FP 1731

TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS [SUBJECT TO REVISION]

DISCUSSION OF THIS PAPER IS INVITED. It should preferably be presented in person at the Lake Superior Meeting, August, 1920, when an abstract of the paper will be read. If this is impossible, discussion in writing may be sent to the Editor, American Institute of Mining and Metallurgical Engineers, 29 West 39th Street, New York, N. Y., for presentation by the Secretary or other representative of its author. Unless special arrangement is made, the discussion of this paper will close Oct. 1, 1920. Any discussion offered thereafter should preferably be in the form of a new paper.

Steam Regenerators Reduce Coal Consumption

By W. H. Schacht,* E. M., Painesdale, Mich.

(Lake Superior Meeting, August, 1920)

In the Lake Superior District, the air indoors must be heated continuously during eight months of the year and occasionally during the remaining months. Incident with mining in this district, therefore, there is need for heating many of the buildings connected with these operations. In addition to the mine buildings, that is, shops, engine houses, offices, change houses, etc., such public buildings as schools, library, and theater, when close to the mines, are often supplied from the mine heating mains.

At the Copper Range Company's mines, Champion, Trimountain and Baltic, the heating surface thus supplied from the mine mains is over 50,000 sq. ft. (4645 sq. m.) which requires a steam consumption, at times, of 18,000 lb. (8165 kg.) per hour, or the equivalent of a rate of over 50 tons of coal per day (were live steam used). This figure is based on a consumption of ⅓ lb. per square foot of heating surface during the coldest weather, and provided the system is not wasting steam by blowing it to the atmosphere or into the return line on account of leaky traps, which so often is the case. Under the latter conditions, steam consumptions of three to four times the above rate are not uncommon. This shows that the cost of heating is of enough importance to be given serious consideration, especially at this time of rising prices of fuel.

The power and heating value of exhaust steam are appreciated by most engineers, and its application for such purposes is general. At our stamp mills, the exhaust from the stamps is used to operate low-pressure turbines, thus reducing the former water rate per horsepower developed by more than 50 per cent.

At the above-mentioned mines, electric motors have replaced the many small steam engines, so that this supply of exhaust steam has been practically eliminated. The larger engines are compound, triple, or quadruple condensing. The hoists, however, in all cases are simple and non-condensing and of two sizes, namely, 24 by 60 in. and 32 by 72 in. (61 by 152 cm. and 81 by 183 cm.). These hoists now offer the only available supply of exhaust steam; but as this flow is intermittent and

* General Manager, Copper Range Co.

varies from extreme violence to zero, the steam so discharged cannot be satisfactorily used without some means of storage, such as is offered by a regenerator that transforms the variable flux into a constant one.

Results Obtained by Using Back-pressure Valves

Efforts were made to use this exhaust steam for heating, without using regenerators, by having it discharge directly into the heating system, using a back-pressure valve weighted so as to provide sufficient pressure to permit the circulation of the steam through the system. The greater portion of it, however, for lack of storage capacity, escaped through the back-pressure valve to the atmosphere. The supply so obtained was not sufficient and had to be supplemented with live steam, introduced by an automatic reducing valve at a pressure usually a few pounds under that at which the relief valve was set. This meant that the hoisting engine would exhaust against a back pressure, which (in cold weather and on account of poor design or condition of the system) sometimes was as high as 10 lb. or more, thereby reducing the efficiency of the hoist, because of the reduction of the range through which the steam used by the engine could expand.

With this reduction in efficiency there was a greater steam consumption for the engine, and although some of this additional steam was used in the heating system most of it was discharged to the atmosphere. As a result, the operation was not as profitable as was expected. In fact, in many instances, there was a loss, for live steam fed directly into the the system without the imposed back pressure on the hoist would have resulted in better economy.

The condensate and non-condensable vapors from the several buildings heated were returned to the boiler house and discharged from the system by using steam-driven wet vacuum pumps. This condensate, on account of the oil contained therein, could not be used for feed-boiler purposes and had to be wasted.

Steam Losses Through Use of Radiator Traps

Various types of radiator traps were used in the different systems, some of which were better than others. In a closed system of this kind, by using these traps there is danger of wasting steam into the return line when the traps get out of order. The importance of this fact was not always realized, so that, no doubt, much steam was thus wasted.

Vibration, corrosion, or dirt usually cause these traps to get out of order. If the trap is of the diaphragm or bellows type, the constant vibration is apt to cause fatigue of the metal which, in some makes, results in the loss of the liquid contained therein. When this happens, the valve remains open, causing a continuous flow of steam to the return line. If the trap is of the expansion-rod type, corrosion or dirt may cause this to stick, with similar results. When these parts give trouble, they are often removed by the workmen who sometimes forget to replace them, so that the waste is permitted to go on.

