HEAT TRANSFER DUE TO STEAM CONDENSATION.

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A VERY important irreversible process which takes place in a steam engine is the to-and-fro exchange of heat between the working fluid and the cylinder walls as the working fluid rises and falls in temperature. This process is called *cylinder condensation* because actual condensation of steam is a very prominent part of the process; and it has a great influence on the efficiency of a steam engine. Some writers on the steam engine describe this effect as if it were a genuine heat conduction from the hot steam to the cool cylinder walls at one stage of the steam-engine cycle and from the cylinder walls to the cooler steam during another stage of the steam-engine cycle. It is generally recognized, however, that this to-and-fro exchange of heat depends very largely upon the condensation of the steam upon the cylinder walls and its subsequent re-evaporation, and the use of a high-temperature steam jacket around the cylinder, or the employment of superheated steam reduces the to-and-fro exchange of heat by eliminating actual condensation. Under these conditions the only exchange of heat is that which is due to the thermal conductivity of the steam and cylinder walls in the narrow sense of that term.

It is the purpose of this paper to compare experimentally the rates of heat flow from steam to cold metal under two conditions as follows: (*a*) When condensation takes place and (*b*) when no condensation takes place. For the purpose of this comparison hot air is assumed to have the same thermal conductivity as superheated steam, and the comparison is made between the rate of heat flow due to the condensation of steam upon a cold metal surface, and the rate of heat flow when hot air is in contact with the cold metal surface. That is to say, the rates of heat flow are determined (*a*) when a cold metal is immersed in steam and (*b*) when a cold metal is immersed in hot air at the same temperature as the steam.

A solid brass ball weighing 250 grams was placed in steam and in hot air for periods ranging from 20 to 300 seconds and the amount of heat absorbed by the brass for each period of exposure was determined by a calorimeter. The hot air bath was produced by adjusting a Bunsen flame under a large galvanized iron vessel about 20 centimeters high and 10 centimeters in diameter. A thermometer was placed with its bulb near the point in the vessel where the brass ball was to be exposed and by carefully stirring the air inside the vessel the desired temperature could be maintained. When a steam-bath was used instead of hot air some water was put in the vessel and the remainder of the procedure was exactly the same as in the case with the air-bath.

In order to determine how much steam was condensed by the cool brass, a small thin copper cup was suspended below the ball to catch the water which would drop from the ball. The ball and cup were weighed before and after exposure to the steam and thus the weight of condensed water was measured. The copper cup was heated to the temperature of the steam and attached to the cold ball just before they were lowered into the steam and thus any error that might be produced by steam condensing on the copper cup was eliminated. The ball after removal from the steam would reëvaporate some of the water clinging to it if allowed to remain exposed to the atmosphere during the weighing. This loss of condensed water was avoided by quickly dropping the ball and cup into a

TABLE I.

Brass in Hot Air at 94° C.

Time Exposed (Sec.).	Temp. of Hot Air (° C.).	Temp. of Brass Before Immersion (° C.).	Heat Absorbed (Calories).	Mean Heat Absorbed (Calories).
20	94	20.5	29.5	
20	93.5	20.7	28.5	
20	94	20.7	31.7	29.7
60	94.5	20.5	90.5	
60	94	20.5	92.9	91.7
120	94	20	161.8	
120	93.5	22	163	
120	93.5	20	163	162.6
300	94	20.5	462	
300	94	18	406.9	433.5

small beaker of water and measuring the increase in weight of the ball, cup, beaker and water.

Table II.

Brass in Steam at 94° C.

Time Exposed (Sec.).	Temp. of Steam (° C.).	Temp. of Brass Before Immersion (° C.).	Heat Absorbed (Calories).	Mean Heat Absorbed (Calories).
20	96	22.2	698	
20	94	20	712.6	
20	94	20.5	669.7	693.4
60	93.5	22.2	1,463.2	
60	93 5.	24	1,499.2	
60	93	22.2	1,484.7	1482.4
120	93	24	1,548	
120	94	24	1,598	1573
300	94	22.2	1,580	
300	94	22.2	1,616	1598.2

Table III.

Brass in Steam at 94° C.

Time Exposed (Sec.).	Temp. of Steam (° C.).	Temp. of Brass Before Immersion (° C.).	Grams of Steam Condensed.	Mean Grams of Steam Condensed.	Heat Liberated (Calories).
20	94	22.1	1.2		
20	94	22.3	1.22		
20	94	21.8	1.21		
20	93.5	22	1.22	1.2125	649
60	94	22	2.62		
60	94	22.2	2.61		
60	94	20.8	2.62	2.616	1400
120	93.5	21.6	2.55		
120	94	22.2	2.53	2.54	1362
300	94	22	2.44		
300	93.5	21.8	2.45	2.445	1310

The accompanying tables and curves show the results of such observations and calculations. The ordinates of curve *A*, Fig. 1, represent the heat absorbed (in calories) and the abscissas represent the time (in seconds) that the brass ball was exposed to hot air. Curve *B* is the relation between the same two quantities when the ball was exposed to steam. The temperatures of the steam and hot air were as nearly as possible the same (94° C.) and the temperature of the ball before being heated was about 20° C. The ordinates of the curve *C* represent the heat liberated by the measured condensed steam and the abscissas represent the time that the ball was exposed to the steam; the heat liberated by condensation being calculated from the weight of the steam condensed and the heat of vaporization of water.

