(*Paper No. 3606.*)

"A Sterilized Water-Supply at Leavesden Asylum."

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The Leavesden Asylum, in Hertfordshire, is situated 3 miles north of Watford, at an elevation of 350 feet above sea-level. In 1899 an exceptionally severe outbreak of diarrhœa was noticed amongst the patients, with a correspondingly high death-rate. On investigation it was found that similar but less severe manifestations had been observed in previous years; and that the death-rate in this Asylum had been much higher than that in sister-institutions elsewhere under the same Board.

Articles of diet were examined, and sanitary details tested, but were found to be fairly satisfactory. The sewage is treated on a farm having a total area of 27 acres, but a large portion of this area is put out of use for lengthened periods.

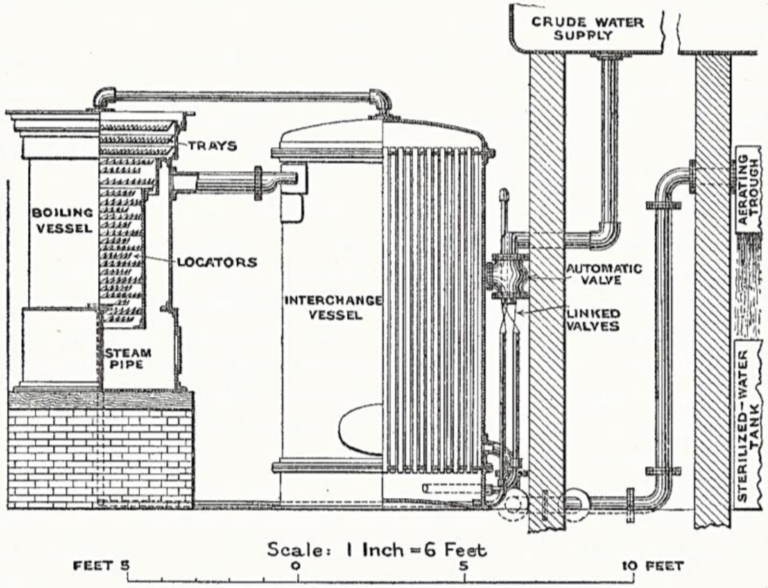
The water-supply was next examined, and, although drawn from a well 225 feet in depth, in the chalk, was found upon bacteriological examination to be contaminated with surface-organisms to a sufficient extent to justify the conclusion that this was the source of the outbreak. The well-water was therefore shut off from the drinking-supplies and a limited service was laid on from an outside source, which was not, however, of sufficient volume to supply the needs of the institution, these requiring 80,000 to 100,000 gallons per day. Various alternatives were considered, the first being that of arranging for supplies from an outside source; and as the Asylum estate comprised portions of districts covered by two entirely distinct water companies, competitive terms were obtained which were presumably the lowest procurable, but nevertheless were not sufficiently attractive to induce the Metropolitan Asylums Board to adopt this method of getting over the difficulty. The next alternative was water-softening by the lime-process; it was suggested that the objectionable organisms would be thrown down with the chalk during the process of "softening," and would thus

be eliminated. As it was not absolutely certain, however, that this would be the case, and as the health and lives of about 2,500 persons depended upon the result, further consideration of this method was discarded. The next scheme considered was the adaptation of some form of sterilization, two forms being discussed, namely, chemical and mechanical; the first was ruled out of court on account of the difficulty of finding a suitable agent which would destroy the injurious organisms and yet be innocuous to human beings, whilst the mechanical method involved some risk, as it could not be ascertained that any attempt had been made to treat by this means so large a volume of water as 9,000 gallons per hour. Here the question of expense arose, and inquiries in various quarters resulted in offers to install a plant which would sterilize the water at costs for fuel ranging between $1\frac{3}{4}d.$ and 1*s.* per 1,000 gallons treated, the treatment consisting in each case of boiling and subsequent aeration. It was thought that if the lowest cost could be adhered to, namely, that quoted by the Lawrence Patent Water-Softening and Sterilizing Company, Limited, who supplied the apparatus described in this Paper, the existing supply, with its accompanying machinery, might be utilized. Moreover, the water would be not only sterilized but also softened—an important consideration, having regard to the fact that the well-water, being drawn from "the chalk," was exceptionally hard—and the whole cost of pumping, sterilizing and softening would not amount to one-half that of either of the outside supplies.