It is bad practice, also, to discharge main traps (such as are used to discharge from the entire return line) directly into a closed sewer system for, should these traps leak (which they frequently do), the escape of this steam is unnoticed.

Losses Due to Air Leaks

Proper precautions were not always exercised to obtain tight heating systems, that is reaonably free from air leaks, for in some instances two vacuum pumps running simultaneously would not maintain more than 5 or 6 in. (12 or 15 cm.) of vacuum on the return line. This required carrying higher pressures on the main to provide the necessary differential for circulation and resulted in the using of more steam by the pumps than should have been necessary and caused waste due to the imposed back pressure on the hoist.

Much of this leakage was the result of improper provision for expansion of the piping; some was caused by faulty expansion joints; and valve-stem stuffingboxes; and some was due to leakage through the rod packing of the hoist. In the metallic piston-rod packing used, steam leakage is prevented by the condensation of the steam, which seals the small passages. With a vacuum on the heating main, there is imposed, also, a vacuum in the hoist cylinder; this difference in pressure causes air to flow into the cylinder through these packings, for there is no condensation to seal the passages. This leakage is considerable and increases with the vacuum carried in the main.

Conditions causing air leakage prevail in all plants, but as long as the steam escaping from the lines is not seen, the system is usually considered to be in good condition by the maintenance man, and the air leaks go unnoticed. The result is that the vacuum pump, which may be large enough to handle moderate leakage, cannot maintain the vacuum, so that the system is operated at a reduced vacuum. This reduction in vacuum is followed by a rise in the working pressure on the main, which rise usually continues until the pressure in the system reaches or exceeds that of the atmosphere. As a result, many persons believe that it is impossible to operate a system at less than atmospheric pressures. Several years of operation at our plants have shown, however, that these engines can be benefited by a vacuum when exhausting into the heating system. This, in reality, is a condenser and, if it is kept tight (as is required of other condensers), there will be no difficulty in operating with main-line pressures of 8 or 10 in. (20 or 25 cm.) provided the steam consumption of the heating system equals or is more than the engine exhausts, while 18 or 20 in. on the return line provide sufficient differential to cause proper circulation under the most severe conditions.

Steam Required to Heat Plant

A survey at that time showed that our steam requirements for heating for more than half of the year were equal to or in excess of that required by the hoists; further, during the coldest weather, at most of the plants, live steam would have to be supplemented, and for the remainder of the year most of the exhaust would be required. Considerable steam is used in the summer months for heating the dry or change houses, water for buildings, and feedwater for the boilers. To use as much of the exhaust steam as possible, it was necessary to provide means for storing this heat and transforming the variable flux into a constant one. For this purpose, steam regenerators of the Rateau design were placed between the hoisting engine and the heating system.

Principles of Operation of Steam Regenerator

The method of treating a flux of intermittent exhaust steam by the use of steam regenerators consists in passing the intermittent flux of steam through a closed vessel, or regenerator, in which the steam is condensed and re-evaporated. Condensation takes place when the steam is in excess of the quantity required to maintain a constant flow of outgoing steam, and re-evaporation takes place when the steam discharged into the regenerator is not sufficient to maintain this constant flow. The condensation and re-evaporation are due to interchanges of temperature between the flowing steam and a large mass of water. In order to keep this water in intimate contact with the steam flowing through the regenerator, the surface of contact must be as great as possible.

In order that the operation of the engine and heating system may be independent of each other, a relief valve located in the steam path limits the range of pressure in the regenerator. This range of pressure, on the other hand, also limits the maximum amount of steam that can be condensed in the regenerator. It is, therefore, essential that the mass of water be brought to the temperature corresponding to the pressure temperature of the flowing steam in order that the maximum storage of heat by the water be obtained before the relief valve blows off.

When the flux of steam received by the regenerator exceeds the amount it is delivering to the heating system, the regenerator absorbs the excess and holds it until some time when less steam is received than is required. When the flux of steam received is just equal to that taken by the heating system, the pressure within the regenerator is constant. No

steam is condensed and the regenerator floats idle. Should the quantity of the incoming steam be less than that required by the heating system, the pressure in the regenerator falls, and the water gives off steam, losing the heat that was absorbed during a time of excess.

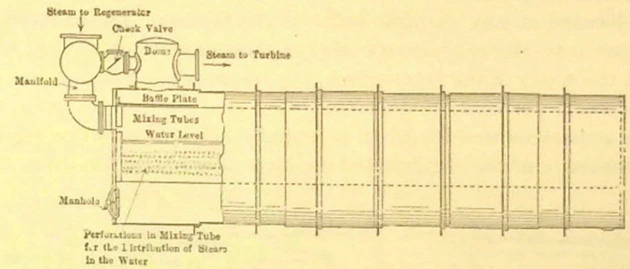

Fig. 1.—Longitudinal section, Rateau patent steam regenerator.

