min. to the tube and should be kept in motion all the time not being allowed to remain in any one place. Air cleaners do not work well with less than 80 lb. pressure and in general are not as satisfactory as water-driven cleaners. Air cleaners should be followed by a stream of water from a hose to wash the loosened scale ahead of the cutter. After boring each tube, put a light at the far end and examine the tube carefully. After cleaning the four bottom rows, open a line of caps running diagonally to the upper corner of the tubes and examine to see how many rows need the cleaner. If cleaned reasonably often, the bottom rows only will need cleaning each time but the whole set should be cleaned whenever the upper rows show much scale.

While the tubes are being cleaned the caps should be soaked in kerosene and the screw threads treated with graphite in oil and the gaskets on the caps and the manheads looked over and renewed if necessary. Before replacing the manheads the gaskets should be painted thickly with red lead or graphite in oil. When the tubes are clean give the boiler a final washing out, close the blow-off, put on caps and heads and fill up with hot water clear full putting on about 80 to 90 lb. water pressure and look for leaks. If any appear that are not stopped by tightening on the nuts the boiler should be emptied and the gaskets, fixed or renewed. Never use a wrench over 24 in. long in tightening cap or manhead nuts and never try to tighten while under working steam pressure. The tubes should be carefully cleaned off and the baffles examined and repaired and the ashes cleaned out from the chambers. If the boiler has mud-drum nipples they should be tested carefully with a hammer for signs of deterioration.

Records.—The weight of coal or breeze used on each shift should be accurately determined. If convenient, all the fuel should go over scales before going to the boiler room and the weight be recorded but if this cannot be done the weight of a barrow or buggy load should be found and a record kept of the number of loads. The coal burned on each shift should be figured separately and special attention should be given to periods when the boiler is running under a very light load as it is then that the coal is most wastefully burned. The weight of ashes removed from the boiler room should be checked in a similar manner.

The weight of water evaporated should be figured whenever possible. A meter should be placed on the line between the feed pump and the boiler. The volume of water measured by the meter can be figured to pounds by the weight per gallon corrected for the temperature. In a large plant a water weigher is a good investment. The weight of water evaporated in a day divided by the pounds of coal burned will give the apparent evaporation per pound of coal as fired. This calculation will give valuable information about the efficiency of the firing and the quality of the coal. For accurate work the figures should be corrected to evaporation from and at 212° per pound of combustible. The water meter should be frequently tested and any error corrected.

A simple boiler-room report should be made out every day when the size of the plant warrants it. The weight of fuel used on each shift, the weight of ashes removed, names of firemen, boilers off for cleaning, compound used, etc., should be entered on it.

Boiler Testing.—It is sometimes desirable to make a test of the efficiency of a boiler and the horsepower developed. This may be carried out quite simply and at the same time the results be fairly satisfactory and significant. If a scientific or extremely accurate test is desired, the method laid down by the American Society of Mechanical Engineers, as described in the Code, may be used. For a somewhat simpler method proceed as follows: With the boiler running as usual, have the fire burned low and cleaned and estimate the amount of coal on the grate accurately. The water should be pumped to a point exactly halfway on the gage-glass. Note the boiler pressure. From now on weigh every bit of coal fired. Read the meter in the feed-water line, or start the weighing if you weigh the water. Clean the ash pit as soon as you have the test started and the first records made..

The draft should be kept uniform throughout the test and the load should be kept as uniform as possible bleeding a pipe to the air if the load falls off very markedly for a time. At the end of the test period, which is usually 10 hr., have the water level and steam pressure exactly as they were at the start and have the fire burned low. Quickly clean the fire, estimate the fuel left on the grate and read the water meter or weigh out the last tank of water, thus closing the test.

The amounts of water evaporated and coal burned can be recorded hourly and separately for the whole period for checking purposes, uniformity of operation and so forth. The coal should be sampled for analysis. The weight of ash and refuse should be determined and if the ash contains much unconsumed coal it might be well to analyze it. If the temperature of the feed water is kept by a recording gage the chart may easily be averaged. If not, 15-min. readings on a thermometer in the line will suffice.

If the water is not metered it should be weighed in a barrel set on scales, arranged to drain into a tank which will supply the feed pump. Results should be recorded as below:

1. Date of trial..
2. Duration of trial..
3. Weight of coal as fired..
4. Per cent. moisture in coal...
5. Total weight dry coal burned...
6. Ash and refuse...
7. Per cent. in coal..
8. Weight water fed to boiler...
9. Equivalent weight evaporated from and at 212°..............................
10. Steam-gage pressure...
11. Equivalent evaporation per hour from and at 212°..........................
12. Horsepower developed (item 11 divided by 34½).............................
13. Rated horsepower..
14. Per cent. rating..
15. Water apparently evaporated per pound of coal as fired............
16. Equivalent evaporation from and at 212° per pound of coal as fired....
17. Equivalent evaporation per pound of dry coal as above..............
18. Equivalent evaporation as above per pound of combustible...........
19. Calorific value of dry coal...
20. Calorific value of combustible..
21. Efficiency of boiler based on combustible.................................
22. Temperature of feed water...
23. Draft over fire...

Item 15 is found by dividing item 8 by item 3. Item 16 is found by dividing item 9 by item 3. Item 17 is found by dividing by the weight of dry coal. The combustible is the weight of coal less the weight of ash, refuse, etc. The calorific value of the coal is found by calorimeter test and that of the combustible is figured from this. The equivalent evaporation is found by multiplying the weight of water fed to the boiler by the factor in a table of factors of evaporation corresponding to the observed boiler pressure and feed-water temperature.

$$\text{The efficiency of a boiler} = \frac{\text{heat absorbed per pound combustible}}{\text{b.t.u. per pound combustible}}.$$

The heat absorbed per pound of combustible is found by multiplying the equivalent evaporation per pound of combustible from and at 212° by 966.

Boiler Compounds.—In nearly all localities of the United States some kind of boiler compound is needed to keep down the formation of scale in the boilers. Boiler compounds are manufactured in great quantities and sold under a variety of names. Very rarely are they worth what they cost and it should be a simple matter to determine what is needed for any particular boiler water and make up a compound that will do the work, purchasing only the raw materials. Soda ash or caustic soda forms the basis of 90 per cent. of all compounds. The choice between them depends somewhat on the nature of the water. The easiest way to find what is needed is to have a sample of the water analyzed by a commercial chemist and get a report telling what constituents are required for treatment.

A simple compound and one easily made and very successful with waters containing magnesium carbonate and sodium sulphate is made as follows: Provide a sound oil barrel and remove the head. Fill it half full of water and heat to the boiling point with live steam. Dissolve 100 lb. of soda ash in the water, add 20 lb. of aluminum sulphate and finally 35 lb. japonica and let the steam boil the solution until all is dissolved and combined. Finally allow it to cool and fill up with water. This compound should be fed into the feed-water heater once a day or dumped into the injector tank if pumps are not used.

The quantity required depends on the conditions and will have to be determined by experiment. Begin by using 1 gal. per day per 100 hp. developed and observe carefully the condition of the boiler when it is next opened for cleaning. The use of graphite for a boiler treatment seems to be on the increase and there is a great deal of evidence to the effect that it is the best treatment possible. It should be used cautiously, however, especially at first or it is apt to bring down large amounts of scale which will settle on the tubes or bottom sheets and cause burns or bags from overheating. When a boiler is cleaned and filled up with fresh water a double dose of compound should be used and the boiler not blown down the first day.

Steam Piping.—All steam piping about the plant should be well protected with sectional pipe covering. For covering valves and fittings use the powdered form of material mixed into a paste and applied with the hands, molding to fit the valve, etc. The entire covering should be wrapped in long spirals of cheese cloth cut in strips and wound around the covering, finally painting over it. Put up in this way covering will last indefinitely. The large piping should be carefully drained to the main boiler header or to traps to prevent slugs of condensed water from traveling to the machinery. Nothing but cast-iron or steel fittings should ever be used on high-pressure steam lines and it pays to buy a fairly high-priced valve. Cheap valves and light fittings should never be used.

Traps and Separators.—On lines leading to engines and water-gas machines, steam separators should be installed, connected to traps. Traps should also be connected to heating coils whether using live or exhaust steam. The discharge from all traps should be piped back to the hotwell, feed-water tank or boiler supply to take advantage of the heat and the water.

CHAPTER VI

CALORIMETRY AND PHOTOMETRY

CALORIMETRY

Calorimeter Room.—Almost any room about the gas works which is clean and can be maintained at a reasonably even temperature may be used. Frequently a corner of the superintendent's office is fixed up for the purpose. For very accurate work more precautions must be taken. If possible the location of the room should be such as to be readily accessible to water, gas and steam supply lines that may be required.

Water Supply.—The water supply should be from the city mains or works system and unless the water is clear it should be run through a stone filter. For supplying the calorimeter an overhead tank should be used, holding at least 25 gal. and strongly built of copper set in a wooden or pipe frame. This tank may be hung near the ceiling in a corner of the room. The supply line should have a valve conveniently located and then run up and over the edge of the tank, terminating below the surface of the water. If there is much dust in the room the tank must be tightly covered with a canvass or wooden cover. The tank should be shallow to aid in bringing the temperature of the water to that of the room quickly. It is very convenient, if possible, to bring a hot-water line into the room and connect it to the cold-water supply with a thermometer in the line leading to the tank. The temperature of the water going to the tank can then be closely adjusted. This is almost a necessity where continuous testing of close accuracy is required.

