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UNITED STATES DEPARTMENT OF AGRICULTURE
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Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief

Washington, D. C.

January 9, 1919

THE ECONOMICAL USE OF FUEL IN
MILK PLANTS AND CREAMERIES

By

JOHN T. BOWEN, Technologist, Dairy Division

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IMPORTANCE OF REDUCING WASTE.

The rapid increase in the cost of fuel and the probability that the present high price will continue makes the efficient use of fuel in commercial plants a question of the greatest importance. In the production of steam power, even in the most up-to-date plants, fuel is by far the largest item of expense. The boiler room, consequently, is the most important part of the plant so far as the cost of production of power is concerned and therefore should receive careful attention.

It should be the aim of every person in charge of a power plant to obtain the greatest efficiency possible, which means the elimination of waste—waste of fuel and material, waste of energy, and waste of time and effort. In order to determine the source and the amount of loss it is necessary to keep records and make tests, and then one must devise means to eliminate the losses or reduce them to a minimum. After determining the total of the various losses the question is whether or not it will pay to correct them. The limit to the capital and labor that should be expended in making changes and repairs is the point where the interest on the money invested in material, labor, repairs, and depreciation balances the saving in operation expense. Beyond that point it is commercially not good policy to go.

COMPARISON OF FUEL CONSUMPTION IN DIFFERENT CREAMERIES.

Although several hundred creameries were reporting regularly to the Dairy Division, it was considered advisable to make a personal inspection of many of them to observe the condition of the machinery and the method of operation and also, so far as possible, to verify the reports submitted. Visits were made, therefore, to 360 creameries and special reports were made on the quantity of butter made, the kind and amount of fuel, the size and type of boiler and its condition and method of firing, the size and condition of the engine, the condition of the piping as well as of all the apparatus using steam, and the operation of the plant in general.¹

Only 206 of the plants inspected used steam exclusively for both power and heating. Some used combinations of steam and electricity or of steam and internal-combustion engines, while a considerable number were operating mechanical refrigerating equipment. Many of the creameries also carried on various side lines which necessitated the use of power and fuel, and it was found impossible to determine how much was used for buttermaking and how much for other purposes. Consequently only the 206 plants which used steam exclusively for both power and heating are considered.

The creameries visited represent all sizes from the smallest to the largest and in order to compare the fuel consumed for the different-sized plants they were grouped as indicated in Table 1.

Before deciding, however, to use only those creameries covered by special reports in averaging the fuel consumption of different-sized plants, the items of the fuel consumption of a large number of other creameries reporting regularly were tabulated and studied. As the averages thus obtained were very close to those shown in the special reports, it was decided to use only the latter as representative of the creameries throughout the United States.

Table 1 shows a comparison of the fuel consumed per 1,000 pounds of butter made for different-sized creameries.

TABLE 1.—Comparison of fuel used per 1,000 pounds of butter made in creameries grouped according to size.

Quantity of butter made annually.	Creameries reporting.	Average quantity of coal used.		Coal consumed per 1,000 pounds of butter made.
		Number.	Tons.		Pounds.
45,000 to 100,000 pounds.....	39	55	1,540	
100,000 to 200,000 pounds.....	82	81	1,120	
200,000 to 300,000 pounds.....	48	100	800	
300,000 to 400,000 pounds.....	19	123	740	
400,000 to 1,000,000 pounds.....	18	145	526	

¹ The creameries were visited and the data collected by O. A. Storvick and the tabulations were made by T. R. Pirtle, both of the Dairy Division.

The results shown in Table 1 have been plotted in the form of curves in figure 1. Curve No. 1 represents the average number of pounds of coal consumed per 1,000 pounds of butter made in 206 plants whose outputs vary from 45,000 to 1,000,000 pounds of butter. Curve No. 2 represents the average of the number of pounds of coal of 72 of the best equipped and managed plants, and curve No. 3 the average of 37 of the poorest equipped and managed plants. These curves are plotted from the average fuel consumption of the total number of plants.

Attention is called to the fact that in curves 1 and 2 very little difference is shown between the groups of creameries making 250,000 pounds and those making 350,000 pounds of butter annually. Curve 2, representing the best practice, is practically vertical between 250,000 and 350,000 pounds of butter made, showing that between those limits the fuel consumed in the better plants is practically the same per 1,000 pounds of butter made. Curve 1, which shows the average full consump-

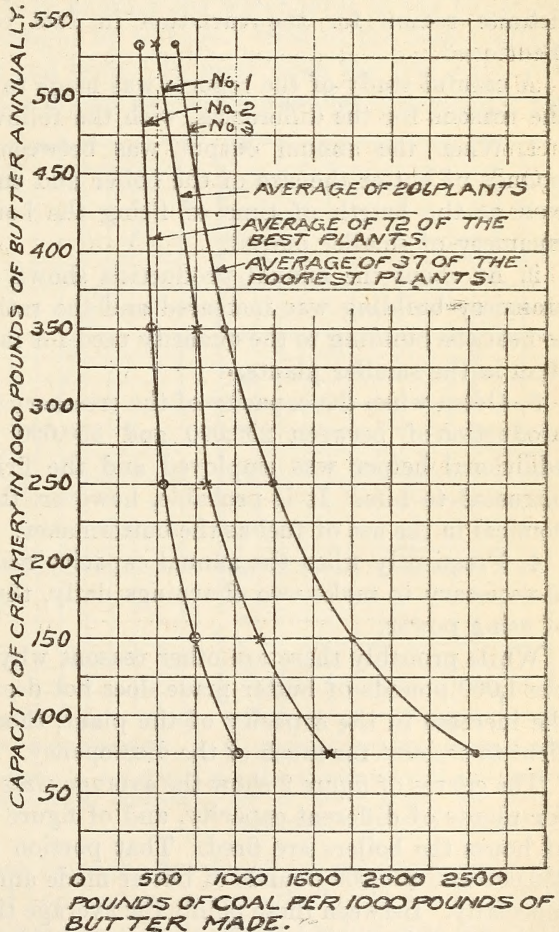


FIG. 1.—Curves showing the variation in coal used for 1,000 pounds of butter made in steam-driven plants of different sizes—(nonpasteurizing plants).

tion of all the creameries, gives only a slight increase in the quantity of fuel between creameries of those sizes. The poorer equipped and managed plants, as illustrated in curve 3, however, show a decided increase in fuel used per 1,000 pounds of butter made in the plants making between 250,000 and 350,000 pounds, the increase averaging about 300 pounds of coal per 1,000 pounds of butter. In

other words, the average of all plants, both good and bad, between these limits shows a variation of about 87 pounds of coal per 1,000 pounds of butter, while the poorer plants show a variation of about 261 pounds. The better plants, however, show practically no variation in the fuel used per 1,000 pounds between plants of that size.

The same condition appears in similar curves plotted from data obtained on fuel consumption in other years; hence there must be a definite reason for the variation in fuel cost in the creameries mentioned.

A careful study of the reports was made to determine, if possible, the reasons for the differences, with the following conclusions:

1. When the annual output was between 250,000 and 350,000 pounds of butter the size of the boiler and engine was increased, as well as the length of time of firing the boiler, compared with a creamery of smaller output.

2. At about the annual production shown above, the size of the creamery building was increased and the ratio of the coal required to heat the building to the quantity used for making butter is greater than in the smaller plants.

3. Often when the capacity of the creamery had reached an annual production of between 250,000 and 350,000 pounds of butter an additional helper was employed and the firing of the boiler was intrusted to him. It is probable, however, that he was not so economical in the use of fuel as the buttermaker.

4. Frequently when the annual capacity reaches 250,000 pounds it is necessary to make two churnings daily, thus increasing the time of using power.

While probably there are other reasons why the fuel consumption per 1,000 pounds of butter made does not decrease in proportion to the increase in the capacity of the plant, those mentioned are sufficient to account for much of the discrepancy.

The curves of figure 2 show the average sizes of engines and boilers for plants of different capacity, and of figure 3 the average number of hours the boilers are fired. That portion of the curves between 250,000 and 350,000 pounds of butter made annually should be noted especially. Between these points the average time of firing the boiler is increased from 7.3 to 8.5 hours, or 1.2 hours daily. There is practically no difference in the size of the boiler or the engine, or in the length of time the boiler is fired, between plants where 150,000 and 250,000 pounds of butter was made. In creameries below 150,000 pounds' capacity, however, both the size of the equipment and the time of firing decrease. Above 350,000 pounds' capacity the size of the equipment and the total time of firing increases, but at a less rate than in the smaller plants.

DEFECTS NOTED.

It is impossible to operate a creamery with any degree of economy if the equipment is not in good order. Some of the creameries had new engines and boilers and were keeping them in fairly good condition, but in by far the greater number the equipment was in very bad condition. For example, in one plant all the water leaked out of the boiler overnight, while in another the water level in the boiler was lowered 30 inches overnight by leakage. Most of the boiler settings were poorly designed and built. In most cases the side walls were only about 13 inches thick, and the result was that the settings were

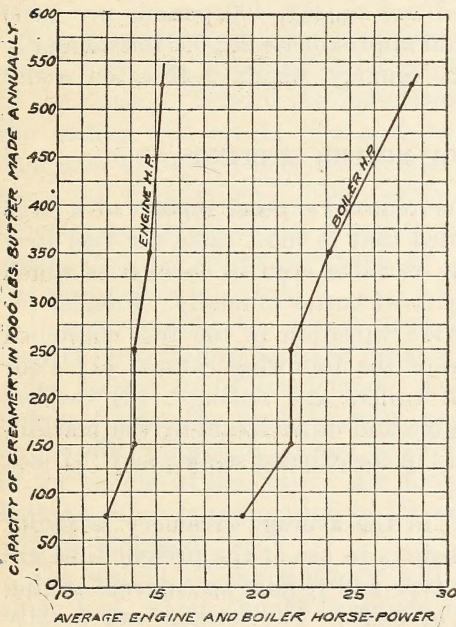


FIG. 2.—Curves showing variation in size of engines and boilers in creameries of different capacities.

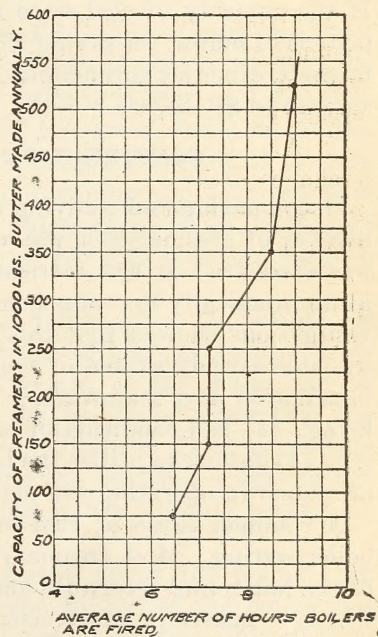


FIG. 3.—Curves showing average number of hours boilers are fired in creameries of different capacities.

full of cracks. In many cases the fire doors, ash-pit doors, and clean-out doors were warped and broken, as were the boiler fronts, and the return-tubular boilers were practically all set too low over the grates. The breechings in many instances were not tight, were too small, and often had right-angle bends. In more than one instance the breeching where it entered the stack was lower than the first bend above the boiler.

One of the greatest losses in fuel was caused by careless firing. The boiler in most cases was fired by the buttermaker or one of his assistants, and in order to lose as little time as possible from other work the fire box was filled with coal and left for from a half to

three-quarters of an hour, with the result that the combustible gases in the coal were distilled and escaped unconsumed up the chimney. Finally, holes were burned in the fire bed so that too much air was allowed to pass through, which cooled the boiler and setting and also carried a large part of the heat up the stack.

The average quantity of coal per 1,000 pounds of butter made of all creameries studied was 1,140 pounds, though many of them produced 1,000 pounds of butter with a fuel consumption considerably less than 400 pounds.

The total quantity of factory-made butter in the United States, as reported by the Thirteenth Census (1910), was 627,145,865 pounds. If the quantity of coal were reduced to, say, 400 pounds per 1,000 pounds of butter, the saving would approximate 232,000 tons annually in the creameries throughout the country, which at \$5 a ton would amount to \$1,160,000.

CONSTRUCTION OF BOILER SETTINGS.

In comparing and studying the itemized expense reports of a large number of creameries it was noted that in most cases the fuel item was excessive. It was extremely variable even in creameries which made practically the same quantity of butter annually. Further investigations showed that this wide variation in the fuel consumed was due largely to one or more of the following causes: (1) Poor installation and maintenance of boilers and settings; (2) careless firing; (3) bad condition of engine and other steam-driven machinery; (4) failure to utilize the heat in the exhaust steam; and (5) lack of system in operating the plant.

A common cause of fuel loss in the average creamery is faulty boiler setting. Most creamery boilers in use at the present time are of the horizontal return-tubular type and require an external setting which is generally constructed of brick. The settings are usually built by local workmen who have had little or no experience in boiler work; hence the construction is nearly always too light and flimsy to withstand the heat and the weight of the boiler and contained water. As a result the settings crack from the heat and weight and thus allow too much air to enter the furnace. This reduces the draft and also causes a direct heat loss, due to the heating of excess air.

Warped and cracked firing doors also contribute to the heat loss by admitting more air into the furnace than is required for complete combustion. The economical burning of fuel requires not only the proper arrangement and proportioning of the furnace, combustion chamber, uptakes, breeching, and chimney, but also that they be practically air-tight. To burn fuel completely a definite quantity of air is required, which must be admitted at the proper place and time and be mixed thoroughly with the combustible gases.

LOCATION OF SETTING.

In placing the boiler it is very important to leave ample space between the sides and ends of the setting and the walls of the room in order that expansion, contraction, or the possible settling of the foundations may not affect the building, and to allow room for inspection, painting, and repairs. In order to avoid long lengths of pipe the boiler should be placed as near the engine as possible, but it is not advisable to have both in the same room, as the dust from the coal and ashes will get into and injure the engine bearings.

FOUNDATIONS.

The foundation of a boiler setting should receive careful consideration, for upon it depends to a great extent the structural strength of the setting. Should the foundation settle it is very probable that the setting will crack. On account of the great variation in the character of the soil it is not practicable to set a standard of proportions for foundations; consequently in planning the foundation it becomes to a great extent a matter of judgment as to its depth and area. It is far better, however, to be on the safe side and have it too strong than too weak.