The efficiency of the regenerator as a piece of power apparatus is, as usual, the ratio of power output to power input. If the regenerator delivers steam at the same pressure as that at which it receives steam, barring the slight losses due to radiation, its efficiency is 100 per cent. On

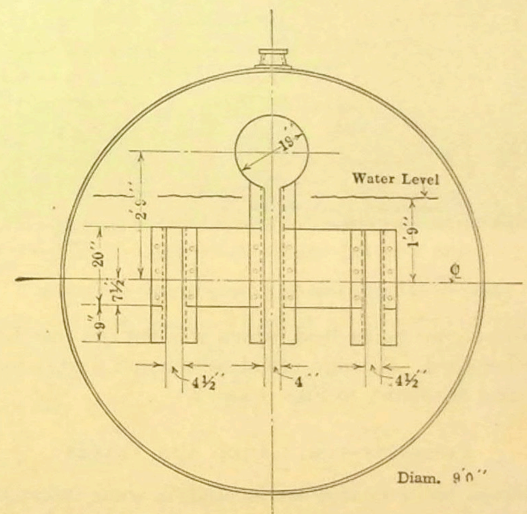

Fig. 2.—Cross-section of regenerator.

the other hand, if the regenerator always receives steam at a higher pressure than that at which it can deliver steam, its efficiency is less than 100 per cent., and the loss is represented by the pressure drop between the absorbing condition and the condition of delivery.

The regenerator is equipped with a suitable steam dome for the discharge of the regenerated steam to the heating system, and with a special automatic water-level device, which removes the water of condensation entrained with the exhaust steam. A relief valve controlling the maximum pressure permissible between the exhaust of the engine and the main inlet is located at any suitable point of the piping. The exhaust steam discharged into the regenerator always contains water. After passing through the water in the regenerator, the steam never contains more than a fraction of 1 per cent. of moisture.

This apparatus was found to be equally efficient as an oil separator. The condensate of the regenerated steam is practically free from oil and

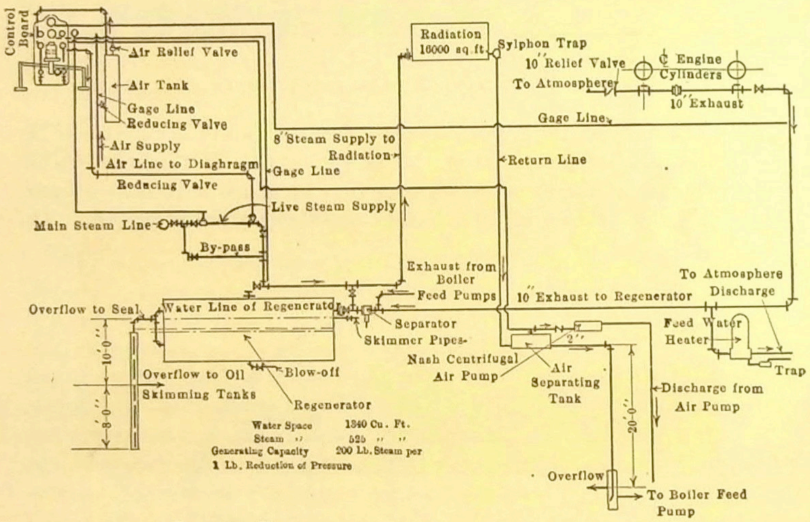

FIG. 3.—DIAGRAMMATIC SKETCH OF PIPING SYSTEM.

suitable, therefore, for boiler feed, which was not the case before regenerators were installed. A longitudinal section and a cross-section of the regenerator used are shown in Figs. 1 and 2.

PIPING SYSTEM, GAGES, AND VALVES

The buildings to be heated are located, in some instances, 2300 ft. from the engine house, and well above the elevation of the boiler house, thus offering ideal conditions for gravity returns and good drainage. As a result, the condensate is returned to boiler house and discharged from the system (operating at 20 in. of vacuum) by means of a water seal. Because of the effectiveness of the regenerator as an oil separator, this condensate is used for boiler feed.

In remodeling the several heating systems, estimates of the steam requirements were made and pipe sizes used that would give a pressure drop through the mains of approximately 1 lb. The return lines installed were also of ample size, so as to cause no undue pressure loss. Advantage was taken of the difference in elevation and the pipes so installed as to eliminate all pockets, thus permitting the entire system to drain back to the boiler house, avoiding, therefore, possibilities of trouble when steam is shut off from the system in freezing weather.