Near the top of the tank an overflow connection should be made of a size of pipe sufficient to carry away any overflow easily. This pipe should terminate in the sink so that the overflow may be observed when making a test or filling tank. The supply to the calorimeter should be of ⅜-in. pipe tapped through the bottom of the tank and protruding 1 in. to avoid getting any sediment that may settle out into the calorimeter. A gage-glass should be connected to the tank so as to show the water level in it.

The pipe to the calorimeter should terminate in a ⅜-in. hose cock at a convenient height.

Gas Supply.—Coal gas, water gas, the "mixed make" and the gas leaving the holders for the city should all be brought into the testing room and hose cocks installed for making connection to the calorimeter. Each of these supply pipes should also be connected to a common header by a valve, from which header a blow-off line provided with a cock runs to the roof. From the other end of the header run a short line to a jet which should be kept burning all the time. Suppose it is desired to test the coal gas as it is being made. The valve to the header is opened, the jet lighted and the blow-off cock opened. The gas will then blow out to the roof and a fresh supply will be assured for the calorimeter. After testing this gas, if a test is required on another gas, open it to the header shut off the coal gas and open the blow-off again which will purge all the coal gas out of the line and insure a fresh supply of the new gas. The blow-off valve should be a self-closing spring valve so that it can not be left open inadvert-

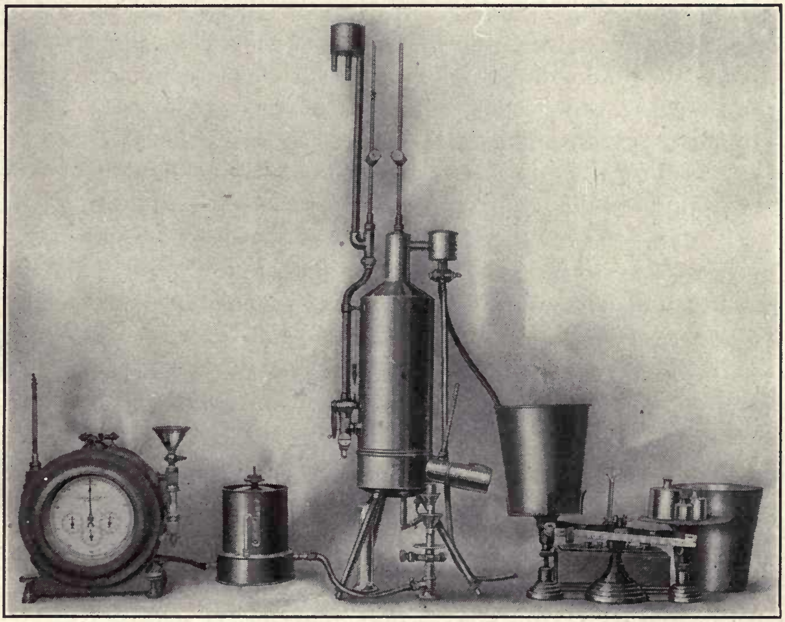


Fig. 73.—Hinman-Junkers calorimeter.

antly. The coal- and water-gas lines should be connected to small purifiers before the line enters the testing room.

For taking a sample over a long period or providing a sample of gas for several consecutive tests a small gas holder is required. This holder should be made up of light galvanized iron and should be 18 in. in diameter and about 3 ft. high which will give a capacity slightly over 3 cu. ft. The holder should be set in an annular tank, the space between the outer and inner sheet of the tank being 1 in. The object of having an annular tank instead of an open one is that it will hold a very small amount of water and therefore be much easier to move and the exposed surface of water being very small the absorption of gas will be slight. The holder should have suitable guides such as are put on meter provers. An old prover will make a very satisfactory holder for this purpose. The little holder can easily be arranged to shut itself off when full by running the inlet pipe up along one of the columns and putting on a cock near the top with a bent lever projecting out over the tank so that as it rises it will move the lever and cut off the gas just before the holder blows. Thus the holder can be connected up to the coal-gas make for instance and an average sample obtained over a period of any number of hours. The gas entering the holder may be passed through a small wash bottle to aid in gaging the flow so as to fill the tank in the desired time. In case the holder fills too quickly the automatic valve will cut off the supply before the holder blows. While the holder is being filled a jet should be kept burning on the line to provide a flow of gas and secure an average sample from the main.

Selection of a Calorimeter.—There are several types of calorimeters on the market but up to the present time authorities are pretty well agreed in recommending only some of the flow types. Of these there are several makes each claiming certain superior advantages. Accessibility for cleaning, compactness and ease of operation should be carefully considered in making a decision. Automatic overflows add a good deal to the ease of operation, but are not essential to accuracy.

Accessories.—In addition to the calorimeter, meter, weighing cans and balance, pressure regulator and thermometers there will be required a barometer, a thermometer for taking room temperature and a wet and dry bulb hygrometer. The barometer should by all means be a mercury and not an aneroid barometer.

They are much more accurate and less liable to derangement. None but a first-class instrument should be considered. The thermometer for taking the room temperature need not be an expensive one but should be known to be accurate or its error determined and applied if it is large enough to affect results. An inexpensive type of wet and dry bulb thermometer may be used. The barometer must be accurate and very closely read as an error of 0.05 in. will cause a difference of 1 B.t.u.

Calorimeter Cabinet and Table.—The calorimeter should be set up on a table not less than 30 in. by 60 in. with a small sink set in one end and connected with the drain. If the expense is not prohibitive it is an excellent idea to surround the calorimeter with a glass-panelled cabinet with a large door provided with a lock. The cabinet should be built the same size as the table and about 60 in. high. It will prevent drafts from affecting the operation of the calorimeter and also prevent anyone tampering with it while it is not in use.

Calibrating the Meter.—Very few gas companies will feel like investing in a cubic-foot bottle for testing the calorimeter meter and unless one can be borrowed dependence must be placed on a meter prover. The meter to be tested should be placed in the same room with the prover over night and great care must be taken that the temperature of the water in the meter and in the prover and of the air in the room are all closely the same. The meter should be filled with water to a point about 1/4 in. higher than the indicated proper level. With the inlet and the outlet of the meter open drain out the water until the bottom of the meniscus in the gage-glass just comes to the mark. Now connect up the meter to the prover, plug the outlet and throw on the pressure of the prover. If in 5 min. there is no movement either of the prover index or the meter there is no appreciable leakage. Allow about 2 ft. of air to pass through the meter in about 20 min. When the pointer is revolving it will be noted that there are four decided fluctuations of the water level in the glass during one revolution. The pointer should be shifted until it crosses the zero midway between two of these fluctuations, that is to say, the fluctuations should occur when the pointer passes 12.5, 37.5, 62.1 and 87.5.

Now pass air through the meter until the pointer is at zero, set the prover and make several tests. If the average of the tests is within 0.2 per cent. of correct it is not necessary to go further. If, however, the error is greater than this the water level should be altered and the test repeated until the proper level is reached. The new level should be carefully marked. A difference of 1/16 in. in the water level makes a difference of 1 per cent. in the registration. The calibration of the meter should be repeated about once a month.

Comparison of Thermometers.—The thermometers as supplied with calorimeters have a certificate correction which should always be applied. After some use, in addition to this, a differential correction should be made. Place the two thermometers in a well-stirred pail of water and take several readings and arrange the results as below:

	No. 1	No. 2
	62.33	62.38
	60.35	60.40
	60.36	60.41
	62.346 Average	62.346 Average
Certificate correction	−0.03	−0.05
	62.346	62.346

Thus the corrected reading of No. 2 is 0.03 higher than that of No. 1. There is a differential reading correction of −0.03 which must be applied to No. 2 in addition to the certificate correction, thus:

	No. 1	No. 2
	62.346	62.396
Certificate correction	−0.03	−0.05
Differential correction		−0.03
Corrected temperature	62.316	62.316

This correction should be checked about once a month.

Setting-up Apparatus.—The calorimeter proper should be set up and the water connections made with the rubber tube provided for the purpose. The balance and water pails should be set so that they will be convenient to handle. The pressure regulator should be connected to the small holder or some source of gas supply and the meter connected between the regulator and the burner. Some outfits are so arranged that the regulator supplied has to be connected up between the meter and the burner. In that case it is advisable to provide an additional regulator to precede the meter. The small holder may be floated on the supply line while making tests which will keep the pressure quite uniform (Fig. 74).

The meter should be set so that its dial is easily seen when standing at the calorimeter to read the thermometers. This makes it easy to watch the meter and thermometers at the same time. The gas connections should all be made of metal tubing but heavy wall black rubber is best for the water except where ¼-in. pipe can be used. Turn on the water and fill the calorimeter full, letting the water flow through and out the waste pipe. Open and shut the quadrant valve a number of times to aid in driving all air out of the body of the calorimeter. Tapping on the outside will help to start this air.

Pass gas through the meter and regulator, lighting the burner and adding weights to the regulator until the flow of gas is about 5 ft. per hour. At least 5 cu. ft. of gas should be burned before making a first test to saturate the water in the meter and the rubber tubing with gas or otherwise the absorption would cause an error in the test. The flow of water should be regulated to about 8 lb. during two revolutions of the dial. If an automatic trip is used, the water should be adjusted to deliver about 5.5 to 6 lb. of water in one revolution. Hang up the room temperature thermometer and the hygrometer in a convenient place where they will not be affected by drafts, etc.

