No. 751,718. PATENTED FEB. 9, 1904.

S. M. COCKBURN.

STEAM GENERATOR.

APPLICATION FILED OCT. 24, 1902.

NO MODEL. 2 SHEETS—SHEET 1.

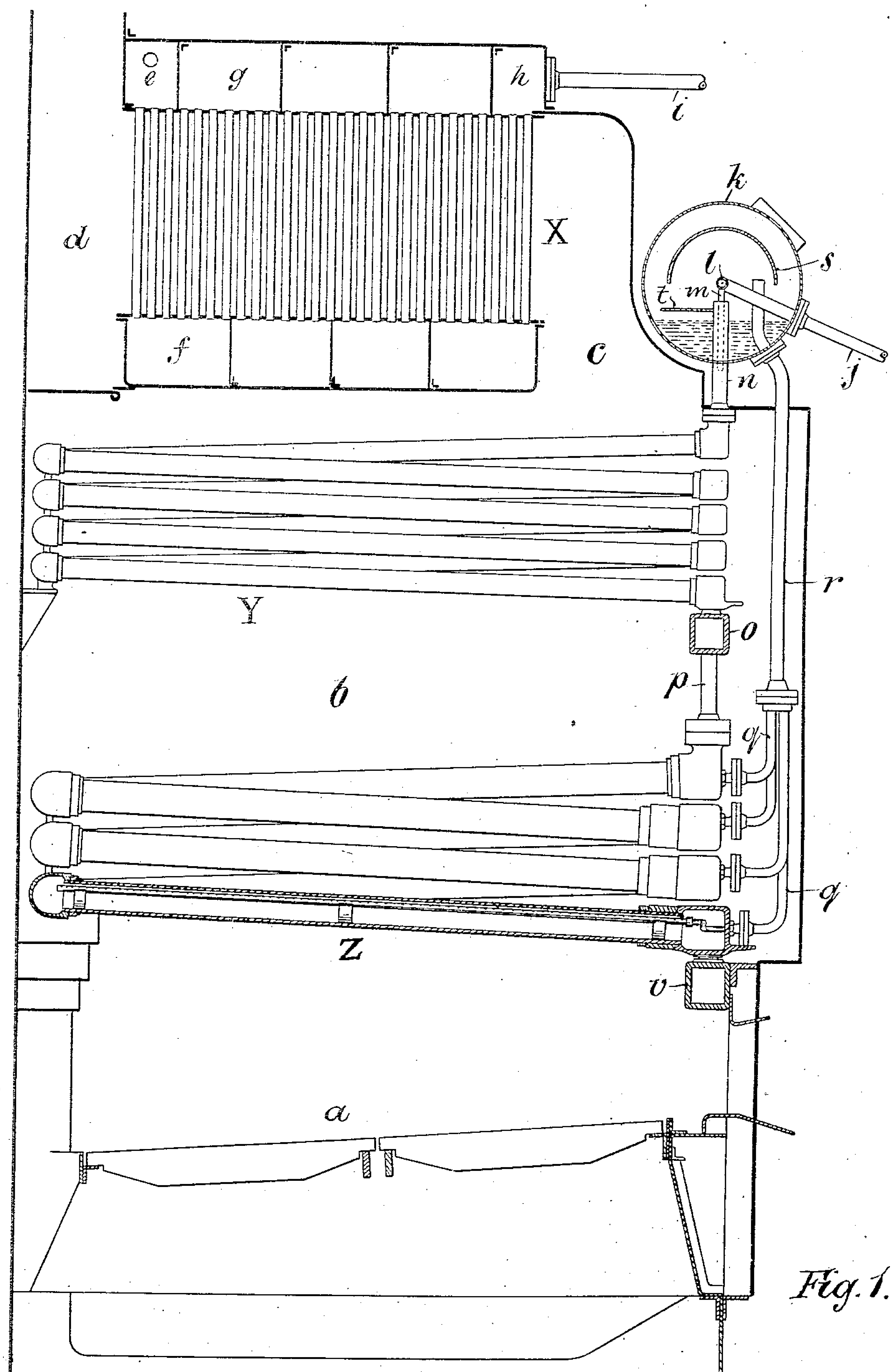

Fig. 1.