Asbestos sponge felt 1 in. (25 mm.) thick was used where the pipe lines are sheltered, that is, where they are suspended in concrete boxes, and 1½ in. thick was used where the pipe lines are exposed to the weather. The return lines are also covered so as to conserve this heat for boiler-feed

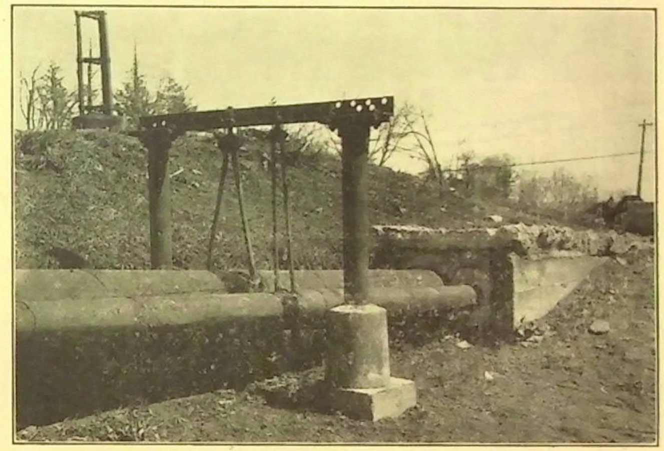

FIG. 4.—METHOD OF SUPPORTING PIPE LINES.

purposes. These coverings are protected from the weather by asphalted asbestos jackets, which when in place are given a coat of asphalt paint.

No slip expansion joints were used, expansion being provided for by offsetting the lines 50 or 60 ft. (15 to 18 m.) at intervals of 500 ft. The piping is usually anchored midway between the offsets. One of the systems at the Champion mine, which has 2300 ft. (701 m.) of mains in which all expansion is provided for in this manner, has not required the use of a wrench on it since it was installed about three years ago.

These pipe lines are suspended in long slings, which are free to swing from an eyebolt having a vertical thread adjustment for pipe alignment. Some sections of these lines span deep ravines, requiring, therefore, bents 30 ft. high in order to avoid pockets and to provide the necessary run for drainage. A diagrammatic sketch of one of these installations is shown in Fig. 3, the methods of supporting the pipes is shown in Figs. 4, 5, and 6.

The exhaust from the hoist cylinders is piped to the regenerator inlet, which is placed at least 6 ft. (1.8 m.) below the cylinders to avoid drawing water from the regenerator back into the cylinders when the engine is idling or drifting, thus causing a vacuum sufficient to raise water several

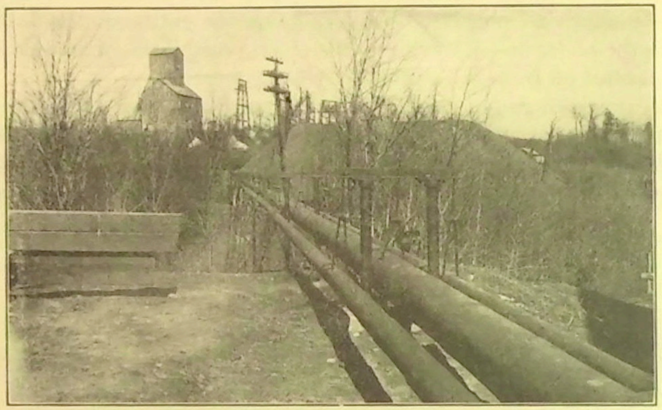

Fig. 5.—A tangent crossing a deep ravine, carried on bents, in some places over 30 ft. high.

feet above the water level in the regenerator. In some installations the regenerators are placed in the basement of the engine house; in others they are placed in the boiler room. An atmospheric relief valve in the

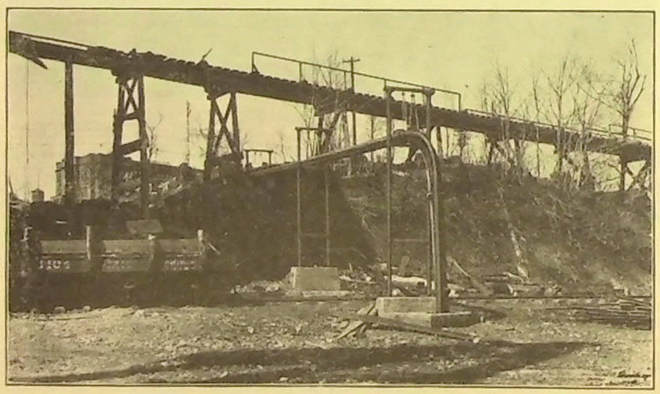

Fig. 6.—Expansion of the tangent taken up where it emerges from the buried box. Long hangers are needed, as a travel of 12 or 13 in. is required.

exhaust line near the engine can be set to maintain any pressure desired but it is usually set to relieve at ½ lb. above atmosphere. The exhausts from the boiler feed pumps, hoist auxiliaries, and trap discharges from the hoist receivers are also piped to the regenerator.

