THE EFFECT OF SOUND WAVES ON THE AVERAGE GAS FILM COEFFICIENT OF HEAT TRANSFER

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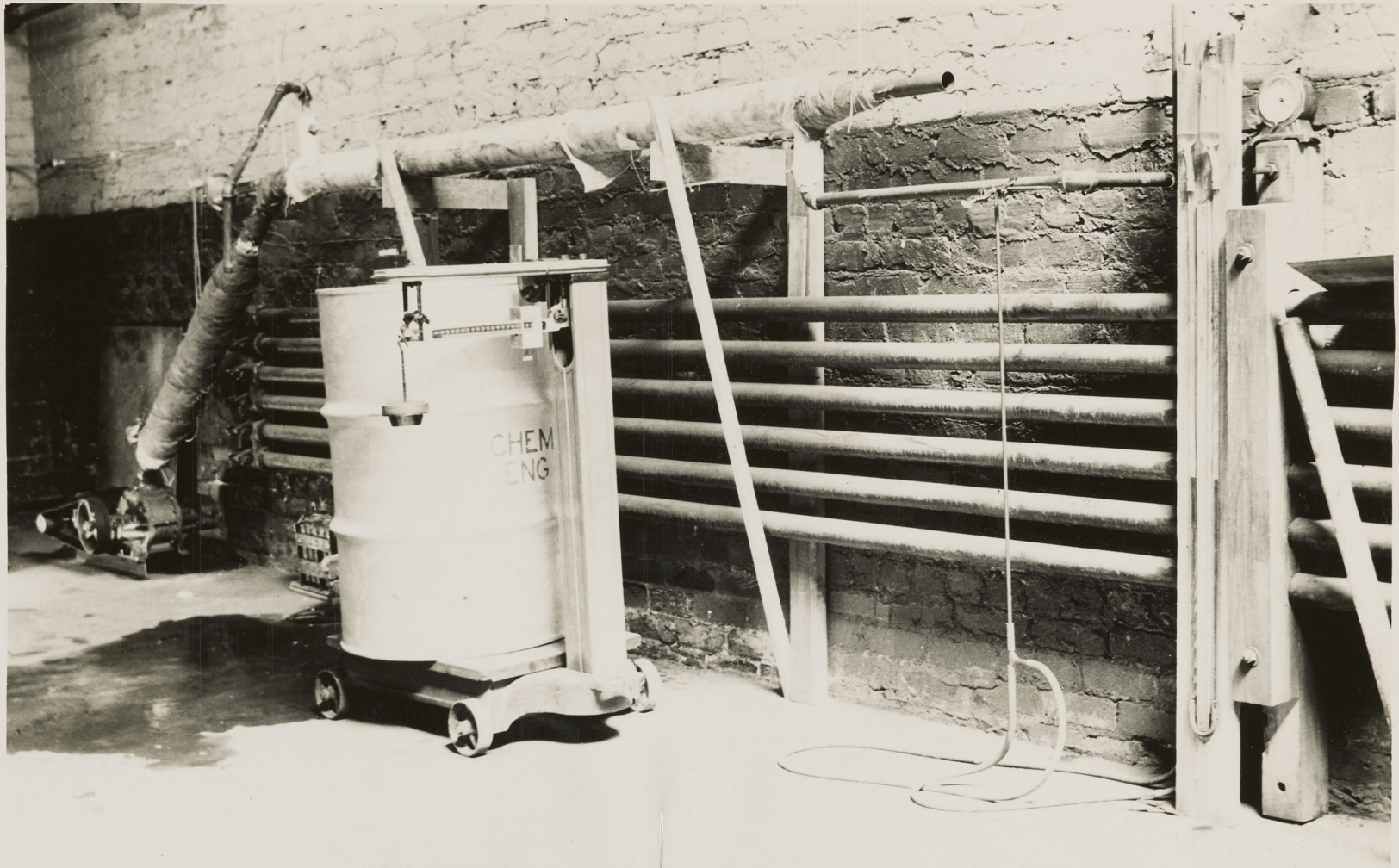


Fig.1 Photograph Showing Complete Set Up

1. INTRODUCTION.

The transfer of heat from hot gases inside pipes to water outside is a problem of industrial importance. The problem is usually studied by means of the Newton equation:[1]

$$\frac{Q}{\theta} = UA\Delta t_m$$

where: $\frac{Q}{\theta}$ = heat transferred in B.t.u. per hour

A = area through which heat is transferred

Δtm = log. mean temperature difference in $^{\circ}F.$ between air and and water.

U = overall heat transfer coefficient in:

B.t.u./ (sq. ft.) (hr.)($^{\circ}F.$)

It has been found that U depends on an average gas film coefficient (h_A), and an average water film coefficient (h_L) as well as the conductivity of of the metal wall. Various formulas have been derived for the various films. For air this coefficient is:

$$h_A = 4v^{0.8}$$

in which v = the mass velocity = $u\rho$

It was suggested by Dr. H.A. Curtis that this velocity might be effectively changed by impressing sound waves on the air. This thesis was undertaken to see just what change in the average gas film coefficient of heat transfer could be found (with and without sound). It was proposed to find this change by calculating the average overall heat transfer coefficient for the system, where presumably only the air film coefficient of heat transfer was varied.

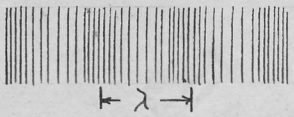
1. Badger & McCabe, Elements of Chemical Engineering, p.117.

II THEORY

No data could be found in literature. It was decided to use a heat transfer apparatus which caused the heat to be transferred from hot air through a copper tube to water. This system was chosen because sound waves can easily be impressed on air and because the heat transfer can be accurately calculated from measurements on the water.

With this apparatus it was hoped that a change in the heat transfer coefficient could be detacted. Such a change would be the result of varying the effective velocity of the air in the tube by setting up a wave action.