The questions to be discussed included the important one of the final temperature of the water when leaving the apparatus, as it could not be allowed to escape at boiling-point and cool down slowly to the desired temperature; it was therefore decided to arrange that the difference in temperature between the incoming and outgoing waters should not exceed 20° F., and the temporary hardness should be reduced from 19° to 9° on the Clark scale. A small apparatus, having a capacity of about 30 gallons per hour, was first tried, and the results obtained were very satisfactory; the temperatures and softening were well within the limits laid down, and the water was pronounced by the Asylum Board's bacteriologist to be absolutely sterile. The larger plant, capable of sterilizing 9,000 gallons per hour, was then considered, and temporary arrangements were made by installing first a plant capable of sterilizing 5,500 gallons per hour. This plant is referred to as No. 7 in the Table given in the Appendix. From the data obtained from its working, the plant which has been finally installed was constructed; it has been in constant use for 12 months, giving very satisfactory results, at a working-cost certainly not exceeding $1\frac{1}{2}d.$ per 1,000 gallons for fuel. The cost for fuel can be easily checked, as asylum-work is very regular, and the coal-bill for any 12 months is readily comparable with that for previous years.

The advantages of the boiler-type of sterilizer lie in the fact that no filtering-material is used, so that the danger of trouble arising from this portion of a plant being left unchanged or uncleaned is entirely avoided; and in the ease with which the various "locator"-plates can be removed and the adhering scale released. The

Fig. 1.

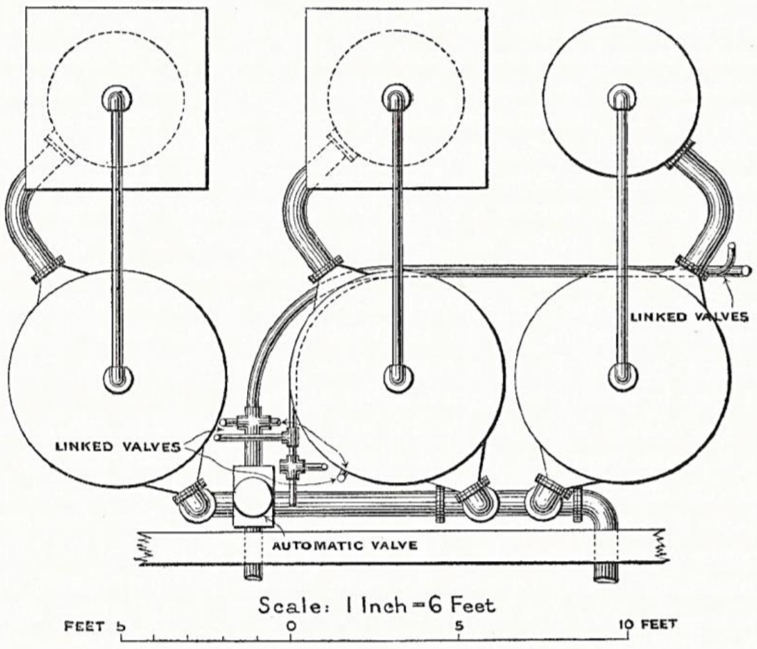


SECTIONAL ELEVATION OF ONE OF THE THREE UNITS OF THE LEAVESDEN ASYLUM PLANT.

apparatus consists of three independent units, each dealing with 3,000 gallons of water per hour, the water being boiled by the injection of live steam only. Each unit, *Fig. 1*, consists of a heat-interchange vessel, similar in form to a surface-condenser, 5 feet 10 inches in internal diameter by 9 feet 6 inches in height between the tube-plates, and containing 580 solid-drawn copper tubes, 2 inches in diameter, expanded into brass tube-plates; and a boiling-vessel of mild steel plate, the upper part holding perforated trays on which a considerable portion of the scale is deposited, and the lower part forming a mud-chamber. Two of the boiling-vessels at Leavesden

have square tops and bottoms, the central part being cylindrical; the third vessel is cylindrical throughout, *Fig. 2*. In the centre of the boiling-vessel a galvanized inner cylinder is fixed, as shown in *Fig. 1*, containing the "locator"-plates, upon which the carbonates are deposited in solid form. The action of the apparatus is as follows:—The water-supply, taken from a large overhead tank, first passes through an automatic valve controlled by a steam-piston, so regulated that should the steam-pressure fall, from any cause, the whole

Fig. 2.