Connected to the exhaust line between the engine and the regenerator is the feedwater heater, which gets its supply of steam from the engine or pump exhaust, or draws from the regenerator when the other supply is insufficient. In other words, the feedwater heating is not dependent on an intermittent supply, but has a constant supply to draw upon, and temperatures of 190° to 200° are easily obtained. As the pressure in this line is below the atmospheric, a power or steam operated steam trap is used to discharge the condensate from the heater. Considerable condensation or entrained water is carried with the exhaust steam into the regenerator, which must be discharged from it. As the working pressure carried is usually below the atmospheric and as ample head can be obtained for a water seal to discharge under these conditions, this method

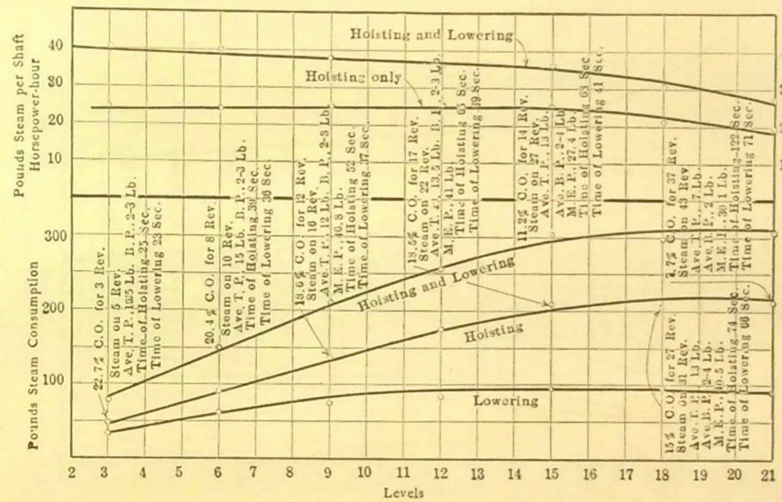

Fig. 7.—Steam consumption for hoisting and lowering, No. 1 shaft. Twin 32 by 72-in. simple engines on atmospheric pressure. Rock load 5 tons.

of relief is used. The overflow of the seal is situated so as to operate either with vacuum or pressure, being able to discharge to the atmosphere with pressure of 4 or 5 lb. (1.8 to 2.3 kg.) plus or minus.

Provision is made to supply live steam to supplement the exhaust automatically. Two reducing valves are used in series, to safeguard the system in case one of these valves should get out of order. By stepping down the pressure in stages in this manner, the cutting action of the steam on the valve and seat is much reduced.

The reducing valve on the high-pressure side is of the ordinary type and reduces down to 15 lb. (6.8 kg.) The other valve is of the diaphragm type operated by auxiliary pressure introduced by means of a special control mechanism. An ordinary reducing valve, depending on the pressure of the atmosphere, will not operate on pressures when less than atmospheric. A telltale pressure gage, which is tapped into the line between the reducing valves, is used to indicate when either of these valves is out of order. Should the gage read above 15 lb., the valve on the pressure side is not tight and may require reseating; should the gage read less than 15 lb. the valve on the lower side is not tight.

These reducing valves automatically admit steam to the system at any predetermined pressure, either above or below atmospheric. This is done with a special control mechanism, made by the Klipfel Manufacturing Co., of Chicago, which consists of a closed chamber or cylinder, the lower end of which contains a flexible rubber diaphragm to which is attached a stem or yoke that connects with a lever arm fulcrumed to one

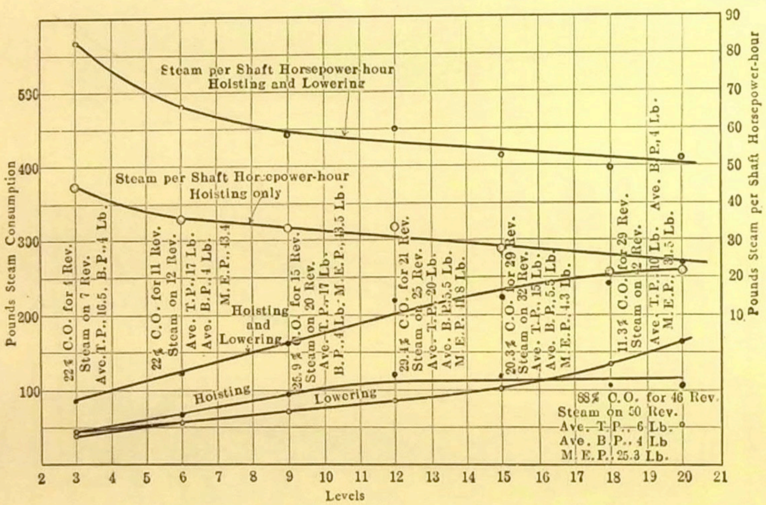

FIG. 8.—STEAM CONSUMPTION FOR HOISTING AND LOWERING, NO. 3 SHAFT. TWIN SIMPLE 24 BY 60-IN. ENGINES. ROCK LOAD 2½ TONS.