Sound waves are longitudinal waves consisting of waves of compression and waves of rarefaction.[2] The waves may be represented graphically by straight lines. When sound travels through air the air molecules are made



to vibrate back and forth. At first, one would believe that this extra agitation of the air particles would cause a better heat transfer coefficient. But, however, it might seem that the sound waves would have no effect on heat transfer, because the added velocity forward would be cancelled by the decreased velocity backward. In other words it seems that the average velocity would be the same as before the sound waves were started. Theoretically, the sound waves cause a decrease in heat transfer. This fact can be shown in the following manner; the formula for heat transfer coefficient of permanent gases inside pipes in forced connection is:

$$h_A = \frac{0.22 C_p T_f^{0.67} v^{0.8}}{D^{0.2}}$$

2. Duff, Lewis, Mendenhal, Carman, Kipp, Physics, p. 502.

where: h_A = the gas film coefficient in B.t.u. per hour per square foot per degree Farenheit.

c_p = the specific heat of the gas at constant pressure in B.t.u. per pound per degree Fahrenheit at mean gas temperature.

T_f = the mean gas film temperature in degrees Rankine.

v = the mass velocity of the gas per square foot cross-section per second.

D = the diameter of the path in inches: [3]

It has been found, that if D is three quarters to two inches and if the film termperature is from 100° to 300° Fahrenheit the film coefficient is given by:

$$h_A = 4\, v^{0.8}$$

The apparatus used fits these conditions; so the latter formula will serve. Since u (the linear velocity) times (the density) = v.

We have $h_A = K\, u^{0.8}$

It is possible to place ρ in with 4 to form a constant because all the particles are moving in one direction in the space which is included between the depth of a rarefaction wave and the height of a compression wave. In this space the density varies from a maximum at the height of a compression wave to a minimum at the depth of a rarefaction wave; it can be seen that the average density will be the density of the air without sound waves impressed. In other words ρ is a constant over any one wave, and hence over the tube.

Using this formula the effect of sound waves can best be shown by a hypothetical example.

Suppose we have the air going through the tube at a velocity of 10

3. Badger and McCabe, Elements of Chemical Engineering. p. 127

feet per second. Suppose, then, we impress sound waves on the air in such a manner that half of the time the vibrations will add to the velocity and half of the time they will subtract from it. Let the amplitude of the sound be such that it will cause the air particles to have an average velocity of one foot per second forward, and of course the same velocity backward. This case is quite impossible, but it will illustrate the point. One half of the time the velocity will be 9 feet per second and the other half of the time it will be 11 feet per second.

So: $h_A = K (9)^{0.8} = 4.01 K$

And: $h_A = K (11)^{0.8} = \underline{6.80 K}$

Average $= 5.40 K$

While, when the sound waves are left off, the heat transfer the coefficient will be:

$$h_A = K (10)^{0.8} = 6.30 K$$

So an impressed vibrating velocity causes the heat transfer to decrease. This proof is true only in the case in which the velocity of the air is greater than the velocity produced by the sound waves.

It is very difficult to calculate the order of change in h_A when subjected to actual sound waves, because no method could be found for measuring the amplitude of the sound waves. The volume or amplitude of the waves will have more effect than the pitch or frequency. This fact may be demonstrated very easily. The maximum distance that any air particles can travel in still air is one quarter of a wave length (i.e. from the height of a compression wave to the depth of a rarefaction wave). Most particles travel less than this distance; therefore the average of all particles may be represented as a function of the wave length.

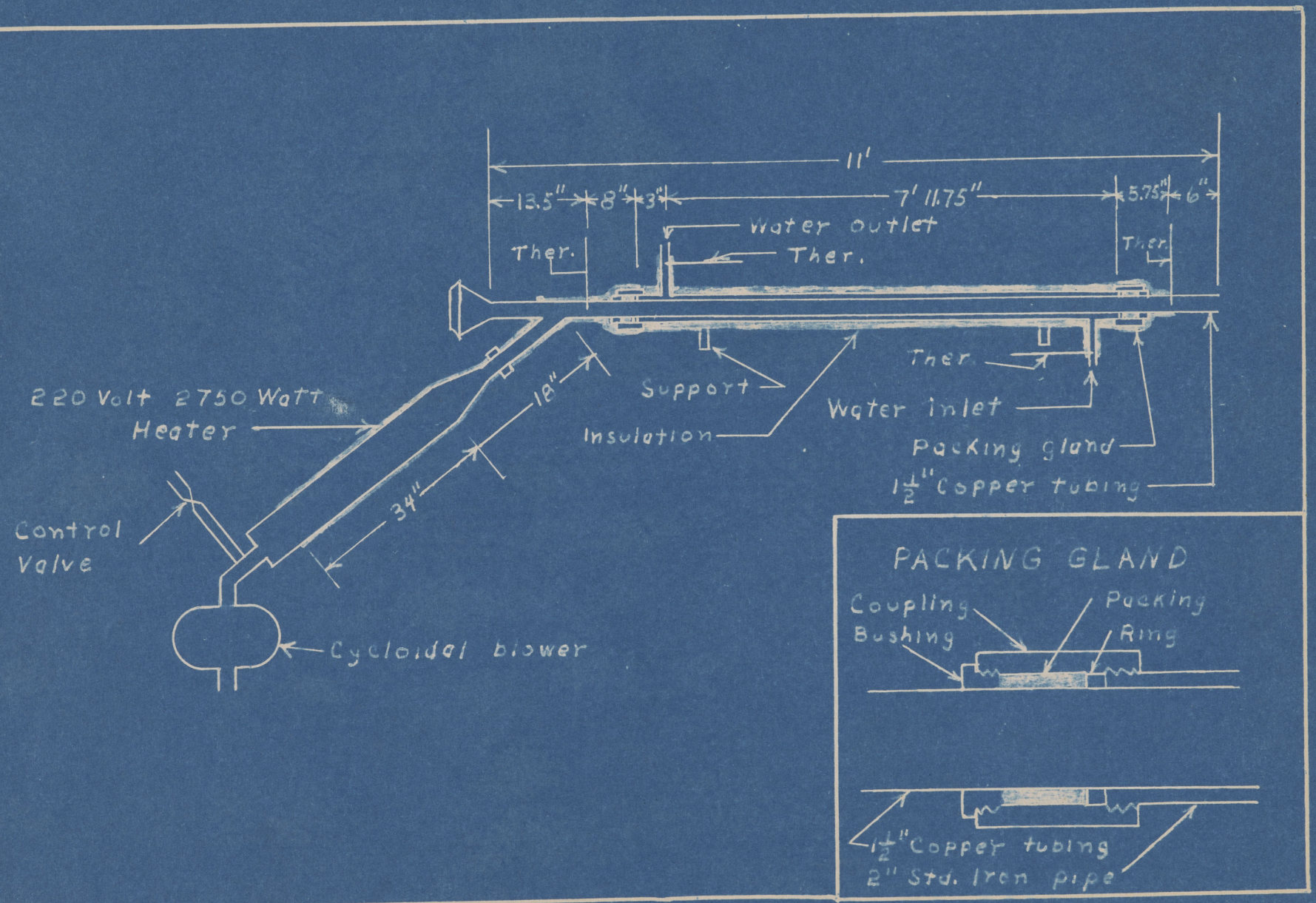
Therefore S (displacement) = K = (constant)(wave length).

