FLUID FLOW PATTERNS IN THE HEAT TRANSFER PASSAGES OF AN INTERNAL COMBUSTION ENGINE

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

A. F. M. ABDUL AZIZ

1953

This is to certify that the

thesis entitled

Fluid Flow Patterns in the Heat Transfer
Passages of an Internal Combusion Engine

presented by

A.F.M. Abdul Aziz

has been accepted towards fulfillment
of the requirements for

M.S. degree in M.E.

Louis L. Otto
Major professor

Date Jan. 26, 1954

O-169

FLUID FLOW PATTERNS

IN THE

HEAT TRANSFER PASSAGES

OF AN

INTERNAL COMBUSTION ENGINE

BY

A. F. M. ABDUL AZIZ,

A THESIS

Submitted to the School of Graduate Studies of Michigan

State College Of Agriculture and Applied Science

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

Department of Mechanical Engineering

1953.

ACKNOWLEDGEMENTS

The author is very grateful to his major professor Dr. Louis L. Otto for his most valuable suggestions in designing the apparatus and adopting test methods, for his wise guidance in the experimental proceedure, and for his keen interest and constant supervision in the whole process without which this investigation would have never been a success. Further it was only his active help which made it possible to finish the work within a limited time. The author, therefore, wishes to express his heartfelt thanks to him and dedicates the work to his name.

The author cannot but express his sincere appreciation of the close co-operation and immense help rendered by Mr. Ray T. Pearson in carrying out all the machine shop work in preparation of the investigation. The author also wishes to thank his friend Mr. A.S.M. Nurullah in preparing and checking the test results.

Lastly the author is indebted to Michigan State College for the materials used in connection with the investigation.

VITA

The author was born in a small village of the Province of Bengal in India (now in Pakistan) on January 31, 1932. His father was a poor farmer and had no means to educate his sons. The author passed his 4th grade from the village Free Primary school and obtained a scholarship from the government. He then was admitted into a high school three miles from his house, where he enjoyed a free studentship and prosecuted his studies upto the end of the eigth grade.

That was the year of 1944 and theyear of famine in Bengal when he was promoted to the ninth grade. His father being extremely unable to give him a single penny for his education wanted to take him back to his farm work. But the author was determined to carry on with education. He therefore fled away from home in search of a charitable High School. Fortunately he met Mr. N. M. Das, the head master of Nandina High School, a village High School. It was for his kind help that theauthor could pass the high school final examination. He passed the high school final examination with distinction and obtained a scholarship from the government. With this scholarship he went to the Dacca

Intermediate College located in East Pakistan and studied there Physics, Chemistry, Mathematics, Botany, English and Vernacular for two years. During this time he got a stipend from the Muslim Education Fund awarded by the Director of Public Instruction, East Bengal. He passed the Intermediate Science final examination with much credit and received a scholarship from thegovernment. At this time he awarded a stipend from his district. With these helps the author was admitted into the Engineering College, Dacca, where also he received a scholarship. In 1952 he received his Bachelor of Science degrre in Mechanical Engineering from this college after four years of studies.

The author had an ambition to become a teacher. So he wanted to go on for higher studies. He received a grant for passage to the United States from the Shakoor Educational Trust Fund in East Pakistan, and took a loan from the Multi purpose Society of Kishorganj, East Pakistan. With these he came to the Michigan State College and became a Graduate student in Mechanical Engineering majoring in Automotive Engineering.

The author is now a candidate for the degree of Master of Science in Mechanical Engineering.

TABLE OF CONTENTS

TABLE OF ILLUSTRATIONS

SUMMARY

This work is an attempt to investigate and to establish relationshop among power demanded by the pump in pumping cooling water through the engine, rate of water circulation in the cooling system, pressures at different significant points and velocities at critical sections, sections of minimum cross sectional area, in the cooling system for an Internal Combustion Engine used in automotive vehicles. The engine for investigation was a Buick straight-eight-cylinder engine of current production.

For the measurements of pressures in the cooling system water was circulated by the pump driven by a motor through a V-belt. Low pressure readings were taken in the piezometric tubes to be able to record small changes in pressures and high pressure readings were taken with the mercury U-tubes.

To determine the rate of circulation through the cooling system and power demanded by the pump, the pump was disconnected from the engine and was couple to a dynamometer.

A venturimeter was put in the water lineoof pump discharge. Rate of water circulation was calculated from the venturimeter readings and the power demanded from the dynamometer readings. Necessary arrangements were made to create the condition for this test identical to that for actual operation.

Velocities were calculated for four sections,

(i) At the section of pump discharge,

(ii) At the minimum section through the flow area of the of the water jacket of the engine block.

(iii)At the section on the flow way from the block to the head of the engine.

(iv) At the section of minimum flow area of the water jacket of the engine head.

Results of pressure distribution have been so arranged in the table, (Table No. 1) that at a quick glance at the table it is very easy to visualize what is happening in the pressure distribution pattern with increase in pump speed as well as with increase in distance from the outlet of the pump.Also graphs have been drawn to show the relationship between pressure and pump speed and between pressure and positions of the pressure points in the system. This second graph, (Graph No. 2) giges a remarkable way of showing the pressure distribution pattern in thesystem.

