HEAT LOSSES AND THEIR DEPENDENCE ON AIR VELOCITY

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ABSTRACT. In this investigation, the variation of convective heat losses with different air velocities, for vessels of different shapes and sizes, has been studied. The rate of heat loss is found to depend upon the shape of the vessel used and varies directly as the square-root of the air velocity

INTRODUCTION

A vessel filled with a liquid at a temperature higher than its surroundings, loses heat by conduction, convection, radiation and also by evaporation of the liquid. With suitable arrangements it is easy to reduce considerably, losses by conduction, radiation and evaporation and under these conditions most of the heat loss will be due to convection alone. Now convection is partly natural and partly forced. The heating of a vessel by a current of hot air and the cooling of a surface with an electric fan are examples of forced convection, whereas, the streams of air rising about a warm surface, a hot metal cylinder etc., are examples of natural convection. Obviously the convection will be greater with greater velocity (and natural convection will be small compared to forced one) of the air stream and with greater difference of temperature between the surrounding air and the warm surface.

In the present paper we have investigated heat losses due to convection from different vessels. For this purpose the rate of heat loss from the surface of calorimeters of different shapes and sizes with air velocities above 250 cm/sec. (*i.e.*, 500 ft./min.) was measured and the relation between the heat losses and the air velocities was then studied.

EXPERIMENTAL ARRANGEMENT

The experimental arrangement used in this investigation is as follows:

A calorimeter *A*, containing some warm water, was placed at a distance of about 70 cm from an electric fan *F* and a stream of air proceeding from the fan was directed on this calorimeter after allowing it to pass through a wire grid *G* situated at a distance of about 15 cm from the fan. The top of the calorimeter was closed by a lid having two holes in it. Through one of the holes passed a sensitive thermometer and through the other a stirrer

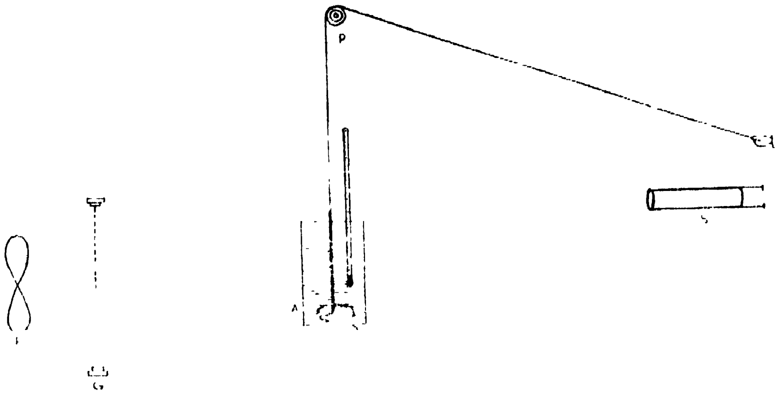

FIG. 1

was kept working so that a uniform temperature was maintained throughout the whole mass of water at any instant. Most of the evaporation was prevented in this way and in some cases a very thin layer of oil was spread on the surface of water inside the calorimeter to help in preventing the evaporation more effectively. The speed of the air stream issuing from the fan was varied by changing the strength of the current in the circuit of the fan and the air velocity was measured by means of a four-cup anemometer placed exactly in the place of the calorimeter *A* before and after the experiment. These values of air velocity were also checked by means of a silvered Kata thermometer (Bedford, 1946). The temperature of the water was measured by focusing a small telescope *S* on the vertical thermometer *T* passing through the lid of the calorimeter *A*. This procedure also eliminated the possibility of affecting the temperature of the calorimeter *A* by the breath of the observer. The stirrer was moved up and down in the calorimeter by connecting it to a string passing over a pulley *P* as shown in figure 1. The other end of the string was held by the observer who could move it to and fro, thus causing a vertical motion of the stirrer in the calorimeter. The temperature of the water was noted at intervals of half a minute and a graph of temperature against time was plotted. From this graph the value of the rate of fall of temperature per unit time, *i.e.*, $\frac{d\theta}{dt}$, for any mean temperature θ could be calculated. The values of $\frac{d\theta}{dt}$ were thus determined for different air velocities as measured by the anemometer and a graph of $\frac{d\theta}{dt}$ against air velocity was plotted. In all the cases investigated, it is found that the rate of fall of temperature is governed by a relation of the type $\frac{d\theta}{dt}=a+b\sqrt{v}$ where a and b are constants and v represents the velocity of the air stream.