It can be seen that this displacement will take place as many times each second as there are waves, or in other words, the velocity will be;

$u = (k)(\lambda)(n)$ where n is the frequency (velocity of sound. $= \lambda n$)

Therefore a change in frequency will cause a change in the wave length but not in u, the gas particle velocity. The amplitude, however, will cause an increase in u. Increased amplitude means the compression waves are more compressed and the rarefaction waves are under less pressure. Consequently more particles will move and u, the average gas particle velocity will be larger. Since no method was available for finding the amplitude of the waves, it was impossible to do any theroretical calculations on the change which should take place in the heat transfer coefficient.

From theoretical considerations, then, it can be concluded that the heat transfer coefficient is affected by sound waves. It has been proved that the sound waves have a detrimental effect on the coefficient, and that this effect is some function of the velocity of sound and the amplitude of the sound waves.


11'
13.5"
8"
3"
7' 11.75"
5.75"
6"
Water outlet
Ther.
Ther.
Ther.
Ther
220 Volt 2750 Watt
Heater
18"
Support
Insulation
Water inlet
Packing gland
1½" Copper tubing
Control
Valve
34"
Cycloidal blower
PACKING GLAND
Coupling
Bushing
Packing
Ring
1½" Copper tubing
2" Std. Iron pipe

III APPARATUS AND OPERATION

The apparatus used in this particular piece of work, (Fig.1 & 2) consisted or a one-half horse power cydoidal blower with adjusting valve, (Fig. 5) an electric heater; a diaphragm automobile horn; an eleven foot piece of 1.5" copper tubing, eight feet of which was inclosed in 2" standard iron pipe; a Pitot tube; four thermometers; and a barrel and scales for weighing the water.

The air was first blown into a heater (Fig.6) where it was heated up to around two hundred degrees, centigrade. On leaving the heater it entered the copper tubing at a distance of about one foot from the end of the tubing. At the end of the tubing, the automobile horn was fastened. The copper tubing passed through a standard two inch iron pipe filled with water, the air giving up part of its heat to the water. The air was then allowed to escape into the atmosphere at a distance of one foot from the water jacket. At the point where the air leaves the copper tube, its velocity was measured by means of the Pitot tube. Ten readings were made with the Pitot tube during each ten minute run, taken at different points along the diameter of the copper tube. The arithmetic mean of these readings was taken for the average velocity. The water, on leaving the system, was run into a barrel and weighed.

The first difficulty that was encountered was the construction of a packing gland at each end of the water jacket. The pipe had to be water tight and, at the same time, some means had to be made for expansion. This was overcome by the use of a standard coupling on each end of the pipe, and inside this coupling was placed a 2 in. ring with a 1.5 in. hole in the center to allow for the passage of the copper tubing. A packing material was added and then the gland closed by a 2 in. iron bushing with a 1.5 in. hole in the center. (Fig.7.)

The frame for the heater was made from steel and consisted of 4.5 in.



Fig.6 The Heater.



Fig.7 Heater Connection and Packing Gland.



Fig.8 Frame for Heating Coils.

by 4.5 in. crosses fastened together by 34 in. steel strips connecting the corresponding arms of the crosses. The crosses were put together by welding one piece of metal to the other at an angle of 90 degrees and the steel strips were also fastened to the crosses by welding. The frame was inclosed in a round, 5 in., galvanized iron shell, and the shell was covered with magnesia insulation.

The steel frame for the heater was insulated by means of two layers of asbestos sheeting, glued to the frame by means of sodium silicate. The ends of the frame were covered with four layers of asbestos sheeting because the end supported the windings which had a tendency to cut into the insulating material. (Fig.8)

This heater was designed to carry 12.5 amperes on a 220 volt line and gave satisfactory service throughout the experiment. This heater consisted of two coils of one ohm per foot resistance wire; each coil was thirty-six feet long. (Connected in parllel)

The automobile horn (Fig.4) was first connected to the copper tubing by means of a cone shaped piece of galvanized tin, the large end of the cone being five inches in diameter and the small end just large enough to slip over the end of the 1.5 in. copper tubing. The horn was first fastened to the cone by means of bolts, but this method caused damping of the vibrations of the horn. The horn was then tied on the cone by means of strings, a rubber gasket being placed between the horn and the metal cone. This did much toward preventing the damping of the vibrations, but the horn was never placed on tight enough to prevent considerable air from escaping from the tube around the horn.

The temperature of the air and water before and after leaving the water jacket had to be recorded. The temperature of the air was taken by thermometers graduated in one degrees. The temperature of the water was taken by thermometers graduated in one tenth of a degree. In the experiment, the system was operated for ten minutes without the horn blowing, the tem-



Fig.4 The Horn Mounting.