In determining the proportions for foundations the weight or load to be sustained and the bearing value of the soil are the principal factors to be considered. The weight of the boiler can be obtained from the manufacturer, and the weight of water that the boiler will contain in normal working condition is about two-thirds of the weight of the boiler. By doubling the shipping weight of the boiler a safe approximation of its weight under working conditions will be obtained.

The weight of the masonry will average about 145 pounds per cubic foot, which should be added to the weight of the boiler and contained water to get the total weight per square foot of surface to be sustained by the soil.

The foundation should be so proportioned as to distribute the weight over a surface so great that the bearing values will not exceed a safe load for the particular soil in question, and to provide a suitable table to take the load. The foundation may be of concrete, brick, or stone. When of concrete the mixture should be in the proportion of 1 part Portland cement to 3 parts clean, sharp sand and 5 parts broken stone or clean, coarse gravel, all to be thoroughly mixed and well tamped into place. When of brick, only the best hard brick should be used, laid in Portland-cement mortar with the joints entirely filled. The bottom course should be laid in a bed of cement mortar.

If a stone foundation is used it should consist of hard, durable stone solidly imbedded in cement mortar. If practicable, the stones should be of a length equal to the width of the foundation trenches, but if stones of that size can not be obtained, two stones may be used, with the joints under the walls:

ERECTION.

After the foundation has been laid and allowed to set thoroughly the boiler should be placed in position and raised to the proper height by means of jackscrews and held by cribbing built up of short pieces of timber. The cribbing should be placed in the spaces that are afterwards to be the furnace and combustion chamber, care being used to clear the location of the bridge wall and blow-off pipe. If the boiler is to be supported by columns and overhead beams, they should be put into place and the slings adjusted. The rear of the

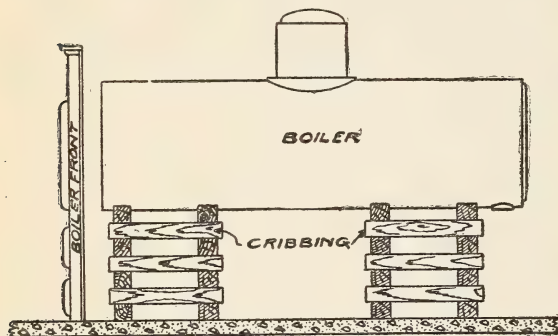


FIG. 4.—Boiler blocked up ready for setting.

boiler should be 1 inch lower than the front so as to drain properly to the blow-off pipe. The boiler front should be placed in position and propped up until the walls have been carried to a height sufficient to enable bolts or anchor rods to be inserted to hold the front in position.

The walls should then be built up to their proper height, allowing pockets for the supporting brackets.

The side stays should then be put into place and drawn tight. The boiler and setting should rest on the cribbing (see figure 4) until the brickwork has thoroughly dried out, when the cribbing may be removed and the weight of the boiler allowed to rest on the walls. Care should be taken to see that the brackets rest squarely on the soleplates in the walls; otherwise there will be a racking strain on the boiler during expansion and contraction. Then the setting should be closed and finished.

There is a general belief that because air is a poor conductor of heat, an air space built in the walls of a furnace will prevent or reduce the dissipation of heat through the walls. Experiments by the United States Bureau of Mines,¹ however, have shown that, so far as loss of heat is concerned, a solid wall of brick or any other

¹ Bulletin of the Bureau of Mines No. 8, "The Flow of Heat Through Furnace Walls."

ordinary material is preferable to a hollow wall of the same total thickness, especially if the air space in the hollow wall is near the furnace side.

While the solid-wall construction for boiler settings may be better from an insulating standpoint than a wall of the same total thickness containing an air space, in practice it is advisable to build the walls in two parts in order to assist in preventing the formation of cracks by the expansion and contraction of the brickwork on the furnace side of the wall. The space between the walls, however, should be filled with some solid insulating material, such as mineral wool, crushed brick, ash, or sand, as that kind of filling offers a higher resistance to the flow of heat through the walls than an air space and, furthermore, reduces air leakage into the furnace, which is a very important feature affecting its operation. The air space, however, should be kept so far as practicable from the furnace side.

The construction of boiler settings differs widely in details, depending on the type of boiler used and the local conditions, but the principles governing it remain the same. The brickwork should be substantial, so that it will not crack and crumble, conditions which always produce air leaks and cause extensive repairs. The exterior walls of the setting should be built of hard-burned brick, laid in cement mortar, while the inside lining of the furnace and combustion chamber should be of fire brick laid with fire-clay mortar, care being taken in both cases to use no more mortar than is absolutely necessary. The fire brick should be thoroughly bonded into the outer walls, but in such way as to allow replacing if occasion demands. The side walls of the furnace and combustion chamber may be either vertical or tapered. In either case from 2 to 4 inches should be allowed on the sides of the boiler just below the water line, so that the hot gases can circulate up to the point where the setting meets the boiler, which is usually just below the water line. The upper half of the boiler may be covered with a brick arch or some nonconducting insulating material. When a brick arch is used it is advisable to lay it over strips of wood about three-quarters of an inch thick. When the boiler is fired these wooden strips are burned out, leaving an open space between the boiler shell and the arch through which the hot gases may circulate. Sand should be spread over the arch to close any small crack that may occur and also to act as an insulator.

METHODS OF SUPPORT.

Two principal methods of supporting horizontal return-tubular boilers are employed. The one more commonly used, especially with comparatively small return-tubular boilers, is to support the weight on the walls of the setting by means of brackets bolted to the boiler

shell. Soleplates are placed on the brick walls to receive the brackets, the endwise expansion being taken care of by rollers between the brackets and soleplates. It is important to have the brackets completely covered by the brickwork; otherwise they will be burned by the hot gases.

The other and better method is to suspend the boiler from a frame made up of channel bars or angle iron supported by columns, the setting being built around the framework. By this method the weight of the boiler and contained water is carried on the piers supporting the columns. With this method the walls of the setting have to support only their own weight; hence the expansion and contraction of the boiler are more easily provided for and the walls of the setting are not so liable to crack. As before stated the back end of the boiler should always be set about 1 inch lower than the front in order to drain the boiler toward the blow-off pipe, which is usually at the back of the boiler. The blow-off pipe should be carefully protected from direct contact with the hot gases by covering with a sleeve or by building a baffle of fire brick on the side next the furnace.

CLEAN-OUT DOORS.

With large boilers two clean-out doors should be provided for the combustion chamber in order to facilitate cleaning, but with small boilers one is usually sufficient. It should be placed in the center of the back wall of the setting and the bottom of the door should be on a level with the bottom of the combustion chamber. Great care should be used in making the clean-out doors air-tight, as air leaking into the combustion chamber at this point seriously affects the draft.

CONSTRUCTION OF FURNACES.

The functions of the boiler and of the furnace are diametrically opposed to each other, that of the furnace being to develop a maximum of heat from the combustion of the fuel on the grates, while that of the boiler is to absorb as much heat as possible of that produced in the furnace. In order that the furnace may develop the maximum quantity of heat from the fuel complete combustion of all material is necessary. The volatile gases which are driven off from the coal must be allowed to ignite before their temperature is lowered to a point at which they will not burn. Even a comparatively slight reduction in temperature will prevent some of the gases from igniting, with the result that quantities of combustible gases are driven off without being consumed and fine particles of carbon are forced up the chimney without combining with the oxygen to produce heat in the combustion chambers. As hot gases and vapors rise at a rate proportional to their temperature, there must be a

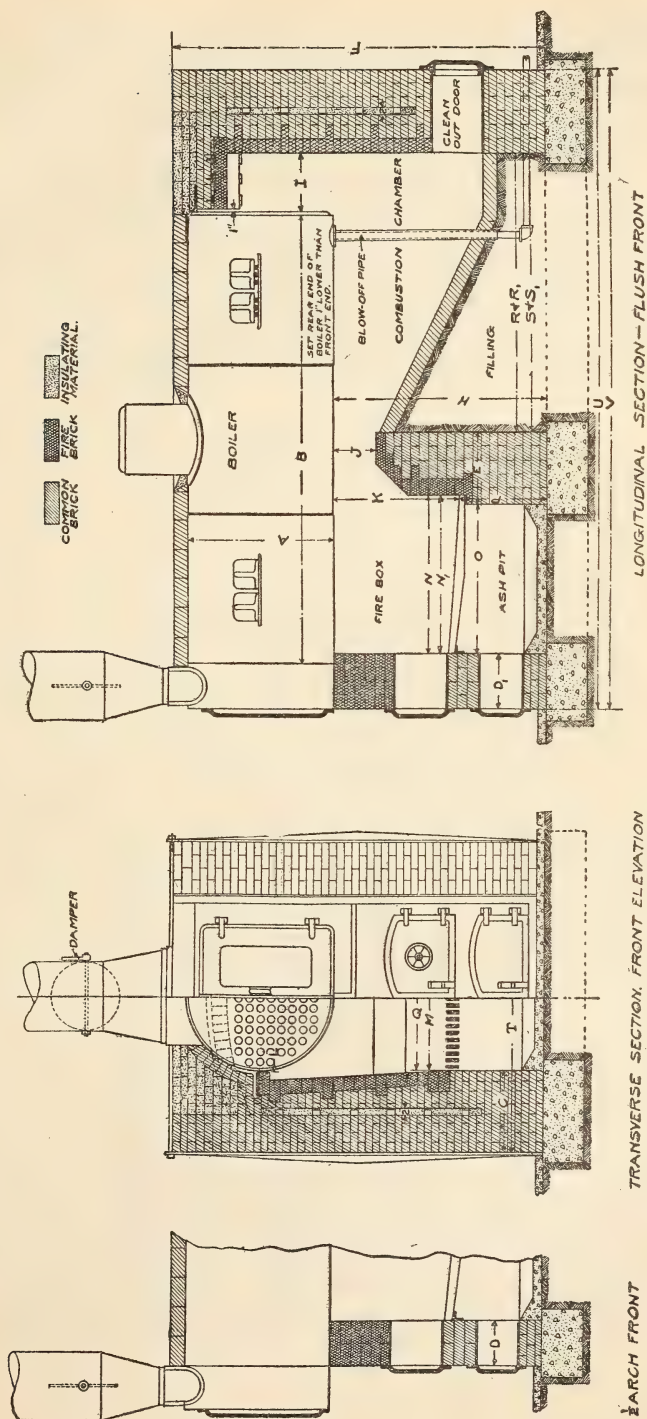


FIG. 5.—Setting for horizontal return-tubular boilers.

sufficient distance between the fuel bed and the boiler shell to allow for their complete expansion and ignition before coming into contact with the boiler shell. Soft coal usually contains a large proportion of volatile matter; consequently it needs considerably more space between the fuel bed and the boiler than anthracite.

The radiation losses from the sides of the furnace and combustion chamber are comparatively small in any well-set boiler and as the combustible gases rise a considerable distance before losing any appreciable heat the distance between the grate bars and the boiler shell should be increased over that generally used in setting boilers. This dimension depends on the kind of coal burned, the rate of burning, and upon other factors, all of which should be known in order

TABLE 2.—Dimensions of settings for

Diameter (inches).	Length (feet).	Horsepower based on 12 square feet heating surface.	Walls.				Spacing shell to—					
			Back and side (inches).	Front.		Bridge (inches).	Height (inches).	Ground (inches).	Back wall (inches).	Bridge wall (inches).	Grate rear (inches).	Side wall (inches).
				One-half arch (inches).	Full front (inches).							
A	B	C	D	D ₁	E	F	H	I	J	K	L	
30	8	12.2	21	9	13	13	84	50	16	9	28	42
32	8	12.5	21	9	13	13	86	50	16	9	28	42
32	10	15.6	21	9	13	13	86	50	16	9	28	42
36	8	15.9	21	9	13	17	94	54	16	9	30	43
36	10	19.8	21	9	13	17	94	54	16	9	30	43
36	12	23.7	21	9	13	17	94	54	16	9	30	43
36	14	27.6	21	9	13	17	94	54	16	9	30	43
36	16	31.5	21	9	13	17	94	54	16	9	30	43
40	10	26.6	25	9	17	17	100	56	18	10	32	43
40	12	32.1	25	9	17	17	100	56	18	10	32	43
40	14	37.4	25	9	17	17	100	56	18	10	32	43
40	16	42.5	25	9	17	17	100	56	18	10	32	43
42	12	33.4	25	9	17	17	102	56	18	10	32	43
42	14	39.2	25	9	17	17	102	56	18	10	32	43
42	16	44.6	25	9	17	17	102	56	18	10	32	43
44	12	36.7	25	13	17	21	106	58	18	10	32	44
44	14	43.0	25	13	17	21	106	58	18	10	32	44
44	16	49.0	25	13	17	21	106	58	18	10	32	44
44	18	55.0	25	13	17	21	106	58	18	10	32	44
48	12	43.0	25	17	21	21	112	60	18	10	34	44
48	14	50.2	25	17	21	21	112	60	18	10	34	44
48	16	57.3	25	17	21	21	112	60	18	10	34	44
48	18	64.8	25	17	21	21	112	60	18	10	34	44
54	12	52.7	29	17	21	25	122	64	20	12	36	44
54	14	61.8	29	17	21	25	122	64	20	12	36	44
54	16	70.5	29	17	21	25	122	64	20	12	36	44
54	18	79.3	29	17	21	25	122	64	20	12	36	44
60	12	62.7	29	21	25	25	128	64	24	12	36	44
60	14	73.0	29	21	25	25	126	62	24	12	36	44
60	16	83.3	29	21	25	25	126	62	24	12	36	44
60	18	93.6	29	21	25	25	126	62	24	12	36	44
60	20	104.8	29	21	25	25	126	62	24	12	36	44

to design a boiler setting that will meet exactly the requirements of a given set of conditions. With the type of setting shown in figure 5 and dimensions in Table 2, however, it is believed that satisfactory results will be obtained when using an average grade of soft coal. The dimensions of the distance between grates and boiler are to be considered as only approximate minimum limitations. If the height of the boiler room will permit, this dimension should be at least the diameter of the boiler, but in most milk plants and creameries to build the boiler-room ceiling higher would necessitate an increased expense in the construction; hence to a certain extent the height given is a compromise between the cost of building and the better combustion of fuel.

horizontal return tubular boilers.