side of this connection and capable of being weighted on either side of its fulcrum. This, in turn, makes contact with the stem of a valve connected to a supply of air under pressure, usually 15 lb. The chamber is connected to the steam space of the regenerator and also serves as a connection for a special gage for indicating pressure carried on the regenerator. This pressure causes a deflection of the diaphragm, which, in turn, acts upon the lever arm. The weights can be adjusted on the lever arm so as to balance against any pressure in the regenerator. For instance, if steam is to be admitted to the system at 4 lb. minus pressure, the weights are so adjusted as to permit the lever to be moved sufficiently by this pressure to operate the air valve, causing it to open and admit air to the diaphragm of the reducing valve. This, in turn, opens and admits

the make-up steam to the system, staying open until pressure rises to the 4 lb., when the action of the lever is reversed and the steam shut off.

For the operation of the low-pressure reducing valve, a supply of compressed air at mine pressure is stored in a large receiver that is connected to the mine air main. Leather-seated check valves prevent the return or loss of the air in storage when the pressure in the main is reduced or the compressor shut down. The storage is sufficient to operate these valves for 48 hr. The air taken from these receivers is reduced to a pressure of 15 lb. by means of a reducing valve and used at that pressure by the control board.

The steam from the regenerator is delivered to the buildings to be

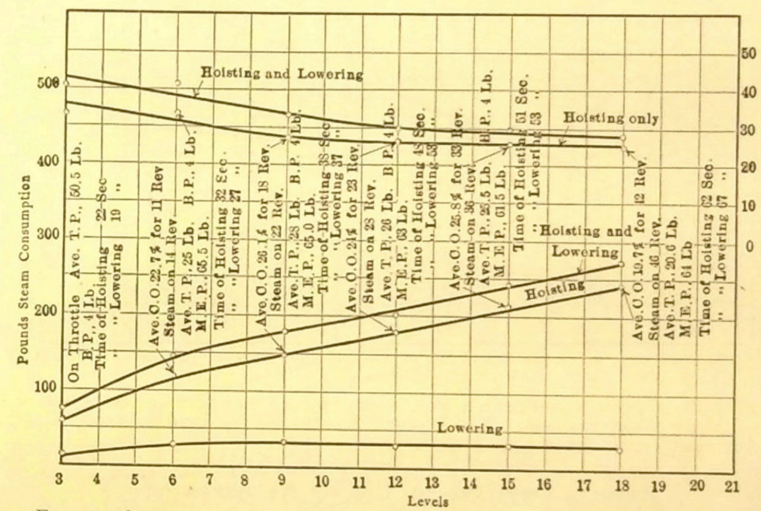

FIG. 9.—STEAM CONSUMPTION FOR HOISTING AND LOWERING, WITH ENGINES ON ATMOSPHERIC PRESSURE, NO. 4 SHAFT. TWIN 24 BY 60-IN. SIMPLE ENGINES. ROCK LOAD 5 TONS.

heated with a drop in pressure not to exceed 2 lb. at times of greatest demand and about 1 lb. during average winter conditions. A two-pipe system is used. In the buildings, the drainage of mains and return lines is in the direction of the flow, thus eliminating all water hammer. Sylphon traps are used on all radiators, direct and indirect, and on all headers and drips.

The air and condensation are collected into and returned by a 3-in. line, the end of which is submerged, forming a water seal that is located in the boiler house. At a point about 20 ft. (6 m.) above the overflow of this water seal is located an air separating tank, from which the air and non-condensable vapors are drawn from the system by a Nash No. 0 vacuum pump, requiring for its operation about 1½ hp. This pump is operated by an electric motor. We have operated some of these pumps for several years, during which time their maintenance costs have been small.

The pressure carried on the regenerator, being also the back pressure on the hoist, varies from 8 to 10 in. vacuum to ½ lb. above the atmosphere; the colder the weather, the lower is the average of the range maintained. The return-line pressure is usually constant at about 18 in. (45 cm.) making a working pressure available, therefore, of about 8 lb. (4 kg.) which is more than sufficient in almost any emergency.