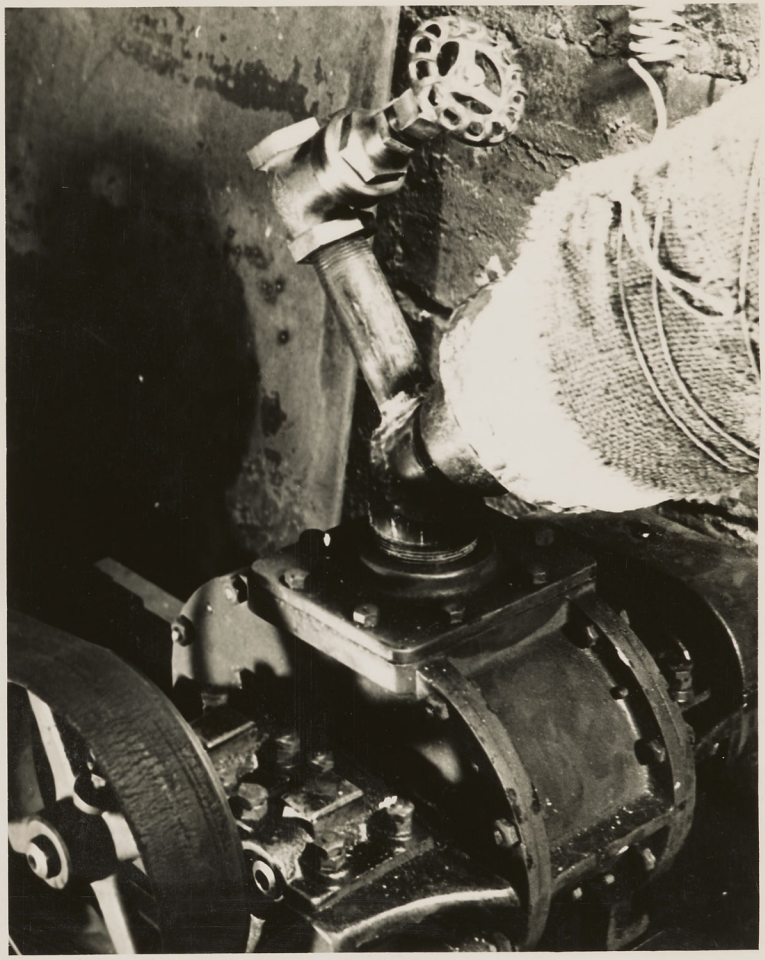


Fig.5 Blower Showing Adjusting Valve.

perature of the water and air and the velocity of the air were recorded every minute, and the weight of the water that passed through the system during the ten minutes was recorded. The above data were then recorded for a period of ten minutes with the horn blowing.

In all twelve sets of runs were made. The conditions of the runs were varied slightly. Some runs were made with the horn blowing first and some runs were made with horn blowing second. Some runs were made with the adjusting valve partly open and some with it all the way open. (See Fig.5). An effort was made to keep the conditions of the two runs in each set as nearly the same as possible. (i.e. with the horn blowing and without the horn blowing).

Table No. 1

EXPERIMENTAL DETERMINATION OF U

No.	Air Vel. (ft./sec.)	Pounds of Water Run # 1	Run # 2	Comments	U With Horn	U Without Horn
I	67.2	20.0	11.5	No.2--with horn 6min.	8.13	8.45
II	66.5 67	16.0	15.5	Horn second	7.85	7.92
III	55.5	46.5	46.5	Horn second	7.70	7.71
IV	44.8	69.7	67.3	Horn second (Av. 2 runs)	7.10	7.11
V	66.6	23.0	22.0	Horn second	8.93	9.04
VI	67.0	21.5	21.0	Horn first	8.60	8.70
VII	68.2	45.5	45.0	Horn second	8.17	8.33
VIII	66.0	44.5	44.5	Horn first	8.36	8.20
IX	52.0	42.0	39.0	Horn first	7.49	7.35
X	52.0	44.5	23.0	Horn first	7.39	7.18
XI	51.5	24.5	24.0	Horn first	6.18	5.75
XII	52.1	23.5	23.5	Horn first	6.03	6.05

Table No. 2

THEORETICAL DETERMINATION OF U

No.	Average water film coefficient h_L	Average Air Film coefficient h_A	Average Overall Coefficient U
I	16.85	12.05	7.01
II	14.05	11.90	6.43
III	33.10	10.40	7.92
IV	45.80	9.00	7.53
V	18.80	12.10	7.39
VI	17.50	12.10	7.17
VII	32.50	12.51	9.06
VIII	32.00	11.98	8.72
IX	28.75	10.10	7.50
X	31.10	10.10	7.62
XI	19.45	10.00	6.61
XII	19.20	10.10	6.61

Conditions same as in table no 1, except that the coefficient was calculated only for those runs without the horn.

Table No. 3

HEAT BALANCE

No.	Heat Transferred Calculated from water in B.t.u.	Heat Transferred calculated from air in B.t.u.
I	4790	3560
II	4490	3460
III	4770	3720
IV	5000	3830
V	4930	3600
VI	4850	3640
VII	4840	4200
VIII	4770	4050
IX	3785	2920
X	3660	2950
XI	3350	2840
XII	3380	2860

Conditions same as in table no. 2

IV SAMPLE CALCULATION

Slide Rule used throughout.

Determination of Experimental value of U. (The temperatures used are average temperatures for the whole run.)

No. 1

The heat transfer coefficient is to be determined by the formula:

$$\frac{Q}{\theta} = UA\Delta t_m$$

Where: Q/θ is the heat transferred in B.t.u. per hour

U is the overall heat transfer coefficient in B.t.u. per hour per sq. ft. per degree temperature difference.

A is the area through which the heat is transferred.

Δt_m is the log. mean temperature difference.

Determination of the log. mean temperature difference:

Temperature difference between air entering and water leaving is 133.08° C. or 240° F.

Temperature difference between air leaving and water entering is 73.65° C. or 132.6° F. Now the log. mean temperature is given by:

$$\Delta t_m = \frac{\Delta t_1 - \Delta t_2}{2.303 \log. \Delta t_2/\Delta t_1}$$

Where Δt_2 and Δt_1 are temperature differences

Therefore

$$\Delta t_m = \frac{240 - 132.6}{2.303 \log. 240/132.6} = \frac{107.4}{(2.303)(.258)} = 180.5^{\circ}$$

Determination of Q/θ the heat transferred:

Difference in temperature of water entering and water leaving is 22.15° C or 39.9° F.

