THE FLOW OF GASES

AND

PROPORTIONING GAS MAINS

Original Diagrams

WITH

EXPLANATORY NOTES, &c.,

BY

F. S. CRIPPS, Assoc.M.Inst.C.E.

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EXPLANATORY OF

FOUR DIAGRAMS

FOR SOLVING AT A GLANCE THE VARIOUS PROBLEMS INVOLVED IN

PROPORTIONING GAS MAINS AND SERVICES

TO SUIT THE VARYING CONDITIONS OF

DIAMETER, LENGTH, PRESSURE, SPECIFIC GRAVITY, AND DISCHARGE;

WITH NOTES AS TO ALLOWANCES TO BE MADE FOR

BENDS, BRANCH MAINS, AND OTHER DISTURBING INFLUENCES.

BY

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PREFACE.

IT was suggested to me a few years since, that a diagram giving at a glance the flow of gas through pipes of various sizes and lengths, under different pressures and other varying conditions, would be of great service to gas engineers generally.

Barlow's tables—which are simply tabulated results derived from the application of Dr. Pole's well-known formula to several examples—are very limited in range, and are scarcely reliable for pipes of small diameter. With a view, therefore, to correcting inaccuracies, and displaying on a much more comprehensive scale the several problems relating to the passage of gas through pipes, I have prepared the present work and the accompanying diagrams.

The diagrams may be termed *straight-lined* diagrams, as no complicated curves are employed. Hence, it is very easy to plot intermediate results, when such cases arise, or even to extend the diagrams if required. As now presented, all cases—from ¼ inch diameter up to 60 inches diameter; from 10 yards to 20 miles in length; from 1 tenth to 100 tenths pressure; from ·4 to ·7 specific gravity; and from 5 cubic feet to 1,000,000 cubic feet discharge per hour—are dealt with. Hence, by simple inspection of these diagrams, a large number of problems may be solved.

It was only after considerable thought and study that the mode of constructing diagrams to accomplish the ends I had in view dawned upon me. Many diagrams exist for other purposes—such as determining the carrying strength of beams, &c.; but all I have met with deal with *three* elements only—*i.e.*, given *two* to find a *third*. In this case, however, the problem presented unusual difficulty, as it consisted of *five* elements mutually depending on one another;

and involved the construction of a diagram in which if *any four* be given, the *fifth* can be seen at a glance. The difficulty was enhanced by having to determine the laws regulating the relative distances apart of the several lines forming the diagrams; and when discovered, they were tedious to handle. One of the great advantages of the diagrams is that it affords ready means of comparison; the influence and effect of varying the conditions being readily discerned. For instance, if any *three* elements be given, all the possible combinations of the remaining *two* are seen at a glance; and the most suitable pair can be selected at once.

The results given by Diagram No. 1 accord with actual experiments, made expressly for this purpose; and it will be found the results differ greatly from those given by Barlow's Tables. The Diagrams Nos. 2, 3, and 4 give results which exactly accord with Dr. Pole's formula. By working through the few examples given in the following pages, the mode of using the diagrams will be found extremely simple, and the scope and what may be termed suggestiveness of the diagrams easily appreciated.

F. S. CRIPPS.

SUTTON, SURREY,

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HOW TO USE THE DIAGRAMS.

The diagrams are numbered 1, 2, 3, and 4 respectively, having the following range :—

No. of Diagram.	Diameters in inches.	Lengths in yards.	Pressures in tenths.	Specific Gravity.	Volumes discharged per hour in cubic feet.
1	¼ to 6	10 to 1,000	1 to 40	·4 to ·7	0 to 11,500
2	2 to 14	10 to 5,000	1 to 100	·4 to ·7	0 to 69,500
3	6 to 29	20 to 15,000	1 to 100	·4 to ·7	0 to 250,000
4	12 to 60	50 to 35,000	1 to 100	·4 to ·7	0 to 1,000,000

The following examples will explain the working of Diagram No. 2 ; but the same process is applicable to all the four diagrams.