WITNESSES
H. M. Kuehne
J. M. Dowling

INVENTOR
Sidney Manthorpe Cockburn
By Richards & Co. ATTORNEYS

No. 751,718.

PATENTED FEB. 9, 1904

S. M. COCKBURN.

STEAM GENERATOR.

APPLICATION FILED OCT. 24, 1902.

NO MODEL.

2 SHEETS—SHEET 2.

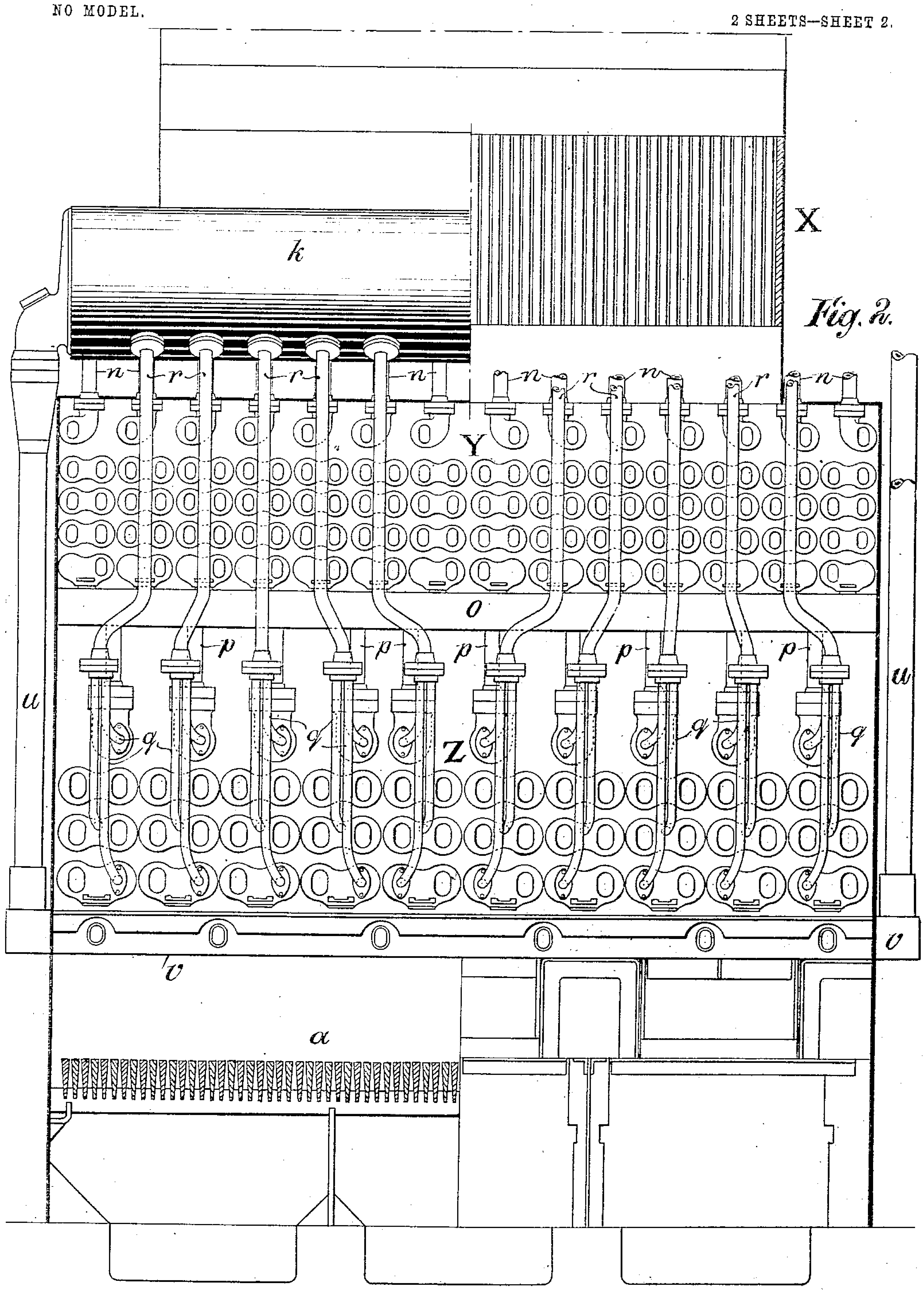

Fig. 2.