The weight of water in the ten minute run was 20 pounds.

Then Q/θ is given by

$$(20)\ (39.9)\ (1)\ (6) = 4{,}790 \text{ B.t.u./hr.}$$

Determination of Area of transferring surface:

The length of copper tube in contact with both air and water was 798 ft.

Outside perimeter of the pipe was:

$$3.1416\ D = \frac{1.5}{12} \qquad 3.1416 = .3925 \text{ ft.}$$

$$.3925 \times 7.98 = 3.137 \text{ sp. ft.}$$

Therefore:

$$U = \frac{Q/\theta = UA\Delta t_m}{A\Delta t_m}$$

$$\text{Therefore } U = \frac{4790}{(3.137)(180.5)} = 8.45$$

Determination of Theoretical U

First it was necessary to find the velocity of the air (in order to determine h_A the gas film coefficient).

Average manometer reading (on Pitot tube) was 6.9 cm.

Since the manometer was a differential one the reading was in head of a fluid whose density is the difference of the densities of the two fluids used. Water (density = 1g./cc.) and kerosene (density = .795 g./cc) were used, and so the apparent fluid density was

$$1 - .795 = .205 \text{ g./cc.}$$

This reading was converted to head of air by means of the following

relationship:

$$\frac{R}{(H)(2.54)\ (12)} = \frac{\text{Density of air}}{0.205}$$

or $$H = \frac{0.205\ R}{(\text{Density of air})\ (21.2)}$$

where H is head of air in feet

R is manometer reading in cm.

Desnity of air is at temperature of leaving air.

$$H = \frac{.205 \times 6.9}{.00945 \times 21.2} = 70.5 \text{ ft.}$$

Then by the Pitot tube formula:

$$H = \frac{U^2}{2g}$$

the velocity U is found by

$$U^2 = 2gH = (64.4)(70.5) = 4540$$

$$U = 67.2 \text{ ft./ sec.}$$

Or v the mass velocity is:

$$v = 67.2 \times .059 = \frac{\text{lb.}}{\text{sq. ft - hr}}$$

Since: $h_A = 4\ v^{0.8}$ (from Badger & McCabe p. 128)

$$h_A = 4(3.96)^{0.8} = 12.05 \text{ B.t.u. / sq. ft. /hr/}^{\circ} \text{ F}$$

Determination of h_A, the water film coefficient:

The dittus and Boelter formula in consistent units is[4]

$$h_2 = \frac{0.0225\ K}{D}\left(\frac{D}{\mu}\right)^{0.8}\left(\frac{C\mu}{K}\right)^{0.4}(v)^{0.8}$$

where h_2 = average liquid film coefficient in B.t.u./(sq.ft.)(hr.)(°F.)

K = the thermal conductivity in $\frac{(\text{B.t.u.})(\text{ft.})}{(\text{hr.})(\text{sq.ft.})(^\circ\text{F})}$

D = diameter of pipe in feet. In this case

D = 4 times the shape factor

μ = viscosity in $\frac{\#}{(\text{ft.})(\text{hr})}$

C = Specific heat (at constant pressure)

v = the mass velocity in $\frac{\#}{(\text{sq.ft.})(\text{hr})}$

Average temperature of water = 34°.F

Z = 1.692 centipoise

μ = 4.08 lb/ ft/hr

C = 0.322

Shape factor = $\frac{\text{Cross-section area of liquid path}}{\text{Perimeter of heating surface.}}$

D = (4)(Shape factor)

Area inside of Iron Pipe =	3.355 sq. in
Area of Cross-section of Copper tube	1.760 "
Cross-section of liquid path	1.595 sq. in.

Perimeter of heating surface.

(2) (3.1416)(r) = (2)(3.1416)(7.5) = 4.71 in.

Shape factor $\frac{1.595}{4.71}$ = .339 in.

D = (4)(.339) = 1.355 in.

4 McAdams, Heat Transmission, p. 165

$$\frac{1.355}{12} = .113 \text{ ft.}$$

Substituting in the formula:

$$h_L = \frac{0.322}{0.113}(0.0225)\left(\frac{0.113}{4.08}\right)^{0.8}\left(\frac{4.08}{(0.322)}\right)^{0.4}(v)^{0.8}$$

$$= (0.641)(0.0276)^{0.8}(12.7)^{0.4}(v)^{0.8}$$

$$= (0.064.)(0.0565)(2.76)(v)^{0.8} = 0.01v^{0.8}$$

The mass velocity is calculated from the weight of water in the following manner;

The area of water space is 1.595 sq. in. or .0111 sq. ft.

The dimensions of mass velocity are:

$$\frac{\text{lb}}{(\text{sq. ft.})(\text{hr.})}$$

So W (pounds per 10 min) times 6 = 6W lb/ hr.

Or

$$V = \frac{6W}{.011} = 54.\ W$$

$$V = 541 \times 20 = 10{,}820$$

$$h = .01^{0.8} = .01\ (10{,}820)^{0.8} = 16.85$$

Then $$U = \frac{1}{\frac{1}{h_A} + \frac{L}{k} + \frac{1}{h_L}}$$

L/k = (Length/thermal conductivity) may be neglected, because the copper tube wall offers little thermal resistance

Therefore

$$U = \frac{1}{\frac{1}{12.05} + \frac{1}{16.85}} = 7.01$$

Heat Balance:

Area of inside of copper tube = $(0.75 - 0.28)^2 (3.1416)$

= 1.637 $in.^2$ or 0.0136 sq. ft.

This value multiplied by the mass velocity and 3600 will give pounds of air per hour: (3.77)(0.0136)(3600) = 184.3 #/hr

The pounds of air times the specific heat times the temperature difference will give the heat given up by the air:

(184.3 #)(0.237)(81.58°) = 3560 B.t.u. per hour.