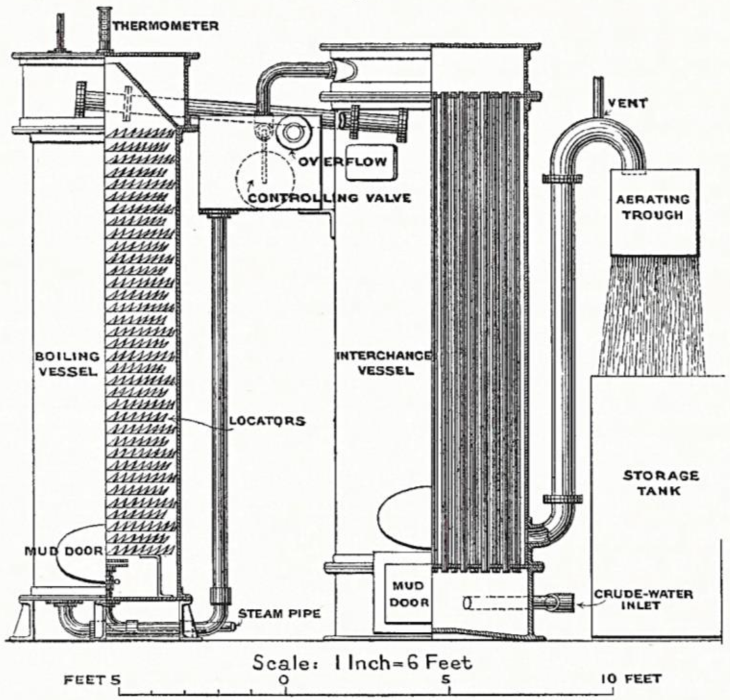
PLAN OF THE LEAVESDEN ASYLUM PLANT.

water-supply is immediately shut off; the water is then led into the bottom boxes of the interchange-vessels, and, slowly rising through the tubes, attains a temperature of about 190° F. by taking up the heat from the return-water outside the tubes. It then passes over from the top box through the cover of the boiling-vessel, falling first over the trays, which are above the water-level. These trays are of mild steel, and are bolted together in groups for easy removal, the edges being "finned" in order to break up the flow of water. Large trays having a hole in the centre alternate with smaller trays having no hole, thus dividing the ebullition-cylinder into a number of chambers and presenting as large a surface as possible for the collection of deposit from the water while it is boiling. Steam is taken in through the bottom of the boiling-vessels and discharges between a pair of flanges in a horizontal direction, rising upwards against the downward flow of water and escaping to atmosphere, if not condensed, through vent-pipes in the covers of the boiling-vessels. The boiled water, having reached the bottom of the ebullition-chamber, rises in the annular space between the two cylinders and passes out by the return-pipe into the heat-interchange vessel just below the top tube-plate. Descending slowly outside the copper tubes, it parts with its heat and leaves by an outlet-connection just above the bottom tube-plate on the opposite side, *Fig. 1*. The three outlet-pipes are taken to one collecting-pipe, which is carried to the proper level to keep the interchange-vessels full of water, and there discharges into a teakwood aerating-trough in the open air, having a copper bottom perforated with fine holes, the size and number of which are so adjusted as to give the "critical head" to ensure fine streams descending individually, without mingling, into the tank below; this results in a most satisfactory re-aeration of the sterilized water. The water is then pumped up into the main storage-tank in the water-tower, whence it flows by gravity to all parts of the Asylum.