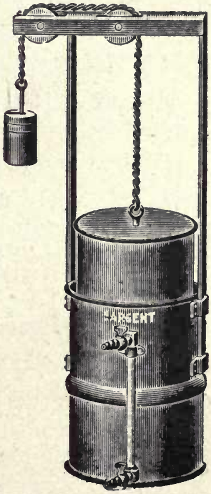


FIG. 74.—Test holder.

Standardizing.—With the water flowing at about the desired rate insert the lighted burner in the calorimeter as far as it will go. If the damper has holes in it, close it but if it is solid it should be left about one-quarter open. After about 15 min. read the temperature of the outlet and inlet thermometers. Reduce the flow of gas gradually until the flow is about 4 ft. per hour and then increase slowly as long as the differential between the thermometers increases. There will be a point where an increase in the amount of gas burned will not increase the differential showing that incomplete combustion has resulted. The flow of gas should be set so that the maximum differential is obtained and then with the calorimeter operating under these conditions the damper should be opened or closed to find the point where the maximum difference in temperature is obtained, the idea being that the greater the opening the more air is passed through the instrument, cooling the combustion, but at the same time enough air must pass to insure complete combustion or the maximum heat will not be obtained.

The gas flow should not be far from 5 cu. ft. per hour and the damper should be nearly closed. The position of the quadrant valve and damper should be noted and always set for the same opening when using the calorimeter. The apparatus should be so set as to obtain about 8 lb. of water in two revolutions of the pointer, with a temperature difference of about 15° or about 6 lb. of water in one revolution with a temperature difference of about 10° when testing with an automatic trip on one revolution of pointer, with gas of about 600 B.t.u.

Making a Test.—Purge connections of all old gas, adjust the water level on the meter, turn on the gas and allow it to flow a moment, then shut the cock on the burner and watch the meter hand for any movement indicating leaks; then, if no leak is shown, light the burner. Start water flowing through calorimeter taking the usual precautions about expelling air. Insert the burner into the calorimeter and check the rate of combustion. Adjust the water flow and set the damper, note the temperature of the room, the temperature of the gas meter, barometer reading and hygrometer reading and enter them on the record.

After about 10 min. start the test by switching water into one of the pails as the meter hand crosses zero. The water pails should be counterbalanced when wet. Observe the inlet and outlet thermometers during one revolution or two revolutions of the meter hand as the case may be, mentally averaging the readings. Just as the meter hand passes the zero point switch the water into the other pail. Weigh the water and enter the weight on the record together with the thermometer readings and repeat the process until ten weighings have been made with ten temperature readings to correspond. The temperature of the outlet products of the calorimeter should be noted. It should be within 2° of the temperature, products temperature, inlet-water and room temperature should all be within 2° of one another.

Record Sheet.—The record sheet shown below is suitable for recording the calorimeter test.

B.T.U. TEST RECORD

Date..................................

Barometer.......................... Temperature of gas..............
Correction factor.................. (C)
Wet-bulb thermometer............. Dry-bulb thermometer...........
Humidity per cent..................
Room temperature .... Exhaust temperature.............
Condensed water collected per foot of gas.............................
Gas consumed, one revolution per test.............................. (G)

READINGS

Thermometer number, inlet	Thermometer number, outlet	Pounds, water heated	Calculation, B.t.u. = $\frac{W \times T}{G \times C}$ (gross)
1.............			
2.............			
3.............			
4.............			
5.............			
6.............			
7.............			
8.............			
9.............			
10.............			

Average
Corrected

Rise in temperature.. (T)
Average pounds water heated.. (W)
Calculated B.t.u..
Correction for humidity...
B.t.u. corrected..
....................Observer.

Calculation.—The inlet and outlet water temperatures are averaged, the difference being the temperature increase. The weights of water collected should be averaged, carrying the calculation to the third place in decimals. The weight of water should be multiplied by the temperature increase and divided by the product of the gas burned in one test times the correction factor. To this result should be added or subtracted the humidity correction. This correction should be found by means of the table below and the accompanying chart (Fig. 75).

TABLE IX.—RELATIVE HUMIDITY TABLE FOR WET- AND DRY-BULB READINGS

Difference in temperature, degrees F.	Temperature of air			
	40,°F per cent.	60,°F per cent.	80,°F per cent.	100,°F per cent.
0	100	100	100	100
1	96	97	97	97
2	93	93	94	94
3	89	90	91	91
4	86	87	88	89
5	82	84	85	86
6	79	81	82	83
7	76	78	79	81
8	73	75	77	78
9	70	72	74	76
10	67	70	72	73
12	61	65	67	69
15	53	58	60	63
18	46	51	54	57
20	42	48	51	53

(Smithsonian Meteorological Tables)

Net Heating Value.—While the calorimeter is in operation collect the condensate in the cylinder provided for that purpose during the consumption of 1 cu. ft. of gas. For each cubic centimeter of condensation collected deduct 2.3 B.t.u. from the gross B.t.u. uncorrected for temperature and barometer, then apply the correction. If the humidity is taken into consideration, multiply the cubic centimeters of condensation by 2.3, divide by the correction factor and subtract from the gross B.t.u. corrected for humidity.

PHOTOMETRY

Photometer Room.—If possible a separate room should be provided for the photometer where no other work is done. The ventilation must be carefully looked into but it must be had without drafts. Very elaborate specifications for photometer rooms have been published by the American Gas Institute and are undoubtedly justified for official testing but for works purposes a simpler arrangement is usually sufficient. The walls of the room and all the furniture in it should be painted a dull non-reflecting black and if there are windows it should be possible to close out every ray of light by a heavy close-fitting curtain.

To provide for ventilation, holes should be pierced in the walls close to the floor and a slanting board fastened on the other side of the wall to exclude light from entering. To induce circulation a square hole should be cut in the ceiling about 12 by 12 in. and an open-ended box about 18 in. long fastened in the hole, terminating in a sort of roof which will allow the air to pass out but will exclude any stray light passing down. A small upright mantle burner fixed in this box will induce a good circulation of air prior to making the readings on the photometer but must of course be extinguished while the readings are being taken. The temperature of the photometer room should be kept as uniform as possible.

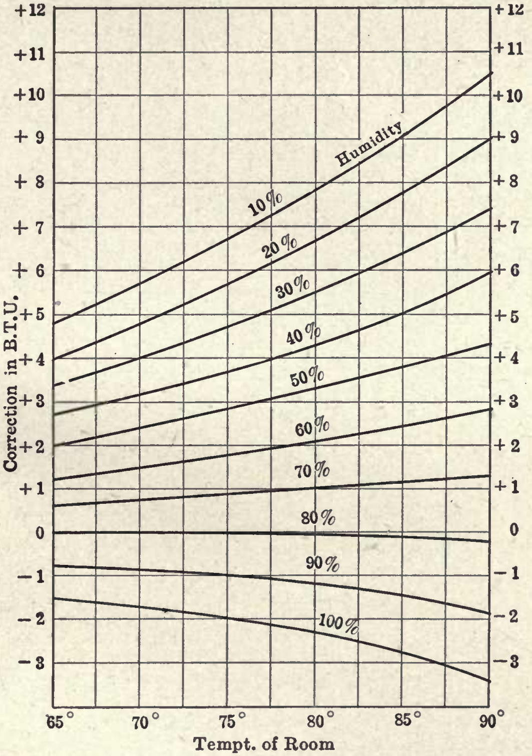


Fig. 75.—Hygrometry correction.

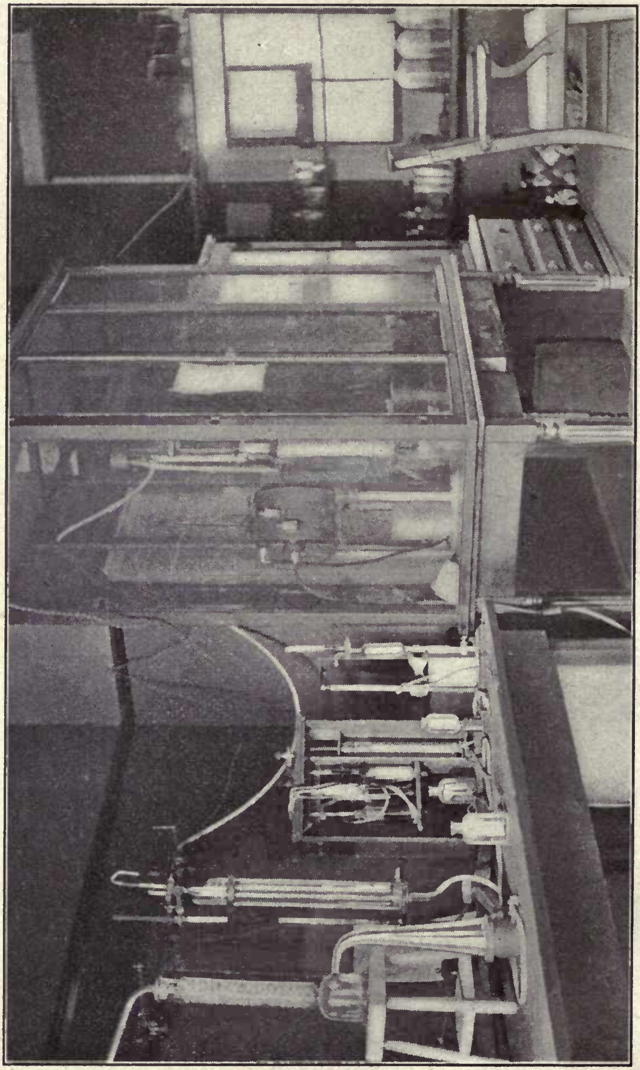


Fig. 76.—Gas-analysis apparatus and calorimeter cabinet.