V DISCUSSION OF RESULTS

The experimental results obtained are not very conclusive. There were almost as many cases in which the horn increased the heat transfer coefficient as there were cases in which the opposite was true. Even the results which went as they theoretically should go are not conclusive. The horn never decreased U more then three percent and most of the time the percent decrease was negligible. It can only be concluded that our apparatus was not accurate enough to measure the decrease in the coefficient. This inaccuracy makes itself manifest in the way the data turned out. The first run usually gave a better coefficient than the second in any set, regardless of whether the horn was blowing first, or second. No particular reason can be given for this behavior other than the general inaccuracy of the apparatus.

Also the heat balance shows the inaccuracy of the apparatus. The heat lost by the air is always less than the heat taken up by the water. This error can probably be explained by the inaccuracy of the Pitot tube. Since the velocity was determined outside of the system this error cannot be used in determining the general accuracy of the apparatus.

The air side of the system seemed to be easy to control. The air system remained almost constant at any velocity and temperature for which it was set. A small amount of air was lost around the horn, but this was before the air entered the water jacket, and so would have no effect on the readings.

The accuracy of the water side was bad at times. When much water was used in other parts of the building, the water velocity fluctuated. One set of runs had to be thrown out because the weight of water run through in the two runs differed by about seven pounds. Most of the time,

however, the weight of water for the two runs of each set did not vary more than one pound. The variation was usually one half pound.

There are two ways of improving the apparatus. First, the apparatus could be made more accurate by the use of more accurate thermometers on the air side, and by the use of some system of control of the water velocity through the jacket. An orifice with a manometer and controlling valve might be put in on the input water line. Because of the extreme low velocity of the water, though, it would be better to get the water from a tank in which the water could be kept at always the same level.

Even though these alterations were made, a better source of sound would be needed. So the second improvement that could be made would be a sound source which produced waves of extremely large amplitude. The amplitude of a high frequency sound wave is limited by the mechanical construction of the sound producer. It is suggested, then, that waves slightly below the wound range be used (say five or ten vibrations per second) Such a source of waves could be made by a sort of piston pump arrangement, With the low frequency, the amplitude of the wave could be made several inches.

These low frequency, high amplitude waves should cause an appreciable decrease in the heat transfer coefficient. After the decrease in U had been studied it might be possible to change the waves so as to increase the coefficient. If the backward moving part of the sound wave could be damped out, this effect would be obtained. Some sort of valve arrangement could be provided so that on the back stroke of the piston the valves open to the air and kill the back wave. (as far as the appratus is concerned.)

VI CONCLUSIONS

1. Ordinary sound waves probably cause a decrease in the heat transfer coefficient, butthis effect is negligible compared to the quantities of heat measured.

2. It is believed that low frequency, high amplitude waves would make tne decrease in U apparent.

3. It is also believed that the heat transfer coefficient could be increased by using compression waves with the corresponding rarefaction waves eliminated.

VII APPENDIX

Run No. 1

Without Horn

	$t^{0}C$ Water		t^{0} Air	
	In	Out	In	Out
0	26.6	49.0	181.0	99.8
1	26.5	48.6	181.2	99.8
2	26.3	48.5	181.1	99.8
3	26.2	48.5	181.2	99.8
4	26.1	48.4	181.1	99.8
5	26.1	48.2	181.1	99.8
6	26.1	48.3	181.6	99.8
7	26.1	48.1	181.5	99.8
8	26.1	47.7	181.9	99.9
9	26.1	48.4	182.0	100.0
10	26.2	48.1	182.0	100.0
Av.	26.2	48.35	181.43	99.85
	With Horn			
0	26.3	48.4	182.0	100.0
1	26.3	48.5	182.0	100.0
2	26.3	48.7	182.0	100.0
3	26.4	48.6	182.0	100.0
4	26.4	48.7	182.0	100.0
5	26.5	48.6	182.0	100.2
6	26.5	48.7	182.0	100.2
Av.	26.4	48.6	182.0	100.06

Run No. II

Without Horn

	t°C water		t° C air	
	In	Out	In	Out
0	28.0	53.0	183.3	102.0
1	28.0	53.1	183.2	102.0
2	27.9	52.7	183.5	102.5
33	27.9	53.2	184.0	103.0
4	27.8	53.2	184.0	103.0
5	27.6	53.9	183.7	103.0
6	27.4	53.9	183.9	103.0
7	27.1	54.0	183.6	103.0
8	26.8	53.5	183.9	102.8
9	26.4	53.2	183.5	102.2
10	26.1	53.2	183.8	102.0
Av.	27.36	53.35	183.67	102.54

With Horn

0	25.6	52.0	183.7	102.0
1	25.5	52.2	184.0	102.0
2	25.5	52.0	184.0	102.0
3	25.5	52.5	184.0	102.3
4	25.4	52.6	184.0	102.4
5	25.4	52.7	184.1	102.7
6	25.4	52.5	184.1	102.6
7	25.4	52.6	184.1	102.7
8	25.4	52.6	184.5	102.8
9	25.4	52.7	184.1	102.8
10	25.4	52.6	184.1	102.8
Av.	25.45	52.45	184.06	102.46

Run No III

Without Horn

	t°C Water In	Out	t°C Air In	Out
0	26.9	36.2	197.0	97.5
1	26.8	36.3	197.2	97.5
2	26.8	36.2	197.5	97.5
3	26.8	36.1	198.0	97.5
4	26.8	36.1	197.5	97.5
5	26.8	36.3	197.8	97.5
6	26.8	36.3	198.0	98.0
7	26.8	36.4	198.0	98.0
8	26.8 36.3	36.3	198.0	98.0
9	26.9	36.4	198.1	98.0
10	26.9	36.6	198.2	98.0
Av.	26.8	26.3	197.8	97.9

With Horn

0	27.0	36.8	198.5	99.0
1	27.0	36.7	199.0	99.0
2	27.0	36.7	199.0	99.0
3	27.0	36.8	199.0	99.0
4	26.9	36.7	199.0	99.0
5	26.9	36.5	199.0	99.0
6	26.9	36.5	199.0	99.0
7	26.9	36.5	199.1	99.0
8	26.8	36.4	199.0	99.0
9	26.8	36.2	199.0	99.0
10	26.8	36.1	199.0	99.0
Av	26.9	36.54	198.96	99.0