Graphs have been drawn to show the relation between rate of circulation and pump speed and between power demand of the pump and the pump speed. These graph give to a different scale, the rate of circulation and power demand of the pump with respect to the engine speed. The table No.3 and the graph No.3 give an idea how the rate of circulation and power demand of the pump are related to thespeed

THE PROBLEM
FOR
INVESTIGATION

In the Internal Combustion Engines power is obtained by burning fuel inside the cylinder. The combustion results in a very high temperature and in the liberation of a large amount of heat. Approximately 30 to 35 per cent of this heat travels into and through the cylinder walls. If the cylinder walls are not properly cooled, the result will be too much heating of the cylinder walls, the lubricating oil will be burnt and the gradually increasing friction between the cylinder walls and the pistons will quickly damage the wearing surfaces. Further inefficient cooling will cause thermal stresses in the material of the cylinder walls. Therefore the cooling should be adequate, proper and efficient.

In present times all of the automotive engines are cooled by the pump circulation system. In this system some power from the engine output is used to drive the pump. So the rate of pumping should be such as to cause correct rate of water circulation, neither more nor less for proper and efficient cooling. If the water rate is greater than this more power is needed to drive the pump, which lowers the mechanical efficiency of the engine. On the other hand if sufficient amount of water is not circulated, the engine will wear out too rapidly. For this reason the present investigation seeks to establish relationships among power demanded by the pump, rate of circulation through the cooling system, and pressure and velocities at significant points in the cooling system.

When the water pump rate is established an attempt is made to find the water velocities through the engine at different speeds of the pump. The pump is driven through a V-belt by the engine crank shaft so water velocities through the engine can be related to the R.P.M. of the engine. The water velocities through the engine at different speeds will help to find the film coefficient of heat transfer between cylinder walls and cooling water. This film coefficient of heat transfer can be utilised to evaluate the rate of heat transfer to the cooling water to determine whether or not the cooling water flow rate is correct. The knowledge of thi optimum amount of water flow at any speed of the engine is a basis for the design of the pump.

An investigation is made to find at various points the pressures in the cooling water through the heat transfer passages. This will give a knowledge of the pressure distribution in the cooling water along the heat transfer passages and hence the nature and magnitude of the drop in pressure at any point from the inlet to the outlet of the water jacket. The point of maximum pressure drop will be seen . This will help the designers to improve their water jacket to produce less drop in pressure. The less drop in pressure means less resistance in the flow path, which saves power to the pump.

The pressure at a few points in the suction line is taken. This will help to check for cavitaion.

So our problem is to find pressure distribution in the cooling water along the heat transfer passages, to find rate of water pumping with respect to engine speed and to find power needed to drive the water pump with respect to the rate of water pumping.

CHOICE AND DESIGN OF TESTING EQUIPMENTS

Necessity wasto choose or to design devices for:

(i) Driving the pump

(ii) recording low speed pressures

(iii) Recording high speed pressures

(iv) Measuring rate of water circulation and

(v) Determining power demand of the pump

For driving the pump a variable speed D.C motor of the following specification, provided with starting and speed control panel was used. A pulley was designed for motor . The pump was driven through a V-belt.

Volts - 220 D.C.

Max. R.P.M. at full load - 1650

Current at full load - 11.9 amps.

For measuring rate of water circulation a venturimeter of the following dimensions was used. The venturimeter was inserted in thedischarge line from the pump with a gate valve for control.

Throat diameter = 1 inch

Diameter at entrance = 2 inches

For the determination of the power demand of the pump a General Electric Co. dynamometer was used. The dynamometer constant was

$$H.P. = \frac{\text{LB PULL} \times \text{R.P.M.}}{5000}$$

For recording low and high speed pressures straight piezometric tubes and mercury U-tubes were designed and made. With the help of gauges the pressure at the point of maximum pressure, and vacuum at the point of maximum vacuum were determined prior to the test for both the highest speed of the low range and highest speed of the high range.

	At low speed	At high Speed
Max. Pressure in lbs/sq.in	3.5	13
Max. vacuum in ins of Hg	4	12

Minimum length required for

(a) Piexometric tube = 3.5 x 34.14.7 = 8.1 ft.

(b) Mercury U-tube = 13 x 30/14.7 = 26.6 inches

(c) Water U-tube for vacuum = 4 x 34/30 = 4.52 ft

DESIGN OF DRIVE MOTOR PULLEY

Maximum R.P.M. of the crankshaft = 4400 = N_1

Diameter of the crankshaft pulley = 5.27 ins = D_1

Diameter of the pump pulley = 5.8 ins = D_2

So maximum R.P.M. of the pump N_2 is

$$\frac{N_2}{N_1} = \frac{D_1}{D_2}$$

Or $$N_2 = 5.27 \times \frac{4400}{5.8}$$

$$= 3940$$

R.P.M. of the motor at full load = 1650 = N_3

Let D_3 be the diameter of the motor pulley in inches

$$\frac{D_3}{D_2} = \frac{N_2}{N_3}$$

Or $$D_3 = \frac{3940 \times 5.8}{1650}$$

$$= 13.5$$

METHODS ADOPTED FOR SOLUTION

The problem of the present investigation was split up into three parts. They are:-

(i) To find the pressure distribution in the cooling water along the heat transfer passages

(ii) To find the rate of pumping water with respect to tne engine speed.