Photometer.—The open-bar photometer is in pretty general use throughout this country, made in one or two well-known types. This apparatus is supplied with $\frac{1}{12}$-cu. ft. wet meter, pressure regulator, candle balance, and gas burner. For works tests no other standard than candles is required. A disappearing star sight box is usually supplied but other discs and sighting devices have been developed and become standard with advantages to recommend them. All piping connections should be iron, no rubber tubing being permissible about the photometer. All cocks and valves ought to be well greased and easily operated.

Burners.—For coal gas and for water gas up to 20 cp., the Metropolitan No. 2 burner is in most general use although some regulating standards require the use of other burners. For water and oil gas of 20 cp. and above the No. 7 L.P. slit union Bray burner is usually used. In using the Metropolitan No. 2 burner the flow of gas should be adjusted to 5 ft. per hour and then the plate at the bottom of the burner should be screwed up until the flane has elongated so that its tip just comes to the top of the chimney but does not stream up above it. This will give the maximum candlepower.

Preparation of Candles.—For a great many years directions for preparing candles for the photometer have required that the candle be cut in halves according to careful directions and the two halves burned at one time but in the specifications of the Bureau of Standards they have discarded this method and recommend the use of two candles of the size running 12 to the pound. The two candles are set up at equal heights on the candle balance and after burning 15 min. to obtain uniform conditions they are carefully centered with respect to the round aperture in the photometer. The same authorities lay no stress on the position of the wicks, whether parallel, at right angles or facing opposite each other. The candles should, however, be allowed to burn until the cups are perfectly formed and if the wick of one candle including toward the other causes the formation of an irregular cup, the wicks should be made to point in opposite directions.

Setting the Gas Flow.—Turn on and light the gas at the burner. Adjust the flow of gas to as near 5 ft. per hour as possible with the pressure governor or a graduated cock. The pointer on the meter should revolve within from 58 to 62 sec. By noting the pressure at which this flow of gas occurs it will be easy to reproduce it in future tests.

Making the Test.—With the gas burner lighted and adjusted to give the maximum illuminating flame, light the candles and allow them to burn about 15 min. While waiting for the candles take the time of the meter and determine the flow in cubic feet per hour and calculate the time for consumption of 1 cu. ft. of gas. When the candles are ready, move the counterbalance until the pointer just falls, then holding the stop watch in hand, closely observe the pointer on the balance and as the candles burn and the pointer rises, start the watch at the exact moment that it crosses the zero point then drop on the pan a 40-grain weight. Now take the first reading, running the sight box back and forth until the end point of the sight is determined, whether by the fading of a disc, star or other method. Read the bar to the nearest tenth and record. The test should continue for approximately 10 min. and during this time 30 readings should be made.

None of the readings should be discarded no matter how far at variance they may seem. Reject all or none. Make five readings and then reverse the disc and repeat the reversal after every five readings. After about 9½ min. have passed the attention should be given to the candle balance. As the pointer begins to move take the watch in hand and just as the pointer crosses the zero stop the watch. Complete the readings on the bar and record. The following test card or record may be used.

Candlepower-Test Record

Date........................Hour..................Gas..............

1	11	21	Time for 1 cu. ft. gas....................	*A*
2	12	22	Meter temperature.......................	
3	13	23	Barometer........Room temperature......	
4	14	24	Corrected factor.........................	*F*
5	15	25	Time for 40 grains of sperm to burn........	*C*
6	16	26	Average settings..........................	*D*
7	17	27	$\frac{5 \times A \times D}{3 \times F \times C} =$	candlepower
8	18	28		
9	19	29		
10	20	30		

....
Observer.

Calculation.—The readings are averaged to the nearest tenth, the barometer, gas temperature and the room temperature are taken and recorded. Convert the minutes and seconds elapsed while the 40 grains of sperm was burning into minutes and decimal parts. Multiply the time of consumption of 1 ft. of gas [by 5 and the result by the average of the settings. Divide this last result by the product of three times the correction factor times the minutes burning the sperm. The result is the candlepower which should be calculated to the nearest tenth only.

APPENDIX

Table I.—Radiation Loss in Iron Pipes

(From Suplee)

Mean temperature of pipes, Fahr. degrees	Units of heat (B.t.u.) emitted, per square foot, per hour. Temperature of air = 70°F.				
	By convection		By radiation alone	By convection and radiation combined	
	Air still	Air moving		Air still	Air moving
80	5.04	8.40	7.43	12.47	15.83
90	11.84	19.73	15.31	27.51	35.04
100	19.53	32.55	23.47	43.00	56.02
110	27.86	46.43	31.93	57.79	78.36
120	36.66	61.10	40.82	77.48	101.92
130	45.90	76.50	50.00	95.90	126.50
140	55.51	92.52	59.63	115.14	152.15
150	65.45	109.18	69.69	135.14	178.87
160	75.68	126.13	80.19	155.87	206.32
170	86.18	143.30	91.12	177.30	234.42
180	96.93	161.55	102.50	199.43	264.05
190	107.90	179.83	114.45	222.35	294.28
200	119.13	198.55	127.00	246.13	325.55
210	130.49	217.48	139.96	270.49	357.48
220	142.20	237.00	155.27	297.47	392.27
230	153.95	256.58	169.56	323.51	426.14
240	165.90	279.83	184.58	350.48	464.41
250	178.00	296.66	200.18	378.18	496.84
260	189.90	316.50	214.36	404.26	530.86
270	202.70	337.83	233.42	436.12	571.25
280	215.30	358.85	251.21	466.51	610.06
290	228.55	380.91	267.73	496.28	648.64
300	240.85	401.41	279.12	519.97	680.53

TABLE II.—FUEL DATA

COAL

A bushel of bituminous coal weights 76 lb. (Pennsylvania) and contains 1.554 cu. ft.; in Ohio and West Virginia the weight is 80 lb.

41 to 45 cu. ft. bituminous coal = 1 ton, 2,240 lb.
34 to 41 cu. ft. anthracite coal = 1 ton, 2,240 lb.

CHARCOAL

A bushel of charcoal weighs 20 lb. and contains 2,748 cu. in. 123 cu. ft. charcoal = 1 ton, 2,240 lb.

COKE

A bushel of coke weighs 40 lb.
70.9 cu. ft. coke = 1 ton, 2,240 lb.

WOOD

2½ lb. of dry wood = 1 lb. of coal.

COMPOSITION OF WOOD

Average		Oak, 120 yr.	Birch, 60 yr.	Willow
Carbon	50	50.97	50.59	51.25
Hydrogen	6	6.02	6.21	6.19
Oxygen	41	41.96	42.16	41.98
Nitrogen	2	1.27	1.01	0.98
Ash	2	1.93	2.1	3.67

The calorific value of dry wood is about 7,000 B.t.u. and of air-dried wood about 5,600 B.t.u.

The calorific intensity is very low.

Ordinary firewood contains, by analysis, from 27 to 80 per cent. of hygrometric moisture.

1 cord of hickory or maple weighs 4,500 lb.
1 cord of white oak weighs 3,850 lb.
1 cord of beach, red oak, or black oak weighs 3,250 lb.
1 cord of poplar, chestnut, or elm weighs 2,350 lb.
1 cord of average pine weighs 2,000 lb.

A cord of wood = 4 × 4 × 8 = 128 cu. ft. = about 56 per cent. solid wood and 44 per cent. interstitial spaces.