Run No. IV

Without Horn

	t°C Water		t°C Air	
	In	Out	In	Out
0	27.3	33.9	223.0	102.0
1	27.4	33.9	223.5	102.0
2	27.4	33.9	224.0	102.5
3	27.4	33.9	224.0	102.9
4	27.5	34.0	224.5	102.9
5	27.45	34.1	225.0	103.0
6	27.45	34.1	225.2	103.0
7	27.45	34.1	225.2	103.0
8	27.5	34.2	225.2	103.0
9	27.5	34.1	225.6	103.0
10	27.5	34.1	226.0	103.0
Av.	27.44	34.03	224.65	102.75
0	27.5	34.1	226.0	103.0
1	27.5	34.1	226.0	103.0
2	27.5	34.1	226.0	103.0
3	27.5	34.1	226.0	103.0
4	27.4	34.1	226.5	103.2
5	27.4	34.1	226.8	103.3
6	27.3	34.0	226.8	103.5
7	27.3	33.9	227.0	103.5
8	27.25	33.9	227.0	103.5
9	27.2	34.0	227.2	103.8
10	27.0	33.9	227.0	103.8
Av.	27.35	34.03	226.6	103.4

Run No. 4 Continued

With Horn

	t°C Water		t°C Air	
	In	Out	In	Out
0	26.8	33.8	227.0	104.0
1	26.8	33.9	227.0	104.0
2	26.9	33.8	227.0	104.0
3	26.9	33.8	227.0	104.0
4	27.0	33.9	227.0	104.0
5	27.1	34.0	227.0	104.0
6	27.2	34.1	227.0	104.0
7	27.2	34.1	227.0	104.0
8	27.2	34.1	227.2	104.1
9	27.2	34.1	227.5	104.2
10	27.2	34.1	227.5	104.3
Av.	27.05	33.97	227.1	104.05
0	27.1	34.1	228.0	104.5
1	27.1	34.1	228.0	104.8
2	27.1	34.1	228.2	105.0
3	27.1	34.0	228.2	104.9
4	27.1	34.0	228.0	104.9
5	27.2	34.0	228.2	104.9
6	27.2	34.1	228.2	104.9
7	27.2	34.1	228.0	104.9
8	27.1	34.1	228.0	104.9
9	27.0	34.1	228.0	104.9
10	27.0	34.1	228.0	104.8
Av.	27.10	34.07	228.07	104.85

Run No. V

Without Horn

	t°C Water		t°C Air	
	In	Out	In	Out
0	27.8	47.5	179.0	96.5
1	27.8	47.6	179.0	96.8
2	27.9	47.3	179.4	96.9
3	27.8	47.1	179.2	96.9
4	27.9	47.4	179.2	96.9
5	27.9	47.6	179.2	96.9
6	27.8	48.1	179.5	97.0
7	27.8	48.1	179.5	96.9
8	27.7	48.1	179.2	96.9
9	27.8	47.7	179.0	96.9
10	27.7	47.7	179.0	96.9
Av.	27.82	47.65	179.2	96.86

With Horn

0	28.1	48.8	179.0	97.0
1	28.1	48.8	179.0	97.0
2	28.1	48.6	179.0	97.0
3	28.2	48.6	179.0	97.0
4	28.2	48.7	178.0	97.0
5	28.2	48.7	178.5	97.0
6	28.2	48.7	179.0	97.0
7	28.2	48.3	179.0	97.0
8	28.2	48.4	179.0	97.0
9	28.3	48.7	179.5	97.5
10	28.3	48.8	179.6	97.5
Av.	28.2	48.62	179.06	97.1

Run No VI

Without Horn

	t°C Water		t°C Air	
	In	Out	In	Out
0	28.3	48.9	179.8	97.7
1	28.3	48.9	179.8	97.8
2	28.2	49.0	179.8	97.8
3	28.2	49.0	179.8	97.8
4	28.2	49.0	180.0	97.8
5	28.2	49.1	180.0	97.8
6	28.1	49.0	180.0	97.8
7	28.1	49.2	179.8	97.8
8	28.1	49.2	180.0	97.8
9	28.1	49.4	180.0	97.8
10	28.1	49.0	180.0	97.8
Av.	28.17	49.06	179.9	97.8

With Horn

0	28.1	49.1	180.0	97.0
1	28.0	49.3	180.0	97.0
2	27.9	48.9	180.0	97.0
3	27.9	48.9	180.0	97.0
4	27.8	48.6	180.0	97.0
5	27.8	48.6	180.0	97.0
6	27.8	48.6	180.0	97.0
7	27.8	48.9	180.0	97.0
8	27.9	49.0	180.0	97.0
9	27.9	48.8	180.0	97.1
10	27.8	48.8	180.0	97.1
Av	27.9	48.86	180	97.03

Run No. VII

Without Horn

	t°C Water		t°C Air	
	In	Out	In	Out
0	26.9	36.6	184.4	95.2
1	26.85	36.8	184.5	95.2
2	26.9	36.7	184.2	95.2
3	26.9	36.8	184.5	95.2
4	26.9	36.8	184.5	95.2
5	26.9	36.9	184.5	95.2
6	26.9	36.8	184.8	95.5
7	26.9	36.8	184.8	95.6
8	27.0	36.8	184.7	95.8
9	27.0	36.8	184.0	95.8
10	27.0	3616	184.0	95.2
Av.	26.92	36.76	184.45	95.38

With Horn

0	27.2	37.3	185.0	96
1	27.2	36.9	185.0	96
2	27.3	37.0	185.0	96
3	27.2	37.0	185.0	96
4	27.2	37.1	185.0	96
5	27.1	36.9	185.0	96
6	27.1	36.9	185.0	96
7	27.1	36.8	185.0	96
8	27.1	36.9	185.0	96
9	27.1	36.8	185.0	96
10	27.1	26.8	185.0	96
Av.	27.15	36.95	185.0	96