The form in which the plant is now made is shown in *Fig. 3*, and is in many respects a distinct advance upon that shown in *Fig. 1*. The automatic valve, with its steam-piston, is dispensed with, and the water is taken directly into the bottom box in two places, to ensure better distribution to the tubes. The internal diameter of the heat-interchange vessel remains the same, but the distance between the tube-plates is 10 feet instead of 9 feet 6 inches, and if 2-inch tubes are adopted 600 tubes are used. A 2-inch plug is provided in the centre of the top tube-plate for the insertion of a hose-pipe to wash away any soft scale that may form in course of time on the outside of the tubes. The top box is made with a flat top, and the outlet is taken from the side opposite to the two inlets, instead of from the centre, the object being to secure the best possible distribution between the tubes. The water flows from the top box into a large ball-valve tank, from which it is taken to the bottom of the boiling-vessel; this tank is provided with an overflow-pipe. The boiling-vessel consists of a cylinder, 10 feet in height by 2 feet 11 inches in internal diameter, and is filled with "locator"-plates, the area of the depositing surface being about double that provided by the apparatus shown in *Fig. 1*.

It is surmounted by a discharge-box of somewhat larger diameter and a movable cone having an opening at the top. The water-level is normally 4 inches below the top of this cone. Until ebullition is attained in the boiling-vessel no water can possibly pass over, and any leakage through the ball-valve would be taken away through the overflow-pipe in the valve-tank, which is at a lower level than the top of the cone. The water-supply valve may therefore always be

Fig. 3.



Lawrence Automatic Steam Sterilizer and Softener.

left open, and the apparatus worked solely by the steam-valve; the amount of water passing through will be directly proportional to the amount of steam used, the process of ebullition being quite sufficient to raise the water over the top of the cone, thus ensuring that every drop of water passing through the apparatus shall have been actually boiled, and therefore sterilized. A vent-pipe to atmosphere is provided in the cover of the boiling-vessel as in the apparatus previously described.

When working at the rate of 3,000 gallons per hour the time taken by each particle of water to pass through the boiling-vessel is 10 minutes, the temperature varying between 212° and 225° F. As soon as the water is discharged over the top of the cone, owing to the difference in statical head between the column of water from the valve-tank to the bottom of the boiling-vessel, and the column of mixed water and steam in the boiling-vessel, the water returns to the heat-interchange vessel by two pipes connecting with that vessel at points 120° from the outlet, and from each other. As the whole of the water in this apparatus must boil for 10 minutes before leaving the ebullition-chamber, any deposit on the outside of the tubes in the interchange-vessel is found to be very slight. The extreme simplicity of this design, both in working and in construction, is obvious. For use in tropical countries as a sterilizer only, where the water is very soft, the sterilizing-chamber might be made quite small and fixed on the top of the heat-interchange vessel, reducing the actual ground-space required, exclusive of the storage-tank, to about 7 feet by 6 feet 6 inches.

Bacteriological test.—As it was absolutely essential that no contact should take place between the incoming and the outgoing water, bacteriological tests were made by putting into the water a special organism not normally present in it. If this organism could be demonstrated to be present in the effluent, it might be concluded that some portion of the supply had escaped the process of sterilization. The organism selected was *Bacillus Prodigiosus*, which produces a brilliant red pigment when grown on ordinary culture-media, and thus enables it to be picked out at once from any other organisms which may be present. In carrying out this experiment it was necessary to ascertain how long the water took to pass through the apparatus, and for this purpose a solution of common starch was used; its presence at the outflow was easily detected by its giving a dark blue colour when tested with a solution of iodine. The apparatus was "fed" with the starch-solution for 10 minutes before the test-organism was introduced, the full quantity of water (9,000 gallons per hour) being passed through, as in ordinary working. The total capacity of the various vessels composing the apparatus is about 6,000 gallons, and the starch-experiment showed that the time required for any particular body of water to undergo the complete cycle of operations was about 45 minutes, the starch being recognized in the effluent after that period. As the *Prodigiosus* emulsion was added immediately after stopping the introduction of the starch, it was an easy matter to decide when to commence taking samples for the bacteriological tests. Thirty-two samples were taken in all, extending over the whole period during which traces of starch could be detected in the effluent, and in no instance was there found any sign of *Prodigiosus*.