I.—To find the DISCHARGE—

given diameter	= 6 inches
,, length	= 3,500 yards
,, pressure	= 4 inches
,, specific gravity	= ·45

Pass along the horizontal line opposite 6 inches (diameter), until immediately under 3500 (yards length), then radiate down to *pressure* table; then radiate up until just below the given pressure (4 inches) ; now run across *horizontally* to *specific gravity* table ; then radiate up until under the given specific gravity (·45) which, it will be found, is on the horizontal line corresponding to a volume of *6000 cubic feet per hour*. This being the answer required.

II.—To find the maximum LENGTH OF MAIN—

given quantity		= 50,000 per hour
,,	specific gravity	= ·4
,,	pressure	= 5·1 inches
,,	diameter	= 12 inches

Pass along horizontal line opposite 50,000 discharge until under sp. gr. ·4; then along horizontal line in pressure diagram, till under the 5·1 inches pressure; now radiate *down* and then up until on the 12 inches diameter horizontal line. By glancing at the top of the diagram, it will be seen that the maximum length of pipe is 2305 yards, which is the required answer.

N.B.—In passing, it is well to note that the radial shows all the diameters of pipes and lengths which will convey this given quantity of gas of this specific gravity and pressure. They may be read off thus—

14 inch pipe,	5000	yds.	9 inch pipe,	540	yds.
13 ,,	3400	,,	8 ,,	300	,,
12 ,,	2300	,,	7 ,,	150	,,
(the above example)			6 ,,	75	,,
11 inch pipe,	1500	,,	5 ,,	30	,,
10 ,,	920	,,	4 ,,	10	,,

The above shows the immense advantage of the table in comparing the effect of varying diameters and lengths.

III.—To find the DIAMETER—

given quantity		= 36,000
,,	specific gravity	= ·5
,,	pressure	= 3·8
,,	length	= 350 yards

Pass along horizontal line opposite 36,000 discharge until under sp. gr. ·5; and radiate down to pressure table; then along horizontal line till under pressure 3·8; radiate down and then up the next diagram until under the given length (350 yards). It will be found to cut the line opposite 8 inches diameter, which is the answer required.

N.B.—If a greater or less *length* be given than in above example (the other conditions remaining the same) by radiating until under the desired length, the corresponding diameter can be seen at once. For example: 600 yds. requires a 9 inch pipe; 1100 yds., a 10 inch pipe; 1700 yds., an 11 inch pipe; 2600 yds., a 12 inch pipe; 3900 yds., a 13 inch pipe.; and so on.

IV.—To find the PRESSURE—

given diameter	= 12 inches
,, length	= 3,100 yards
,, discharge	= 17,000
,, specific gravity	= ·55

Pass along diameter line (12 inches) till under length (3100); then radiate down to pressure table and note the point; now follow the discharge (17,000) horizontally until under sp. gr. ·55; radiate down to pressure table, and then pass along horizontal line until it cuts the line radiating up from the point previously determined. In this case it will be immediately under 1·1 inches, which is the pressure sought.

N.B.—It will be seen at a glance that by increasing the pressure to, say, 2 inches for the same diameter and length of pipe, 23,000 cubic feet could be passed at the same specific gravity, or 27,000 at ·4 sp. gr.

By following the same *pressure* radial (up or down) corresponding to that diameter and length, the various discharges for the different pressures can be seen at once. Substituting ·4 sp. gr. for the ·55 in the above example: For 3 inch pressure, 33,000 will pass; for 4 inch pressure, 38,000; 5 inch pressure, 42,500; 6 inch pressure, 46,500; 7 inch pressure, 50,200; 8 inch pressure, 52,800; 9 inch pressure, 57,000; and for 10 inch pressure, 60,000; or, going back to ·1 pressure, 6000 will pass, and so on.

V.—SPECIFIC GRAVITY—

From this part of the diagram, the different discharges for various specific gravities of gas can be seen. For instance: 65,000 cubic feet at ·4 sp. gr. is reduced to 60,000 at ·47 sp. gr.; 58,000 at ·5 sp. gr.; 55,000 at ·56 sp. gr.;

53,000 at ·6 sp. gr.; 51,000 at ·65 sp. gr.; and 49,000 at ·7 sp. gr. Again, 15,000 at ·7 sp. gr. is increased to 20,000 at ·4 sp. gr., the other conditions being equal.

VI.—To find the PRESSURE AT ANY GIVEN POINT in a long stretch of main. For example: A pipe 10 inches diameter 5000 yards long discharges 30,000 cubic feet per hour under an initial pressure of 10 inches, the pressure at the outlet end being *nil.* What would be the pressure at a point 1300 yards from the inlet end?