(iii) To find the power demand of the pump to the required flow to water.

The method adopted for solution of the first part was as follows:-

The engine was dismantled, water flow passages were observed and an engine head of the same type of our investigation model was dissected to observe the flow passages in order to locate the representententative pressure tapping points at the best available static zones. The pressure tapping points were connected either to the straight piezometric tubes in case of low pressures to read very small drops between points or to the U manometer tubes in case of high pressures. A few pressure taps were made in the suction line to r ead vacuum. The pump was run at the various speeds and the readings were taken at the corresponfing speeds.

To get the solution of the second part, ie., to find the rate of pumping water with respect of the engine speed, the pump was disconnected from the engine under investigation and was tested separately where it was possible to measure the flow rate of water with the help of a venturimeter. The pump was driven directly by a dynamometer through a coupling. A venturimeter was inserted in the line from the pump discharge to the radiator inlet. A gate valve in this line was used to check and control the flow of water in order to produce a predetermined pressure at the discharge point of the pump. This predetermined pressure at the pump discharge is the pressure which was obtained under actual conditions of pumping water through the system at various speeds. Readings of the venturimeter were taken and rates of water circulation calculated for various required speeds. At low speeds the venturimeter did not show any indication, and hence flow rate was established by extrapolating the curve drawn from the high speed readings.

To find the power needed to drive the pump at various speeds, the pump was connected to a dynamometer of known constant and by creating the same operating conditions as were under actual test the reading of the scale was taken.

TEST CONDITIONS

For the determination of the pressure distribution pattern in the cooling system there were two objectives:-

(a) Pressure response with respect to the increase in engine speed in an wide range of engine speed. This was achieved by selecting quite large number speeds from the idling to the top speed of the engine.

(b) Pressure drop in the system at the same speed with respect to the distance covered from the pump outlet to the jacket outlet. In order to achieve this end observations of flow passages were made to know their way and nature. Thirty significant points for pressure tapping in the discharge line and four in the suction line were decided and made at the best available static pressure zones.

Similar conditions under which the water pump was run to force water into the cooling system were set up when the pump was tested separately for the rate of circulation of water. The idea of putting the pump under similar conditions isto get from the pump in the test condition the same flow rate as was obtained in the actual condition at the various specified speeds. This could be done by equating the energy of water at a given point of the pump for both the test and the actual conditions.

Let the subscripts a and t stand for actual and test conditions respectively. The energy of water at a given point is by the well known Bernoulli Equation

$$\frac{V^2}{2g} + \frac{P}{w} + Z$$

where

V = velocity of water at that point in ft.sec.

P = pressure of water at point in lbs/sqin

Z = elevation of that point referred to any datum in ft.

w = specific weight of water at that temperature in pounds per cubic foot

In the actual condition the energy is

$$\frac{V_a^2}{2g} + \frac{P_a}{w} + Z_a$$

and in the test condition

$$\frac{V_t^2}{2g} + \frac{P_t}{w} + Z_t$$

at the same point.

If the two energies are to be equal

$$\frac{V_a^2}{2g} + \frac{P_a}{w} + Z_a = \frac{V_t^2}{2g} + \frac{P_t}{w} + Z_t$$

If the flow rates are equal V_a must be equal to V_t as the crossectional areas remain the same. So the equation stands

$$\frac{P_a}{w} + Z_a = \frac{P_t}{w} + Z_t$$

If we refer the elevation for both the cases to a convenient point which will be common for both the case, we can make

$$Z_a = Z_t$$

This was done by referring to the pump shaft. The height of the pump shaft from the zero datum of manometer board in the test condition was so set that the height of the pump shaft from the zero datum of the new manometer board was equal. So ultimately the equation is

$$\frac{P_a}{w} = \frac{P_t}{w}$$

By regulating the check valve inserted in the water line P_t was made equal to P_a for a given speed.

First, the inlet side of the pump was connected through a valve to the water supply tank and outlet side through another valve. It was arranged to regulate both the valves in order to get equal P_a's and P_t's for the suction as well as discharge side pressures. But the resistance offered by the valve in the suction line was so large that with the available water tank the necessary suction could not be obtained even with the valve wide open. So the inlet side was then connected to the radiator in the same position as it was in the engine. It was argued that since the resistances in the suction line remained same, if the valve in the discharge line is regulated to bring about the same pressure (to made $P_a = P_t$) for the discharge side only suction vacuums will automatically adjust to corresponding vacuums at different speeds.

For the determination of flow of water with respect to engine speed the pump could be driven at any speed. But the pump was driven at same speeds as it was driven when taking pressure readings for only at those speedsthe pressures were known for the discharge side.

When the flow rate, the resistance to the flow, and the pump operating head are same for both the actual and test conditions the power demanded by the pump must be the same.

So the test to know the power to drive the pump has three conditions to fulfil.

(a) To create same flow:- This was achieved to perform the second part of the investigation.