WITNESSES
H. M. Kuehne
J. M. Dowling

INVENTOR
Sidney Maudslay Cockburn
By Richards & Co ATTORNEYS

UNITED STATES PATENT OFFICE.

SIDNEY MANTHORP COCKBURN, OF LONDON, ENGLAND.

STEAM-GENERATOR.

SPECIFICATION forming part of Letters Patent No. 751,718, dated February 9, 1904.

Application filed October 24, 1902. Serial No. 128,611. (No model.)

To all whom it may concern:

Be it known that I, SIDNEY MANTHORP COCKBURN, Assoc. M. Inst. C. E., of No. 22 Southampton Buildings, London, W. C., England, have invented certain new and useful Improvements in Steam-Generators; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

This invention relates to a new system whereby heat may be more efficiently transferred than hitherto from the products of combustion of fuel to water which is required to be converted into steam; and it consists in the provision of three heat-transmitting portions of the steam-generator, each of which has a distinct function to perform, through which in succession the water is caused to flow and past which the products of combustion are required to proceed in a reverse order. The first portion through which the water flows is provided with sufficient heating-surface to transmit the heat requisite to raise the temperature of the feed-water up to 100° centigrade. This feed-heater is required to have only a little more strength than would be necessary if it were open to the atmosphere. The path of the water through this low-pressure feed-heater (L. P. F. H.) is elongated by so constructing the vessel that the water is required to make a succession of excursions, in each succeeding one of which it comes in contact with surfaces on the other side of which are products of combustion at a temperature higher than in the previous excursion, and thus the temperature of the feed-water will be elevated by a series of steps to 100° centigrade, and, conversely, the products of combustion will be lowered in temperature by an equal number of steps. At the end of its transit through this low-pressure feed-heater (L. P. F. H.) the water is pumped through a somewhat similarly constructed high-pressure feed-heater (H. P. F. H.) in which the pressure is approximately the same as in the boiler and in which by a second succession of excursions the water is raised in temperature up to the boiling-point which corresponds to the boiler-pressure. In this operation also the products of combustion are lowered in temperature by a succession of steps, these steps being antecedent to those which take place in the low-pressure feed-heater. The high-pressure feed-heater is provided with sufficient heating-surface to transmit the heat requisite to raise the temperature of the feed-water from 100° centigrade to the boiling temperature of the boiler-pressure, having regard to the difference of temperature between the products of combustion and the water which is the cause of the flow of heat from one to the other. The water thus heated flows into the third portion of the heating apparatus, where it receives heat at the constant temperature of boiling and is turned into steam. This portion is the boiler proper or evaporator, and the supply of heat to it is derived from the burning fuel largely by radiation during the process of combustion and from the products immediately after combustion while they are at a very high temperature.

On account of the high temperature of the source of heat the large quantity requisite to supply what is necessary for the evaporation of the water can be transmitted through a comparatively small extent of heating-surface, as will be presently shown.

In order to more explicitly set forth the nature of my invention and the effect of it on the design and construction of a steam-generator, I will take as a representative example a case in which it is desired to generate steam at a pressure of two hundred pounds per square inch (by gage) from water which is initially at a temperature of 38° centigrade.

