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SOME NOTES OF EXPERIMENTS IN THE TRANSMISSION OF HEAT FROM NON-LUMINOUS FLAMES THROUGH THIN WATER-COOLED PLATES.

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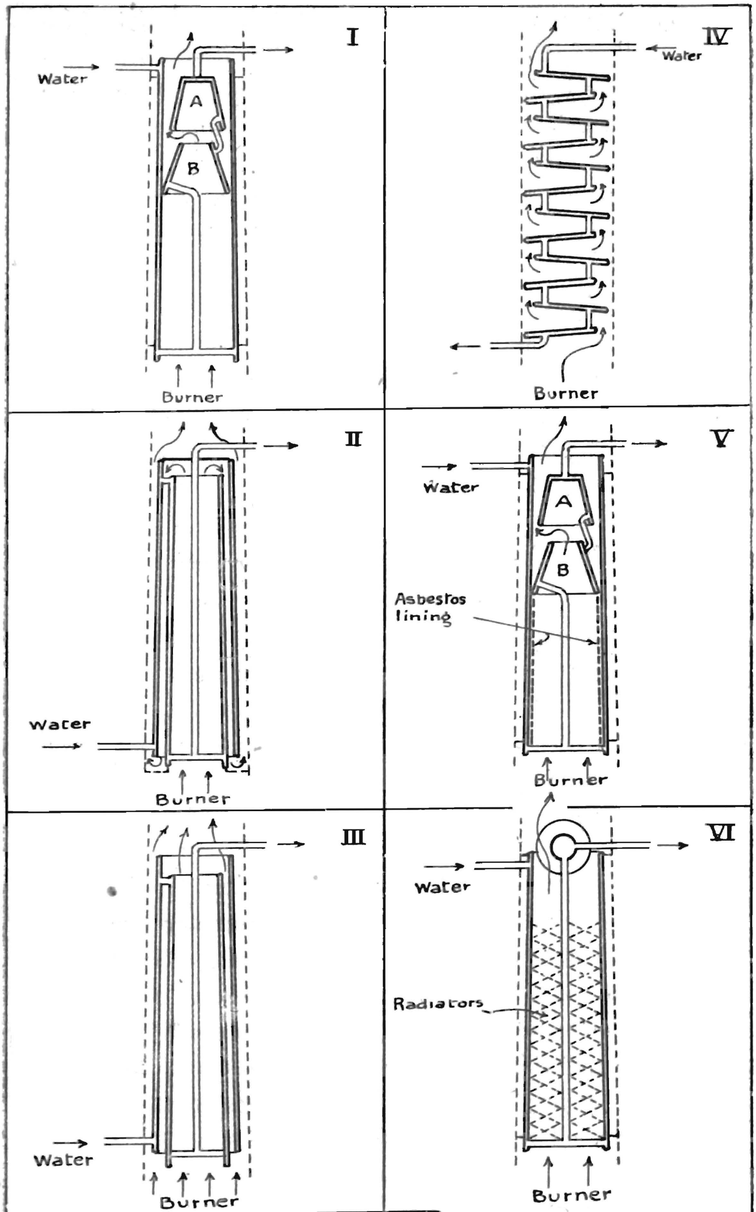
In any discussion that may ensue on the few notes that I have the pleasure to present to you this evening I would request that the limitation expressed by the title to the paper be kept in view.

The experiments to which I am about to refer were undertaken with a view to ascertain a simple, and, at the same time, efficient, construction to adopt for the purpose of rapidly heating a flow of water of about 1½ gallons per minute from a temperature of about 60 deg. F. to 120 deg. F., the heat being supplied by a bunsen flame consuming carburetted hydrogen, viz., town gas.

The construction deduced from the experiments was to be used as the heating element of an ordinary household bath heater, and had it been suggested to me at the commencement of the experiments that they might possibly furnish any matter of interest suitable for presentation in the form of a paper before this Association I should probably have ridiculed the idea.

Some time previously I had had considerable experience in the use of both luminous and non-luminous producer gas on a large scale for the purpose of supplying heat to zinc distillation furnaces, ore roasting furnaces, and to steam boilers of the Babcock and Wilcox type, and was therefore well aware of the method that it is necessary to adopt for each or either kind of flame. In case there should be any uncertainty in the minds of some of my audience, may I be permitted to remind you that a luminous source of heat, such as a yellow gas flame, or a mass of incandescent material, is capable of radiating heat, and that in the case of coal fire boilers a very large proportion of the heat produced is transmitted through the shell of the boiler by the radiant rays of heat, quite independently of that transmitted by conduction or by the contact of the flame or incandescent material with the surface to be heated. As a non-luminous flame possesses little or no power of radiating heat, the heat from it can only be conveyed by actual contact of the flame with the surface to be heated. Hence when non-luminous gas, such as carbon monoxide, hydrogen, or commercial combinations of these, such as Mond gas, are used for heating boilers, it is necessary to provide a honey-combed mass of fire-resisting material, such as fire-brick, in which the gas is burnt, and this incandescent material provides the radiation necessary for transmitting heat to the boiler, thus making up for the absence of radiation in the flame itself. The hot products of combustion, also, of course, furnish a means of transmitting heat in the usual way, in just the same manner as they would if they were the product of a luminous source of heat.