Coal-consumption.—A test was made to ascertain the cost of fuel necessary for sterilizing-purposes, but this could not be accurately carried out owing to the necessity of using one of the four Lancashire boilers installed at the Asylum, which was much too large for the purpose and was situated some 200 feet away from the sterilizer. The specially long steam-main required to isolate the plant from the rest of the institution accounted for very large losses due to radiation, whilst under ordinary conditions the supply of steam is taken from a main supplying the general requirements of the Asylum and passing within 20 feet of the sterilizer. The cost of fuel for this test was $2\frac{1}{8}d.$ per 1,000 gallons, when sterilizing 9,000 gallons per hour, and with coal costing 17*s.* 1*d.* per ton delivered at the Asylum, but returns extending over 12 months under ordinary working conditions show that the cost does not exceed $1\frac{1}{2}d.$ per 1,000 gallons.

Temperatures.—The monthly records of the average temperatures of the incoming and outgoing water are given in the following Table,

Date.	Average Temperature of Incoming Water during Month.	Average Temperature of Outgoing or Sterilized Water during Month.	Difference in Temperature between Incoming and Outgoing Water.
1904	°F.	°F.	°F.
October	53	76	23
November	53	75	22
December	52	74	22
1905			
January	52	74	22
February	52	73	21
March	52	72	20
April	52	71	19
May	52	73	21
June	53	74	21
July	54	74	20
August	54	75	21
September	54	75	21

from which it will be seen that the smallest differences in temperature were obtained, not in the winter months, when the losses from radiation might be expected to be greatest, but in the summer months, and when the various cooling-tubes of the apparatus were incrusted with an accumulation of carbonates to a thickness of $\frac{1}{4}$ inch at the upper ends of the copper tubes in the heat-interchange vessels, thus showing that under certain conditions the accumulation of scale, even to an extensive degree, does not materially affect the transmission of heat through metal surfaces protected by such incrustation.

Experiments made in connection with the design of the apparatus.—Experiments were made to determine the following points in connection with the design of this plant:—

(*a*) The size of tubes which would give the best results.

(*b*) Whether any advantage would accrue from the use of a tube bent in the form of a spiral.

(*c*) Whether by disturbance of the water outside the tubes in the interchange-vessel a more rapid transference of heat could be brought about.

(*d*) Whether the use of baffle-plates to prevent local vertical displacement of the water was advantageous.

(*e*) The critical speed for the water passing through the interchange-vessel.

(*f*) The effect of increasing the space between the tubes.

(*g*) The effect of varying the area of the surface presented by the interchange-vessel.

In order to investigate these points, experiments were made with the following apparatus:—

(1) An ordinary 20–25-gallon Lawrence plant.

(2) A tubular heat-interchange vessel, $4\frac{3}{4}$ inches in diameter, containing nineteen tubes, each $\frac{3}{4}$ inch in diameter, $\frac{1}{30}$ inch in thickness and 2 feet in length between the tube-plates, the tubes being so arranged as to facilitate as much as possible the interchange of heat.

(3) The same arrangement as in (2) but with baffle-plates introduced so as to cause the water to circulate backwards and forwards between the tubes in its descent through the vessel.

(4) An annular vessel, 10 inches in external diameter and $16\frac{1}{4}$ inches in height, containing a spiral formed from a copper tube 38 feet in length, $\frac{3}{4}$ inch in diameter and $\frac{1}{30}$ inch in thickness.

(The area of the heat-interchange surface in all these apparatus was as nearly as possible identical, and in the case of (2) and (3) the diameter of the containing vessel was so proportioned as to give nearly the same volume of water inside and outside the tubes, in order to make the velocity of the water ascending through the tubes the same as that of the water descending outside them.)

(5) A tubular heat-interchange vessel, $7\frac{1}{2}$ inches in diameter, containing six tubes, $\frac{1}{15}$ inch in thickness, 2 inches in diameter and $22\frac{1}{8}$ inches in length; these tubes were flattened throughout most of their length to an elliptical form, the minor axis being $\frac{3}{4}$ inch. The capacity inside and outside the tubes was made double that of (2) and (3) so as to double the time taken for a given volume of water to pass through the apparatus.