Having obtained the values of $\frac{d\theta}{dt}$, the convective heat loss from the calorimeter was calculated by the relation

$$(M+M_0S)\frac{d\theta}{dt}=H=CA\sqrt{v}\Delta\theta$$

where H = heat lost per hour ;
A = area of the calorimeter surface exposed ;
$\Delta\theta$ = difference of temperature between the calorimeter and the surroundings ;
and C = a constant, which will be called the shape-constant hereafter, as it depends only on the shape of the calorimeter used.

It was found that when the calorimeter was subjected to forced convection, practically all the heat loss was due to convection alone. Care was, of course, taken to ensure that no appreciable heat was lost by conduction, radiation or evaporation. For avoiding conduction the base of the calorimeter was made to rest on three points of a tripod stand, small pieces of asbestos being fixed at those points. Radiation was avoided by polishing the calorimeter surface and evaporation was prevented by closing the top of the calorimeter by a lid and also by spreading a thin layer of oil on the surface of the water inside the calorimeter.

Vessels of different shapes and sizes were used as calorimeters in these experiments and the shape constant C was determined for each of them. As will be seen from the results discussed below the shape constant C is found to possess a remarkably constant value for vessels of different materials having different sizes provided their shape was the same. These determinations are expected to give some idea of the comparative efficiency of differently shaped vessels as containers of different fluids.

RESULTS

Figure 2 shows how the convective heat losses vary with different air velocities in the case of vessels of different shapes and sizes, the actual observations being recorded in the Table I. The graphs also show that the convective heat loss decreases as the diameter of the vessel increases.

In figure 3, the heat loss is plotted against the square-root of air velocity and it is found that in every case the graph is a straight line, showing clearly that the relation between heat loss and square-root of air velocity is linear.*

Vessels of copper and tinned iron were used as calorimeters in these experiments and different shapes like cylinders, spheres, rectangular parallelopipeds, etc., were used to find out whether the shape constant C defined

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* The exact nature of the graphs in figures 2 and 3 for velocities below 300 cm./sec. is not fully known as yet. Experiments are being carried out to investigate in this region and the results will be reported in due course.

TABLE I

Shape of the vessel.	Diameter in cm.	Area in sq. metres.	Air velocity in cm/sec	Square-root of air velocity	Heat losses in K cal/hr/m^2/1°C	Shape constant
Cylindrical	15.0	0.1201	400	20.00	20.25	0.95_3
			445	21.10	21.75	
			540	23.24	23.56	
			624	24.98	25.47	
			694	26.34	26.59	
			761	27.58	27.75	
			811	28.48	28.48	
			877	29.62	29.61	
			913	30.23	30.27	
			952	30.86	30.75	
	21.8	0.1807	395	19.87	19.72	0.93_2
			445	21.10	20.94	
			505	22.47	22.32	
			580	24.27	23.88	
			667	25.83	25.46	
			735	27.11	26.50	
			795	28.19	27.32	
			854	29.20	28.47	
			913	30.23	29.49	
			952	30.86	29.77	
Rectangular	..	0.1417	328	18.10	22.79	1.07_1
			395	19.87	24.98	
			505	22.47	27.65	
			580	24.27	29.51	
			667	25.83	31.50	
			735	27.11	32.66	
			795	28.19	33.91	
			854	29.20	34.90	
			901	30.02	35.87	
			940	30.66	36.58	
	...	0.1952	376	19.40	23.70	1.05_9
			445	21.10	25.63	
			540	23.24	27.91	
			624	24.98	29.70	
			694	26.34	30.98	
			761	27.58	32.35	
			811	28.48	33.50	
			877	29.62	34.68	
			913	30.23	35.25	
			956	30.92	35.87	
Spherical	15.8	0.0784	376	19.40	22.25	1.62_9
			445	21.10	25.25	
			540	23.24	28.53	
			624	24.98	31.21	
			694	26.34	33.65	
			761	27.58	35.77	
			811	28.48	37.26	
			877	29.62	39.01	
			913	30.23	39.79	
			956	30.92	41.43	
	20.4	0.1307	395	19.87	22.62	1.56_8
			445	21.10	27.73	
			505	22.47	26.92	
			540	23.24	28.05	
			589	24.27	29.63	
			667	25.83	32.11	
			735	27.11	34.16	
			795	28.19	35.88	
			854	29.20	37.50	
			940	30.66	39.81	

by the relation

$$H = CA\sqrt{v}\,\Delta\theta$$

remains constant. Table I gives the results obtained with vessels of different shapes and different sizes. Following the practice adopted by other