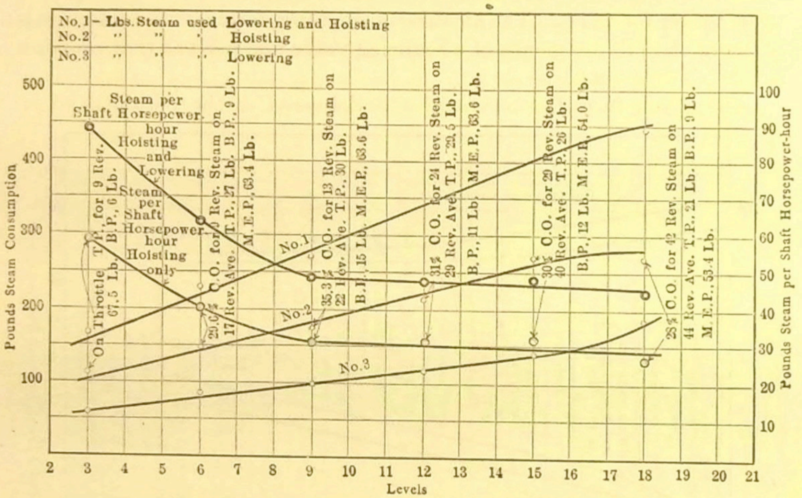

FIG. 10.—STEAM CONSUMPTION FOR HOISTING AND LOWERING, NO. 4 SHAFT. TWIN 24 BY 60-IN. ENGINES. NO. 1 TEST. ENGINE ON HEATING SYSTEM. L. H. ENGINE INDICATED. ROCK LOAD 5 TONS.

RESULTS OBTAINED BY USE OF REGENERATORS

The coal consumption of the several plants before and after installing regenerators, also the tons of rock hoisted during same periods and the radiation involved in each plant are given in the accompanying table.

TABLE 1.—*Results Obtained by Installation of Regenerator*

Shaft	Coal Consumption				Rock Hoisted				Radiation Involved
	Before Regenerator Installation		After Regenerator Installation		Before Regenerator Installation		After Regenerator Installation		
	Years	Tons	Years	Tons	Years	Tons	Years	Tons	Sq. Ft.
Nos. 2–3, Champion	1916	5,340	1917	2,076	1916	290,000	1917	240,000	18,000+
No. 4, Champion	1916	4,296	1917	2,256	1916	335,000	1917	292,000	11,000+
No. 2, Trimountain	1918	4,235	1919	2,908	1918	303,650	1919	295,510	7,000+
Nos. 2–3–4, Baltic	1918	11,410	1919	9,766	1918	373,150	1919	349,970	11,000+
		25,281		17,006		1,301,800		1,177,480	47,000+

There was a slight reduction in the tons hoisted in most plants during the year following the regenerator installations, but this did not affect the coal consumption materially, for, in most cases, some live steam was used for heating, there not being enough hoisting to supply the need. At Nos. 2 and 3 Champion, the live steam thus used would have been available for additional hoisting, so that only a few more tons of coal would have been used had the same tonnage of rock been hoisted. The results exceeded our expectations and, in some instances, the installation and remodeling costs were returned by the savings made during the first year's operation. In all cases at least one boiler was shut down, and in some, two were discontinued.

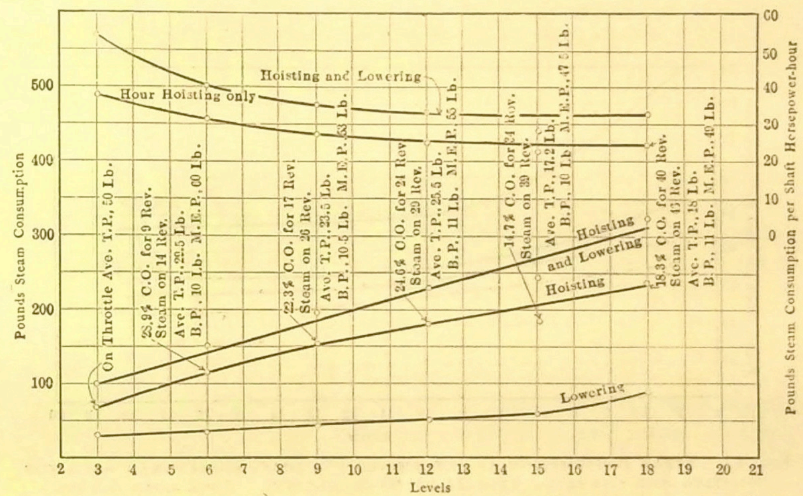

FIG. 11.—STEAM CONSUMPTION FOR HOISTING AND LOWERING, NO. 4 SHAFT. TWIN 24 BY 60-IN. SIMPLE ENGINES. ROCK LOAD 5 TONS.

In the forepart of the paper it was stated that the exhaust from some of the hoists was used for heating before regenerators were installed and that back pressures of 10 lb. or more had to be carried at times to supply the necessary steam for heating. It was desirable to know the relative steam consumption of the hoists operating under these conditions as compared with their operation when exhausting to the atmosphere. We were concerned, not so much with the actual, but rather with the relative consumption of steam, so steam-indicator diagrams were used. It was assumed that the condensation in the engine cylinders and pipe lines under both conditions would be the same, so that the diagram should reveal, approximately, the actual difference.