(b) To put in same resistance to flow path:- Since the same radiator with the same hose length in the same condition was used, the resistance in the suction side was unchanged. The valve in the discharge line acted as a resistor By regulating the valve the resistance in the line was adjusted until P_t was equal to P_a for a given speed. It was argued that since the speed of the pump and the discharge pressure for the test were same as for the actual condition this resistance must be equal to the resistance to the flow path offered in the actual investigation.

(c) The pump operating head is the difference between the pressure head and the suction head. As in both the cases these heads were same the pump operating head was same.

PROCEDURE

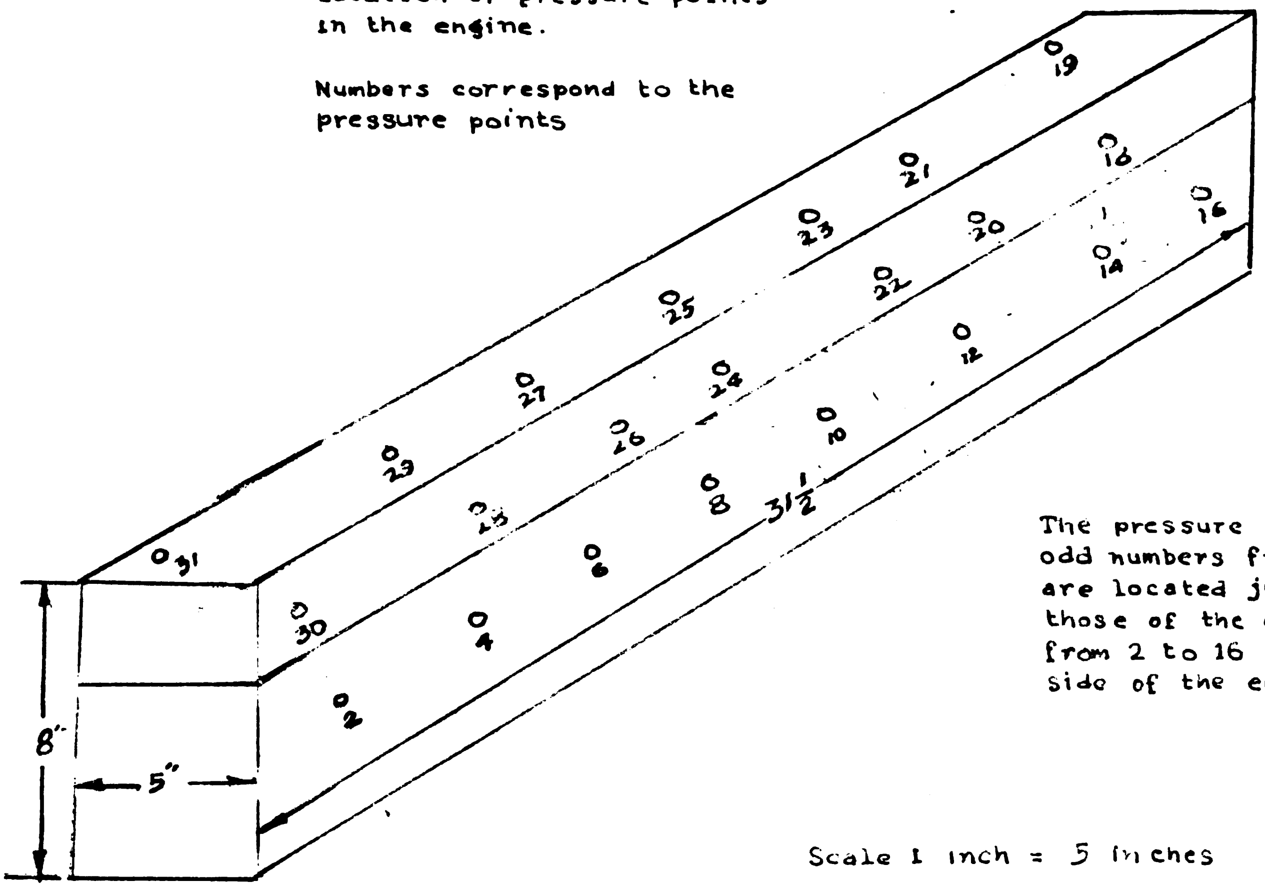
A. For pressure readings:-

All the pressure and vacuum points were connected either to the piezometric and water filled U-tubes, in case of low speed tests or to the mercury U-tubes, in case of high speed tests with the help of brass nipple and plastic tubes. The radiator was filled with water at room temperature to maintain the water level upto the filling point. The pump was driven at various speeds by means of a variable speed D.C. shunt wount motor. Readings were noted from the graph attached to the manometer board against the tubes. Parallax error was avoided. For every speed the reading of the reference pressure point was taken.

Fig 1

Location of pressure points in the engine.