Table III.—Firebbick for Various Circles[1]

Inside diameter of circle		Arch bricks			Total	9-in. key bricks					Total	Wedge bricks			Total	13½-in. key bricks			Total
		No. 2 arch	No. 1 arch	9-in.		No. 4 key	No. 3 key	No. 2 key	No. 1 key	9-in.		No. 2 wedge	No. 1 wedge	9-in.		No. 2 wedge	No. 1 wedge	Straights	
Ft.	In.																		
1	6	...	...	...	...	25	...	...	...	...	25	...	...	...	...	...	...	...	...
2	0	42	...	...	42	17	13	...	...	...	30	60	...	...	60	...	...	...	...
2	6	10	40	...	50	9	25	...	...	...	34	48	20	...	68	...	...	...	...
3	0	...	57	...	57	...	38	...	...	...	38	36	40	...	76	...	...	...	...
3	6	...	57	7	64	...	32	10	...	...	42	24	59	...	83	...	...	...	...
4	0	...	57	15	72	...	25	21	...	...	46	12	79	...	91	...	...	...	...
4	6	...	57	22	79	...	19	32	...	...	51	...	98	...	98	...	...	...	...
5	0	...	57	29	86	...	13	42	...	...	55	...	98	8	106	...	...	...	...
5	6	...	57	37	94	...	6	53	...	...	59	...	98	15	113	...	...	...	...
6	0	...	57	44	101	...	...	63	...	...	63	...	98	23	121	53	...	...	53
6	6	...	57	52	109	...	...	58	9	...	67	...	98	30	128	52	5	...	57
7	0	...	57	59	116	...	...	52	19	...	71	...	98	38	136	48	12	...	60
7	6	...	57	67	124	...	...	47	29	...	76	...	98	46	144	42	21	...	63
8	0	...	57	74	131	...	...	42	38	...	80	...	98	53	151	36	30	...	66
8	6	...	57	82	139	...	...	37	47	...	84	...	98	61	159	30	40	...	70
9	0	...	57	89	146	...	...	31	57	...	88	...	98	68	166	24	49	...	73
9	6	...	57	97	154	...	...	26	66	...	92	...	98	76	174	18	58	...	76
10	0	...	57	104	161	...	...	21	76	...	97	...	98	83	181	12	67	...	79
10	6	...	57	112	169	...	...	16	85	...	101	...	98	91	189	8	74	...	82
11	0	...	57	119	176	...	...	11	94	...	105	...	98	98	196	6	79	...	85
11	6	...	57	127	184	...	...	5	104	...	109	...	98	106	204	4	84	...	88
12	0	...	57	134	191	...	...	...	113	...	113	...	...	...	...	...	91	...	91
12	6	...	57	142	199	...	...	...	113	4	117	...	...	...	...	...	91	3	94
13	0	...	...	...	...	...	...	...	113	9	122	...	...	...	...	...	91	6	97
13	6	...	...	...	...	...	...	...	113	13	126	...	...	...	...	...	91	9	100
14	0	...	...	...	...	...	...	...	113	17	130	...	...	...	...	...	91	13	104
14	6	...	...	...	...	...	...	...	113	21	134	...	...	...	...	...	91	16	107
15	0	...	...	...	...	...	...	...	113	26	139	...	...	...	...	...	91	19	110
16	0	...	...	...	...	...	...	...	113	34	147	...	...	...	...	...	91	25	116

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[1] From the Stowe-Fuller Co.'s catalog.

Table IV.—Height of Water Column in Inches

Press oz. per sq. in.	Decimal parts of an ounce									
	0.00	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.17	0.35	0.52	0.69	0.87	1.04	1.21	1.38	1.56
1	1.73	1.90	2.08	2.25	2.42	2.60	2.77	2.94	3.11	3.27
2	3.46	3.63	3.81	3.98	4.15	4.33	4.50	4.67	4.84	5.01
3	5.19	5.36	5.54	5.71	5.88	6.06	6.23	6.40	6.57	6.75
4	6.92	7.09	7.27	7.44	7.61	7.79	7.96	8.13	8.30	8.48
5	8.65	8.82	9.09	9.17	9.34	9.52	9.69	9.86	10.03	10.21
6	10.38	10.55	10.73	10.90	11.07	11.26	11.43	11.60	11.77	11.95
7	12.11	12.23	12.46	13.63	12.80	12.97	13.15	13.49	13.32	13.67
8	13.84	14.01	14.19	14.36	14.53	14.71	14.88	15.05	15.22	15.40
9	15.57	15.74	15.92	16.09	16.26	16.45	16.62	16.79	16.96	17.14
Head in inches	Pressure in ounces per square inch									
0	0.00	0.06	0.12	0.17	0.23	0.29	0.35	0.40	0.46	0.52
1	0.58	0.63	0.69	0.75	0.81	0.87	0.93	0.98	1.04	1.09
2	1.16	1.21	1.27	1.33	1.39	1.44	1.50	1.56	1.62	1.67
3	1.73	1.79	1.85	1.91	1.96	2.02	2.08	2.14	2.19	2.25
4	2.31	2.37	2.42	2.48	2.54	2.60	2.66	2.72	2.77	2.83
5	2.89	2.94	3.00	3.06	3.12	3.18	3.24	3.29	3.35	3.41
6	3.47	3.52	3.58	3.64	3.70	3.75	3.81	3.87	3.92	3.98
7	4.04	4.10	4.16	4.22	4.28	4.33	4.39	4.45	4.50	4.56
8	4.62	4.67	4.73	4.79	4.85	4.91	4.97	5.03	5.08	5.14
9	5.20	5.26	5.31	5.37	5.42	5.48	5.54	5.60	5.66	5.72

TABLE V.—FACTORS FOR REDUCTION OF GAS VOLUME TO 60°F. AND 30 IN. OF MERCURY PRESSURE AND SATURATION WITH MOISTURE

TEMPERATURE °F.	BAROMETER																			
	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5
107	0.816	0.820	0.823	0.826	0.829	0.832	0.835	0.838	0.841	0.844	0.847	0.851	0.854	0.857	0.860	0.864	0.867	0.870	0.874	0.877
106	0.820	0.823	0.826	0.829	0.832	0.835	0.838	0.841	0.844	0.847	0.851	0.854	0.857	0.860	0.863	0.867	0.870	0.874	0.878	0.881
105	0.823	0.827	0.830	0.833	0.836	0.839	0.842	0.845	0.848	0.851	0.855	0.858	0.861	0.864	0.867	0.871	0.874	0.878	0.881	0.884
104	0.827	0.830	0.833	0.836	0.839	0.842	0.845	0.848	0.851	0.854	0.858	0.861	0.864	0.867	0.871	0.874	0.878	0.881	0.884	0.887
103	0.830	0.834	0.837	0.840	0.843	0.847	0.849	0.852	0.855	3.858	0.862	0.865	0.868	0.871	0.874	0.878	0.881	0.885	0.888	0.891
102	0.834	0.837	0.840	0.843	0.847	0.850	0.853	0.856	0.859	0.862	0.865	0.868	0.871	0.874	0.878	0.881	0.885	0.888	0.891	0.894
101	0.837	0.840	0.843	0.846	0.850	0.853	0.856	0.859	0.862	0.865	0.868	0.872	0.875	0.878	0.882	0.885	0.888	0.891	0.895	0.898
100	0.840	0.843	0.846	0.849	0.853	0.856	0.859	0.862	0.865	0.868	0.872	0.875	0.878	0.881	0.885	0.888	0.891	0.895	0.898	0.901
99	0.844	0.847	0.850	0.853	0.857	0.860	0.863	0.866	0.869	0.872	0.876	0.879	0.882	0.885	0.889	0.892	0.895	0.898	0.902	0.905
98	0.847	0.850	0.853	0.856	0.860	0.863	0.866	0.869	0.872	0.875	0.879	0.882	0.885	0.888	0.892	0.895	0.898	0.902	0.905	0.908
97	0.850	0.853	0.856	0.859	0.863	0.866	0.870	0.873	0.876	0.879	0.882	0.885	0.888	0.891	0.894	0.898	0.901	0.905	0.908	0.911
96	0.854	0.857	0.860	0.863	0.867	0.870	0.873	0.876	0.879	0.882	0.886	0.889	0.892	0.895	0.898	0.901	0.904	0.908	0.911	0.914
95	0.857	0.860	0.863	0.866	0.870	0.873	0.876	0.879	0.882	0.885	0.889	0.892	0.895	0.898	0.901	0.904	0.908	0.911	0.914	0.918
94	0.860	0.863	0.866	0.869	0.873	0.876	0.879	0.882	0.885	0.888	0.892	0.895	0.898	0.901	0.904	0.907	0.911	0.914	0.918	0.921
93	0.863	0.866	0.869	0.872	0.876	0.879	0.883	0.886	0.889	0.891	0.895	0.898	0.901	0.904	0.907	0.910	0.914	0.918	0.921	0.924
92	0.866	0.869	0.872	0.875	0.879	0.882	0.885	0.889	0.892	0.894	0.898	0.902	0.904	0.907	0.910	0.914	0.917	0.921	0.924	0.928
91	0.869	0.872	0.875	0.879	0.882	0.885	0.889	0.892	0.895	0.898	0.902	0.905	0.908	0.911	0.914	0.917	0.921	0.924	0.928	0.931
90	0.872	0.875	0.878	0.881	0.885	0.888	0.892	0.895	0.898	0.901	0.905	0.908	0.911	0.914	0.917	0.920	0.924	0.927	0.931	0.934
89	0.875	0.878	0.882	0.885	0.889	0.892	0.895	0.898	0.901	0.904	0.907	0.910	0.914	0.917	0.920	0.923	0.927	0.931	0.934	0.937
88	0.878	0.881	0.885	0.888	0.892	0.895	0.898	0.901	0.904	0.907	0.910	0.913	0.917	0.920	0.923	0.926	0.930	0.934	0.937	0.940
87	0.881	0.884	0.888	0.891	0.895	0.898	0.901	0.904	0.907	0.910	0.913	0.916	0.920	0.923	0.926	0.929	0.933	0.937	0.940	0.943
86	0.884	0.887	0.890	0.894	0.898	0.901	0.904	0.907	0.910	0.913	0.916	0.919	0.923	0.926	0.929	0.932	0.936	0.940	0.943	0.946
85	0.887	0.890	0.893	0.896	0.900	0.903	0.906	0.909	0.913	0.916	0.919	0.922	0.926	0.929	0.932	0.936	0.939	0.943	0.946	0.949
84	0.889	0.893	0.896	0.899	0.903	0.906	0.909	0.912	0.915	0.919	0.922	0.925	0.928	0.932	0.935	0.939	0.942	0.946	0.949	0.952
83	0.892	0.895	0.899	0.902	0.906	0.909	0.912	0.915	0.918	0.921	0.924	0.928	0.931	0.935	0.938	0.942	0.945	0.949	0.952	0.955
82	0.895	0.898	0.901	0.905	0.908	0.911	0.914	0.918	0.921	0.924	0.927	0.931	0.934	0.937	0.941	0.945	0.948	0.951	0.954	0.958
81	0.898	0.901	0.905	0.908	0.911	0.914	0.917	0.921	0.924	0.927	0.930	0.934	0.937	0.940	0.944	0.948	0.951	0.954	0.957	0.960