I will assume that the fuel from which the heat is derived has a calorific value per pound of eight thousand and fifty centigrade thermal units, of which five per cent. is unavailable on account of imperfect combustion. I will further assume that seventeen pounds of air are consumed per pound of fuel, forming eighteen pounds of products, and that these products are permitted to escape into the chimney at a temperature of 200° centigrade. A reference to the appropriate tables will show that the temperature of boiling under the assumed pressure is 198° centigrade and that the quantities of heat requisite to perform the three functions of heating the water from 38° to 100° centigrade, heating the water from 100° to 198° centigrade, and evaporating the water will be, respectively, sixty-two, ninety-eight, and four hundred and sixty-six centigrade thermal units per pound of water or, respectively, ten, sixteen, and seventy-four per cent. of the whole heat requisite. Suppose these quantities of heat to be abstracted from the products of combustion in a reverse order, then supposing also that the specific heat of the products is constant throughout and equal to .245, the effect of the abstraction of heat in lowering the temperature of the products can be most easily determined and expressed by estimating what the initial temperature of the gases would be if all the heat of combustion were momentarily to reside in the gases immediately after combustion. Such an initial temperature would be equal to $\frac{95}{100}\cdot\frac{8050}{18\times .245}$ plus the initial temperature of the atmosphere $=1734+17$, or, say, 1750° centigrade. The actual temperature of the furnace may not be and probably would not be as great as this on account of the delayed combustion by disassociation effect; but this figure from which two hundred is to be subtracted will give a measure of the heat available. The total heat available equals that derivable from the reduction of the temperature of the products from 1750° to 200° centigrade.

To provide the seventy-four per cent. wanted for evaporation, the products will suffer reduction of temperature to 603° centigrade. To provide the sixteen per cent. wanted in the high-pressure feed-heater, they will be further reduced to 355° centigrade and finally to 200° centigrade in yielding the further ten per cent. wanted in the low-pressure feed-heater.

The mean of the two extreme temperatures in the low-pressure feed-heater will be $\frac{1}{2}(355+200)=278°$ centigrade, the mean temperature of the water in that heater being $\frac{1}{2}(100+38)=69°$ centigrade. In the high-pressure feed-heater the mean temperature of the gases will be $\frac{1}{2}(603+355)=479°$ centigrade, and of the water $\frac{1}{2}(198+100)=149$.

In determining the mean temperature in the evaporator it will probably not be correct to take 1750° centigrade as the initial temperature, but something less—say 1700°—giving a mean $=\frac{1}{2}(1700+603)=1152°$ centigrade, the water receiving heat at the constant temperature of 198° centigrade. Now the rate of flow of heat from the gases to the water will be some function of the difference of temperature, being proportional to, say, $(t-t')^n$. Experiments show that the value of n on the whole approximates to two, being probably greater than two for high temperatures and less than two for low temperatures.

Assuming the rate of flow of heat to be proportional to the square of the difference of temperature and that the other conditions which affect the rate are the same in each of the three portions of the system, the area of the heating-surface requisite on these assumptions in the evaporator, the high-pressure feed-heater, and the low-pressure feed-heater, respectively, may be calculated as being relatively to one another in the proportions

$$\frac{74}{(1152-198)^2} : \frac{16}{(476-149)^2} : \frac{10}{(278-69)^2}$$

that is, 18 : 32 : 50 per cent. of the whole heating-surface very approximately.

Effects which have not been taken into account in the previous calculation may alter the proportionate magnitude of the required heating-surfaces to some extent. Some effects will tend to an increase of certain figures, others to a decrease of these figures, the general result being that under a comparatively large range of circumstances about twenty per cent. of the total heating-surface of the steam-generator will be wanted in the evaporator, about thirty per cent. in the high-pressure feed-heater, and the remaining fifty per cent. in the low-pressure feed-heater. These figures exhibit one of the pronounced features of my invention—namely, that about one-half of the whole steam-generating apparatus may be constructed with a strength only a little more than sufficient to bear the atmospheric pressure, and the joints of this vessel will not be subjected to a pressure tending to cause leakage except to an insignificant amount.

Although the two other parts of the generator are subjected to the full boiler-pressure, the larger of the two—namely, the high-pressure feed-heater—is not required to provide for the generation of steam and its joints and surfaces are not subjected to any considerable temperature.

The relatively small vessel, the evaporator alone, is subjected to the trying conditions to which the whole of the steam-generator as at present constructed and used is exposed.