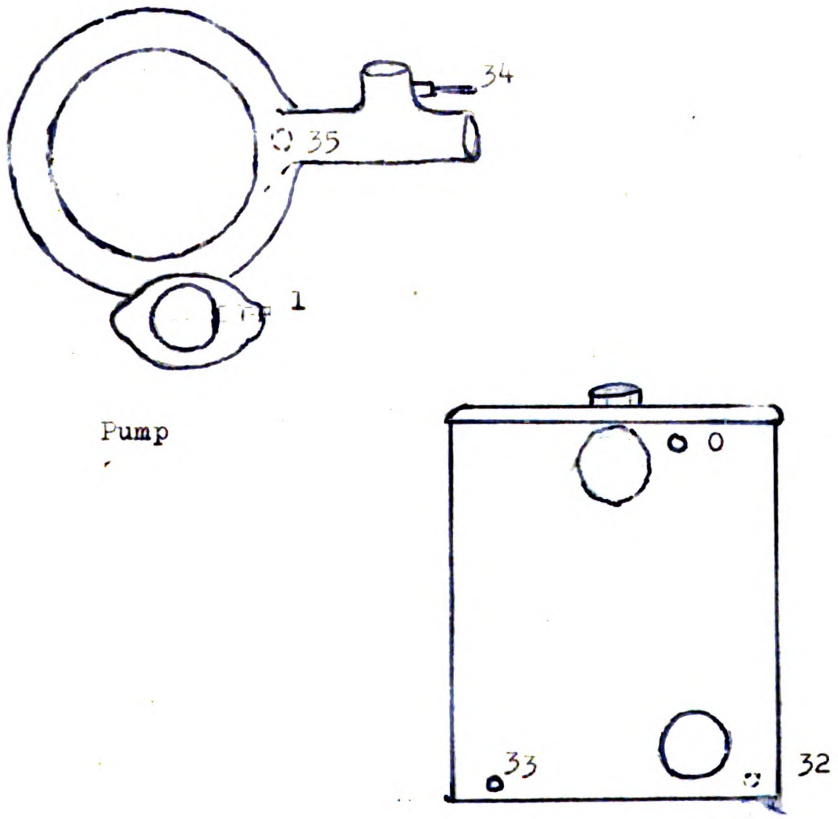
Numbers correspond to the pressure points



The pressure points of the odd numbers from 3 to 17 are located just opposite to those of the even numbers from 2 to 16 on the other side of the engine block.

Scale 1 inch = 5 inches

Pressure points in the pump and in
<u>the radiator</u>



Pump

Radiator

Fig. 2

LOW SPEED PRESSURE READINGS

Speed of the motor in R.P.M.	280	395	470	610
Pressure points	Height of water level in the piezomter tubes in inches			
0	1	1	1	.8
1	13	22.65	33.3	59
2	10.8	18.65	28.3	47.9
3	10.7	18.20	27.4	46.9
4	10.75	18.50	27.8	47.4
5	10.75	18.60	28.2	47.9
6	10.7	18.40	27.8	47.4
7	10.7	18.55	27.9	47.6
8	10.65	18.30	27.6	47.0
9	10.8	18.4	27.7	47.0
10	10.6	18.3	27.5	46.6
11	10.6	18.3	27.6	46.8
12	10.5	18.10	27.25	46.1
13	10.5	18.15	27.4	46.2
14	10.4	17.9	26.8	45.6
15	10.5	18.1	27.3	46.1
16	10.5	18.1	27.3	46.2
17	10.5	18.3	27.3	46.2

LOW SPEED PRESSURE READINGS

(Contd.)

Speed of the motor in R.P.M.		280	395	470	610
18		9.4	16	24	40.2
19		9.9	16.74	25.2	42.6
20		9.1	15.35	22.9	38.9
21		9.15	15.4	22.9	38.9
22		8.9	15.2	22.5	38
23		8.9	15.2	22.6	38.2
24		8.65	14.8	22	37.2
25		8.65	14.75	21.9	37.2
26		8.5	14.4	21.35	36.2
27		8.4	14.4	21.3	36.2
28		8.35	14.1	20.7	35.2
29		8.3	14.2	20.9	35.3
30		7.9	13.4	19.7	33.4
31		8.1	13.7	20.2	34.3
		Height of water level in the U-tubes			
32	Closed end	23.3	24.3	25	29.5
	Open end	20.7	19.7	18.7	15.4
33	Closed end	23.7	24.5	24.8	26.7
	Open end	21.4	20.6	20.2	18.4

LOW-SPEED PRESSURE READINGS
(Contd.)

Speed of the motor in R.P.M.		280	395	470	610
34	Closed end	52.6	55.4	56.7	60.8
	Open end	49.6	46.8	46.3	41.4
35	Closed end	50.2	51.8	53.3	56.6
	Open end	44.8	42.2	40.7	36.3

Vacuum in inches of water

32	2.6	4.6	6.3	4.1
33	2.3	3.9	4.6	2.3
34	3.0	6.6	10.4	19.4
35	5.4	9.0	12.6	20.3

MEDIUM-SPEED PRESSURE READINGS

1	2	3	4	5	6	7
Speed of the motor in R.P.M.	840			880		
	Height of the water level in the piezometer tube	Readings of the U-tubes				
		Water level in the press. limb	Closed limb		Open limb	
			Hg	H_2O	Hg	H_2O
0	.75	1.8				
1 Hg in the open limb	45.5	19.1	8.5	14	17.0	17.2
Hg in the closed limb	24.5					
H_2O in the press. limb	29.4					
2	90	12.5	12.2	13.8	18.3	
3	87.8	13	10	11.8	16.1	16.3
4	89	12.2	8.8	12.3	15.4	
5	89.9	15.1	9.7	17.2	16.5	
6	88.8	12.7	10.2	15.4	17	
7	89.1		9.6	9.6	16.4	
8	88.1		9	9	15.7	
9	88.5	4.7	9.1	11.3	15.4	

MEDIUM-SPEED PRESSURE READINGS
(Contd.)