Grate.					Ash pit.		Combustion chamber.				Outside walls.			
Width (inches).	Coal.		Wood.		Length (inches).	Depth (inches).	Width (inches).	Length.				Width (feet and inches).	Length.	
	Length (inches).	Area (square feet).	Length (inches).	Area (square feet).				Coal.		Wood.			One-half arch (feet and inches).	Full front (feet and inches).
								One-half arch (inches).	Full front (inches).	One-half arch (inches).	Full front (inches).			
M	N		N ₁		O	P	Q	R	S	R ₁	S ₁	T	U	V
30		7.5	60	12.5	.....	22	30	56	65	32	41	6 0	11 0	12 0
32	36	8.1	60	13.3	.....	22	32	56	65	32	41	6 2	11 0	12 0
32	36	8.1	60	13.3	.....	22	32	80	89	56	65	6 2	13 0	14 0
32	36	8.1	60	13.3	.....	24	32	52	73	28	49	6 2	11 0	13 0
32	36	8.1	60	13.3	.....	24	32	76	85	52	61	6 2	13 0	14 0
36	36	9.0	60	15.0	.....	24	36	100	109	76	85	6 6	15 0	16 0
36	48	12.1	60	15.0	.....	24	36	112	121	100	109	6 6	17 0	18 0
36	48	12.1	60	15.0	.....	24	36	136	145	124	133	6 6	19 0	20 0
36	42	10.5	60	15.0	.....	24	36	72	81	54	63	7 2	13 6	14 10
36	42	10.5	60	15.0	.....	24	36	96	105	78	87	7 2	15 6	16 10
36	48	12.1	60	15.0	.....	24	36	114	123	102	111	7 2	17 6	18 10
48	48	16.0	60	20.0	.....	24	48	138	147	126	135	8 2	19 6	20 10
42	42	12.4	60	16.5	.....	24	42	96	105	78	87	7 8	15 6	16 10
42	48	14.1	60	16.5	.....	24	42	114	123	102	111	7 8	17 6	18 10
48	48	16.0	60	20.0	.....	24	48	138	147	126	135	8 2	19 6	20 10
42	46	13.5	60	16.5	.....	26	42	85	98	71	84	7 8	15 6	16 10
42	48	16.0	60	16.5	.....	26	42	107	120	95	108	7 8	17 6	18 10
42	54	15.9	72	21.0	.....	26	42	125	138	107	120	7 8	19 6	20 10
44	54	16.5	72	22.0	.....	26	44	149	162	131	144	7 10	21 6	22 10
42	48	14.1	72	21.0	.....	26	42	78	96	54	72	7 8	15 6	17 0
44	48	14.8	72	22.0	.....	26	44	102	120	78	96	7 10	17 6	19 0
44	54	16.5	72	22.0	.....	26	44	120	138	102	120	7 10	19 6	21 0
46	54	17.4	72	23.0	.....	26	46	144	162	126	144	8 0	21 6	23 0
48	48	16.0	72	24.0	.....	28	48	77	95	53	71	8 10	15 10	17 4
54	48	18.1	72	27.0	.....	28	54	101	119	77	95	9 4	17 10	19 4
54	54	20.3	72	27.0	.....	28	54	119	137	101	119	9 4	19 10	21 4
54	54	20.3	72	27.0	.....	28	54	143	161	125	143	9 4	21 10	23 4
54	48	18.1	72	27.0	.....	28	54	79	99	55	75	9 4	16 2	17 10
54	54	20.3	72	27.0	.....	26	54	97	117	79	99	9 10	20 2	19 10
60	54	22.5	72	36.0	.....	26	60	121	141	103	123	9 10	20 2	21 10
60	54	22.5	72	36.0	.....	26	60	145	165	127	147	9 10	22 2	23 10
60	54	25.0	72	36.0	.....	26	60	163	183	145	165	9 10	24 2	25 10

While the designs of furnaces may vary widely in the details of construction, they all require the following necessary parts: A grate for supporting the fuel and on which the fixed carbon is burned; means for supplying and controlling the air required for combustion and for removing the incombustible gases; and an ash pit for catching the refuse from the fuel.

GRATES.

The object of the grates is not only to support the fuel but to admit the proper proportion of air to get the best combustion with the particular kind of fuel used. The area of openings between the bars is usually from 30 to 50 per cent of the total grate area. The individual openings between bars vary from one-eighth inch to 1 inch, depending on the kind of fuel used. For fine sizes of anthracite the openings vary from one-eighth to three-eighths of an inch. For large sizes of anthracite and for ordinary soft coal the openings are often as wide as 1 inch. With coal that forms clinkers narrow air spaces are objectionable since they are liable to become clogged, causing the bars to burn, and, furthermore, it is difficult to keep the openings clear for the free passage of air. For ordinary conditions when soft coal is used the straight bar is preferable to other types. The bars are usually made in lengths not exceeding 3 feet and if a greater length of grate is required two sections of the proper length are used. For hand-fired furnaces 6 feet is about the limit to which it is practicable to fire, on account of cleaning the rear portion of the grate. It is very important that the surface of the grate bars be regular and even. An uneven and inadequate grate surface tends to a rapid deterioration of the bars, which is caused by the heat of the fire and contact with the firing tools combined.

Grate bars are usually supported by strips made fast to the front of the setting and to the bridge wall. They should have a pitch of about 1 inch per foot toward the bridge wall. It is obvious that there must be some intimate relation between the amount of grate surface on which the fuel is burned to produce heat and the amount of heating surface in the boiler required to take up the heat. This ratio of grate surface to heating surface, however, varies widely because it depends upon the type of boiler, the method of setting, the draft conditions, and the kind of fuel used. Under ordinary conditions, with anthracite coal, the ratio of grate surface to heating surface is from 1 to 30 or 40, with an average of from 1 to 36. If bituminous coal is used for fuel this ratio should be increased by from 25 to 40 per cent, giving a ratio of from 1 to 45 or 50 of grate to heating surface. For wood burning the ratio should be about 1 to 65 or 70.

Grates that can be shaken, because of smaller opening of the fire doors, are generally more economical in the use of fuel than the ordinary grates, provided they are handled carefully and fuel is not shaken through into the ash pit.

Grates are usually furnished by the boiler manufacturer as an integral part of the boiler, without reference to the kind of fuel to be burned. It is, of course, impossible to get the best results in all cases with a standard type of grate bars which may not be suited to the particular grade of fuel used. The purchaser, therefore, when buying the boiler, should specify the kind of bar and the size of openings desired.

FIRE BOX.

The space immediately above the grates constitutes the fire box. The combustion of a considerable part of the gases driven off from the coal takes place in the fire box, the remainder being consumed in the combustion chamber proper. The horizontal dimensions of the fire box are fixed by the size of grate required for the given conditions, but with tubular boilers the height from the grate bars to the underside of the boiler is determined by the kind of fuel.

It was formerly believed that the grate bars should be set close to the shell of the boiler, the idea being that there is a loss of radiant heat, which increases with the distance. From 12 to 18 inches, therefore, was the ordinary distance in externally fired tubular boilers, and most of the boilers used at present in milk plants, creameries, and dairies are set with the grate bars approximately from 18 to 20 inches from the shell. With dry anthracite coal satisfactory results may be obtained with a grate setting of this kind, but with bituminous coal it is hard to imagine a more unsatisfactory fire box, and practically all the creameries burn soft coal or wood.

It is impossible to get good results when burning soft coal in a furnace designed for burning anthracite. With dry anthracite coal, which burns with very little flame, almost any kind of furnace will give good results, but with bituminous coal, which burns with a long flame, the distance from the grate to the underside of the boiler shell must be such that the flame will not strike against the comparatively cold boiler shell and be extinguished before the gases are completely consumed. In order to burn fuel completely it is necessary to maintain a high temperature. With steam at a gauge pressure of 100 pounds the temperature of the boiler shell will be approximately 338° F., which is about the temperature of the water in the boiler. If the flame is allowed to strike against the comparatively cool shell, it will be extinguished, soot will be deposited on the heating surface, and the unconsumed gases and smoke will be carried up the chimney.

The functions of the fire box are to provide means for burning the fixed carbon in the fuel, for the distillation of the gases, and for the thorough mixing of air at a high temperature with the unburned gases.

COMBUSTION CHAMBER.

The combustion chamber is really an extension of the fire box in which the burning of the volatile gases takes place and where the heat thus produced is absorbed by the water through the heating surfaces of the boiler. With horizontal return-tubular-boiler settings the term "combustion chamber" is applied to the space between the bridge wall and the ends of the boiler tubes. The horizontal dimensions of the combustion chamber are fixed to a great extent by the type of boiler setting. The depth seems to have little effect on the efficiency of the setting; consequently, the depth of the combustion chamber may be as great as the form of setting will permit. The common practice of sloping the floor of the combustion chamber downward from the bridge wall to the clean-out door seems to have little value other than facilitating the removal of ashes.

ASH PIT.

The ash pit beneath the grates is to catch the ashes and refuse from the fire above and to provide an air reservoir for supplying air to the burning fuel. The depth of the ash pit should be sufficient to provide plenty of air for the burning of the fuel and to hold a considerable accumulation of ashes and clinkers without choking the air supply and burning the grate bars. The bottom of the ash pit should be made wedge-shaped, of cement, to facilitate cleaning and to allow water to be placed under the grates to prevent them from being burned. It should not be necessary to keep water in the ash pit except when the boiler is being forced.

ASH-PIT AND FLUE DOORS.

The ash-pit door, usually called the "ash-pit damper," is an opening to the ash pit for the removal of ashes, and it also serves to control the air supply through the fuel bed. It is very important to have this door tight fitting in order to control effectually the air supply through the grates.

The flue doors provide an opening to the smoke box at the front ends of the flues. These doors, unless they fit tightly, are a source of air leaks.

CHIMNEY.

The function of a chimney is to provide a draft to effect combustion of fuel on the grate and to carry off the resulting obnoxious gases. The chimney should be built carefully to prevent cracks

where leakage of air through the walls may occur and to give as smooth a surface inside as possible so as to lessen the resistance to the flow of escaping gases.

The area of the chimney should be approximately 20 per cent greater than the combined flue area of the boiler or boilers which it is to serve. Table 3 gives the size of chimney for steam boilers.

TABLE 3.—Size of chimney for steam boilers.

[Calculated from Kent's formula assuming 5 pounds of coal per horsepower-hour.]

Area (square feet).	Diameter (inches.)	Height in feet.												Equivalent square chimney side of square.			
		30	40	50	60	70	80	90	100	110	125	150	175		200		
		Commercial horsepower.															
1.23	15	10	12	13	14	16	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	13
1.77	18	18	20	23	25	27	29	-----	-----	-----	-----	-----	-----	-----	-----	-----	16
2.41	21	-----	31	25	38	41	44	-----	-----	-----	-----	-----	-----	-----	-----	-----	19
3.14	24	-----	44	49	54	58	62	66	-----	-----	-----	-----	-----	-----	-----	-----	22
3.98	27	-----	-----	65	72	78	83	88	-----	-----	-----	-----	-----	-----	-----	-----	24
4.91	30	-----	-----	84	92	100	107	113	119	-----	-----	-----	-----	-----	-----	-----	27
5.94	33	-----	-----	-----	115	125	133	141	149	156	-----	-----	-----	-----	-----	-----	30
7.07	36	-----	-----	-----	141	152	163	173	182	191	204	-----	-----	-----	-----	-----	32
8.30	39	-----	-----	-----	-----	183	196	208	219	229	245	268	-----	-----	-----	-----	35
9.62	42	-----	-----	-----	-----	216	231	245	258	271	289	316	342	-----	-----	-----	38
12.57	48	-----	-----	-----	-----	-----	311	330	348	365	389	426	460	492	-----	-----	42
15.90	54	-----	-----	-----	-----	-----	-----	427	449	472	503	551	595	636	-----	-----	48
19.64	60	-----	-----	-----	-----	-----	-----	536	565	593	632	692	748	800	-----	-----	54

For pounds of coal burned per hour for any given size of chimney, multiply the figures in the table by 5.

DAMPERS.

Each boiler should be provided with a damper in the uptake or breeching which should have an effective opening of at least 25 per cent greater area than that of the combined area of the tubes. It should be arranged for convenient manipulation by the fireman; otherwise there will be a tendency to neglect its use. The control of the draft should be done through the manipulation of this damper rather than by the ash-pit doors.

BRIDGE WALL.

The wall just back of the grates is known as the bridge wall and extends across the entire width of the furnace to a height somewhat above the level of the bars. It has for its object the directing of the hot furnace flames and gases, forcing them to rise toward the shell of the boiler, and also to hold the fuel at the rear of the grates. The distance between the top of the bridge wall and the boiler shell depends on the kind of fuel used. With anthracite, or hard coal, the distance should be less than if soft coal or wood is used. As the bridge wall above the grate bars is in the direct path of the flames and hence is subjected to a very high temperature, it should be faced with fire brick, as ordinary brick soon fuses or crumbles.

FIRE DOORS.

The fire doors should be of substantial construction and should fit tight in order to prevent cold air from entering the furnace over the top of the fuel bed. An adjustable opening having a clear area of about 4 square inches per square foot of grate area should be provided in the door through which air may be supplied above the fuel bed. The admission of air through these openings also tends to keep the door from overheating and warping.

UPTAKES.

The smoke connections between the boiler and breeching are called uptakes. These connections should be as straight as possible, with ample cross-section area in order not to hinder the draft. The cross-section area should be from 20 to 25 per cent greater than the combined tube area, or approximately 25 per cent of the grate area. If it is impossible to run the uptake connections straight to the breeching, large, easy bends should be employed. Abrupt bends materially reduce the draft. Uptakes are often fitted loosely to the smoke outlet of boiler and to breeching, thus allowing cold air to enter and cut down the draft. Care should be taken to see that these connections as well as all others are made tight.

BREECHINGS.