Find the pressure required to force the same quantity of gas through the last part of the pipe, or 3700 yards. This, from the diagram, is seen at once to be 7·4 inches, which is the pressure of the gas at a point in the main 1300 yards from the inlet end.

The pressure at a point half way along the length, or 2500 yards from the end, is found from the diagram to be 5 inches. This, of course, accords with the law that the pressure required varies exactly as the length of the pipe.

EXPLANATORY NOTES.

A few words may be necessary to explain the long horizontal lines at the foot of the diagrams. In case a *radial* strikes the *bottom* of the diagram, instead of the side of the adjoining section, follow the lead of the lettered line at foot. A in "pressure" diagram corresponds or leads into A "in diameter-length" diagram, B to B, C to C, and so on.

It must be borne in mind that the pressure given by the *diagram* is the *difference* between the pressure at the inlet and outlet ends of the pipe. Hence, if the gas is to be discharged with a given terminal or outlet pressure, the diagram must be used as if the only pressure required was that to just drive the given quantity of gas out at the other end at *no* pressure. The fixed terminal pressure must then be added to the pressure thus found. For example: If a certain pipe will pass a certain quantity at 6 inches pressure at the inlet but no pressure at the outlet end, and it is required to have a 3 inch terminal pressure, the inlet pressure must be increased by 3 inches, making it 9 inches.

By the aid of these diagrams, more problems may be solved in one day than could be calculated in many months by working the usual formulæ. A few trials will demonstrate the facility with which results may be obtained.

The accuracy of the diagrams may be proved by comparing the results obtained by Barlow's Tables as far as they reach, or by working out the formulæ which, for convenience of reference, are given on page 15.

CORRECTION FOR CURVES, BENDS, &c.

The resistance offered by bends is influenced by the velocity with which the gas passes through the pipe. The greater the velocity, the greater is the resistance caused by friction of the gas against the bend turning it out of its straight course.

The sharpness of the bend—*i.e.*, whether its radius of curvature bears a small or large proportion relatively to the diameter of the pipe, and whether it be what is termed a "quarter" or an "eighth" bend or any other part of a circle—likewise affects the result.

Formulæ embodying the influences of the shape of the bend are necessarily very unwieldy; so much so as to be much too troublesome to use in ordinary practice. Hence, in what follows, a standard type of bend has been taken, having a radius of about 2½ times the diameter. The results given are for *quarter* bends. Therefore if any other kinds are to be allowed for, they may by judgment be reduced to as many quarter bends as are considered to about equal them in effect; or corrections may be made as given hereafter in paragraph IV.

I. To find the resistance (in inches of water) caused by the introduction of *one* quarter bend in a straight run of pipe :—

(*a*) Determine the velocity of gas in feet per second, V:—Take from the diagram the *quantity* of gas discharged per hour from the straight pipe, and divide it by 20 times the diameter (d) of the pipe (in inches) squared.

$$(1) \quad \text{or, } \frac{Q}{20\, d^2} = V.$$

(*b*) Square the velocity of gas (in feet per second) and divide by the constant 10,700. The quotient will be the back pressure (p) caused by the bend,

$$(2) \quad \text{or,} \quad \frac{V^2}{10{,}700} = p.$$

Then p is the pressure to be added to the original initial pressure of gas if the quantity of gas passing is not to be reduced.

To save unnecessary work, the following table will be found very useful :—

Velocity of Gas in feet per second. (V.)	Back pressure caused by 1 bend (in inches).	Velocity of Gas in feet per second. (V.)	Back pressure caused by 1 bend (in inches).	Velocity of Gas in feet per second. (V.)	Back pressure caused by 1 bend (in inches).
4	·0015	20	·0374	36	·121
5	·00234	21	·0412	37	·128
6	·00336	22	·0452	38	·135
7	·00458	23	·0494	39	·142
8	·00598	24	·0538	40	·149
9	·00757	25	·0584	41	·157
10	·00934	26	·0632	42	·165
11	·0113	27	·0681	43	·173
12	·0135	28	·0733	44	·181
13	·0158	29	·0786	45	·189
14	·0183	30	·0841	46	·197
15	·0210	31	·0898	47	·206
16	·0239	32	·0957	48	·215
17	·027	33	·102	49	·224
18	·0303	34	·108	50	·233
19	·0337	35	·114	51	·242

After finding V by formula (1), the resistance caused by the bend will be found opposite the nearest velocity in the table. This pressure must be added to the initial pressure, as before stated, if the same quantity of gas is to pass through the pipe after introducing the bend.