The skip, in each case, was filled with what was considered an average load of rock; this load was used throughout the test for all hoisting. Continuous indicator cards were taken, hoisting from every third level. From these diagrams, the average cut-off pressure and the length of cut-off were determined and the weight of the apparent steam consumption ascertained. These tests were made with various back pressures on the engines, and were run on a 24 by 60-in. (61 by 152 cm.) engine, using a 5-ton skip, at No. 4 shaft of the Champion mine; a 32 by 72-in. engine, using a 5-ton skip, at No. 1; a 24 by 60-in. engine, using a 2½-ton skip, at No. 3; and a 32 by 72-in. engine, using a 2½ ton skip, at No. 2. The revolutions made by the engines were counted for each run, and the time in which runs were made ascertained by stop watch. The mean effective pressure,

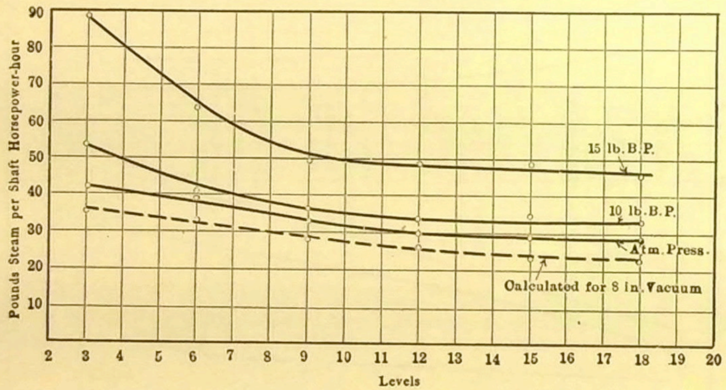

FIG. 12.—STEAM CONSUMPTION AS DETERMINED PER SHAFT-HORSEPOWER HOUR FOR HOISTING AND LOWERING WITH 24 BY 60-IN. ENGINES. ROCK LOAD 5 TONS.

total steam consumption, and pounds steam per shaft horsepower-hour were determined for both hoisting and lowering from the various depths. No account was taken of the steam of condensation, the amounts represented are as determined by the diagrams.

Curves showing these values are shown in Figs. 7 to 12. Fig. 12 makes a comparison of the steam consumption per shaft horsepower-hour for a 24 by 60-in. engine hoisting a 5-ton loaded skip when operating at various back pressures. The dotted line shows the calculated consumption were the hoist to operate at 8 in. vacuum, which is the back pressure obtainable when regenerators are used; this result has since been verified. This comparison shows why a saving of one-third of the coal is possible.

Method Used for Calculating Regenerator Requirements

To show method of figuring regenerator requirements, the requirements for the large plant at Champion, viz., No. 2 and 3 have been taken as an example.

The radiation to be heated at that time totaled 16,000 sq. ft. Allowing ⅓ lb. of steam per square foot for coldest weather, the maximum requirements per hour would be 5300 lb., and for average winter conditions, with a consumption of ¼ lb. per square foot, 4000 lb. per hour. In addition to this, about 600 lb. are required for heating boiler feedwater, and 10 per cent. must be allowed for condensation in transmission, requiring, therefore, approximately 5000 lb. per hour as the average consumption. The hoisting averaged about fifty-five trips during the 8-hr. working period, and was from an average depth of 1600 ft. The time to make the complete hoisting cycle was 110 sec. The idle period, or time during which no steam flows, was 6.9 min., and under actual conditions at that time did not often exceed 12 minutes.

The exhaust from two hoists are used to supply the regenerator. The average steam consumption of these engines per cycle when hoisting from the sixteenth level (this being the average hoisting depth) was found to be 275 lb., making available an average of 3800 lb. per hour. To this must be added steam from the auxiliary cylinders of the hoists, which amounted to an additional 12 per cent. or about 400 lb.; also, 200 lb. from boiler feed pumps, making a total available of 4400 lb. per hour.

For a 12-min. idling period of both hoists, a steam storage of 1200 lb. was required to provide for the heating requirements during the coldest weather. The amount of water required to store that amount of steam, when using a pressure range on the regenerator from 8 in. vacuum to zero, can be determined as follows:

Latent heat of steam at 4 in. of vacuum, or average of the working range = 975 B.t.u.

975 × 1200 lb. steam equals 1,170,000 B.t.u.'s required.

Temperature of water in presence of steam at atmospheric pressure, 212°; temperature of water at 8 in. of vacuum, 197.7°; difference, 14.3°.

Pounds of water required to store this heat = 1,170,000 ÷ 14.3 = 81,818 lb.

Weight of water at the above temperature equals 60 lb. per cubic foot; amount of water required, 81,818 ÷ 60 = 1363 cu. ft.

Storage capacity of the regenerator installed, 1190 cu. ft.