Breechings are the connections between the uptake and the chimney. They should be run as straight as possible and bends, if unavoidable, should be large and sweeping. Breechings may be horizontal, but it is much better to have them rise from the uptake to the chimney. Under no consideration, however, should they drop below the horizontal. They should have a cross-sectional area of at least 25 per cent greater than the combined tube area, or one-fourth of the grate area. Round or square breechings are preferable to broad, flat ones, as the resistance offered to the flow of gases is not so great in the former as in the latter. In no case should a breeching be used in which one dimension is twice that of the other. Both uptakes and breeching should be tight and carefully covered with a good quality of heat-insulating material.

HAND FIRING OF BOILER FURNACES.

Boilers employed in the dairy industry are generally small, although ranging from the smallest size which is used on the dairy farm to several hundred horsepower in the largest milk plants. The great majority, however, range from 10 to 50 horsepower. The conditions and methods of operation used in these small plants are entirely different from those plants employed solely for the genera-

tion of power; consequently the economical firing of the boiler presents problems different from those in plants that operate under practically constant load throughout the day. In many large power plants instruments are used to measure the temperature and composition of the flue gases, which greatly aids the fireman in maintaining the fire bed in the best condition. In the smaller plants, where the load is intermittent and the boilers are fired for only a few hours during the day, it is impracticable to use flue-gas instruments; consequently the fireman is forced to depend entirely on his judgment as to the condition of the fire.

The chemical action that goes on in the furnace during the combustion of the fuel is an exceedingly complicated one and is not very well understood. While important, it is not absolutely necessary, in order to get good results, for the fireman to understand in general the chemical changes that take place during the combustion of the fuel. Hand firing of a boiler furnace is a combination of science and skill which is generally acquired through long experience and by careful observation of the conditions of the fire.

To get the best results definite proportions of fuel and air must be used, and the air must be evenly distributed throughout the fuel bed so that all parts will get the proportion of air necessary to effect complete combustion. Too much air absorbs heat from the fire and furnace walls, and the heat is carried up the chimney, while too little air causes the fire to smoulder, with the result that the combustible gases from the fuel are carried off without being consumed. The fireman must learn from the appearance of the fire whether the required proportion of air is being admitted, and if it is properly distributed. He must be able also to recognize any defects in the fuel bed, due to clinkers, ashes, holes, too thick or too thin fires, etc. With an even fuel bed clinkers or ashes on the grate are indicated by dark spots on the fuel bed or by shadows cast on the floor of the ash pit. In order better to observe the condition of the fuel bed through the casting of shadows in the ash pit the floor of the pit should be kept clean. Holes or thin spots may be noted by the white color of the burning fuel, indicating that too much air is being admitted at that point. The color of the fire bed indicates whether it is too thin or too thick. If too thin, the fire shows a uniformly white color, but if too thick it is more of a red color. An uneven fire bed shows dark and bright spots.

Different kinds of coal require different treatment in firing to obtain the best results. For instance, with soft coal the best results are obtained when the fires are kept level and relatively thin, from 6 to 8 inches, under average conditions of draft. Coal should be added often and in small quantities, and carefully spread evenly over the thin spots in the fuel bed. The fuel bed as a whole should

be kept level. In small milk plants and creameries where a regular fireman is not employed it is customary to shovel into the furnace a large quantity of coal, expecting it to last for a considerable length of time, thus giving the employee more time to attend to other work around the factory. It is hard to conceive of a more wasteful method of firing, for when the fire box is freshly filled with coal the draft is throttled, the temperature of the furnace is lowered, the fire smoulders and smokes, and the volatile gases are driven off without being burned. In time holes burn in the fuel bed, allowing too much air to enter the furnace, which finally chills the furnace by absorbing heat from the fire and furnace walls. Such a method of firing combines the two features most detrimental to the economical burning of fuel, namely, an insufficient supply of air for complete combustion when fuel is first added, and later, when the coal is partially burned, there is too much air, which chills the fire and furnace.

For the complete combustion of fuel a definite quantity of air must be admitted to the furnace and brought into close contact with the fuel, and the temperature in the furnace must be kept above the ignition point. The exact quantity of air necessary to burn 1 pound of coal completely depends on the kind of coal used. The grade or quality of coal generally used in milk plants and creameries requires about 12 pounds, or approximately 161 cubic feet of air, to burn 1 pound of coal completely, provided that it were possible to supply the air uniformly to all parts of the fuel bed, so that each particle of coal would receive enough for its complete and thorough combustion. This is, of course, impossible of accomplishment in actual practice; hence it is necessary to supply about twice the theoretical quantity of air in order to burn the fuel satisfactorily. The rate of supplying the air must be varied according to the requirements. For instance, when fresh coal is thrown into the furnace, large quantities of gas are immediately given off; consequently more air must be supplied at this time to obtain satisfactory combustion. After the distillation and burning of the gases from the fresh fuel is completed, the air necessary for burning the solid matter is only a fraction of that required just after charging with fresh fuel. The quantity of air needed at any particular time depends on the quantity of fresh fuel added and the condition of the fuel bed. It is impracticable to supply the theoretical quantity of air necessary to burn the fuel completely under service conditions, and it is necessary, therefore, to add fuel often and in small quantities. Just after firing, air should be admitted over the fuel bed through the openings in the fire door. When the fuel has burned down the supply of air over the fuel bed is greater than is needed for the complete combustion, and consequently it must be reduced. Thus it is seen that by small and frequent firing it is possible to regulate more nearly the

air supply to the demand of the burning fuel. The leakage of air through the walls of the boiler setting and through warped and broken furnace doors is practically constant.

The loss of heat due to the admission of an excessive supply of air through or over the fuel bed is the greatest single loss in a boiler plant.

In good practice there is a loss of about 23 per cent in the stack, due to heating air. This loss, however, is necessary in order to maintain draft through the furnace, and hence can not be avoided.

In the average creamery the heat loss due to heating an excessive amount of air is 40 or 45 per cent on account of air leaks in the setting. At least half of the loss can be eliminated by stopping the cracks in the boiler setting.

The tools necessary for firing should be provided and the floor from which the coal is to be shoveled should be hard and smooth. If the coal is shoveled directly from a wheelbarrow or specially designed coal car, the inside surfaces should be made smooth by dressing off all rivet heads or other obstructions against which the edge of the shovel may strike. The coal should be placed near the furnace door in such position that it may be shoveled quickly and easily into the furnace, thus making it necessary to keep the furnace doors open only a short time. Dampers should be provided in the uptake with means for operating from the fireman's position in front or at the side of the furnace doors. It is important that damper connections be conveniently placed so that the dampers can be easily and accurately adjusted; otherwise there will be a tendency to neglect their use and, instead, control the draft by means of the ash-pit door. Under no circumstances should the ash-pit door be used to control the draft in a furnace; with the ash-pit door closed or partly closed there is little or no air admitted through the grates and combustion is incomplete, and valuable fuel in the form of combustible gases which have been driven off from the green fuel is wasted by being carried off unconsumed up the stack.

Ordinarily the firing tools consist of a shovel, rake, hoe, and slice bar, which should be of the proper size to suit the particular furnace and should be kept in good condition. The front or cutting edge of the shovel should be kept straight and never be allowed to become bent or gapped. The tines of the rake and the blade of the hoe should not be bent or otherwise distorted. The slice bar should be bent to an angle suited to the particular furnace with which it is to be used.

The floor surrounding the boiler from which the coal is to be shoveled should be of concrete, with a smooth and hard surface, or better still, some form of car or truck should be used and the coal

shoveled directly from the car into the furnace. By using a car the dust and dirt from the coal are kept down to a minimum and the inconvenience and unsightly appearance of coal scattered over the floor is prevented to a great extent.

Ample room for working should be allowed the fireman. In many small plants the space for firing is often so limited that it is difficult to fire effectively. The fireman is forced to stand so close to the firing door and the heat from the furnace is so great that to avoid the heat as much as possible he stands to one side so far that he can not see where coal is needed, thus making it necessary to level the fuel bed frequently by the use of the rake.

In firing bituminous coal the large lumps should be broken up into pieces about the size of a man's fist or smaller. Adding large lumps of coal makes it impracticable to regulate the draft so as to get an even flow of air through the fuel bed; especially is this true in small boiler plants which are fired at a slow rate and in which a comparatively thin fuel bed is maintained.

METHODS OF FIRING.

There are three methods of hand-firing boiler furnaces, known as the spreading, alternate, and coking methods.

The spreading system, which is the simplest and perhaps the one most commonly used, consists in spreading the coal in a thin and even layer over the entire fuel bed. With this system it is harder to prevent smoking than with the other systems, especially if too much coal is added at a time. Consequently, the firing should be done often and only a small quantity of coal fired at a time, thus providing for better combustion. When the coal is spread in a thin layer over the entire fuel bed the volatile gases are quickly driven off and burned. This system of firing is particularly applicable to small boilers that have only one firing door, since the entire surface of the fuel bed can be easily seen. A difficulty experienced with the spreading system is that, unless specially guarded against, holes are liable to be formed in the fuel bed near the bridge wall. A modification of the spreading system is sometimes used which consists in keeping the fuel bed much thicker at the bridge wall than at the front, thus preventing it from burning out so quickly. Except for the fact that the fuel bed is kept wedge-shaped, the firing is the same as previously described. In firing hard coal the spreading system is used almost entirely, as coal of that kind contains very little volatile matter.

In order to prevent smoke a system of firing has been devised known as the alternating method. It consists in alternately adding coal to the front and back of the furnace or to the right and left sides. The object is to burn the volatile gases which are driven off in large volumes when soft coal is heated. By placing fresh coal on

one side of the furnace while the other side is partly burned the fresh coal upon being heated discharges large quantities of volatile gases which require a great deal of air for combustion. The air needed for burning the volatile gases is supplied to a great extent by the excess air which comes through the fuel bed on the opposite side of the furnace. As soon as the combustible gases from the charge of fresh coal have been distilled off and burned the opposite side of the grate is fired, with the same result. Instead of firing the sides of the furnace alternately some prefer to alternate in charging the front and back of the furnace. The principle, however, is the same in each case, and it is simply a matter of personal preference. When firing in this manner comparatively small quantities of coal are used at frequent intervals.

The coking method of firing soft coal has for its object the lessening of the smoke nuisance as well as the economical burning of a highly volatile coal. The method consists in shoveling just inside the furnace door a moderate quantity of coal, which is gradually heated, thus distilling off slowly the volatile gases which pass over the fuel bed in the rear and are burned by mixing with the excess air coming through the fuel bed. After the coking process has been completed the mass is broken up and pushed back over the fuel bed, taking care that all holes and thin spots are covered, and a fresh supply of coal added as before. Coke is the solid substance which remains after all the volatile gases have been driven off from coal through the application of heat. When pure it consists almost entirely of carbon and burns without smoke and with very little flame. The frequency of firing by the coking method depends upon the draft and rate at which steam is used, but under ordinary conditions it should be from 10 to 15 minutes. It is believed that this method of firing is the best for creameries, where the fireman has duties to perform in addition to firing the boiler, as the time between firings is somewhat longer than in either the spreading or alternate methods. The fireman should determine for himself how much coal should be fired at a time and the length of time between firings. This can be easily determined by noting the condition of the fuel bed as to holes, the thickness and color of the fuel bed, the quantity of coke required, and the degree of coking for different lengths of time.

AIR LEAKS.

In order to burn fuel economically, all air leaks into the boiler setting must be found and stopped. One way to find the points at which air leaks into a boiler setting is to have the boiler under steam and the fire burning rapidly. When the fuel bed is a glowing heap of coals cover the fire with a layer of fuel and close the dampers tight. The fresh fuel will liberate large quantities of gases which

on account of lack of air to burn them will cause smoke. The smoke thus formed will issue from all cracks and openings in the setting and boiler doors, which should be marked for repairs.

Another method is to go over with a lighted candle the outside surface of the setting around the boiler front, flue doors, clean-out doors, and other points where air leaks are liable to occur. Where leaks occur the flame of the candle will be drawn in, due to the inrush of air. In order to make the flame more sensitive, the candle may be placed in a box having both ends open, one end of the box being moved over the surface of the setting.

After finding the leaks the openings should be packed with asbestos rope saturated with fire-clay mortar. The rope should be forced well into the crack and the latter pointed up with the mortar. After all the leaks have been stopped several coats of a good quality of heat-proof paint should be applied to the entire setting. The paint effectually seals all small cracks that may have escaped detection

and also prevents the absorption of air through the walls, due to the porosity of the bricks.

A large part of the excess air which enters through cracks in the walls of the setting does little or no good in completing the combustion of the fuel. Air entering at the rear of the setting or into

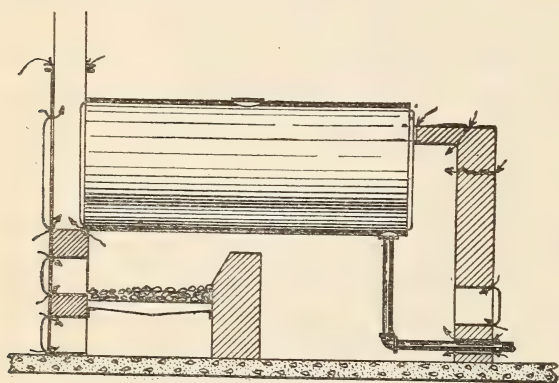


FIG. 6.—Common sources of air leaks in horizontal return-tubular boiler settings.

the uptake, breeching, or chimney not only has no effect on the combustion of the fuel but cuts down the draft at those points and makes it difficult to get the necessary volume of air through and over the fuel bed. It is very important, therefore, that all parts of the setting, uptakes, breeching, and chimney be made tight.

Figure 6 shows the points where air leaks are most commonly found in a horizontal return-tubular boiler and its setting.

The cast-iron boiler front is a frequent source of air leaks, as it is frequently warped or broken, due to the heat from the furnace, and often it is not placed in position properly, cracks through which the air passes being left between the front and the brickwork. When installed the space between the front and the brickwork should be carefully filled with cement mortar. Should a crack

develop after the setting has been in operation it can be stopped easily with asbestos rope and fire-clay mortar, as previously described. When the front is broken it is difficult to repair and when badly broken should be replaced with a new one. Care should be taken to construct the masonry so as not to allow the intense heat of the furnace to be conducted to the cast-iron front.