1	2	3	4	5	6	7
12	86.8	13.7	9.2	10.3	15.5	
13	87.4	15.6	10.8	16.1	17.2	
14	86	13.5	9.3	10.3	15.5	
15	86.7	14.5	9.4	14.3	16	
16	87	13	8.5	12.2	15	15.2
17	86.7	13.9	8.5	11.3	15.1	
18	75.5	15.7	8.2	13.5	13.8	
19	75.4					
20	72.3					
20	72.3					
21	72.3					
22	70.6					
23	71.3	14	8.9	14	14.1	
24	69.3					
25	69.6					
26	67.5					
27	67.6	5	10.4	14.4	15.4	17.5
28	65.9	11	8.3	10.3	12.7	12.9
29	66.2	9.5	7.9	12.3	12.7	

1	2	3	4	5	6	7
30	62.4	13.5	8.2	10.9	12.1	13.1
31	64.1	13.2	11.4	11.6	15.6	

Speed = 840

Pressure points	Water levels in the U-tubes Closed limb	Open limb
32	36	7.5
33	32.2	12.4
34	64	30
35	74	19

Speed = 880

Pressure points	Readings of the U tubes Water level in the press limb	Closed limb Hg	Closed limb H_2O	Open limb Hg	Open limb H_2O
32		5.3		3.8	4.8
33		15.5		14.1	
34		10.1		5.8	
35		13.5		9.4	10.2

HIGH-SPEED PRESSURE READINGS

Speed = 1440

1	2	3	4	5	6
Pressure points	Readings in the U-tubes				
	Water level in the press. limb	Closed limb		Open limb	
		Hg	H_2O	Hg	H_2O
0	1.1				
1	16	4.3	9	20.8	
2	18.8	8.8	19.9	21.9	
3	19	6.6	8	19.6	
4	19	5.6	8.2	18.4	
5	19.5	6.4	14	18.4	
6	18.2	7.1	11	20	
7	19.5	6.1		19.5	
8		5.6	5.6	19	
9		5.4	15.6	18.5	
10	18.4	4.8	7.3	17.5	
11	19.5	7.3	10.1	20.2	
12	19.5	6.1	7.6	18.9	
13	19.5	7.6	12.3	20.4	

1	2	3	4	5	6
13	19.5	7.6	12.3	20.4	
14	19.5	6.1		18.8	
15	19.5	6.3	9.4	19	
16	18.5	5.3	8.5	17.2	
17	18.4	5.9	8.3	18.8	
18	19.5	4.9	11	16.7	
23	19.5	6.1	10.3	16.8	17.1
27	11	7.7	11.8	18.4	20.4
28	19	5.5		15.5	15.9
29		5.1	15	15.7	
30		5.6	17	14.5	15.5
31	18	8.9		18.3	
32		7.2		3.1	5
33					
34		12.6		3.2	
35		15.8		7.3	8.2

HIGH-SPEED PRESSURE READINGS
(Contd.)

Speed = 1630

1	2	3	4	5	8
Pressure points	Readings of the U-tubes				
	Water level in the press. limb	Closed limb		Open limb	
		Hg	H_2O	Hg	H_2O
0	1.1				
1		2	15.5	23.5	
2		7.7	17.5	23.1	
3		3.5	15	21.5	21.8
4		3.6	15	20.6	
5		4.3	12	22.1	
6		5	16.5	22.3	
7		4	4	22.2	
8		3.3	3.3	21.1	
9		3.7	14	20.8	
10		2.7	14	19.8	
11		5.2	16.5	22.3	
12		4	16	21	
13		5.5	14	22.6	

1	2	3	4	5	6
14		4	15.5	20.6	
15		4.3	15	20.9	
16		3.5	16	20	
17		4.1	15.5	21	
18		3.4	13	10.4	
20		-1.4		12.7	13
23		4.6		12	18.5
27	13.7	6.7	10.4	19.6	21.7
28		5.2	17	15.2	15.5
29		4.4			
30		3	16	16	17
31	18.5	9		16.6	
32		8.2		2.0	4
33		4.6	12	18.5	
34		13.7		2.1	
35		16.6		6	7

HIGH-SPEED PRESSURE READINGS
(Contd.)