Run No. VIII

Without Horn

	t°C Water		t°C Air	
	In	Out	In	Out
0	27.3		185.5	96
1	27.3	37.2	185.3	96
2	27.3	37.3	185.5	96
3	27.3	37.2	185.1	96
4	27.3	37.5	185.4	96
5	27.3	37.4	185.5	96
6	27.3	37.3	185.2	96
7	27.4	37.1	185.2	96
8	27.4	37.2	185.0	96
9	27.4	37.2	185.0	96
10	27.4	37.2	185.0	96
Av.	27.34	37.26	185.2	96

With Horn

0	27.2	37.1	185.0	96
1	27.2	37.4	185.1	96
2	27.2	37.4	185.0	96
3	27.2	37.5	185.0	96
4	27.2	37.4	185.0	96
5	27.2	37.4	185.0	96
6	27.2	37.2	185.0	96
7	27.2	37.3	185.0	96
8	27.3	37.3	185.1	96
9	27.3	37.4	185.2	96
10	27.3	37.2	185.4	96
Av.	27.23	37.33	185.07	96

Run No. IX

Without Horn

	t°C Water In	Out	t°C Air In	Out
0	27.0	35.9	167.2	86.8
1	27.0	36.2	167.2	86.8
2	26.9	36.3	167.2	86.8
3	26.9	36.4	167.1	86.6
4	26.7	36.0	167.1	86.2
5	26.4	36.6	167.0	86.2
6	26.1	35.2	167.1	86.0
7	25.95	34.9	167.1	86.0
8	25.95	34.4	167.1	86.0
9	25.95	34.3	167.2	86.0
10	25.95	34.6	167.0	86.0
Av.	26.39	35.07	167.12	86.57

With Horn

0	27.0	35.4	167.5	86.8
1	26.95	35.3	167.5	86.5
2	26.9	35.3	167.2	86.1
3	26.9	35.3	167.2	86.1
4	26.8	35.1	167.5	86.1
5	26.8	35.1	167.2	86.1
6	26.8	35.0	167.0	86.1
7	26.8	35.2	167.0	86.0
8	26.9	35.2	166.9	86.0
9	26.9	35.1	167.1	86.1
10	26.9	35.3	167.2	86.1
Av.	26.88	35.22	167.22	86.18

Run No. X

Without Horn

	t°C Water		t°C Air	
	In	Out	In	Out
0	26.3	34.6	167.5	86.0
1	26.3	34.6	167.5	86.0
2	26.3	34.5	167.4	86.0
3	26.4	34.4	167.5	86.0
4	26.4	34.5	167.5	86.0
5	26.5	34.6	167.4	86.0
6	26.6	34.7	167.2	86.0
7	26.6	34.6	167.5	86.0
8	26.65	34.9	167.5	86.1
9	26.7	34.9	167.5	86.1
10	26.7	34.9	167.5	86.2
Av.	26.5	34.65	167.45	86.04

With Horn

0	25.8	34.0	167.0	85.8
1	25.8	33.9	167.0	85.7
2	25.8	33.9	167.0	85.8
3	25.8	33.9	167.0	85.8
4	25.9	33.9	167.0	85.8
5	25.9	34.0	167.0	85.8
6	25.95	34.0	167.0	85.8
7	26.1	34.1	167.0	85.8
8	26.2	34.2	167.0	86.0
9	26.2	34.2	167.1	86.0
10	26.2	34.0	167.1	86.0
Av.	25.97	34.01	67.02	85.85

Run No. XI

Without Horn

	t°C Water		t°C Air	
	In	Out	In	Out
0	27.65	40.4	162.0	85.0
1	27.65	40.4	162.1	85.0
2	27.65	40.6	162.5	85.0
3	27.65	40.8	162.5	85.0
4	27.65	40.6	162.7	85.0
5	27.65	40.7	162.5	85.0
6	27.65	40.6	163.0	85.0
7	27.65	40.5	162.7	85.0
8	27.65	40.6	163.0	85.0
9	27.65	40.7	163.0	85.0
10	27.65	40.9	163.0	85.0
Av.	27.65	40.61	162.64	85.0
		With Horn		
0	27.65	41.4	162.5	85.8
1	27.65	41.3	162.5	85.9
2	27.65	41.0	162.8	85.9
3	27.65	41.0	162.6	85.0
4	27.65	40.4	162.0	85.0
5	27.65	40.3	162.0	85.0
6	27.65	40.6	162.0	85.0
7	27.65	40.6	162.0	85.0
8	27.65	40.9	162.0	85.0
9	27.65	40.8	162.0	85.0
10	27.65	40.3	162.0	85.0
Av.	27.65	40.8	162.1	85.24

Run No. XII

Without Horn

	$t^{\circ}C$ Water		$t^{\circ}C$ Air	
	In	Out	In	Out
0	27.6	40.7	162.7	85.5
1	27.6	40.9	162.7	85.3
2	27.6	40.9	162.5	85.2
3	27.6	41.1	162.5	85.2
4	27.6	40.9	162.5	85.2
5	27.5	41.0	162.5	85.2
6	27.5	40.8	162.5	85.2
7	27.45	40.7	162.5	85.3
8	27.4	40.6	162.7	85.2
9	27.4	40.6	163.0	85.3
10	27.35	40.6	163.1	85.8
Av.	27.51	40.8	162.65	85.31

With Horn

0	27.7	41.0	163.0	86.0
1	27.7	40.9	163.0	86.0
2	27.7	41.0	163.0	86.0
3	27.65	41.0	163.0	86.0
4	27.6	40.9	163.0	85.9
5	27.6	40.9	162.7	85.7
6	27.6	40.8	162.9	85.5
7	27.6	40.7	162.5	85.5
8	27.55	40.8	162.3	85.3
9	27.55	40.7	162.0	85.0
10	27.55	40.5	162.0	85.2
Ave.	27.62	40.84	162.67	85.65

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APPROVAL.

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn herein, but approves the thesis only for the purpose for which it is submitted.

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