Fire and ash-pit doors are often badly fitted, warped, or broken, allowing too much cold air to enter the furnace. While it is necessary for air to be admitted at those points, the doors should fit tightly, and the volume of air admitted should be under the control of the fireman.

Flue doors seldom close tight, or if they are capable of being closed tight the fireman often neglects to do so. As the hot gases leaving the tubes impinge directly upon these doors, they are often warped and broken from excessive heat, thus allowing the entrance of air at that point.

With the horizontal return-tubular boiler it is very common to find that the weight of the boiler has caused the settling of the brick arch, thus leaving an opening between the end of the boiler and the top of the brickwork, through which the hot gases from the furnace pass directly to the stack instead of taking the path from the furnace through the combustion chamber and the boiler tubes, resulting in a high stack temperature. This short circuiting of the flue gases causes a large loss of heat in the stack with a corresponding decrease in furnace efficiency.

Almost invariably the opening through the wall of the setting through which the blow-off pipe passes is made larger than necessary, thus allowing cold air to enter the combustion chamber and lower the temperature of the gases and consequently reducing the effective draft. The door and frame of the clean-out door are more often than not found to be cracked or badly fitted. The back arch is forced back, due to the expansion of the boiler, until there is a permanent opening between the end of the boiler and the arch, through which large quantities of air pass directly to the boiler tubes. The back wall of the setting is very often cracked from the expansion of the boiler at the points indicated in figure 5.

While the foregoing are the places in the setting of a horizontal return-tubular boiler where air leaks occur most frequently, there are other points through which outside air finds its way into the furnace and combustion chamber. The side walls of the setting frequently develop cracks, and the entire brickwork is more or less porous and allows air to "soak" through even though there are no visible openings. It is obvious that in order to obtain reasonable economy in a boiler plant the air leaks must be stopped.

BELT-DRIVEN PUMPS.

The ordinary steam-driven pump requires from 100 to 200 pounds of steam per horsepower hour; therefore it is more economical to use a belt-driven pump which can be driven directly from the line shaft. By this means the power for pumping is furnished by the engine, which will develop a horsepower hour on from 40 to 70 pounds of steam, depending on the type of engine, steam pressure, the conditions of its valves, etc. One disadvantage of the belt-driven pump is that it becomes necessary to run the engine when it is desired to pump water into the boiler, but that is not a serious objection, as the engine is usually in operation during the time steam is kept on the boiler and can be easily run for the purpose. The belt-driven pump can be easily adjusted to feed the boiler continuously at just about the rate required. It is usually provided with a tight and loose pulley or some form of clutch so that the pump can be started and stopped at will when the machinery is in operation.

It may be well to state here that in order to pump hot water satisfactorily the pump should be placed always below the source of supply. If this is not done the pump will either fail entirely or operate very unsatisfactorily, depending on the temperature of the water. In pumping cold water there is an atmospheric pressure of 14.7 pounds per square inch on the surface of the water, which will support a column of water approximately 30 feet high. Allowing for frictional resistance in the suction pipe and valves, if the pump is within 20 feet above the supply it will operate satisfactorily, provided the piston speed of the pump is not too great to allow the water to follow the piston. The vapor pressure of water at 50° F. is only about one-quarter of a pound per square inch, and therefore is negligible as compared with atmospheric pressure. With water at 212° F. the vapor pressure is just 14.7 pounds per square inch, or just equal to the atmospheric pressure, and if we try to lift water at that temperature by suction the body of water will not rise at all, but the steam vapor will rise from the surface of the water and follow the piston. With water at 200° F. there will be about 3.3 pounds' pressure by the atmosphere in excess of the vapor pressure, which is sufficient to raise the water approximately 7.9 feet, but with no excess pressure to overcome the frictional resistance of the pipe and to lift the valves, to say nothing of giving velocity to the water. The pump, therefore, should be placed at least 3 feet below the supply when pumping hot water in order to have head enough to force it through the supply pipe at the required velocity and to lift the valves in the pump chamber. The pump should be placed near the water supply, and the supply pipe should be as straight and free from bends as possible. The springs of the pump valves should be made as light as practicable in order to insure proper operation.

If, however, the pump is at such a distance from the supply tank, or the supply pipe has so many abrupt bends that the head of 3 feet is not sufficient to force the required quantity of water through the supply pipe close to the pump, the standpipe may be vented to the air or back to the top of the supply tank. In either case the benefit of the full head will be obtained at the pump. To pump hot water successfully it is necessary to keep a solid body of water at all times against the pump plunger, otherwise the pump will not operate successfully. The packing for a pump required to pump hot water, of course, should be adapted to the temperature it will have to withstand.

STEAM LEAKS.

But few realize the enormous indirect fuel loss caused by leaks in the piping system. A single leak in itself does not appear to be serious, but a number of leaks around valve stems, blow-off cocks, pipe flanges and unions, safety valves, and at other points throughout the system will reduce the available horsepower of the boiler very greatly and indirectly increase the quantity of fuel burned. For instance, if the sum of the openings through which steam escapes to the atmosphere should equal one hundredth (0.01) of a square inch and the steam pressure in the piping is 75 pounds' gauge, or 89.7 absolute, the amount of steam that will escape in one hour will be approximately: $\frac{89.7 \times 0.01}{70} \times 60 \times 60 = 46$ pounds, or 1.3 boiler horsepower.

Should these leaks continue to exist and the plant be operated 10 hours a day for 310 days in a year, the annual loss in steam would be $46 \times 10 \times 310 = 142,600$ pounds. This would require the burning of 21,283 pounds, or 10.6 short tons, of average coal to produce the amount of steam mentioned, if we assume a boiler and furnace efficiency of 50 per cent, which is greater than is found in most creameries and milk plants. If the coal costs \$5 a ton the money loss will amount to \$53 annually, to say nothing of the inconvenience, unsightly appearance, and deterioration of valves and fittings due to the escaping steam. It is obvious therefore that all leaks should be stopped as soon as they appear.

HEAT LOSSES FROM BARE PIPE.

But few creamerymen insulate their steam piping. They are either not aware or are negligent of the serious loss in heat that goes on continuously when pipes or apparatus carrying steam are left bare. A square foot of bare piping inside a building will radiate about 3 B. t. u.¹ per hour for each degree difference in temperature between

¹ B. t. u.—British thermal unit, the amount of heat required to raise 1 pound of pure water 1 degree Fahrenheit.

the inside and outside of pipe. Suppose there is an equivalent of 50 square feet of steam piping in the average creamery and the steam pressure carried in the piping is 70 pounds' gauge, and the average room temperature is 70° F. (The temperature of the steam inside the pipe when at a pressure of 70 pounds' gauge is 316° F.); then the loss per hour is $50 \times 3(316 - 70) = 36,900$ B. t. u. If the plant is operated 8 hours a day for 300 days in a year the loss will be $36,900 \times 8 \times 300 = 88,560,000$ B. t. u. With a boiler and furnace efficiency of 50 per cent and coal containing 12,500 B. t. u. per pound it would require the burning of $\frac{88,560,000}{12,500 \times .50} = 14,009$ pounds, or about 7 short tons, which at \$5 a ton would amount to \$35' annually. Good insulation will reduce this loss about 85 per cent, in which case the loss would be only \$5.25, which would mean an annual saving of \$29.75. The cost of the insulation put on the pipes should not exceed 50 cents a square foot, making the cost of insulating the piping $50 \times .50 = \$25$. The insulation, therefore, will more than pay for itself through the saving of fuel in one year.

SELECTION OF POWER.

The accepted boiler horsepower is the evaporating of 34.5 pounds of water an hour from a feed-water temperature of 212° F. into steam at the same temperature, corresponding to atmospheric pressure. This is equivalent to the absorption of $34.5 \times 970.4 = 33,478.8$ B. t. u. There is, therefore, no direct connection between the horsepower rating of a boiler and that of a steam engine or other steam-driven machine. For instance, the latest and most improved triple-expansion engines condensing with high-pressure steam have produced a horsepower hour on about 9 pounds of steam, whereas the ordinary small slide-valve engine commonly employed in the smaller dairy establishments will use anywhere from 40 to 80 pounds of steam per horsepower hour. One boiler horsepower when used in connection with the most improved engines will furnish sufficient steam to produce nearly four horsepower hours, but if used in the smaller engines may produce only about one-half of a horsepower hour. Consequently, in estimating the size of boiler necessary the steam consumption of the engine and auxiliaries must be taken into consideration. For example, a 12-horsepower engine of the type generally used in the smaller creameries requires at full load about 60 pounds of steam per horsepower per hour at a gauge pressure of 70 pounds, or $12 \times 60 = 720$ pounds. The horsepower capacity of the boiler to supply steam will be $\frac{720}{34.5} = 20.8$. But this is assuming that the feed water is fed to the boiler at a temperature of 212° F., or at the boil-

ing point, and that steam is generated at atmospheric pressure. If the water is fed to the boiler at a temperature other than 212° F., or if steam is generated at a pressure other than atmospheric, it is obvious that a correction factor must be employed in order to reduce the results to an equivalent evaporation from and at 212° F. This factor is known as the "factor of evaporation." The heat actually required to evaporate a pound of water into steam is the total heat at the boiler pressure less the sensible heat at feed-water temperature. Since 970.4 B. t. u. are required to evaporate a pound of water from a temperature of 212° F. into steam at atmospheric pressure the factor of evaporation is $F = \frac{Th - Sh}{970.4}$, in which Th is the total heat in steam at boiler pressure and Sh the sensible heat in the feed water.

If the boiler feed water is at a temperature of 60° F. and steam is generated in the boiler at a gauge pressure of 70 pounds, the factor of evaporation, $F = \frac{1183.3 - 28.08}{970.4} = 1.191$. Therefore, if the 720 pounds of steam required per hour by the 12-horsepower engine were generated from a feed-water temperature of 60° F. into steam at 70 pounds' gauge pressure, the equivalent evaporation from and at 212° F. would be $720 \times 1.191 = 857.5$ pounds and the boiler capacity would be $\frac{875.5}{34.5} = 24.8$ boiler horsepower.

With a pasteurizer efficiency of 80 per cent it requires 382,500 B. t. u. to heat 4,000 pounds of milk from 60° F. to a final temperature of 145° F. If the heating is done in 30 minutes by using live steam directly from the boiler, it will require $\frac{382,500}{33,479} \times 2 = 22.8$ boiler horsepower. This added to the boiler horsepower required for furnishing steam to the engine makes the total capacity of the boiler, $24.8 + 22.8 = 47.6$ horsepower. In practice about 25 horsepower is used and it is forced during pasteurization. Before beginning to pasteurize a full head of water is fed to the boiler and the fires crowded. As pasteurization proceeds the water level in the boiler falls until at the end of the operation the water level has fallen perhaps to the bottom of the gauge. This method of operation puts a severe strain on the boiler and is attended with more or less danger.

On the other hand, if the heat in the exhaust steam is used for pasteurizing, the necessity of forcing the boiler during pasteurization is avoided, for there are $720 \times 800 = 576,000$ B. t. u. per hour, or 288,000 B. t. u. per half hour available in the exhaust steam. By storing this heat in a specially designed tank it becomes unnecessary to draw

live steam from the boiler and the boiler capacity can be reduced practically one-half with a corresponding reduction in fuel, to say nothing of the lessened strain placed on the boiler through forcing and the extra labor required in firing. By feeding the boiler with water heated by exhaust steam, expansion and contraction strains are greatly lessened, the fuel consumption is reduced as well as the work of firing, and the capacity of the boiler is increased in proportion to the temperature to which the feed water is heated. Where there is use for the heat in the exhaust steam from the engine, pumps, and other steam-driven machinery the power developed becomes a by-product of the heating system, and hence costs but little. In a milk plant or creamery in which pasteurization is practiced steam power is, generally speaking, the cheapest, for it is necessary to provide a boiler to furnish steam for the pasteurizing and as there is about 85 per cent of the heat in live steam at 70 pounds' gauge pressure remaining in the exhaust steam from the engine, it is economy to use the steam first in the engine to produce the required power for operating the machinery and then for the purpose of pasteurizing, heating water, and heating the building.

The size of boiler will be approximately the same whether it is used for pasteurizing only or for furnishing steam first to the engine and then employing the exhaust steam in the pasteurizer. Especially is this true if the engine is operated only a few hours daily, as it is necessary to raise steam for pasteurizing and after the boiler is once fired up but little additional fuel is required to furnish steam for power purposes for, say, three or four hours.

There are certain conditions, however, in which it is more economical to install a boiler for heating and a gas engine or electric motor for power. For instance, in nonpasteurizing plants where only a comparatively small quantity of heat is required for heating the wash water, a small boiler may be used for generating low-pressure steam for heating, and a gas engine or electric motor for running the machinery. The advantages in employing a gas engine or electric motor are that it is ready for instant use and that power costs cease with the stopping of the machine. With a steam-engine, however, time is required to raise steam in the boiler and firing must be continued while the engine is in use. Furthermore, it requires about 10 pounds of coal per horsepower capacity of the boiler for raising steam. That is, a 20-horsepower boiler requires about 200 pounds of coal for heating the walls of the setting and raising steam to a pressure of 70 pounds' gauge pressure. In some cases the apparatus requiring power is operated intermittently throughout the day, in which case it may not be advisable to use a steam engine, as

a greater economy may be obtained by using a gas engine or an electric motor that can be put into or out of service as required.

The relative cost of coal, gasoline, or electricity delivered at the factory must also be taken into account in selecting the kind of power best suited for any particular plant. In some cases the factory is a considerable distance from the railroad, and the inconvenience and expense of getting coal to the plant may be such as to prohibit the use of a steam engine. In other cases the cost of electricity may be so small as to make its use profitable. By utilizing the heat in the jacket water and exhaust gases of internal-combustion engines it is possible in some plants to produce the necessary quantity of hot water for heating, or the heat may be used to supplement that of a steam boiler, thus reducing the size of the boiler. A typical arrangement of such an equipment is illustrated in figure 9. In short, there is such a wide variation in the operating conditions of creameries throughout the country that it is impracticable to state in general just which form of power is the most economical, as each case requires a special study.

UTILIZING THE EXHAUST STEAM.