A second great feature of my invention lies in the opportunity it offers for the more complete utilization of the heat in the products of combustion. Such a low temperature of escape as 200° centigrade would hardly be possible under the present normal circumstances of the working of a boiler in which the temperature is 198° centigrade; but with my system I have, even at the end of the operation, a difference of temperature equal to 200° minus 38° available for causing a flow of heat. Thus the temperature could easily be reduced below 200° centigrade and a still higher degree of efficiency obtained. Not only does economy of heat result from these circumstances, but also a saving of heating-surface for the maintenance of a considerable difference of temperature throughout the operation will enable a less area of heating-surface to pass all the heat required.

For example, to pass the heat which flows from the products of combustion through the high-pressure feed-heater into water which has a temperature of 198° centigrade instead of into water which has a mean temperature of 149° centigrade would require thirty-seven per cent. more heating-surface than is requisite in the high-pressure feed-heater.

While almost any type of boiler can be adapted to carry out my system of heating, the Belleville type of construction, which I have chosen for illustration, is specially suitable for the purpose.

Referring to the accompanying drawings, Figure 1 is a side elevation partly in section; and Fig. 2 is a front elevation, also partly in section.

X is the low-pressure feed-heater, situated in the highest portion of the uptake for the furnace-gas. Y is the high-pressure feed-heater, and Z is the evaporator, exposed in its lowest portion to the immediate radiant heat of the fire.

The heated products of combustion flow upward from the furnace *a* between the tubes of Z into a space *b*, from which they flow upward between the tubes of Y, streaming toward the front of the boiler into the space *c*, from which they pass between the tubes of X to the passage *d*, which leads to the chimney or funnel. As the gases proceed they get gradually reduced in temperature by contact with the colder surfaces of the tubes which they encounter.

The feed-water from the hot-well or feed-tank enters the compartment *e* of the feed-heater X, which is subjected to a pressure only a little greater than the atmosphere. It flows through some of the tubes of X into the compartment *f* and then upward through some more tubes into *g*, and so on. After undergoing eight excursions, as shown in the drawings, it will arrive at *h*, from which it is conducted by the pipe *i* to the uptake of a feed-pump, whereby it is forced into the high-pressure feed-heater against the boiler-pressure. From this pump the water is delivered through the pipe *j* into the drum *k*. The pipe *j* is connected to the pipe *l*, which extends along the length of the drum, from which a number of branches *m* lead downward into the upper terminals *n* of the zigzag elements of Y. The branches *m* fit loosely into the terminals *n*, leaving a free passage for the escape of any steam or air which may be generated or liberated in Y at starting or when the conditions are abnormal. The water in separate streams then proceeds downward along the zigzag channels of the elements of Y and arrives at the horizontal tube *o*, where the streams intermingle. From *o* a number of vertical branches *p p* conduct the water, which is now heated to the boiling-point of the boiler-pressure, into the upper ends of the zigzag elements of the evaporator Z, along which it flows downward, being gradually converted into steam on its way.

Into each of the front junction-boxes of the evaporator Z is fitted a steam-extracting tube *q*, which preferably, but not necessarily, will have internal extensions consisting of perforated pipes supported in the upper portion of the generator-tubes. The four tubes *q* of each element of Z join into one tube *r*, which leads into the steam-drum *k*. By such means the steam generated in Z will be quietly conducted to the steam-space with little displacement or commotion of the water in the evaporator. In the tubes *q* and *r* there will be a quantity of steam. Thus there will be a difference of head in the tubes *q* and in the generator-tubes into which they are fitted. This will induce a flow of fluid from the latter to the former. The steam which will rise to the top side of the generator-tubes will, on account of the situations of the orifices of *q* and its perforated extensions, have precedence of entry; but if steam is not generated as quickly as it can under the existing difference of head flow through the tubes *q* then some water will accompany the steam and occupy a portion of the tubes *q* and *r*. Consequently in general there will be a quantity of water discharged with the steam through the upper ends of the tubes *r*. This will strike against the curved baffle-plate *s* and falling on the flat baffle-plate *t* will occupy first the lower portion of the drum *k* and then proceed from there by the down-comers *u*, of which there is one at each end, to the horizontal pipe *v*.