The following example will make the above clear :—

A straight pipe 20 inches diameter, 6500 yards long, passes 150,000 cubic feet of gas at ·4 sp. gr. at 10 inches pressure. How much must the pressure be increased to allow for *one* quarter bend ?

$$\frac{150{,}000}{20 \times 20^2} = V = 18{\cdot}75$$

Opposite the nearest velocity (19) in the table we find ·0337, which is the pressure in inches required. The total pressure will then be 10·0337 inches.

If the initial pressure be not increased, the discharge is necessarily reduced.

II. To find the *reduced* volume of gas *discharged* due to *one* bend :—

Subtract p (the bend resistance) from P (the original pressure). Then take from the diagram the quantity of gas discharged due to this reduced pressure, the other conditions as before.

If greater accuracy be desired (the discharge being sometimes reduced by such an insignificant amount that it is scarcely appreciable on the diagram) it may be found by the use of the following formula :—

$$(4) \quad \frac{Q \times \sqrt{P - p}}{\sqrt{P}} = Q_1.$$

where Q = the original discharge.
P = the original pressure.
p = the back pressure caused by bend.
Q_1 = the reduced discharge due to bend.

Applying this formula to the forgoing example, we have

$$\frac{150{,}000 \times \sqrt{9{\cdot}9663}}{\sqrt{10}} = 149{,}744$$

or a reduction of 256 cubic feet per hour due to *one* bend.

III. To obtain the pressure necessary to overcome the resistance of a *succession of bends* in the same pipe: Multiply the pressure for *one* bend by the number of bends, the product will be the pressure to be added for overcoming the resistance of all of them.

This is only approximately correct, as it does not quite agree with experiment.

If greater accuracy be required, it may be arrived at thus—

(5) $\frac{Q}{Q_1} = R$ the *common ratio* between the volumes passed by a succession of bends. Then to find the reduced volume due to say n number of bends:

$$(6) \quad \frac{Q}{R^n} = \text{the reduced discharge,}$$

or, the discharge for straight pipe, divided by the common ratio raised to the power corresponding with the number of bends = the discharge required.

Applying this to the above example,

$$R = \frac{150{,}000}{149{,}744} = 1\cdot0017$$

For 100 bends the reduced discharge will then be:

$$\frac{150{,}000}{1\cdot0017^{100}} = 126{,}704 \text{ cubic feet.}$$

or a total reduction of *23,296* cubic feet, corresponding to a reduction in pressure of about 3 inches by the diagram.

Therefore in the above example for 100 bends, to pass the same quantity of gas as through the straight pipe, the pressure should be increased 3 inches; otherwise the quantity discharged is reduced from 150,000 to 126,704.

IV. As a rough approximation, the relative resistances offered by bends of different proportions may be taken as follows:—

Where the radius of a quarter bend equals the diameter of the pipe, the resistance is *double* of that determined by the foregoing rules.

For a radius three-quarters of the diameter, the resistance is *4 times;* for a sharp corner (*i.e.* radius of bend = half the diameter) it is *14 times;* and for the right-angle branch of a tee pipe drawing from a trunk main, *20 times.*

None of the above formulæ, &c., are absolutely correct; but they are sufficiently accurate for all practical purposes.

Absolute accuracy is unattainable on account of the corrosion and other disturbing influences to which the pipes are subject—all more or less of an accidental character. Hence it has been deemed desirable to give practical rules simple and easy, and which approximate very closely to results obtained from actual experiments made expressly for the purpose, rather than mere theoretical complications useless on account of their unwieldiness.

CORRECTION FOR GRADIENT.