It should be the aim of any one in charge of a steam plant to utilize as much of the heat energy contained in the fuel as practicable, and there are few classes of steam plants that offer more varied opportunities for the utilization of exhaust steam from the engine, pumps, and other steam-driven machinery than those used in the dairy industry. In plants in which steam is generated for power purposes only, even with the best possible apparatus and arrangement, only a small portion of the heat in the coal is utilized. In the dairy industry, however, where much low-temperature heating is required which can be accomplished through the use of exhaust steam, even the smallest plants with little or no extra expense can be made much more efficient than the most modern steam plant when used only for the generation of power. There are dairy plants, however, that are taking advantage of their opportunities to use the heat available in the exhaust steam.

In the dairy industry large quantities of hot water are required for washing apparatus and utensils, pasteurizing, boiler feed water, and other purposes around the plant. The heating is done at present for the most part by live steam from the boiler, whereas the large amount of exhaust steam going to waste might be used for the purpose.

Exhaust steam at atmospheric pressure contains between 85 and 90 per cent of the heat of the live steam at 70 pounds' gauge pressure.

Consequently, if used for heating below the temperature of 212° F. exhaust steam is practically as good as live steam. As the exhaust steam when not used for heating is entirely lost, it is obvious that by its use the efficiency of the plant will be greatly increased.

Allowing for radiation from pipes, pasteurizers, hot-water tanks, etc., it is safe to assume that 800 B. t. u. are available for useful heating in each pound of exhaust steam.

The exhaust steam available from the engine, pumps, and other steam-driven equipment in milk plants, creameries, and dairies is, in general, not quite sufficient to take care of the maximum heating load which comes when pasteurizing is being done. But as the engine and pumps are operated for some time before pasteurization commences, it is perfectly feasible to store up the heat contained in the exhaust steam and draw on it when needed.

Pasteurization is now done almost entirely by the use of hot water, the water being heated either in the jacket space included in the construction of the pasteurizer or in a separate tank heater designed for the purpose and pumped from the heater through the pasteurizer and back into the heater.

The ordinary feed-water heater found on the market is not suited for use in milk plants except when it is used for heating the boiler feed water only, as it has little or no storage capacity and the heating surface is entirely inadequate. As hot water in dairy plants is used intermittently it becomes necessary to provide a large storage capacity in order to have a large quantity ready without delay when needed. Storage heaters especially designed for creameries and milk plants can be obtained from a number of manufacturers.

In designing water heating and storage tanks for use in the dairy industry the size should be based on the quantity and temperature of the water required or on the quantity of exhaust steam available for heating. In other words, the heat-transmitting surface should be proportioned so that approximately all the heat available in the exhaust steam will be transmitted to the water, provided, of course, there is use for the hot water.

Table 4 gives the capacity of water heating and storage tanks for different-sized creameries, with the amount of heating surface necessary to heat the water in each instance by exhaust steam at atmospheric pressure and temperature, from an initial temperature of 50° F. to a final temperature of 200° F. in one hour. The heating surface is supposed to be made up of steel or brass pipe.

TABLE 4. Capacities of storage heaters for different-sized creameries, and the amount of coil surface necessary with brass and iron pipe, respectively, to heat water from 50° to 200° F., in one hour with steam at a temperature of 212° F.

BRASS PIPE.

Annual capacity of creamery.	Size of heater.			Coil surface.	Piping.				
	Diameter.	Length.	Capacity.		1½-inch.	1½-inch.	2-inch.	2½-inch.	3-inch.
Pounds of butter:	<i>Inches.</i>	<i>Inches.</i>	<i>Gallons.</i>	<i>Sq. feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>
100,000 to 150,000.....	30	72	220	24	55	48	38	32	26
150,000 to 200,000.....	36	72	315	34	78	68	54	45	37
200,000 to 300,000.....	36	96	420	45	104	90	72	60	50
300,000 to 400,000.....	42	96	575	60	138	120	96	80	66
400,000 to 600,000.....	48	96	750	81	186	162	129	108	89

IRON PIPE.

Pounds of butter:									
100,000 to 150,000.....	30	72	220	40	92	80	64	53	44
150,000 to 200,000.....	36	72	315	58	133	116	93	77	64
200,000 to 300,000.....	36	96	420	76	175	152	122	101	84
300,000 to 400,000.....	42	96	575	105	242	210	168	140	116
400,000 to 600,000.....	48	96	750	137	315	274	219	182	150

It is estimated by a number of creameries which have recently installed a water heating and storage tank similar to those shown in figures 7 and 8 that a saving in fuel of from 15 to 25 per cent has been effected, and it is believed that in most cases an even greater saving in fuel can be made if sufficient care and attention are given

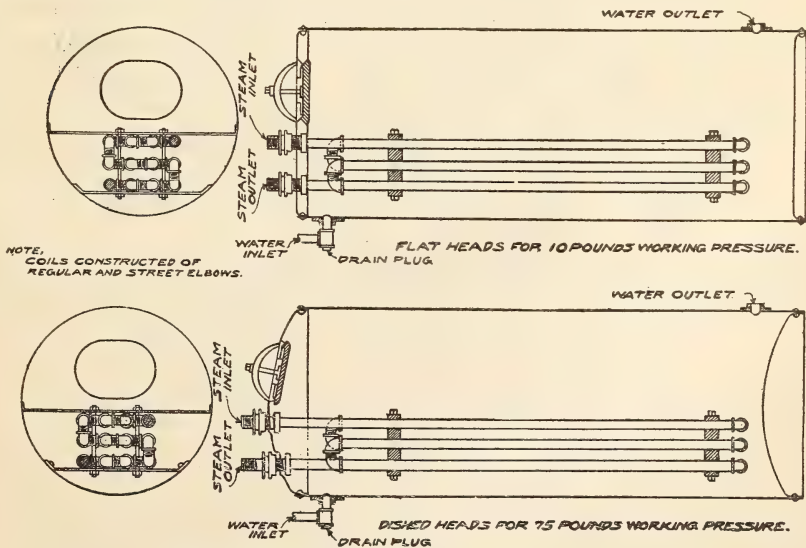


Fig. 7.—Horizontal exhaust-steam water heater and storage tank.

to the utilization of all the heat in the exhaust steam, or as much as can be used profitably in the factory.

The importance of effectively insulating hot-water tanks and piping is not appreciated by most dairymen. A good quality of heat insulation properly installed will pay for itself in fuel saved in from six months to a year. Not only will the insulation prove to be a good investment from the standpoint of fuel saved, but it will maintain

the water at higher temperature, thus preventing the possibility of the water freezing over night and bursting the tank.

The water-heating and storage tank should be placed in the boiler or engine room, where the temperature of the surrounding air will assist in maintaining a high temperature inside the tank. The tank should be used for a general supply of hot water for all purposes around the creamery, such as boiler feed, wash water, pasteurizing, etc. When practicable it is advisable to place the tank high enough

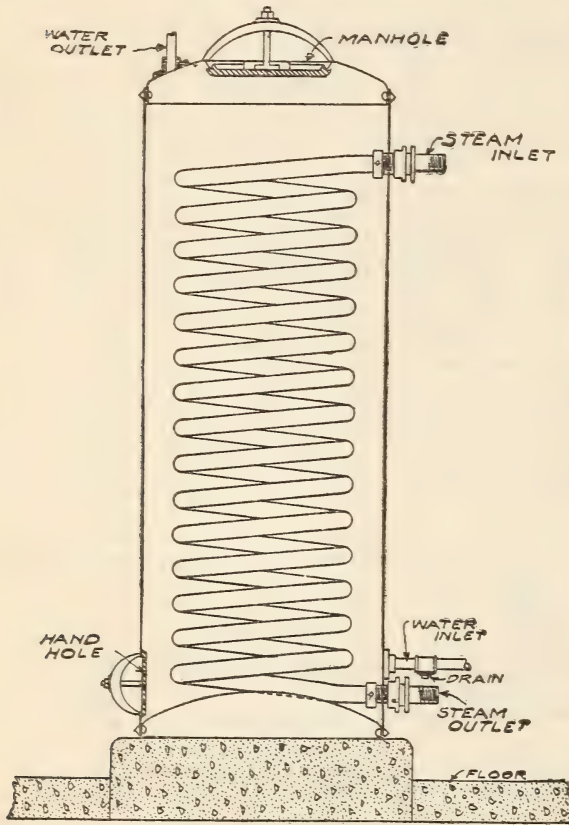


FIG. 8.—Vertical exhaust-steam water heater and storage tank.

to allow the hot water to flow by gravity for washing floors, utensils, etc., but for pasteurizing it is necessary to install a circulating pump in the pipe line, preferably in the return line between the pasteurizer and the tank, so that a forced circulation of hot water will be maintained. It is also necessary to provide a boiler-feed pump, designed for handling hot water, as an injector will not handle satisfactorily water of high temperature.

SAVING IN FUEL THROUGH HEATING BOILER-FEED WATER BY EXHAUST STEAM.

It is the common practice in creameries to feed the boiler with low-temperature water; that is, water of the temperature at which it comes from the well or other source of supply. The temperature is generally about 60° F., and in some instances, as when the water is drawn from a stream or from a storage tank, it is near the freezing point. The contraction strains which are set up in the boiler plates and seams, due to feeding cold water, are enormous and are liable to weaken the plates and open up the riveted joints. In addition to causing deterioration in the boiler itself, the feeding of cold water in large quantities reduces the temperature and consequent pressure inside the boiler and makes it difficult if not impossible to keep a

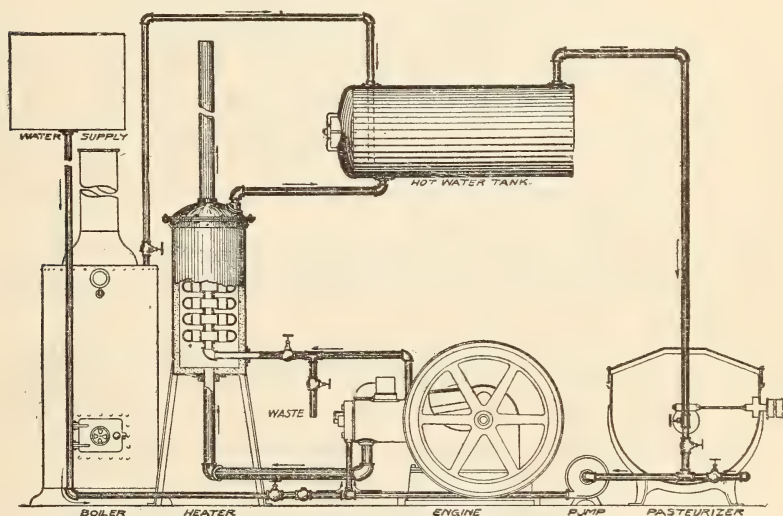


FIG. 9.—General arrangement for utilizing heat in exhaust gases and jacket water from internal-combustion engine.

uniform pressure. It also reduces the output of the boiler, for it is obvious that the boiler must furnish the heat required to raise the temperature of the feed water from its initial temperature to that corresponding to the steam pressure carried in the boiler.

It is advantageous to "preheat" the boiler-feed water, even though it is necessary to take live steam direct from the boiler to accomplish it, for by so doing the life of the boiler is prolonged, its output is increased, and there is a direct fuel saving due to the more even temperature maintained in the boiler. But by utilizing the heat in the exhaust steam which is otherwise wasted, not only are the contraction and expansion strains avoided to a great extent but there is a saving in fuel and the boiler output is materially increased.

The possible saving in fuel due to the "preheating" of the boiler-feed water may be readily found by the use of the following formula:

$$\text{Per cent of saving} = \frac{(T-t)}{(H-t)} \times 100$$

where T=B. t. u. in water above 32° F. after passing through heater.

t=B. t. u. in water above 32° F. before passing through heater.

H=B. t. u. in steam above 32° F. at boiler pressure.

As an illustration of the formula shown above, suppose the steam pressure in the boiler is 70 pounds' gauge and the initial temperature of the feed water is 60° F. If the water is heated to 200° F. by exhaust steam before entering the boiler, the per cent of saving in fuel will be

$$\frac{(167.94-28.08)}{(1,183.3-28.08)} \times 100 = 12.11 \text{ per cent.}$$

The maximum gain that can be realized by using exhaust steam for heating feed water in an open heater is, with a gauge pressure of 70 pounds per square inch on the boiler, approximately 15.2 per cent, this being the case when taking water at an initial temperature of 32° F. and delivering it to the boiler at 212° F., the highest temperature that it is possible to heat water at sea level in an open vessel under atmospheric pressure.

Table 5 gives the per cent of saving in fuel by "preheating" the boiler feed water from various initial temperatures to different final temperatures.

For every 11° F. that the feed water is heated before entering the boiler approximately 1 per cent less fuel is required to generate the same amount of steam, and for each 11° F. increase in feed-water temperature, the boiler capacity is increased approximately 1 per cent.

Besides the direct saving in fuel due to heating the feed water, the injurious effects of unequal expansion in the boiler, caused by having feed water at a low temperature, are diminished, and the life of the boiler is prolonged. It is easier also to keep a constant pressure on the boiler. There will be a further gain because of the smaller quantity of fuel consumed, due to the even firing, for when a fire is crowded to take care of a temporary overload a considerable amount of heat in the coal is lost by admitting an excess of air into the furnace and by a portion of the combustible matter being carried up the stack unconsumed.

To reduce the per cent of saving in fuel, as shown in Table 5, to their equivalents in dollars and cents, let us assume that the boiler has a capacity of 40 horsepower and that it is operated 8 hours a day for 310 days in the year. With a combined boiler and furnace efficiency of 50 per cent, about 6½ pounds of coal per boiler horsepower hour will be consumed, or 2,080 pounds per day of 8 hours, when the feed water is admitted to the boiler at 40° F. If the feed water,

TABLE 5.—Per cent of saving in fuel by heating feed water. Steam at 70 pounds' pressure.