From *v* there are short nipple connections to the bottom tube of each of the elements of Z. Thus there will be a certain amount of circulation of water through the evaporator Z; but all this water will be more or less exactly at the constant temperature of boiling and the effect will not be inconsistent with my principle of progressive heating.

In the drawings the low-pressure feed-heater X is shown as if constructed in the most economical manner capable of bearing little more than the atmospheric pressure. When so made, it will in general be requisite to submit the feed-water to two successive pumping operations—one to pass it into and through the low-pressure feed-heater from the hot-well of the condenser and the other to pump it a second time after it has been heated to 100° centrgrade into the high-pressure feed-heater against the pressure of the boiler. It may under certain circumstances be considered desirable to avoid this double operation, in which case it will be requisite to make the whole of the heating apparatus capable of standing the boiler-pressure. This can be readily effected by extending the dimensions of the part Y by increasing the number of tubes in each of its elements. There will then be no break in the continuity of the process of heating the water from the feed-water temperature to the temperature of boiling and the heating will be entirely progressive, as by the present construction. This process of amalgamation may be carried still further if convenience of construction should render it desirable by joining an element of Y directly on to an element of Z instead of intermingling the streams which pass through Y in the horizontal tube *o* before the water passes into the elements of Z. By making the portion X separate from Y, as in the drawings, it will in the case of a marine boiler be possible on an emergency to use X as an evaporator of sea-water to make up loss of feed-water by leakage and use the portions Y and Z to provide the steam for the engines.

I claim—

1. A steam-generator comprising a steam-chamber and a plurality of water-containing devices arranged in series, means for causing a flow of water through the series of water-containing devices from one end to the other, means for applying heat to said water-containing devices at temperatures decreasing toward the water-inlet end of the series, means for withdrawing the steam from the heating-surface immediately it is generated so as to maintain the heat-receiving portion of the generator entirely full of water and means for returning direct to the steam-generating portion any boiling water conveyed with the steam therefrom.

2. A steam-generator comprising a steam-chamber and a plurality of water-containing devices arranged in series consisting of nearly horizontal tubes, means for causing a flow of water through the series of water-containing devices from the upper end to the lower, means for applying heat to said water-containing devices at temperatures decreasing toward the upper water-inlet end of the series, means for withdrawing the steam from the lower portion of the water-containing devices and conducting it to the steam-chamber consisting of perforated steam-extracting pipes and ascension-pipes connected therewith and down-comer pipes leading direct from the steam-chamber to the lower portions of the water-containing devices.

3. A steam-generator comprising a steam-chamber and a plurality of water-containing devices arranged in series consisting of nearly horizontal tubes, means for causing a flow of water through the series of water-containing devices from the upper end to the lower, means for applying heat to said water-containing devices at temperatures decreasing toward the upper water-inlet end of the series, means for withdrawing the steam from the lower portion of the water-containing devices and conducting it to the steam-chamber consisting of perforated steam-extracting pipes and ascension-pipes connected therewith, down-comer pipes leading direct from the steam-chamber to the lowest portion of the water-containing devices and means for keeping separate the water supplied at the upper end of the series of water-containing devices from that conveyed with the steam through the steam-extracting pipes until they meet in the steam-generating portion of the boiler.

4. In a device of the class described, a water-containing device comprising a plurality of tubes, junction-boxes connecting the ends of said tubes, the consecutive tubes lying side by side and sloping in opposite directions, a feed-pipe having a branch inserted into the upper end of said device, a steam-drum, a steam-extracting pipe inserted in the lower junction-box and also into the steam-drum, a horizontal pipe connected to the lowest junction-box and a down-comer pipe connecting the steam-drum to the horizontal pipe.

In testimony that I claim the foregoing as my invention I have signed my name in the presence of two subscribing witnesses.

SIDNEY MANTHORP COCKBURN.

Witnesses:
T. A. HEARSON,
WALTER J. SKERTEN.