(6) The same apparatus as in (2), the number of tubes being reduced from nineteen to ten, thus reducing the heat-interchange surface from 7·5 square feet to 4 square feet, and increasing the spacing of the tubes from $1\frac{1}{2}$ inch to $2\frac{1}{4}$ inches.

(7) Full-size apparatus capable of dealing with 5,540 gallons per hour.

The results of the experiments are shown in tabular form in the Appendix, but before proceeding to draw any conclusions from them it may be well to consider the conditions which control the interchange of heat between two sides of a plate kept at a constant difference of temperature. The rate of interchange per unit of area depends (1) on the conductivity of the metal; and (2) on the difference of temperature between the two sides of the plate, being proportional to that difference. Column G in the Appendix gives the number of heat-units given up per square foot of interchange-surface by the sterilized water, in cooling, to the unsterilized water passing through the heat-interchange vessel to the boiling-vessel. The number is obtained by multiplying the number of gallons passing through per hour (Column B) by the rise of temperature (difference of Columns C and D), and dividing by the area of the interchange-surface, and is expressed in British Thermal Units. Column H gives the heat lost by the sterilized water in cooling, being the discharge (Column B) multiplied by the difference of the temperatures given in Columns E and F and divided by the area of the interchange-surface.

The conclusions which may be drawn from the results of the experiments are:—

(*a*) The best results have been obtained with flattened tubes 2 inches in diameter (No. 5).

(*b*) No advantage is gained by adopting a spiral instead of a straight tube (No. 4).

(*c*) The water when cooling down is much better left undisturbed. (The results of the experiment from which this conclusion is drawn are not shown in the Table.)

(*d*) The use of baffle-plates in the small apparatus appeared to produce no beneficial effect (compare Nos. 3 and 2).

(*e*) The effect of varying the rate of flow (Column B) is very much less marked than might have been expected, comparing (3) and (5).

(*f*) The effect of increasing the spacing of the tubes, within certain limits, did not decrease the efficiency (compare Nos. 6 and 2).

(*g*) In No. 6 the interchange surface was 4 square feet; in No. 2 it was 7·52 square feet; and the amount of heat interchanged is almost proportional to the surface.

The mechanical difficulties attending the use of elliptical tubes led to the final adoption of a round tube of 2 inches diameter for the Leavesden apparatus; this probably accounts for the fact that the results obtained with the actual apparatus installed (No. 8) are not quite so good as those obtained with the experimental plant (No. 5).

With regard to the rate of interchange of heat through the walls of the tubes, no conclusions can be drawn as to the relative efficiency of tubes of different materials, as only copper tubes were used in the experiments. As to the thickness of the tube, in (1) and (7) the metal was $\frac{1}{50}$ inch in thickness, in (2), (3), (4) and (6) it was $\frac{1}{30}$ inch, and in (5) it was $\frac{1}{15}$ inch, but the actual results obtained show that the thickness of the metal can have very little effect. The explanation of this lies probably in the fact that the mean path for the transference of heat from the water, through the plate, to the water, lies for a considerable distance through water, the conductivity of which is low, and only for a very short distance through copper, the conductivity of which is high. The total resistance to the flow of heat would therefore be practically that offered by the water, the resistance offered by the copper being negligible. For the same reason it is probable that other metals, of less conductivity, might be used for the tubes without materially affecting the results, and this contention is supported by the fact that, as already pointed out, a considerable quantity of scale may accumulate on the tubes themselves without materially diminishing the efficiency. The interchange of heat is shown by the results to be proportional to the difference between the mean temperatures of the water inside and outside the tube.

In conclusion, the Author is of opinion that the process of sterilizing water by the application of heat is of immense importance where certainty of action, simplicity of construction, and the use of unskilled labour are necessities.

The particulars given in this Paper refer to steam-heated apparatus only, but there is no reason why the heat should not be applied directly by means of a Bunsen burner, oil-lamp or coal-fire; indeed, portable plants heated by one or other of these means have been already tried by the War Office authorities.

The Author desires to express his indebtedness to Mr. W. J. E. Binnie, M. Inst. C.E., for valuable aid in connection with the apparatus, to Dr. Cartwright Wood, for the results of the bacteriological tests, and to Mr. G. W. Westrope, of the Lawrence Sterilizing Company, Limited, for the very ingenious suggestion of using the cone at the top of the boiling-vessel, instead of the automatic control-valve, to cut off the supply of unsterilized water should actual boiling not take place.