Initial temperature of feed water.	Temperature to which feed water is heated.														
	100° F.	110° F.	120° F.	130° F.	140° F.	150° F.	160° F.	170° F.	180° F.	190° F.	200° F.	210° F.	220° F.	230° F.	300° F.
35° F.	5.30	6.35	7.19	8.04	8.89	9.73	10.57	11.42	12.28	13.13	13.97	14.83	15.68	16.50	22.59
40° F.	5.10	5.95	6.80	7.65	8.49	9.34	10.20	11.05	11.90	12.75	13.61	14.46	15.32	16.16	22.59
45° F.	4.98	5.54	6.40	7.25	8.11	8.96	9.81	10.67	11.52	12.38	13.24	14.10	14.96	15.81	21.93
50° F.	3.87	4.73	5.59	6.45	7.38	8.17	9.03	9.90	10.76	11.62	12.86	13.73	14.59	15.45	21.59
60° F.	3.45	4.31	5.18	6.04	6.91	7.77	8.64	9.51	10.37	11.24	12.49	13.35	14.22	15.09	21.25
65° F.	3.03	3.90	4.77	5.64	6.50	7.37	8.24	9.11	9.98	10.86	12.11	12.97	13.85	14.72	20.91
70° F.	2.60	3.48	4.35	5.23	6.10	6.97	7.84	8.72	9.57	10.46	11.35	12.22	13.10	13.98	20.57
75° F.	2.18	3.06	3.94	4.82	5.69	6.56	7.44	8.32	9.19	10.08	10.96	11.83	12.72	13.60	20.22
80° F.	1.76	2.64	3.51	4.39	5.27	6.15	7.03	7.91	8.80	9.68	10.56	11.43	12.31	13.19	19.87
85° F.	1.32	2.21	3.09	3.97	4.85	5.74	6.62	7.51	8.39	9.28	10.17	11.06	11.95	12.83	19.52
90° F.	.88	1.77	2.66	3.55	4.43	5.32	6.21	7.10	7.99	8.88	9.77	10.67	11.56	12.45	19.17
95° F.	.44	1.34	2.23	3.12	4.01	4.90	5.79	6.68	7.58	8.47	9.37	10.27	11.17	12.06	18.81
100° F.	.00	.89	1.79	2.68	3.58	4.47	5.37	6.27	7.17	8.06	8.97	9.87	10.77	11.66	18.45

however, is admitted to the boiler at 200° F., there would be a saving of 13.61 per cent—that is, the quantity of coal consumed per day would be reduced to 1,797 pounds. The saving in coal would be therefore 283 pounds a day, or 43.86 tons a year. If the coal cost \$5 a ton delivered in the bunkers, the annual saving in fuel would be

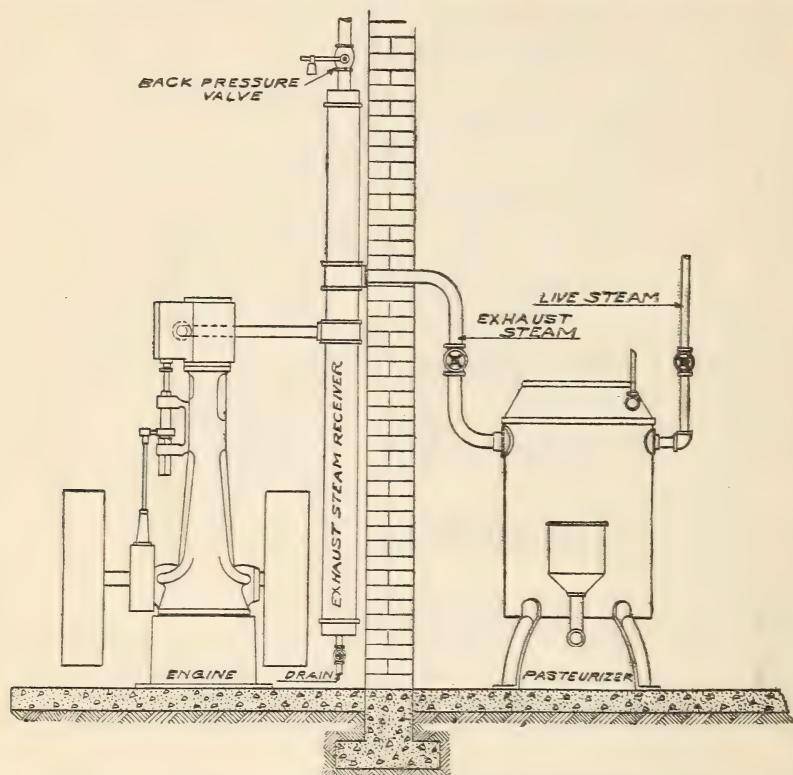


FIG. 10.—Connections for using exhaust steam in continuous pasteurizer.

\$219.30. Table 6 shows the sums annually saved under various conditions of feed-water temperature and cost of coal:

TABLE 6.—Amounts annually saved by heating feed water to 200° F. from various initial temperatures with coal at stated prices per ton. (Assuming a 40-horsepower boiler working 310 days of 8 hours and 6.5 pounds of coal burned per horsepower hour.)

Cost of coal per ton (2,000 pounds) in bunker.	Initial temperature of feed water.							
	40° F.	60° F.	80° F.	100° F.	120° F.	140° F.	160° F.	180° F.
\$2	\$87.72	\$78.12	\$68.00	\$54.70	\$47.40	\$36.10	\$24.60	\$12.24
\$2.50	109.65	97.65	85.00	68.37	59.25	45.12	30.75	15.30
\$3	131.58	111.18	102.00	82.05	71.10	54.15	36.90	18.36
\$3.50	153.51	136.71	119.00	95.73	82.95	63.17	43.05	21.42
\$4	175.44	156.24	136.00	109.40	94.80	72.20	49.20	24.48
\$4.50	197.37	175.77	153.00	123.07	106.65	81.22	55.35	27.54
\$5	219.30	195.30	170.00	136.75	118.50	90.25	61.50	30.60
\$5.50	241.23	214.83	187.00	150.42	130.35	99.27	67.65	33.66
\$6	263.16	234.36	204.00	164.10	142.20	108.30	73.80	36.72
\$6.50	285.09	253.89	221.00	177.77	154.05	117.72	79.95	39.78
\$7	307.02	273.42	238.00	191.45	165.90	126.35	86.10	42.84

Figures 10 and 11 illustrate methods of utilizing the exhaust steam in a continuous and in a vat pasteurizer, respectively. Figure 12 shows certain arrangements of machinery, not all intended for use at the same time, but rather to illustrate the general principles involved in utilizing the heat in the exhaust steam; they are easily adapted to almost any ordinary condition which is liable to occur in the average creamery. All pipes and devices necessary or desirable for utilizing the heat in the exhaust steam are shown shaded in order to distinguish them more readily from the other piping and apparatus. The exhaust steam from all steam-driven machines is piped into a common exhaust pipe. This pipe just before entering the ex-

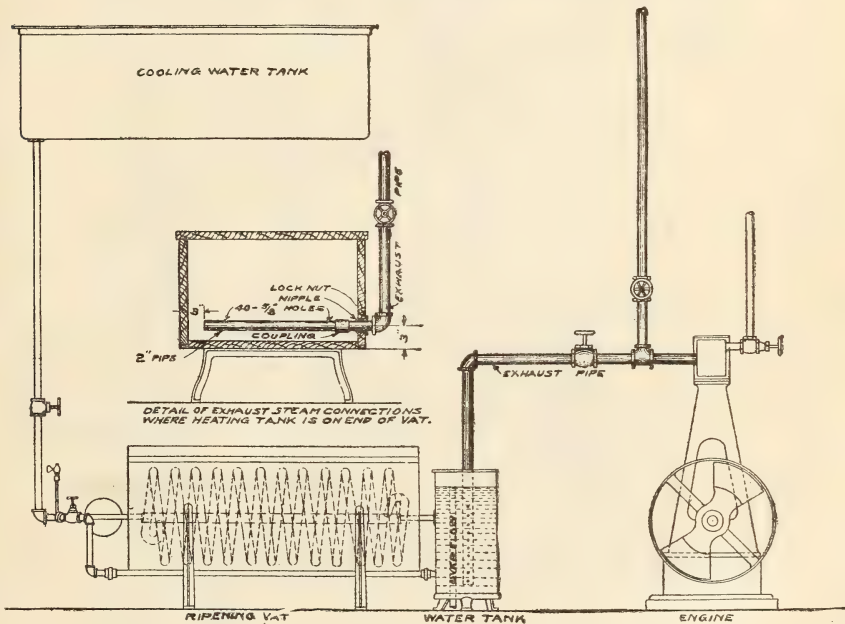


FIG. 11.—Connections for using exhaust steam in batch pasteurizer.

haust receiver is provided with an oil separator for the elimination of any oil that may be in the exhaust steam from the various machines. By having the exhaust from all steam-driven units exhaust into a common exhaust main, only one oil separator is necessary.

The object of the exhaust receiver is to prevent fluctuation in the back pressure of the different machines, as would be the case if they were allowed to exhaust directly into the smaller pipes. From the exhaust receiver the steam is piped under practically a steady pressure to the different creamery machines requiring heat. The receiver is fitted with a back-pressure valve so that in case the pressure in the system should build up above that at which the valve is set it will open and allow the excess steam to flow to the atmosphere. On

the other hand should the supply of exhaust steam be insufficient for the requirements of the creamery live steam is taken from the boiler

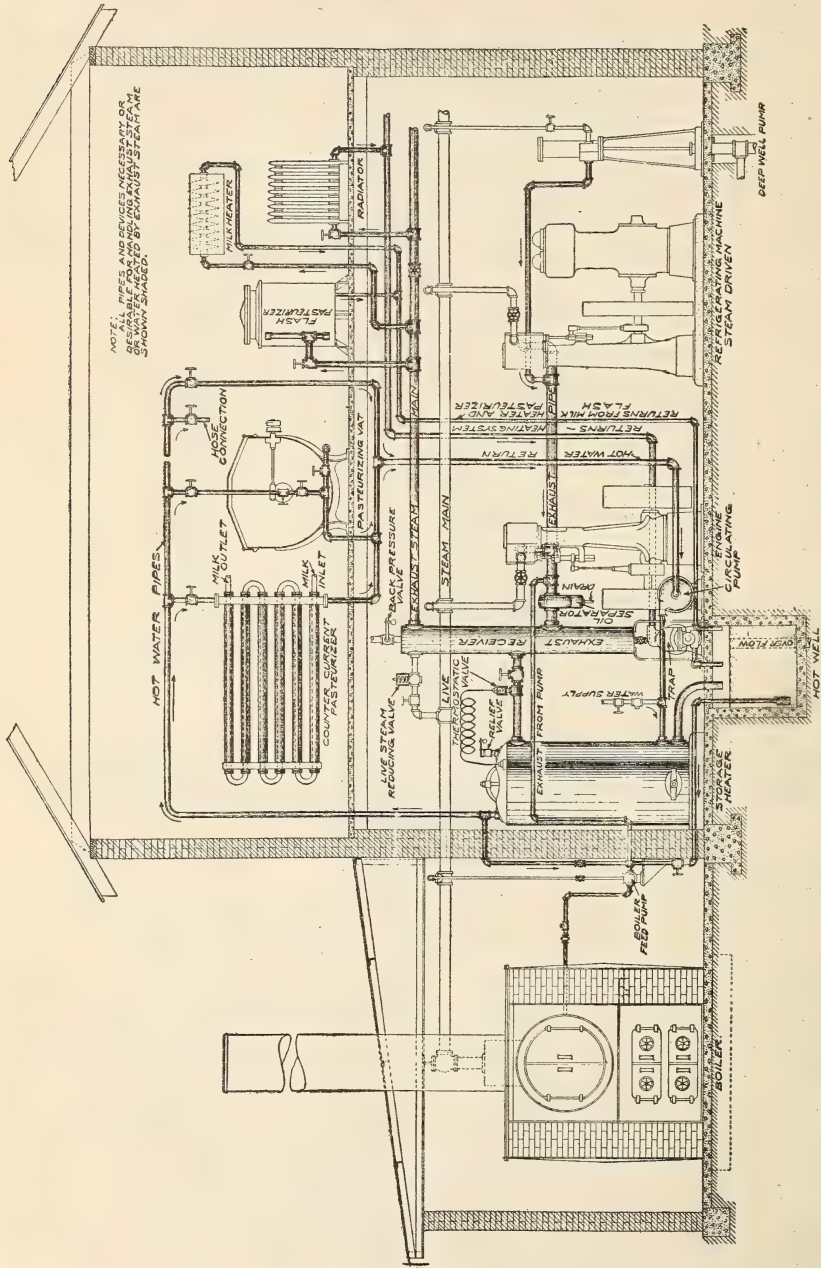


Fig. 12.—Diagrammatic arrangement for utilizing exhaust steam in creameries.

through a reducing valve to make up the shortage, thus insuring automatically a constant pressure in the system at all times. Should

the engine and other steam-driven units be shut down the reducing valve will open up and supply the full amount of steam required and at the pressure desired.

In figure 12 there are shown, connected to the exhaust-steam main, a flash pasteurizer, a milk heater, and one radiator of the heating system. The steam pressure on these units is maintained constant automatically by the use of the back pressure and reducing valves as previously explained. The steam is delivered under water in the jacketed space surrounding the pasteurizer and is all condensed. The steam delivered to the disk milk heater is also condensed in the heater. The condensation from these two units is piped direct to the hot well, from which it is pumped by the boiler-feed pump to the boiler, thus utilizing a large portion of the heat in the water. The condensation is returned to a low-pressure steam trap, which also discharges to the hot well. The boiler-feed pump, however, should be placed within about 3 feet of the surface of the water in the hot well in order to handle the hot water satisfactorily. The temperature of the water in the hot well will be cooled down to a point at which the pump will handle it satisfactorily if placed 3 feet above its surface.

The storage-water heater is connected to the exhaust receiver, as shown. A stop valve is placed in the pipe connecting the two so that the supply of exhaust steam may be entirely cut off if desired. Just after the stop valve a thermostatic valve is placed in the pipe supplying steam to the heater. The function of this valve is to maintain automatically a fixed temperature of the water in the heater. If the temperature of the water in the heater falls through supplying cold water the thermostatic valve will open and admit steam to the heater coils; if on the other hand the temperature of the water rises to the point at which the thermostatic valve is set it will immediately cut off the steam supply. The capacity of the storage heater should be sufficient to keep on hand a large volume of hot water ready for instant use. A large volume of water also has the advantage of allowing the heat in the exhaust steam to be stored at a time when but little or no use is being made of it. The boiler-feed pump is so connected that it can draw from either the hot well or the storage heater as desired.