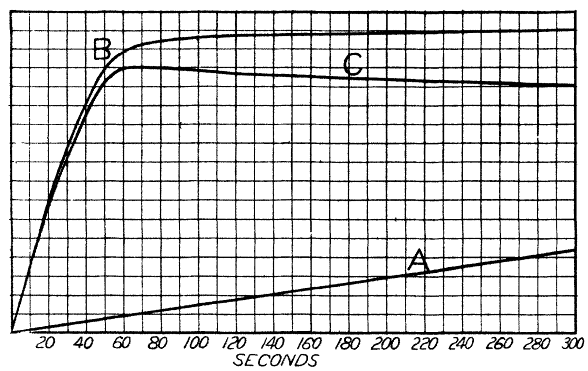

Fig. 1.

The near approach of curve *C* to curve *B* throughout a large portion of their range shows that nearly all the heat given to the ball can be accounted for by the heat of vaporization of the condensed steam. The small slope of curves *B* and *C* beyond a period of exposure greater than 60 seconds is on account of the ball nearly reaching the temperature of the steam at this time.

The temperature of the ball rises so quickly when it is in steam, that the effect of the condensed steam must be determined by comparing the rates of absorbing heat when the periods of exposure to steam and to hot air are short. The ratio of corresponding ordinates of curves *B* and *A* at an abscissa of 20° is about 24 which means that the heat is conducted to a cold metal 24 times as fast from steam at 94° C. as from hot air at the same temperature.

The data of Tables IV., V., VI., VII., VIII. and IX. were taken similarly to that of Tables I., II. and III., but the temperature of the bath from which the metal absorbed heat was higher. Curves

TABLE IV.

Brass in Steam at 98° C.

TABLE V.

Steel in Steam at 98° C.

Time Exposed (Sec.).	Temp. of Brass Before Immersion (° C.).	Heat Absorbed (Calories).	Temp. of Steel Before Immersion (° C.).	Heat Absorbed (Calories).
10	23	729	24.2	741
10	33.7	767		
20	24	1,101	24	1,095
20	24.2	1,030		
40	24	1,375	24	1,635
60	24.2	1,536	25	1,798
120	25	1,576	24.2	1,811
180	24.2	1,595	24.2	1,850
300	24.2	1,590	24.2	1,870

TABLE VI.

Brass in Hot Air at 98° C.

TABLE VII.

Steel in Hot Air at 98° C.

Time Exposed (Sec.).	Temp. of Brass Before Immersion (° C.).	Heat Absorbed (Calories).	Temp. of Steel Before Immersion (° C.).	Heat Absorbed (Calories).
20	24	36	24	27
20	24	28	24	32
60	24	93	24	69
180	24	242	24	192
300	24	425	24	312

TABLE VIII.

Brass in Steam at 99° C.

TABLE IX.

Steel in Steam at 99° C.

Time Exposed (Sec.).	Temp. of Brass Before Immersion (° C.).	Heat Absorbed (Calories).	Temp. of Steel Before Immersion (° C.).	Heat Absorbed (Calories).
20	24	1,373	24	1,569
40	24	1,536	24	1,800
60	24	1,586	24	1,879
180	24	1,577	24	1,912
300	24	1,600	24	1,923

D and *E* show the relation of heat absorbed by a brass ball from a steam-bath to the time of exposure of the ball to steam at temperatures of 98° and 99° C. respectively. Curves *F* and *G* show the relation between the same two quantities for a steel ball exposed to steam at temperatures of 98° and 99° C. respectively. At the higher temperature less air is mixed with the steam and the higher rate of heat absorption from the pure steam is noted from the divergence of curves D and E or F and G.

Curves H and I show the rates at which the brass and steel balls, respectively, absorb heat from hot air. The ratio of ordinates of curves E and H at an abscissa of 20 seconds shows that the

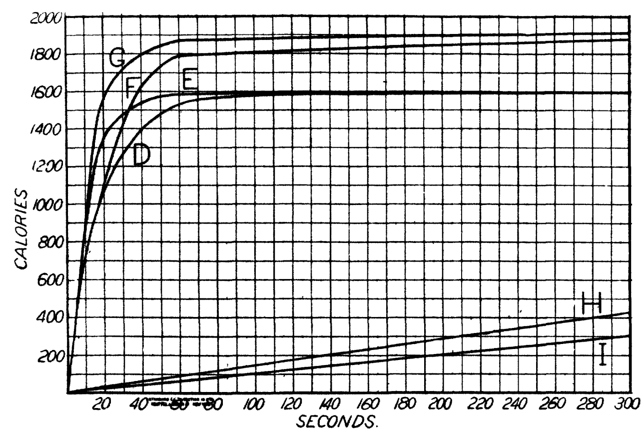

Fig. 2.

brass ball absorbs heat about forty times as fast from steam at 99° C. as from hot air at the same temperature. The ratio of ordinates of curves G and I at an abscissa of 20 seconds shows that the steel ball absorbs heat about fifty times as fast from steam at 99° C. as from hot air at the same temperature.

CONCLUSION.

The rate of delivery of heat by hot steam to a cold metal surface is at least forty times as great as the rate of delivery of heat to the cold metal surface by hot air at the same temperature as the steam, and therefore assuming superheated steam to be approximately the same as air in its thermal conductivity it is evident that the elimination of actual condensation on the cylinder walls of a steam-engine greatly reduces the exchange of heat between the working fluid and the cylinder walls.

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