The Paper is accompanied by three sun-prints, from which the Figures in the text have been prepared.

APPENDIX.

Results of Tests of Water-Softening and Sterilizing Apparatus.

No.	Nature of Apparatus.	Discharge in Gallons per Hour.	Temperature of Cold Unsterilized Water.	Temperature of Hot Unsterilized Water.	Temperature of Hot Sterilized Water.	Temperature of Cold Sterilized Water.	Heat Units taken up by Unsterilized Water per Square Foot of Interchange Surface per Hour.	Heat Units lost by Sterilized Water per Square Foot of Interchange Surface per Hour.	Column G corrected to a Temperature Difference between Inflow and Outflow (col. F—col. C) of 20° F.	Time taken for Water to pass through apparatus.
	Column A.	Column B.	Column C.	Column D.	Column E.	Column F.	Column G.	Column H.	Column L.	Column M
		Gallons.	°F.	°F.	°F.	°F.	B.Th.U.	B.Th.U.	B.Th.U.	Minutes.
1	Lawrence 20–25 gallon (nominal) apparatus, copper about $\frac{1}{50}$ inch in thickness; interchange surface, 7·5 square feet . . .	6·4	37	183·5	206	53	1,250	1,300	$1,250\times\frac{20}{16}=1,560$	$7\frac{1}{2}$
		16·8	45·5	169	208·5	81·5	2,770	2,840	$2,770\times\frac{20}{36}=1,540$	3
2	Tubular interchange-vessel, nineteen $\frac{3}{4}$-inch tubes, $\frac{1}{30}$ inch in thickness, 2 feet in length, spaced $1\frac{1}{8}$ inch apart; interchange surface, 7·5 square feet	15	45·5	169	208·5	80	2,410	2,570	$2,410\times\frac{20}{34\cdot5}=1,400$	$3\frac{1}{2}$
		20·3	45·5	147·5[1]	189[1]	84·5	2,760	2,830	$2,760\times\frac{20}{39}=1,410$	$2\frac{1}{2}$
3	Same as (2), with baffle-plates introduced to circulate the water	6·1	37	172·5	204	53	1,100	1,230	$1,100\times\frac{20}{16}=1,380$	8
		19·25	43	133[1]	171[1]	79	2,310	2,360	$2,310\times\frac{20}{36}=1,280$	2·5
4	Spiral of 38 feet of copper tube, $\frac{3}{4}$ inch in diameter, $\frac{1}{30}$ inch in thickness, in an annular vessel; interchange surface, 7·5 square feet	11·5	46	174	208·5	69·5	1,960	2,130	$1,960\times\frac{20}{23\cdot5}=1,670$	5·5
5	Tubular interchange-vessel, six 2-inch tubes, $\frac{1}{15}$ inch in thickness, $22\frac{3}{8}$ inches in length, spaced $2\frac{5}{8}$ inches apart; interchange surface, 5·9 square feet	5	45	189	208·5	57	1,220	1,280	$1,220\times\frac{20}{12}=2,030$	24
		13·2	45	172·5	208·5	77	2,850	2,940	$2,850\times\frac{20}{32}=1,780$	9
6	Same interchange-vessel as (2), with only ten tubes, spaced $2\frac{1}{4}$ inches apart; interchange surface, 4 square feet . . .	7·3	48	172·5	205	77	2,270	2,340	$2,270\times\frac{20}{29}=1,570$	10
7	Mean results of experiments made on plant of 5,540 gallons capacity. Thickness of tubes, $\frac{1}{50}$ inch; interchange surface, 6,200 square feet	5,540	57	191	212	72·9	1,200	1,240	$1,200\times\frac{20}{15\cdot9}=1,510$	20
8	Leavesden Asylum plant; copper tubes 2 inches in diameter; thickness 18 S.W.G.; interchange surface, 8,649 square feet	9,000	52	191	212	73	1,450	1,450	$1,450\times\frac{20}{21}=1,380$	40

[1] In these cases the water was not boiling in the boiling-vessel.