TABLE V.—FACTORS FOR REDUCTION OF GAS VOLUME TO 60°F. AND 30 IN. OF MERCURY PRESSURE AND SATURATION WITH MOISTURE.—(*Continued*)

TEMPERATURE °F.	BAROMETER																			
	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5
80	0.901	0.904	0.907	0.910	0.914	0.917	0.920	0.923	0.927	0.930	0.933	0.937	0.940	0.943	0.946	0.950	0.954	0.957	0.960	0.963
79	0.904	0.907	0.910	0.914	0.917	0.920	0.923	0.926	0.930	0.933	0.936	0.939	0.943	0.946	0.949	0.953	0.956	0.960	0.963	0.967
78	0.906	0.909	0.913	0.916	0.919	0.923	0.926	0.929	0.932	0.936	0.939	0.942	0.946	0.949	0.952	0.956	0.959	0.962	0.966	0.969
77	0.909	0.912	0.915	0.919	0.922	0.925	0.928	0.931	0.935	0.938	0.942	0.945	0.948	0.951	0.955	0.958	0.962	0.965	0.968	0.972
76	0.911	0.915	0.918	0.921	0.925	0.928	0.931	0.935	0.938	0.941	0.944	0.948	0.951	0.954	0.958	0.961	0.964	0.968	0.971	0.975
75	0.914	0.917	0.921	0.924	0.928	0.931	0.934	0.937	0.940	0.943	0.947	0.950	0.954	0.957	0.960	0.963	0.967	0.971	0.974	0.978
74	0.917	0.920	0.924	0.927	0.930	0.933	0.937	0.940	0.943	0.957	0.950	0.953	0.957	0.960	0.963	0.966	0.970	0.973	0.977	0.980
73	0.920	0.923	0.926	0.930	0.933	0.936	0.940	0.943	0.946	0.949	0.953	0.956	0.960	0.963	0.966	0.969	0.972	0.976	0.980	0.983
72	0.922	0.925	0.929	0.932	0.935	0.939	0.942	0.945	0.949	0.952	0.955	0.959	0.962	0.965	0.968	0.972	0.975	0.979	0.982	0.986
71	0.925	0.928	0.931	0.935	0.938	0.941	0.945	0.948	0.951	0.954	0.958	0.961	0.965	0.968	0.971	0.975	0.978	0.981	0.985	0.989
70	0.927	0.931	0.934	0.937	0.941	0.944	0.947	0.950	0.954	0.957	0.960	0.964	0.967	0.970	0.974	0.977	0.980	0.984	0.988	0.991
69	0.930	0.933	0.937	0.940	0.944	0.947	0.950	0.953	0.957	0.960	0.963	0.967	0.970	0.973	0.977	0.980	0.983	0.987	0.990	0.994
68	0.932	0.936	0.939	0.942	0.946	0.949	0.952	0.956	0.959	0.962	0.966	0.969	0.972	0.976	0.979	0.983	0.986	0.989	0.993	0.997
67	0.935	0.938	0.942	0.945	0.949	0.952	0.955	0.959	0.962	0.965	0.968	0.972	0.975	0.979	0.982	0.985	0.989	0.992	0.996	1.000
66	0.938	0.941	0.944	0.948	0.951	0.954	0.958	0.961	0.964	0.968	0.971	0.974	0.978	0.981	0.985	0.988	0.992	0.995	0.998	1.002
65	0.941	0.944	0.947	0.950	0.954	0.957	0.960	0.963	0.967	0.970	0.973	0.977	0.980	0.984	0.987	0.991	0.994	0.997	1.001	1.005
64	0.943	0.946	0.949	0.953	0.956	0.959	0.963	0.966	0.969	0.973	0.976	0.980	0.983	0.986	0.990	0.994	0.997	1.000	1.004	1.008
63	0.945	0.949	0.952	0.955	0.959	0.962	0.965	0.969	0.972	0.975	0.979	0.982	0.985	0.989	0.993	0.996	1.000	1.003	1.006	1.010
62	0.947	0.951	0.954	0.958	0.961	0.964	0.968	0.971	0.975	0.978	0.981	0.985	0.988	0.991	0.995	0.999	1.002	1.005	1.009	1.013
61	0.950	0.954	0.957	0.961	0.964	0.967	0.971	0.974	0.977	0.981	0.984	0.987	0.991	0.994	0.998	1.001	1.005	1.008	1.011	1.015
60	0.952	0.956	0.959	0.963	0.966	0.969	0.973	0.976	0.980	0.983	0.986	0.990	0.993	0.997	1.000	1.004	1.007	1.010	1.014	1.017
59	0.955	0.959	0.962	0.966	0.969	0.972	0.976	0.979	0.983	0.986	0.989	0.992	0.995	0.999	1.003	1.006	1.010	1.013	1.016	1 020
58	0.957	0.961	0.964	0.968	0.971	0.975	0.978	0.981	0.985	0.988	0.992	0.995	0.998	1.002	1.005	1.009	1.012	1.016	1.019	1.023
57	0.960	0.963	0.967	0.970	0.974	0.977	0.980	0.984	0.988	0.991	0.994	0.997	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025
56	0.962	0.966	0.969	0.973	0.976	0.979	0.982	0.986	0.990	0.993	0.996	1.000	1.003	1.007	1.010	1.014	1.017	1.021	1.024	1.028
55	0.965	0.968	0.972	0.975	0.979	0.982	0.985	0.989	0.993	0.996	0.999	1.002	1.006	1.009	1.013	1.016	1.020	1.023	1.027	1.030
54	0.967	0.970	0.974	0.977	0.981	0.984	0.988	0.991	0.995	0.998	1.001	1.005	1.008	1.012	1.015	1.019	1.022	1.026	1.029	1.033

Table V.—Factors for Reduction of Gas Volume to 60°F. and 30 in. of Mercury Pressure and Saturation with Moisture.—(*Continued*)

TEMPERATURE °F.	BAROMETER																			
	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5
53	0.969	0.973	0.976	0.980	0.983	0.986	0.990	0.993	0.997	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025	1.028	1.031	1.035
52	0.971	0.975	0.978	0.982	0.985	0.989	0.992	0.996	0.999	1.003	1.006	1.010	1.013	1.017	1.020	1.024	1.027	1.031	1.034	1.038
51	0.974	0.977	0.981	0.984	0.988	0.991	0.995	0.998	1.002	1.005	1.009	1.012	1.016	1.019	1.023	1.026	1.030	1.033	1.037	1.040
50	0.976	0.980	0.983	0.987	0.990	0.994	0.997	1.001	1.004	1.008	1.011	1.015	1.018	1.022	1.025	1.029	1.032	1.036	1.039	1.043
49	0.979	0.982	0.986	0.989	0.993	0.996	1.000	1.003	1.007	1.010	1.014	1.017	1.021	1.024	1.028	1.031	1.035	1.038	1.042	1.045
48	0.981	0.985	0.988	0.992	0.995	0.999	1.002	1.006	1.009	1.013	1.016	1.020	1.023	1.027	1.030	1.034	1.037	1.041	1.044	1.048
47	0.984	0.987	0.991	0.994	0.998	1.001	1.005	1.008	1.012	1.015	1.019	1.022	1.026	1.029	1.033	1.036	1.040	1.043	1.047	1.050
46	0.986	0.990	0.993	0.997	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025	1.028	1.032	1.035	1.039	1.042	1.046	1.049	1.053
45	0.989	0.992	0.996	0.999	1.003	1.006	1.010	1.013	1.017	1.020	1.024	1.027	1.031	1.034	1.038	1.041	1.045	1.048	1.052	1.056
44	0.991	0.994	0.998	1.001	1.005	1.008	1.012	1.015	1.019	1.022	1.026	1.029	1.033	1.036	1.040	1.043	1.047	1.050	1.054	1.058
43	0.993	0.997	1.001	1.004	1.008	1.011	1.015	1.018	1.022	1.025	1.029	1.032	1.036	1.039	1.043	1.046	1.050	1.053	1.057	1.060
42	0.995	0.999	1.003	1.006	1.010	1.013	1.017	1.020	1.024	1.027	1.031	1.034	1.038	1.041	1.045	1.048	1.052	1.055	1.059	1.063
41	0.998	1.001	1.005	1.009	1.012	1.016	1.019	1.023	1.026	1.030	1.034	1.037	1.041	1.044	1.048	1.051	1.055	1.058	1.062	1.065
40	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025	1.028	1.032	1.036	1.039	1.043	1.046	1.050	1.053	1.057	1.060	1.064	1.068
39	1.002	1.006	1.010	1.013	1.017	1.020	1.024	1.028	1.031	1.035	1.038	1.042	1.045	1.049	1.052	1.056	1.059	1.063	1.066	1.070
38	1.005	1.009	1.012	1.016	1.020	1.023	1.027	1.030	1.034	1.037	1.041	1.044	1.048	1.051	1.055	1.058	1.062	1.065	1.069	1.073
37	1.007	1.011	1.015	1.018	1.022	1.025	1.029	1.032	1.036	1.039	1.043	1.046	1.050	1.053	1.057	1.060	1.064	1.068	1.072	1.076
36	1.009	1.013	1.017	1.020	1.024	1.027	1.031	1.035	1.038	1.042	1.045	1.049	1.052	1.056	1.060	1.063	1.067	1.071	1.074	1.078
35	1.012	1.015	1.019	1.022	1.026	1.030	1.033	1.037	1.041	1.044	1.048	1.051	1.055	1.058	1.062	1.065	1.069	1.073	1.077	1.081
34	1.014	1.018	1.022	1.025	1.029	1.032	1.036	1.040	1.043	1.047	1.050	1.054	1.057	1.061	1.064	1.068	1.072	1.075	1.079	1.083
33	1.016	1.020	1.024	1.027	1.031	1.034	1.038	1.042	1.046	1.049	1.053	1.056	1.060	1.063	1.067	1.070	1.074	1.078	1.082	1.086
32	1.019	1.023	1.027	1.030	1.034	1.037	1.041	1.044	1.048	1.051	1.055	1.058	1.062	1.066	1.069	1.073	1.077	1.081	1.085	1.089
31	1.021	1.025	1.029	1.032	1.036	1.039	1.043	1.047	1.050	1.054	1.057	1.061	1.064	1.068	1.072	1.075	1.079	1.083	1.087	1.091
30	1.023	1.027	1.031	1.034	1.038	1.042	1.045	1.049	1.053	1.056	1.060	1.063	1.067	1.071	1.074	1.078	1.082	1.086	1.090	1.094