Speed = 1690

1	2	3	4	5	8
Pressure points	Readings of the U-tubes				
	Water level in the press. limb	Closed limb		Open limb	
		Hg	H_2O	Hg	H_2O
0	1.1				
1		1.5	13.5	24	
2		6,9	15.8	23.9	
3		4.1	14	22	22.2
4		3.3	14	21	
5		4	12	22.2	
6		4.6	12	22.4	
7		3.8	3.8	22.3	
8		3.3	3.3	21.4	
9		3.7	12.5	21	
10		2.2	11	20	
11		5	12.5	22.6	
12		4	12.5	21.4	
13		5.2	11	22.9	

1	2	3	4	5	6
14		4	15	21.1	
15		4.1	11.5	21.6	
16		3.1	11.5	20.9	
17		4.1	15	21.1	
18		3.2	10	18.7	
23		3.5	10.5	18.7	
27	13.2	6.1	10	19.8	
28	19.6	3,8	5	17	17.3
29	18.5	3.5	7.5	16.9	
30		4	14.5	16.2	17.2
31		7.3	17.5	19.9	
32		8.1		2.1	
33		17		12.6	
34		14.0		2	
35		6.6	6	6.8	

SAMPLE CALCULATION FOR MEASUREMENTS OF PRESSURE BY PIEZOMETRIC TUBES

Let the height of water column in the piezometer tube with reference to zero datum in inches = H

the height of water column in the piezometer tube to which all other readings to be referred for datum = h

So the pressure in inches of water above adopted master datum plane = H - h

$$\text{Pressure in inches of Hg} = \frac{H - h}{13.6}$$

$$\text{Pressure in lbs/sq.in} = (H - h) \times \frac{1}{34 \times 12}$$

$$= (H - h) \times .00362$$

Let us take a numerical example,

Speed = 610

Pressure point = 1

Then H = 59

h = .8

Pressure in inches of water above adopted master datum plane

$$= H - h$$

$$= 59 - .8$$

$$= 58.2$$

Pressure in inches of Hg $= \dfrac{58.2}{13.6}$

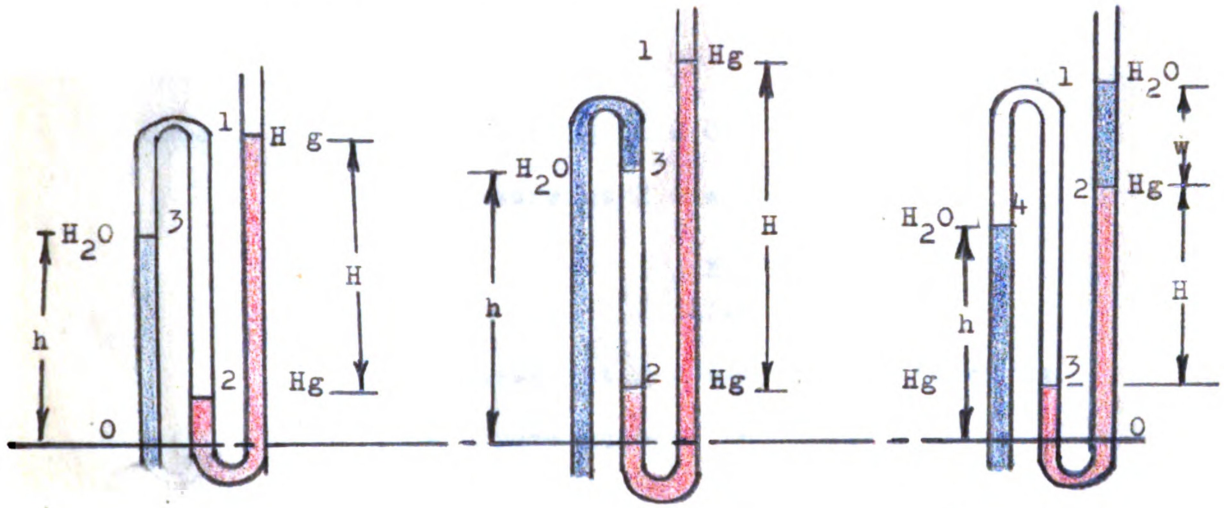
$$= 4.28$$

Pressure in lbs/sq.in $= 58.2 \times .00362$

$$= .211$$

Fig. 3

Blue - water Red - Mercury



Case 1 Case 2 Case 3

SAMPLE CALCULATION

FOR

<u>MEASUREMENTS OF PRESSURE BY U-TUBES</u>

To find pressure at the plane 0 0

Case 1 & Case 2	Pressure at 1	= 0 gauge
	Pressure at 2	= H ins of Hg
	Pressure at 3	= H ins of Hg

(weight of air negligible)

Pressure at O O = H ins of Hg + h ins of H_2O

$$= H + \frac{h}{13.6} \text{ ins of Hg}$$

Case 3. :- Pressure at 1 = 0

Pressure at 2 = w ins of H_2O

$$= \frac{w}{13.6} \text{ ins of Hg}$$

Pressure at 3 = w/13.6 + H ins of Hg

Pressure at 4 = " "

$$\text{Pressure at O O} = \frac{w + h}{13.6} + H \text{ ins of Hg}$$

Numerical Example

Speed = 1440 and

Pressure Point No = 14	Pressure point No 9
Case 1	Case 2
H = 18.8 - 6.1	H = 18.5 - 5.4
h = 19.5	h = 15.6
Pressure = $H + \frac{h}{13.6}$	Pressure = $H + \frac{h}{13.6}$

$$\text{Pressure} = 12.7 + \frac{19.5}{13.6} = 14.14 \text{ ins of Hg}$$

$$= 13.1 + \frac{15.6}{13.6} = 14.24 \text{ ins of Hg}$$

Case 3.