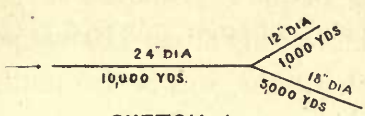
The ordinary rule applies for making corrections to the natural rise and fall of pressure due to varying altitudes—viz., to maintain a standard outlet pressure, *add* one-tenth to the initial or inlet pressure for every ten feet *descent* below the horizontal, and *vice versâ.* Or, in other words, if the gas-main *rises* 10 feet, *deduct* one-tenth from the initial pressure; if it *falls* 10 feet, *add* one-tenth, in order that the outlet pressure may remain constant.

The following question may arise: The length, diameter, and inlet pressure being given, how much must be deducted from the volume as obtained from the diagram if the pipe descends or rises any given number of feet? By diagram, the quantity of gas that can be discharged through a 27-inch diameter *horizontal* pipe, 13,000 yards long, at 20 tenths pressure, is 100,000 cubic feet per hour. What will be the corrected volume due to a *net* rise or fall of 110 feet? Adding 1 tenth for every 10 feet rise, makes the pressure 20 + 11 = 31 tenths, which from the diagram gives 125,000 feet as the corrected quantity in the first case. Whereas, deducting 11 tenths = 9 tenths, gives by diagram 67,500 cubic feet for the second case.

N.B.—By "*net* rise or fall" is meant the difference in level of the inlet and outlet ends of the main.

EFFECT OF BRANCH-PIPES.

It is obvious that the effect of taking off branch mains from the trunk main, is to reduce the quantity of gas left in the trunk to flow on towards its extremity; and, as a consequence, the remaining gas suffers a reduction in pressure. It will be convenient to examine the subject by treating of simple examples, and advancing gradually to more complex ones.



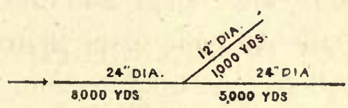
SKETCH 1.

(1) A simple case is that in which the pipe branches into two. Suppose a 24-inch pipe to branch into an 18 inch and a 12 inch (see sketch 1).

Assume the outlets are fully open. Assume also for the 12-inch pipe an initial pressure of 31 tenths, then 60,000 cubic feet of gas per hour will pass. The 18-inch pipe at the same pressure will pass 72,500 feet, or a total quantity of 132,500 feet to be passed through the 24-inch pipe, which requires, therefore, 47 tenths (see Diagram 3) just to pass the gas. To this add the pressure where the pipe divides—viz., 31 tenths—making a total initial pressure required of 78 tenths. If, however, the terminal pressure at each outlet is to be 20 tenths, the initial pressure must be increased to 98 tenths, or practically 10 inches.

(2) Supposing, in the above example, less gas is required to be delivered by the 18-inch than by the 12-inch branch, how will this affect the initial pressure required? At the branching point, it must still be 31 tenths in order to pass the 60,000 feet through the 12-inch pipe. Hence the outlet of the 18-inch pipe must

be closed sufficiently to prevent more than the desired quantity of gas passing—say, 30,000 cubic feet. The total quantity passing along the 24-inch pipe will therefore be 90,000 cubic feet. From the diagram, we see that 90,000 feet only requires 22 tenths instead of 47 tenths. Hence, the total initial pressure required is 53 tenths, as against 78 tenths in the former case.

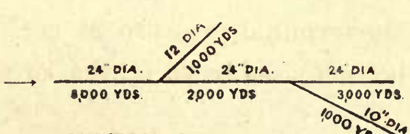


SKETCH 2.

(3) Now take the case of a 24-inch pipe with 12-inch branch, as sketch 2. The 12-inch pipe will deliver 60,000 cubic feet of gas at a pressure of 31 tenths, as before. But assuming the resistance offered by the Y piece as equivalent to one right-angle bend (having radius = ¾ diameter), the pressure obtained from the table corresponding to the velocity of gas (20 feet per second) = *·0374*, which, after allowing for the extra sharpness, will be 1·5 tenths.

If, therefore, it is required to pass the whole of the 60,000 cubic feet of gas as before, the pressure must be increased from 31 tenths to 32·5 tenths to overcome the effect of the Y piece. Now, if the 24-inch pipe is *fully* open, 154,000 feet will be discharged from it at 32·5 tenths pressure. The total quantity passing through the first 8000 yards of 24-inch pipe is, therefore, 154,000 + 60,000 = 214,000 cubic feet. This demands a pressure of 101·5 tenths, to which must be added the 32·5 tenths, giving an initial inlet pressure of 134 tenths.