TABLE VI.—TABLE OF MEAN SPECIFIC HEATS AT CONSTANT PRESSURE
(In B.t.u. per Pound)
(Latta)

Deg. F.	Carbon diox.	Water vapor	Nitrogen	Oxygen
212	0.201	0.446	0.244	0.214
392	0.210	0.462	0.249	0.218
572	0.219	0.478	0.253	0.222
752	0.227	0.494	0.257	0.225
932	0.236	0.510	0.262	0.229
1,112	0.245	0.526	0.266	0.233
1,292	0.254	0.541	0.270	0.237
1,472	0.263	0.557	0.275	0.241
1,652	0.271	0.573	0.279	0.244
1,832	0.280	0.589	0.284	0.248
2,012	0.289	0.605	0.288	0.252
2,192	0.298	0.621	0.292	0.256
2,372	0.307	0.637	0.297	0.260
2,552	0.315	0.652	0.301	0.264
2,732	0.324	0.668	0.305	0.267
2,912	0.333	0.684	0.310	0.271
3,092	0.342	0.700	0.314	0.275
3,272	0.351	0.716	0.318	0.279
3,452	0.360	0.732	0.323	0.282
3,632	0.368	0.748	0.327	0.286
3,812	0.377	0.764	0.331	0.290
3,992	0.385	0.780	0.336	0.294
4,172	0.394	0.796	0.340	0.298
4,352	0.403	0.812	0.344	0.301
4,532	0.412	0.828	0.349	0.305

TABLE VII.—SPECIFIC GRAVITY AND ABSOLUTE WEIGHT OF GASES

Gas	Formula	Molecular wt. 0 = 16	Weight of 1 liter in grams at 0°C. and 760 mm. pressure	Sp. gr. Air = 1	Wt. of 1 cu. ft. in lb. at 32°F. and 29.92 in. pressure
Acetylene	C_2H_2	26.016	1.1708	0.90561	0.07309
Air	....	....	1.2928	1.0000	0.08071
Aldehyde	C_2H_4O	44.032	1.9811	1.5324	0.12368
Ammonia	NH_2	17.034	0.7708	0.59623	0.04812
Alcohol, ethyl	C_2H_5OH	46.048	2.0862	1.6137	0.13024
Alcohol, amyl	$C_5H_{11}OH$	88.096	4.0696	3.1479	0.25406
Alcohol, methyl	CH_3OH	32.032	1.4483	1.1203	0.09042
Argon	Ar	39.88	1.7809	1.3776	0.11118
Arsine	AsH_3	77.984	3.4589	2.6755	0.21593
Benzene	C_6H_6	78.048	3.5821	2.7708	0.22362
Boron chloride	BCl_3	117.38	5.09	3.937	0.3177
Boron fluoride	BF_3	68.00	2.99	2.312	0.1867
Bromine	Br_2	159.84	7.1437	5.5258	0.44597
Butane	C_4H_{10}	58.08	2.65	2.050	0.1654
Cyanogen	C_2N_2	52.05	2.335	1.806	0.14577
Chlorine	Cl_2	70.92	3.222	2.4923	0.20114
Chlorine monoxide	Cl_2O	86.92	3.8820	3.0028	0.24235
Chlorine dioxide	ClO_2	67.96	3.0192	2.3354	0.18848
Carbon dioxide	CO_2	44.00	1.9768	1.5291	0.12341
Carbon monoxide	CO	28.00	1.2504	0.96720	0.07806
Carbonyl chloride	$COCl_2$	98.92	4.47	3.457	0.2791
Carbonyl sulphide	COS	60.07	2.721	2.1047	0.16987
Ethane	C_2H_6	30.048	1.3562	1.0496	0.08467
Ethylene	C_2H_4	28.032	1.2609	0.97532	0.07872
Fluorine	F_2	38.00	1.635	1.2647	0.1021
Helium	He	4.002	0.1782	0.1378	0.01112
Hydrobromic acid	HBr	80.928	3.50	2.707	0.2185
Hydrochloric acid	HCl	36.468	1.6392	1.26794	0.10233
Hydrofluoric acid	HF	20.008	0.9220	0.71318	0.05756
Hydriodic acid	HI	127.928	3.657	2.8287	0.22830
Hydrogen	H_2	2.016	0.08987	0.069516	0.005610
Hydrogen arsenide	AsH_3	77.984	3.4589	2.67755	0.21593
Hydrogen selenide	H_2Se	81.216	3.628	2.80639	0.22650
Hydrogen sulphide	H_2S	34.086	1.539	1.1904	0.07431
Hydrogen phosphide	PH_3	34.064	1.5293	1.18293	0.09547
Hydrogen telluride	H_2Te	129.516	5.80	4.486	0.3621
Hydrocyanic acid	HCN	27.018	1.226	0.9483	0.5920
Iodine	I_2	253.84	11.271	8.7183	0.70363
Krypton	Kr	82.92	3.708	2.8682	0.23148
Methane	CH_4	16.032	0.7168	0.55446	0.04475
Neon	Ne	20.0	0.9002	0.69634	0.05620
Methyl chloride	CH_3Cl	50.484	2.3045	1.78261	0.14387
Mercury	Hg	200.6	9.0210	6.97850	0.56317
Nitrogen	N_2	28.02	1.2057	0.93265	0.07527
Nitrous oxide	N_2O	44.02	1.9782	1.53021	0.12250
Nitric oxide	NO	30.01	1.3402	1.03669	0.08367
Nitrogen tetroxide	N_2O_4	92.02	4.1133	3.18178	0.25679
Nitrogen tetroxide	NO_2	46.01	2.0567	1.59092	0.12840
Nitrosyl chloride	NOCl	65.47	2.9253	2.26282	0.18262
Oxygen	O_2	32.00	1.4291	1.02803	0.08921
Phosphine	PH_3	34.064	1.5193	1.09788	0.90487
Phosphorus	P_4	124.16	5.6318	4.35639	0.35158
Propane	C_3H_8	44.064	1.9660	1.558	0.12273
Propylene	C_3H_6	42.048	1.8783	1.45293	0.11726
Silicon fluoride	SiF_4	104.3	4.6603	3.60490	0.29093
Sulphur dioxide	SO_2	64.07	2.9266	2.26390	0.18264
Xenon	Xe	130.2	5.851	3.7524	0.36527
Radium emanation	Nt	222.4	9.727	7.5241	0.60724
Water	H_2O	18.016	0.8063	0.6237	0.050336

TABLE VIII.—SCALE OF TEMPERATURES BY COLOR OF IRON

Dark red—hardly visible	970°F.	Orange	2,000°F
Dull red	1,300°F.	Yellow	2,150°F
Cherry—dark	1,450°F.	White heat	2,350°F
Cherry—red	1,650°F.	White welding	2,600°F
Cherry—light	1,800°F.	White—dazzling	2,400°F

TABLE IX.—THERMOMETRIC DEGREES
Centigrade and Fahrenheit
(Latta)

Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.
−40.0	−40	18.3	65	55.0	131	95.0	203	200.0	392
−34.4	−30	20.0	68	57.2	135	96.1	205	204.4	400
−30.0	−22	21.1	70	60.0	140	98.9	210	260.0	500
−28.9	−20	23.9	75	62.8	145	100.0	212	300.0	572
−23.3	−10	25.0	77	65.0	149	104.4	220	400.0	752
−20.0	− 4	26.7	80	65.6	150	110.0	230	500.0	932
−17.8	0	29.4	85	68.3	155	115.6	240	600.0	1,112
−12.2	10	30.0	86	70.0	158	120.0	248	700.0	1,292
−10.0	14	32.2	90	71.1	160	121.1	250	800.0	1,472
−6.7	20	35.0	95	73.9	165	126.7	260	900.0	1,652
−1.1	30	37.8	100	75.0	167	130.0	266	1,000.0	1,832
0	32	80.0	104	76.7	170	132.2	270	1,100.0	2,012
1.7	35	40.6	105	79.4	175	137.8	280	1,200.0	2,192
4.4	40	43.3	110	80.0	176	140.0	284	1,300.0	2,372
5.0	41	45.0	113	82.2	180	143.3	290	1,400.0	2,552
7.2	45	46.1	115	85.0	185	148.9	300	1,500.0	2,732
10.0	50	48.9	120	87.8	190	150.0	302	1,600.0	2,912
12.8	55	50.0	122	90.0	194	162.8	325		
15.0	59	51.7	125	90.6	195	175.0	347		
15.6	60	54.4	130	93.3	200	176.7	350		

TABLE X.—THE EQUIVALENT OF OUNCES PER SQUARE INCH PRESSURE IN INCHES OF WATER AND OF MERCURY

(Latta)

Ounces	In. of water	In. of merc.	Ounces	In. of water	In. of merc.
1	1.7	0.125	9	15.5	1.125
2	3.4	0.250	10	17.2	1.250
3	5.2	0.375	11	19.0	1.375
4	6.9	0.500	12	20.8	1.500
5	8.6	0.625	13	22.5	1.625
6	10.3	0.750	14	24.2	1.750
7	12.0	0.875	15	26.0	1.875
8	13.8	1.000	16	27.7	2.000

Table XI.—International Atomic Weights for 1905 of the More Usual Chemical Elements

		0 = 16	H = 1
Aluminum,	Al	27.1	26.9
Antimony,	Sb	120.2	118.3
Arsenic,	As	75.0	74.4
Barium,	Ba	137.4	136.4
Bismuth,	Bi	208.5	206.9
Boron,	B	11.0	10.9
Bromine,	Br	79.96	79.36
Cadmium,	Cd	112.4	111.6
Calcium,	Ca	40.1	39.7
Carbon,	C	12.0	11.91
Chlorine,	Cl	35.45	35.18
Chromium,	Cr	52.1	51.7
Cobalt,	Co	59.0	58.55
Copper,	Cu	63.6	63.1
Fluorine,	F	19.0	18.9
Gold,	Au	197.2	195.7
Hydrogen,	H	1.008	1.0
Iodine,	I	126.97	126.01
Iridium,	Ir	193.0	191.5
Iron,	Fe	55.9	55.5
Lead,	Pb	206.9	205.35
Lithium,	Li	7.03	6.98
Magnesium,	Mg	24.36	24.18
Manganese,	Mn	55.0	54.6
Mercury,	Hg	200.0	198.5
Molybdenum,	Mo	96.0	95.3
Nickel,	Ni	58.7	58.3
Nitrogen,	N	14.04	13.93
Oxygen,	O	16.0	15.88
Phosphorus,	P	31.0	30.77
Platinum,	Pt	194.8	193.3
Potassium,	K	39.15	38.85
Silicon,	Si	28.4	28.2
Silver,	Ag	107.93	107.11
Sodium,	Na	23.05	22.88
Strontium,	Sr	87.6	86.94
Sulphur,	S	32.06	31.32
Tin,	Sn	119.0	118.1
Titanium,	Ti	48.1	47.7
Tungsten,	S	184.0	182.6
Uranium,	U	238.5	236.7
Vanadium,	V	51.2	50.8
Zinc,	Zn	65.4	64.9

TABLE XII.—SPECIFIC GRAVITY CALCULATION

The following method of calculating specific gravities was developed by E. C. Jones: Multiply the per cent. of carbon dioxide by 22, add the C_2H_4 carbon monoxide and nitrogen together and multiply by 14, multiply the oxygen by 16, the hydrogen by 1, the methane by 8. Find the sum of all these products and divide by 14.43, which is the specific gravity of air as compared with hydrogen. This result divided by 100 gives the specific gravity of the gas when air is 1. The method is based on the relation between the constituent gases and hydrogen rather than on air and thus simplifies the calculation. The calculation is as follows:

Per cent.		Atomic weight		
CO_2	×	22	=	....
C_2H_4	..	..	..	....
CO	×	14	=	....
N_2	..	..	..	....
O	×	16	=	....
H	×	1	=	....
CH_4	×	8	=	....

Total......................................

Total ÷ 14.43 × 0.01 = specific gravity.

TABLE XIII.—WEIGHT OF CUBIC FOOT OF SATURATED GAS

60 Deg. F. 30″ Barometer

Gases	Lb. per cu. ft.
Carbon dioxide	0.1140
Carbon monoxide	0.0726
Ethylene	0.0726
Hydrogen	0.0052
Methane	0.0415
Nitrogen	0.0728
Oxygen	0.0830

TABLE XIV.—LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4013	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	56	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4952	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6374	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6335	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6676	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	6	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	6	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	6	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

TABLE XIV.—LOGARITHMS—(*Continued*)

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	4	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	4	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	4	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	4	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	3895	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	9733	9739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	3	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9579	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9949	9952	0	1	1	2	2	3	3	4	4
99	9967	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	4	4
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

Tabte XIV.—Numbers—(*Continued*)

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
0.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
0.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
0.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
0.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
0.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
0.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
0.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
0.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
0.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
0.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
0.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
0.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	3	3
0.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
0.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
0.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
0.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
0.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
0.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
0.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
0.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	2	3	3
0.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
0.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
0.22	1661	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
0.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
0.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
0.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
0.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
0.27	1862	1866	1871	1875	1879	1884	1888	1897	1897	1901	0	1	1	2	2	3	3	3	4
0.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
0.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
0.30	2995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
0.31	2042	2046	2051	2056	2061	2065	2071	2075	2080	2084	0	1	1	2	2	3	3	4	4
0.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
0.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
0.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	0	1	2	2	3	3	4	4	5
0.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
0.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	3	3	3	4	4	5
0.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
0.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
0.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
0.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
0.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
0.42	2630	2626	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
0.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
0.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
0.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
0.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
0.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
0.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
0.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

TABLE XIV.—NUMBERS—(*Continued*)

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
0.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
0.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
0.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
0.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
0.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
0.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
0.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
0.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
0.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3884	1	2	3	4	4	5	6	7	8
0.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
0.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
0.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
0.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
0.63	4266	4276	4285	4295	4305	4315	4325	4335	4335	4355	1	3	3	4	5	6	7	8	9
0.64	4366	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
0.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
0.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
0.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
0.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
0.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
0.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	10
0.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
0.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
0.73	5370	5383	5395	5408	5420	5433	5445	5438	5470	5483	1	3	4	5	6	8	9	10	11
0.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
0.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
0.76	5754	5768	5781	5694	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
0.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
0.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
0.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
0.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
0.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
0.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
0.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
0.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
0.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
0.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
0.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
0.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
0.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
0.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8101	2	4	6	7	9	11	13	15	17
0.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
0.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
0.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
0.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
0.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
0.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
0.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
0.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
0.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

TABLE XV.

A French calorie = 1 kg. of water heated 1°C. at or near 4°C.
A British thermal unit = 1 lb. of water heated 1°F. at or near 32°F.
A pound-calorie unit = 1 lb. of water heated 1°C. at or near 4°C.
1 French calorie = 3.968 B.t.u. = 2.2046 pound-calorie.
1 B.t.u. = 0.252 French calorie = 0.555 pound-calorie.
1 pound-calorie = 1.8 B.t.u. = 0.45 French calorie.
1 B.t.u. = 0.252 French calorie = 0.555 pound-calorie.
1 pound-calorie = 1.8 B.t.u. = 0.45 French calorie.
1 B.t.u. = 778 foot-pounds = Joule's mechanical equivalent of heat.

TABLE XVI.

Hydrogen (H).							
Equation............	$2H_2$	+	O_2	=	$2H_2O$		
Relation by volume...	(2 vols.)	+	(1 vol.)	=	(2 vols.)		
Relation by weight....	1	+	8	=	9		
Carbon Monoxide (CO).							
Equation............	$2CO$	+	O_2	=	$2CO_2$		
Relation by volume..	(2 vols.)	+	(1 vol.)	=	(2 vols.)		
Relation by weight....	7	+	4	=	11		
Ethylene, or Olefiant Gas (C_2H_4).							
Equation............	C_2H_4	+	$3O_2$	=	$2CO_2$	+	$2H_2O$
Relation by volume...	(1 vol.)	+	(3 vols.)	=	(2 vols.)	+	(2 vols.)
Relation by weight....	7	+	24	=	22	+	9
Methane, or Marsh Gas (CH_4).							
Equation............	CH_4	+	$2O_2$	=	CO_2	+	$2H_2O$
Relation by volume...	(1 vol.)	+	(2 vols.)	=	(1 vol.)	+	(2 vols.)
Relation by weight....	4	+	16	=	11	+	9

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