In many creameries it is desirable to pasteurize milk and cream by the use of hot water instead of steam. Piping connections from the storage heater to a counter-current heater and pasteurizing vat are shown in the diagram, as well as hose connection for drawing off hot water for washing purposes. A circulating pump is shown connected to the pipe line in order to force the hot water through the system at a high velocity. When not using hot water for pasteurizing the circulating pump may be stopped. As the hot-water piping

system is a closed one a circulation will be maintained due to the difference in temperature of the water in the heater and that in the piping, thus making it possible at any time to draw off hot water through the hose connections. The clearance through the pump is sufficient to allow the water to pass through when the pump is not in operation. The water supply required to make up for that used in feeding the boiler for washing and for leakage is to be furnished from a pressure system, either from the city supply lines or from an overhead tank. The connection should be made through a check and stop valve, as shown. Stop valves are shown at the different units for controlling the supply of steam or hot water.

DISTRIBUTION OF HEAT ENERGY FROM COMBUSTION OF COAL.

Table 7 shows the distribution of the heat energy obtained from the combustion of the coal in the boiler furnace in an average gath-

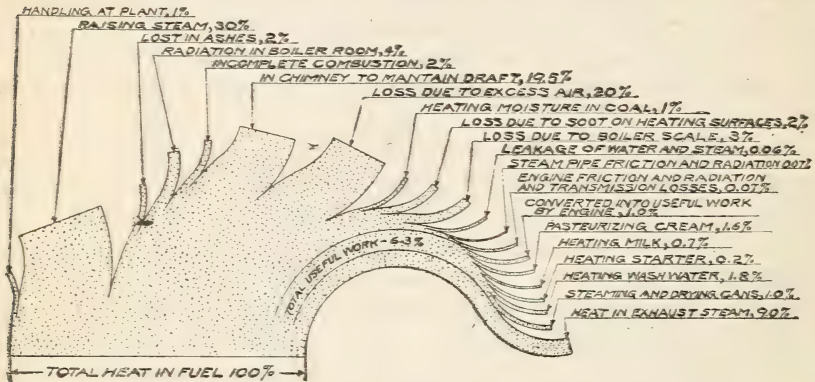


FIG. 13.—Graphic illustration of the distribution of heat energy between the coal pile and machinery in an average creamery making 500,000 pounds of butter annually from pasteurized cream, live steam being used for all purposes.

ered-cream plant making approximately 500,000 pounds of butter annually. The results are illustrated graphically in figure 13. The figures are based on actual tests and on careful estimates. The type of creamery selected is one in which all heating is done by live steam direct from the boiler. The distribution of heat energy covers a full day's operation, starting with raising steam in the boiler and ending when the fire in the furnace is burned out.

By studying the following table of the heat losses it will be noted that many items are excessive and can either be eliminated entirely or be greatly reduced. The loss of coal at the plant is one that can be entirely eliminated by exercising care in handling. It is often the case that the coal is stored some distance from the boiler room, necessitating its transfer from the bunker to the boiler by means of a

wheelbarrow or a specially designed coal truck. The barrow or truck is often overloaded and the coal falls off and is trampled into the dirt. This loss is one due entirely to slovenliness or carelessness, and not only results in a direct loss of coal but causes the plant to present an untidy and unkempt appearance. A little care and the use of a broom will eliminate this loss and also improve the appearance of the plant.

TABLE 7.—*Distribution of heat energy between the coal pile and machinery in an average creamery making 500,000 pounds of butter annually from pasteurized cream, live steam being used for all purposes.*

Total B. t. u. in coal $1,000 \times 13,500,000 = 100$ per cent.

Heat distribution in boiler room:	B. t. u.	Per cent.
Lost in handling at plant.....	135,000	1.00
Lost in raising steam.....	4,050,000	30.00
Lost in ashes.....	270,000	2.00
Lost by radiation in boiler room.....	540,000	4.00
Lost by incomplete combustion.....	270,000	2.00
Lost in chimney to maintain draft.....	2,632,500	19.50
Lost due to excess air driven through grates and leaks in boiler setting.....	2,700,000	20.00
Lost through heating moisture in coal.....	135,000	1.00
Lost due to soot on heating surfaces.....	270,000	2.00
Lost due to scale in boiler.....	405,000	3.00
Lost due to leakage of water and steam.....	8,100	.06
Heat distribution in engine room:		
Lost due to friction and radiation from steam pipes.....	9,450	.07
Lost due to engine friction, radiation, etc., and loss in transmission from engine to machinery.....	9,450	.07
Amount consumed in engine as useful work.....	135,000	1.00
Amount used in pasteurizing cream.....	216,000	1.60
Heating milk for separating.....	94,500	.70
Heating starter milk.....	27,000	.20
Heating wash water.....	243,000	1.80
Steaming and drying cans.....	135,000	1.00
Lost in exhaust steam.....	1,215,000	9.00
	<hr/> 13,500,000	<hr/> 100.00

In the great majority of creameries the boilers are kept fired only a few hours a day, the fires being allowed to burn out entirely or just fire enough maintained to keep the boiler warm overnight. It is necessary, therefore, to build a fire in the furnace each morning. The average boiler requires about 10 pounds of coal per horsepower capacity of boiler for heating up the boiler and the brickwork of the setting and for raising steam. A large portion of this heat which is stored in the brickwork of the setting, in the boiler shell, and in the water contained in the boiler is dissipated over night and must be supplied again the next morning. On account of the comparatively short time the boiler is operated each day this loss is one of the

largest and one that can be reduced only slightly by careful firing and by stopping all air leaks in the setting, firing doors, doorframes, and other places. Even in the case of a well constructed and maintained boiler setting, 10 pounds of coal per horsepower capacity of boiler will be required for raising steam. With poorly constructed and maintained settings this quantity of coal will be exceeded.

The loss of small particles of unburned coal which fall through the openings in the grate bars and are removed with the ashes may be reduced by more careful firing. The coal is broken up and falls through into the ash pit on account of stirring the fuel bed with the firing tools. If proper attention is given to the fire it is not necessary to stir up the fuel bed, and the percentage of unburned coal in the ashes will thus be reduced. While it is impracticable to eliminate this loss entirely, careful firing will greatly reduce it.

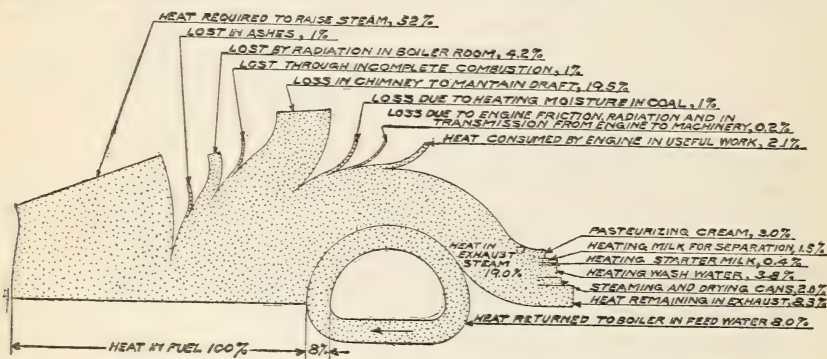


FIG. 14.—Graphic illustration of the possible distribution of heat energy in a creamery making 500,000 pounds of butter annually from pasteurized cream.

The quantity of heat radiated from the setting, uptakes, breeching, and from the exposed positions of the boiler itself depends, of course, on the arrangement of the particular plant, and while it is given in the table at 4 per cent, it is often considerably more. While some loss by radiation is unavoidable, the greater portion can be prevented through insulating the exposed surfaces. Efficient insulation not only conserves the heat but reduces the temperature in the boiler room, increases the draft, and when applied to iron surfaces prolongs their life. The insulation of the uptake and breeching may be effected by applying asbestos or magnesia blocks held in position and covered with a half-inch coat of asbestos or magnesia plaster. The walls of the boiler setting should be made amply thick to begin with, and should have a 2-inch space constructed in the wall. The United States Bureau of Mines, through exhaustive experiments, has proved that a wall with an air space will lose more heat than one of the same thickness constructed of solid masonry. The air space, however, is valuable in reducing the liability to crack. It should be filled with

ashes or sand or some similar material, thus reducing heat losses, and should cracks form in the walls, this fine material will run into and fill them and prevent the air from leaking into the furnace or combustion chamber. The exposed top of the boiler should also be covered with a layer of sand or ashes, or a layer of asbestos blocks or insulating brick may be substituted. By properly insulating the boiler setting, uptakes, and breeching the heat loss can be easily reduced one-half or more.

The heat loss through incomplete combustion is an extremely variable quantity in creameries where the firing of the boiler is done at irregular intervals. In most of the smaller plants no regular fireman is employed, but some one engaged in other work around the plant is depended upon to fire the boiler; consequently the firing is not given the proper attention. In the larger and better-managed plants, however, this loss is not more than about 2 per cent, which can be practically eliminated through careful firing.

There is a certain amount of heat loss in the stack that is necessary to maintain the draft for burning the fuel, and hence can not be eliminated. In practice it is found that twice the theoretical amount of air is necessary for complete combustion of the fuel. Assuming that twice the theoretical amount of air is supplied and that the coal used has a heat value of 13,500 B. t. u. per pound, then the necessary heat lost in the stack, as given in the table, is 19.15 per cent. It is impracticable to reduce this loss to any appreciable extent.

The greatest operating loss is that due to excess air which is allowed to leak into the furnace and combustion chamber through cracks in the walls of the setting, firing doors, doorframes, and other points. This is a loss that can be entirely eliminated if all cracks are carefully stopped and the air supply through the openings in the ash pit and firing doors is properly controlled.

The loss due to heating the moisture in the coal is one that is impracticable to eliminate or reduce. The loss depends, of course, upon the amount of moisture contained in the coal, but seldom exceeds 2 or 3 per cent.

Soot is one of the best-known insulators. Consequently if allowed to collect on the heating surfaces of the boiler it will reduce materially the amount of heat passing through the heating surfaces to the water inside the boiler. The loss from this source may be entirely prevented. The remedy lies in keeping all heating surfaces clean.

Nearly all boiler-feed water contains scale-forming impurities. Rain water, while not containing scale-forming material, always contains carbonic and often sulphuric acid, and hence should never be used as boiler-feed water on account of pitting and corroding the boiler plates. The heat loss from scale deposit depends, of course, on the thickness and nature of the scale formed. While in the foregoing

table it is estimated as averaging only 3 per cent, it often amounts to several times as much. In addition to cutting down the passage of heat it causes the plates to become overheated and is often the direct cause of explosions. Creamery boilers as a rule are not cleaned internally at regular intervals, and the scale is allowed to form until it greatly reduces the efficiency of the boiler and in extreme cases is liable to cause an explosion. The remedy lies in keeping the internal parts of the boiler thoroughly clean, either by treating the feed water with chemicals before admitting it to the boiler, or by cleaning mechanically at regular intervals. It is possible to eliminate entirely the heat loss through scale formation.

Leaky pipe joints, valve stems, blow-off valves, etc., are the rule instead of the exception in many small plants. This is due entirely to carelessness. It is an easy matter to stop leaks in pipe joints, pack valve stems, and regrind the blow-off valve, and thereby stop leakage losses entirely.

Heat losses through radiation from steam piping can easily be reduced 85 per cent by covering the bare pipes with a good grade of pipe covering, thus reducing the loss to a negligible quantity.

The losses due to engine friction and bearing, belt, and shaft friction may be reduced by better lubrication, proper size and tension in the belts, and careful alignment of the shafting. Small plants in particular often suffer power loss through an unnecessarily large amount and from poorly installed and maintained shafting. With care these losses can be reduced at least one-half in the average creamery.

We now come to the heat consumed in the useful work. The heat actually used in the engine for pasteurizing cream, heating milk before separation, heating starter and wash water, and steaming and drying cans amounts to only 6.3 per cent of the total heat units contained in the coal consumed in a day's operation. The heat lost in the exhaust steam amounts to 9 per cent of the total in the fuel. Exclusive of the heat energy consumed in useful work in the steam engine only 5.3 per cent of the heat in the fuel is used for other purposes. The 9 per cent of the total heat in the fuel lost in the exhaust steam, therefore, is more than sufficient to perform all the heating required in the creamery, and also to heat the boiler-feed water.

Table 8 is based on the same plant as that covered by Table 7, and shows the possible distribution of heat energy through improvements in the plant. Table 7 is based on 1,000 pounds of coal burned to produce a certain amount of work. Table 8 shows that after stopping leaks, utilizing the exhaust steam, and otherwise improving the operation of the plant the quantity of coal consumed in performing the same amount of work was only 470 pounds, or less than one-half the former amount.

TABLE 8.—Possible distribution of heat energy in same plant as in Table 7.

Total B. t. u. in coal $470 \times 13,500 = 6,400,000 = 100$ per cent.

	B. t. u.	Per cent.
Heat distribution in boiler room:		
Lost in raising steam.....	3,324,550	52.0
Lost in ashes.....	64,000	1.0
Lost by radiation in boiler room.....	266,000	4.2
Lost by incomplete combustion.....	64,000	1.0
Lost in chimney to maintain draft.....	1,248,000	19.5
Lost through heating moisture in coal.....	64,000	1.0
Heat distribution in engine room:		
Loss due to engine friction, radiation, and in transmission from engine to machinery.....	9,450	.15
Heat consumed by engine in the production of useful work.....	135,000	2.1
Heat in exhaust steam.....	1,215,000	19.0
	<u>6,400,000</u>	<u>100.0</u>
Heat returned to boiler through heating feed water.....	512,000	8.0
Distribution of heat contained in exhaust steam:		
Pasteurizing cream.....	216,000	3.4
Heating milk for separating.....	94,500	1.5
Heating starter milk.....	27,000	.4
Heating wash water.....	243,000	3.8
Steaming and drying cans.....	135,000	2.0
	<u>715,500</u>	<u>11.1</u>