N.B.—These pressures would be excessive for ordinary working; they are simply adopted to show the range of the diagrams.



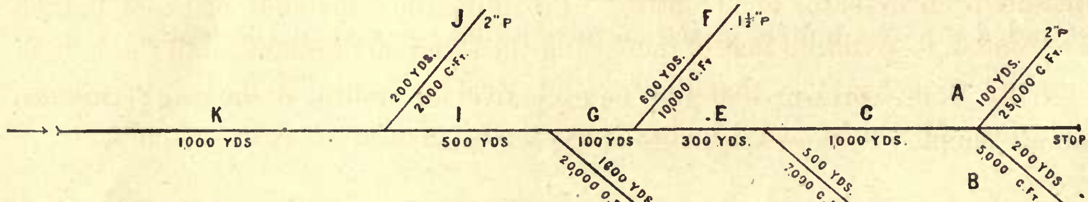
SKETCH 3.

(4) As a step further in advance, it will now be supposed that the latter part of the 24-inch pipe in the above example again branches out, as shown by sketch 3. The effect of tapping the main at this second position is to cause a

diminution of pressure, if the same quantity of gas passes through the system of pipes. Thirteen tenths (see diagram) is sufficient to drive the gas from the first to the second Y piece (2000 yards); so that the pressure just at the second Y piece would be 32·5 – 13 = 19·5 tenths. 154,000 cubic feet of gas at a pressure of 19·5 tenths is to be split up into two streams—one going along the 24-inch main 3000 yards long, and the other along the 10-inch main 1000 yards long. If the 10-inch main is to pass its full quantity—viz., 30,000 feet, 154,000 – 30,000 = 124,000 feet only will be left for the 24-inch main. This 24-inch main will, under 19·5 tenths pressure, pass 154,000 feet when fully open. Hence it must be partly closed at the outlet, if the maximum supply is to be maintained through the 10-inch branch. If the 10 inch and 24 inch mains are fully open, it is obvious the gas would flow out with less resistance; and the pressure at the first branch would be reduced, so that the maximum supply could not be got through it. Hence the necessity of reducing the gas passage at the final outlet, if the full supply is to be kept up through the branches.

In the foregoing cases no notice has been taken of terminal or outlet pressures; they have been taken as *nil.*

The following example is of a much more general and comprehensive character:—



SKETCH 4.

(5) It is required to determine the *sizes of the pipes* in the system shown by sketch 4, which, it will be seen, consists of a trunk main having several branches of various lengths at various distances apart. Each branch pipe to be so proportioned as to yield a given pressure at its extremity or outlet end.

To simplify the matter, the pipes will be considered as horizontal throughout, and the influence of bends disregarded. It is best to commence at the extremity and work backwards; filling in by reference to the diagrams thus :—

Ref. letter.	Volume (cubic feet).	Length (in yards).	Diameter Required (in inches).	Frictional Resistance.		Terminal Pressure.	Total Initial Pressure.
A.	25,000	100	**8**	5	+	20	=25 tenths.
B.	5,000	200	**4**	(25−10)=15	+	10	=25 ,,
C.	30,000	1000	**16**	2	+	25	=27 ,,
D.	7,000	500	**5½**	(27−15)=12	+	15	=27 ,,
E.	37,000	300	**16**	1	+	27	=28 ,,
F.	10,000	600	**7**	(28−15)=13	+	15	=28 ,,
G.	47,000	100	**16**	1	+	28	=29 ,,
H.	20,000	1600	**10**	(29−15)=14	+	15	=29 ,,
I.	67,000	500	**16**	4	+	29	=33 ,,
J.	2,000	200	**3**	(33−20)=13	+	20	=33 ,,
K.	69,000	1000	**16**	10	+	33	=**43** ,,
Or if K be increased to **18**-inch, resistance reduced to				6	+	33	=**39** ,,

So that the initial pressure will be either 43 tenths or 39 tenths, according to whether K is made 16 inches or 18 inches diameter.

It may be asked, what would be the effect of increasing the main inlet pressure from 43 tenths to 63 tenths? Providing the consumption at each branch is as stated, it would be that of increasing the terminal pressure in all the branch pipes by 2 inches; so that they would read 4 inches, 3 inches, 3½ inches, 3½ inches, 3½ inches, and 4 inches respectively, instead of as in sketch 4.