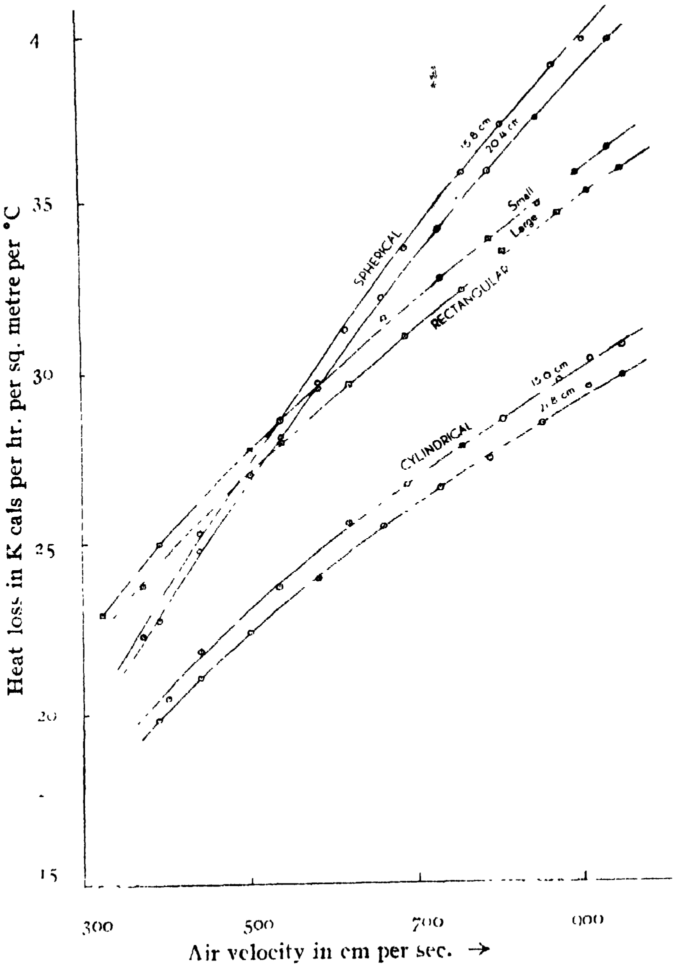

FIG. 2

workers, the heat loss was measured in terms of kilo-calories per hour per square metre per degree Centigrade and the air velocity in centimetres per second.

It will be seen from the table that amongst the different shapes of vessels employed in our experiments, the shape constant C has the lowest value for cylindrical vessels and hence the convective heat loss appears to be least in the case of vessels having a cylindrical shape.

This study is of interest in connection with the thermo-dynamics of heat interchange between the body and the surroundings under different ambient conditions. Recently, a lot of work has been done in this field

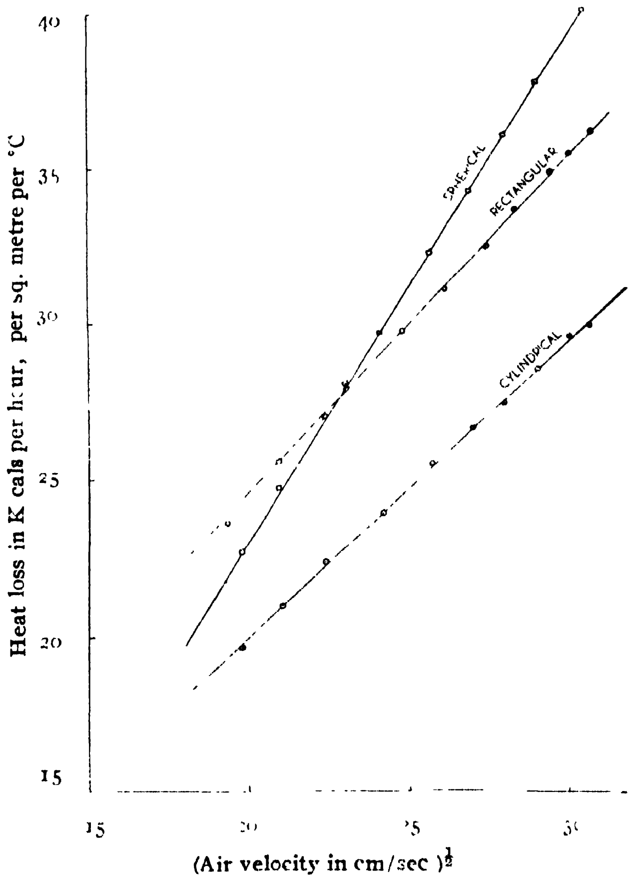

FIG.3

(Buttner, 1934; Winslow and others, 1937, 1939; Plummer, 1944; etc.) but as yet no satisfactory understanding has been obtained.

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