For the purpose of economical construction it was decided at the outset to adopt a design in which combustion takes place inside a vertical tube, the walls of which are hollow, forming an annular enclosure around the flame, and in this enclosure flows the stream of water that it is desired to heat; and in order to deflect the flame against the walls of the tube two deflectors, A and B, also having hollow walls through which the water passed, were provided. Fig. 1 illustrates this construction. The arrows show the path of the flame and the



Outer Casings shewn in dotted lines.

water. Although shown straight in the figures, the interior wall of the main tube is corrugated, these corrugations are helical to the axis of the tube, and are for the purpose primarily of imparting to it sufficient radial depth to withstand the pressure to which it will be subject, and at the same time also provide a path for the passage of the water. The tube is slightly tapered, being approximately 7½ ins. internal diam. at the bottom and 6½ ins. at the top. The length is about 29 inches. The water enters at the top of the tube and descends, and its exit is provided by a pipe which leaves the apex of the upper deflector and rises to a height about 6 inches above the outer tube, so as to ensure that the upper part of the main outer tube is always flooded.

A coal gas bunsen burner was placed as indicated, and the products of combustion leave by a flue 3 inches in diameter and about 8 feet in height.

In all the experiments to be described the combustion of gas was at the rate of 2.33 cube feet per minute. Two gas meters in series were used for measuring the flow of gas. The pressure in the pipe supplying the gas was, during the periods of the experiments, remarkably constant, and showed 30-10 in an ordinary glass tube U gauge.

The quantity of water flowing was measured by allowing the discharge to fall over a thermometer placed in the neck of a standard one-gallon measure, the time taken to fill the measure being noted on a watch, and each reading is the mean of the three consecutive readings. The temperature of the cold water supply was only taken at the commencement and end of each experiment and was for all practical purposes constant at 60 deg. F.

Figure 1 shows the variations in the form of the heating element for each experiment, and Table A is furnished, giving the results obtained.

TABLE A.

Calorific value of gas taken as 550 B.Th.U. per cubic foot.
Inlet temperature of water 60° F.

	Experiment No. I.			Experiment No. II.			Experiment No. III.			Experiment No. V.			Experiment No. VI.		
Galls. per minute.	1·12	·81	·75	1·04	·84	·75	1·C0	·86	·62	1·50	1·00	·79	1·50	1·20	1·00
Temp. of Exit water in °/F.	105	125	130	110	123	128	133	137	154	110	120	137	108	119	125
Degrees rise.	45	65	70	50	63	68	73	77	94	50	60	77	48	59	65
% Recovered Heat.	39·3	41·1	41·0	40·6	41·3	39·8	57·0	51·6	45·5	58·5	46·8	47·5	56·1	55 2	50 7

Gas consumption 2·33 cube ft per minute.

You will note that in experiment I. the recovery of heat was about 40 per cent. This seemed a comparatively poor result considering the temperature of the flame, the area of the heating surface, and that the flame appeared to have so intimate a contact with the heating surface, but no one seemed able to put forward a reasonable hypothesis to account for it. The most plausible explanation offered was that there was insufficient space in the tube and too many changes of direction of the flame to permit of proper combustion.

In experiment No. II. the form of the heating element was changed as indicated in figure II., and incidentally the area of the heating surface increased. In this case the flame has an unrestricted space to burn in, viz., within the inner tube; it then descends a portion of the distance down the annular space between the inner and the outer tubes, and the hot products of combustion ascend on the outside of the outer tube. An asbestos-lined outer casing was provided. The temperature of the outer casing was about 200 deg. F. The table shows that the results from this construction were just about the same as in experiment No. I.