From the foregoing examples, it will be seen that, by the aid of the diagrams, difficult and complicated questions may be solved with comparative ease and in an expeditious manner. It would be tedious, however, to attempt to proportion every pipe throughout a large district to the exact theoretical requirements—especially when the branches and services are very numerous and of insignificant dimensions. In such cases, by exercising a little judgment, the pipes may be grouped together in sections, and the approximate quantity of gas demanded by each group assumed to be given off at what may be termed their mean points in the trunk main.

In new districts, where entirely new mains are required, much may be done by treating the matter scientifically. On the other hand, in many towns where the mains have been laid almost without any regard to system, or where circumstances have been such as to upset all rules of proportion, much difficulty necessarily arises in endeavouring to reduce the complications to any rule. Experience, experiment, and the "rule of thumb" are then chiefly relied upon for solving the difficulties respecting pressure and supply which constantly arise. Mr. George Livesey in writing to me on this subject makes the following remarks:

In our case [South Metropolitan Gas Company] we have a number of leading mains all connected and all tapped for services, as well as having branches at every street, which branches are all connected through to some other mains. It is, therefore, a matter of impossibility to ascertain what quantity of gas flows through any particular main, or what quantity ought to flow through it. I have, therefore, never been able to use any rules or tables; being governed entirely by the pressures. When the supply in any district becomes deficient, and we have to put on an excessive pressure, we simply trace the pressures along the line of main, find where the falling off takes place, and then relay with larger mains, or increase the supply by another route. I must, however, say that, for many purposes, your most simple and perfect tables will be exceedingly useful. For instance, in the case of trunk mains conveying gas from a manufacturing station to a gasholder, or from the works to a distant point in the district, and particularly for mains and connections in the works, a ready means of ascertaining the quantity of gas that will flow at a given pressure through a given length and diameter of main will be invaluable, particularly as the information can be obtained by simply looking at the diagrams which you have so cleverly compiled. These diagrams are the charm of the work, as they save no end of trouble; and not only that, but at the same time ensure correctness. Although, as I have said, I doubt whether your diagrams can be generally used in relation to the supply of gas through the complicated system of mains in such a district as ours, I am sure that every gas manager will find them exceedingly useful for a great number of purposes in his works, and to some extent in his district. I cannot, therefore, but express the hope that the demand will be so general as to recompense you for the labour and skill you have expended upon the work.

FORMULÆ AND NOTES ON SAME.

The general formula was compiled by Dr. Pole, F.R.SS.L.&E., in his masterly demonstration of the laws governing the "Motion of Fluids in Pipes"*

$$\text{It is } V = 1350d^2\sqrt{\frac{p\,d}{s\,l}}$$

where 1350 is a constant derived from experiment.
d = diameter of pipe in inches.
p = pressure in inches of water.
s = specific gravity of gas. Air being 1.
l = length of pipe in yards.
v = discharge in cubic feet per hour.

By transposition we get the following :

$$d = \sqrt[5]{\frac{V^2 s\,l}{(1350)^2 p}}; \qquad p = \frac{V^2 s\,l}{(1350)^2 d^5}$$

$$s = \frac{(1350)^2 d^5 p}{V^2 l}; \qquad l = \frac{(1350)^2 d^5 p}{V^2 s}$$

To these formulæ may be added the following :

V varies directly as $\sqrt{p}$
" " " " $\sqrt{d^5}$
" " inversely " $\sqrt{l}$
" " " " $\sqrt{s}$

(1) The discharge of gas is *doubled* by the application of four times the pressure.

(2) If the *length* be increased four times, the discharge is *halved.*

(3) If the *length* be decreased to one-fourth, the discharge is *doubled.*

(4) If the diameter be increased fourfold, the discharge will be increased 32 *times.*

(5) If the length be increased four times, four times the pressure is required to pass the same quantity of gas.

(6) From (5) it is evident the pressure required to pass a given quantity of gas varies exactly as the length of the pipe.

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* See "King's Treatise on Coal Gas," where it is to be found *in extenso.* This somewhat difficult investigation is handled by Dr. Pole in such a clear and methodical manner that what is otherwise abstruse is made to appear extremely simple.

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