In No. III. the same construction was used as in No. II., except that the cap A. on the outer tube was removed and the flame allowed to ascend partly up the inside of the centre tube, partly up the annular space between the tubes, and partly up on the outside of the outer tube. The results showed an improvement of about 10 per cent. in the recovery of heat. It was noted, however, that the outer asbestos-lined casing became fairly hot, viz., about 500 deg. F., and the question arose as to whether the radiant heat from this on to the outside of the outer tube did not contribute towards the better result. Hitherto the idea had been to entirely rely upon intimate contact of the flame with the surface to be heated in order to obtain the required transmission of heat. The experiments Nos. I. and II. were repeated; it was noticed that some unburnt gas escaped from the top of the flue, and this gas could be ignited after it left the flue. It was difficult for the moment to account for the presence of this unburnt gas, seeing that it must have passed up the tube in the presence of the flame. Repetition of the experiments, however, proved conclusively that quite a large percentage of the gas did in some manner manage to exist in an unconsumed condition while in contact with the flame of the bunsen burner.

A consideration of the matter suggested the following theory. As is well known, the phenomena of flame is merely one phase of the process of combustion. Combustion or oxidation in some form or other is going on all around us, at varying temperatures; even the desk upon which these notes rest is gradually oxidising away. When the temperature of combustion is anything above 1500 deg. F. the phenomena of flame is usually present

Since the walls of the tube were maintained at a comparatively low temperature by the constant flow of water, was it possible that the cool surface lowered the temperature of the flame sufficiently rapidly to extinguish it adjacent to the walls of the tube, thus forming a thin layer of unburnt gas and air between the flame and the tube? Such gas, once extinguished would not again ignite unless raised to approximately flame temperature, and as it was kept cool by contact with the walls of the tube until it had left the tube, the gas had by then passed down the flame, and thus could escape unburnt up the flue. Further, this layer of unburnt gas between the flame and the walls of the tube, if it existed as here suggested, would also act as an insulator.

In treatises relating to combustion, references have been occasionally made to the fact that when a vessel containing water is being heated, the cold water prevents contact between the boiler and the flame, and that all heat reaching the boiler shell has to be transmitted across this thin cold space by means of radiation.

If the suggested extinction of the flame where it approaches contact with the cold walls of the tube be correct, then if the inside of the tube were lined with an insulator of less resistance to the passage of heat than the film of chilled gas, and moreover of such a nature that it would remain in position and therefore become hot, a greater transmission of heat from the flame to the cold metal wall of the tube should take place. To test this, Experiment No. V. was carried out; exactly the same apparatus and conditions were used as in Experiment No. II., except that the lower half of the inside of the inner tube was lined with asbestos millboard sheet ⅛in. thick. The results showed an increase in the recovery of heat, viz., about 10 per cent. above that obtained in the original experiment, and further, no unburnt gas could be detected at the top of the flue. Had a thin iron lining been used instead of asbestos, the recovery of heat would probably have been greater. The experiments were not carried further.

The data obtained would indicate, contrary, I think I may say, to the generally accepted idea, that in those cases where it is desired to rapidly heat a flow of cold liquid through a metal plate with a non-luminous flame that better results will be found to be obtainable if the plate is comparatively thick instead of being thin. The thick plate permits of a heat gradient between the flame and the cold water, and the side of the plate next the flame being comparatively hot does not tend to extinguish the flame.

Further investigation, if one had the time, would, I think, show that with any particular temperature of fluid some particular thickness would give the best result.

The phenomena referred to does not seem to apply in such a marked manner when the temperature of the water is above about 150 deg. F., although I have not had an opportunity of fully investigating this; it may be that with the temperature of 150 deg. F. on the cooler side of the plate that the upper temperature of the thermal gradient is then sufficiently high not to seriously interfere with flame temperature; but it hardly seems credible that so small an increase in temperature as about 100 deg. F. should do this.

Early in the course of the experiments, and prior to Experiment No. V. being made, a heating element was constructed according to Fig. IV. This was done with a view to obtaining better results, it being considered that if the surfaces with which the flame came in contact were more nearly horizontal than vertical better recovery of heat would be made. In this construction a series of twelve hollow plates, about 8 inches diameter, of thin sheet metal, were assembled as shown, the water entering the top one and leaving at the bottom, the whole being encased in an outer cover.

The result obtained was so poor that no record was kept of the figures; as a matter of fact it was impossible to maintain the flame above the second tray; the extinguishing effect of the water-cooled surfaces on the flame was very marked, and the unburnt gases escaping at the top of the flue produced a larger flame than that under the heater.

As the experiments made indicated that the results obtainable were very poor if the mere contact of the non-luminous flame with the water-cooled surfaces was relied upon to transmit heat, the ultimate construction decided on was a simple tube with hollow walls, as has already been described, and in the interior of which are placed radiators made of any suitable material. These radiators are of such dimensions that they practically fill the tube and make contact with the walls, and at the same time leave room for the flame to play among them. Fig. VI. is a sectional view showing this construction.

The results obtained are given under Experiment No. VI. in the Table, and appear to indicate conclusively that heat can be much more readily transmitted by radiation than by flame contact under the conditions obtaining.

Possibly everyone present has noticed that if you place a cold piece of metal in a non-luminous flame that the surface of the metal is immediately covered with moisture, which, later on, disappears as the metal rises in temperature. This is due to the cold surface condensing the water vapor present in the flame; and if the reduction of temperature of the flame where it touches the cold surface is sufficient to permit this, it should also be low enough to extinguish the flame.

The same phenomena occurs with economiser tubes if the feed water is cold. In the case of the experiments I have referred to this was especially noticeable, particularly in the case of Experiments Nos. I. to IV., where flame contact alone was relied upon for the transmission of heat, quite a trickle of water being noticeable from the inside of the tube. This suggests that the first two or three sets of tubes in an economiser might with advantage be made much thicker than that merely necessary to withstand the internal pressure that such tubes have to resist, thus permitting a greater range in the heat gradient in the thickness of the tube.

It occurred to me that if what I have suggested as taking place when a non-luminous flame impinges upon a continuously cooled thin plate be true, viz., the extinguishing of the flame immediately adjacent to the plate, that in boiling water in a thin metal vessel, such as a billy can or kerosene tin, the rate of increase in temperature should be slower at the commencement than later on. The rate for the transmission of heat through clean plates is generally given as the square of the differences of the temperatures of the fire and the water. This being so, the rate of increase in the temperature of the water per unit of time ought to be greater at the commencement than say, at 200 deg. F. That is, if the law just enunciated is of general application. If, however, it only refers to the transmission of heat through clean plates when the water on the other side of the plate is boiling, then it may not apply.

In order to test this I made a few experiments, but I regret to say, without any very definite result. The temperature rise was taken at minute intervals, and I have included the results here (Table B) for what they may be worth. The rise in temperature all through appears to be irregular, although each test shows a slow rate at the commencement; possibly some of the irregularities may be due to irregularities in the capillary tube of the thermometer, and possibly others to the cooling effect of currents of cooler air on the exterior of the vessel being heated.

TABLE B.

Progressive temperatures observed on heating water in thin metal vessel over carburetted hydrogen bunsen flame.

Time in Minutes.	°F.	Rise	°F.	Rise	°F.	Rise	°F.	Rise
1	68		66		67		65	
		17		19		5		5
2	85		85		72		70	
		20		23		8		17
3	105		108		80		87	
		15		22		10		16
4	120		130		90		103	
		20		20		4		9
5	140		150		94		112	
		16		17		9		9
6	156		167		103		121	
		9		18		7		4
7	165		185		110		125	
		20		20		5		19
8	185		205		115		144	
		10		7		5		8
9	195		212		120		159	
		7				6		10
10	212		...		126		162	

In conclusion, I would say that I shall welcome your unreserved discussion, even if it should have the result of showing that I am labouring under a delusion. I wish to emphasise that the experiments were not made with the object of achieving high heat recoveries, but merely to demonstrate the relative recoveries, and that they are workshop experiments, and not laboratory experiments. If the subject matter has been somewhat crudely presented to you this evening, I would ask your indulgence, as the spare time at my disposal recently, that I have been able to devote to the preparation of these notes, has been very limited.

I have to thank Messrs. Anthony Hordern & Sons, Ltd., for their courtesy in allowing me to present these notes, as the investigations have been made on their behalf.

Discussion.

Mr. McEwin said he had great pleasure in proposing a vote of thanks to the author for his paper that evening.

He had but a few remarks to make upon the paper. He considered that the burner was too close to the heater during the experiments, and in Fig. 5, where the Combustion Chamber was formed by the asbestos, much better results could possibly be obtained by lowering this Chamber. Present heaters were inefficient, and there was certainly room for improvement in their design. In Fig. 6 it is almost impossible to put in so much radiating material and keep it hot; the heat would be dissipated quicker than it could be carried to the water. The author suggested that better results could be obtained with a thick plate, but he considered it would not be economical to use a thick plate in the class of heater, as, owing to the short time that the flow would be in contact with the plate, the difference in tempertaure between the two sides of a plate heated to 180° F. would not be very great. He had known of a case where brass condenser tubes were unobtainable at a certain place on the Continent, so thick tubes had to be installed. The results quite unexpectedly showed no difference over those that would obtain when thin plates were used.

Mr. Sinclair asked why coils had not been tried in the heater, and said that he considered that in the design of the heater adopted, the walls had no heating value whatever. Perhaps the walls of the tube were covered with smoke during the experiment, although the author said they were quite clear. If a wire gauze had been used instead of asbestos, the experiment might have shown better