Pressure point 28

$$w = 15.9 - 15.4 = .5$$

$$H = 15.5 - 5.5$$

$$h = 19$$

$$\text{Pressure} = \frac{19.5}{13.6} + 10$$

$$= 11.45 \text{ ins of Hg}$$

These are the pressures at the zero datum. The pressure above adopted master plane ([illegible]) is found by subtracting from this pressure the pressure at the plane O O.

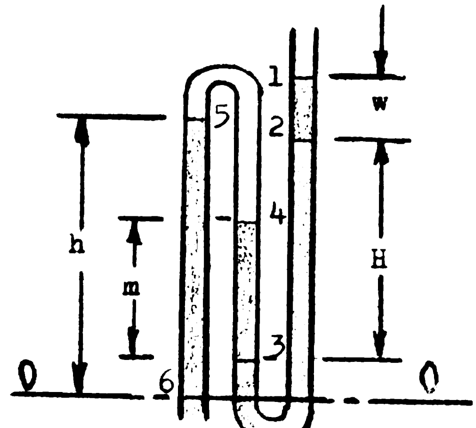


Fig. 4

Case 4

Pressure Point 1

Speed = 1440

Pressure at 1 = 0 g

Pressure at 2 = w ins of H_2O

Pressure at 3 = $\frac{w}{13.6}$ + H ins of Hg

Pressure at 4 = $\frac{w}{13.6}$ + H - $\frac{m}{13.6}$ ins of Hg

Pressure at 5 = " " "

Pressure at 6 = $\frac{w}{13.6}$ + H - $\frac{m}{13.6}$ + h/13.6 ins of Hg

RESULTS

IN INCHES OF Hg

Table No 1.

R.P.M. of the pump	653	921	1090	1420	1953	2040	3350	3800	3940
Pressure points 1	.684	1.67	2.44	4.26		9.38	17.25	22.8	23.41
2	.720	1.29	2.01	3.44	6.62	6.77	14.2	18.0	18.07
3	.715	1.26	1.94	3.37	6.45	6.80	14.23	18.4	18.67
4	.717	1.28	1.97	3.4	6.54	7.1	14.2	18.5	18.75
5	.717	1.29	2.00	3.44	6.6	7.23	14.2	18.5	18.80
6	.715	1.27	1.97	3.4	6.54	7.23	14.24	18.4	18.76
7	.717	1.28	1.98	3.5	6.55	7.37	14.3	18.5	18.81
8	.711	1.27	1.95	3.37	6.46	7.23	14.3	18.4	18.69
9	.72	1.27	1.96	3.37	6.5	7.2	14.2	18.3	18.60
10	.705	1.27	1.95	3.36	6.44	7.1	14.1	18.1	18.5
11	.705	1.27	1.95	3.36	6.36	7.13	14.1	18.2	18.53
12	.7	1.26	1.93	3.31	6.38	7.09	14	18	18.44
13	.7	1.26	1.94	3.32	6.42	7.1	14.1	18.1	18.46
14	.69	1.24	1.89	3.28	6.32	6.95	14	17.9	18.39
15	.7	1.26	1.93	3.31	6.37	6.8	14	17.9	18.27

RESULTS (Contd.)

IN INCHES OF Hg

R.P.M of the Pump	653	921	1090	1420	1953	2040	3350	3800	3940
Pressure points									
16	.7	1.26	1.93	3.32	6.4	6.9	13.9	17.8	18.18
17	.7	1.27	1.93	3.32	6.37	6.75	13.9	17.8	18.1
18	.617	1.1	1.69	2.88	5.55	6.10	12.8	15.8	16.16
19	.653	1.16	1.7	3.06	5.54				
20	.595	1.05	1.61	2.78	5.32				
21	.597	1.06	1.61	2.78	5.32				
22	.587	1.04	1.58	2.72	5.18				
23	.58	1.04	1.58	2.72	5.24	5.71	11.8	14.7	15.89
24	.562	1.01	1.54	2.65	5.11				
26	.55	.985	1.49	2.58	4.96				
27	.545	.985	1.49	2.58	4.96	5.3	11.3	13.7	14.31
28	.535	.96	1.44	2.51	4.84	5.2	11.1	13.1	14.28
29	.535	.97	1.45	2.51	4.86	5.2	11.1	12 7	14.19
30	.505	.91	1.37	2.38	4.58	5.02	10.8	11.5	14.0
31	.52	.94	1.41	2.44	4.71	5.1	10.7	12.9	13.88
25	.562	1.01	1.54	2.65	5.11				

RESULTS

VACUUM IN INCHES OF Hg

Table 2

R.P.M. of thePump	653	921	1090	1420	1953	2040	3350	3800	3940
Pressure Points 33	.169	.386	.338		1.46	1.4	3.7	5.91	6.0
32	.185	.338	.46		2.07	1.52		6.45	
34	.22	.631	.765	1.43	2.5	4.3	8.43	9.08	
35	.396	.665	.911	1.5	4.05	4.0	9.4	11.6	12

SAMPLE CALCULATION FOR VACUUM

Case 1. :- U-tubes filled with water

Let the closed limb read H_w inches of water

and the open limb read h_w inches of water

$$\text{Vacuum in inches of Hg} = \frac{H_w - h_w}{13.6}$$

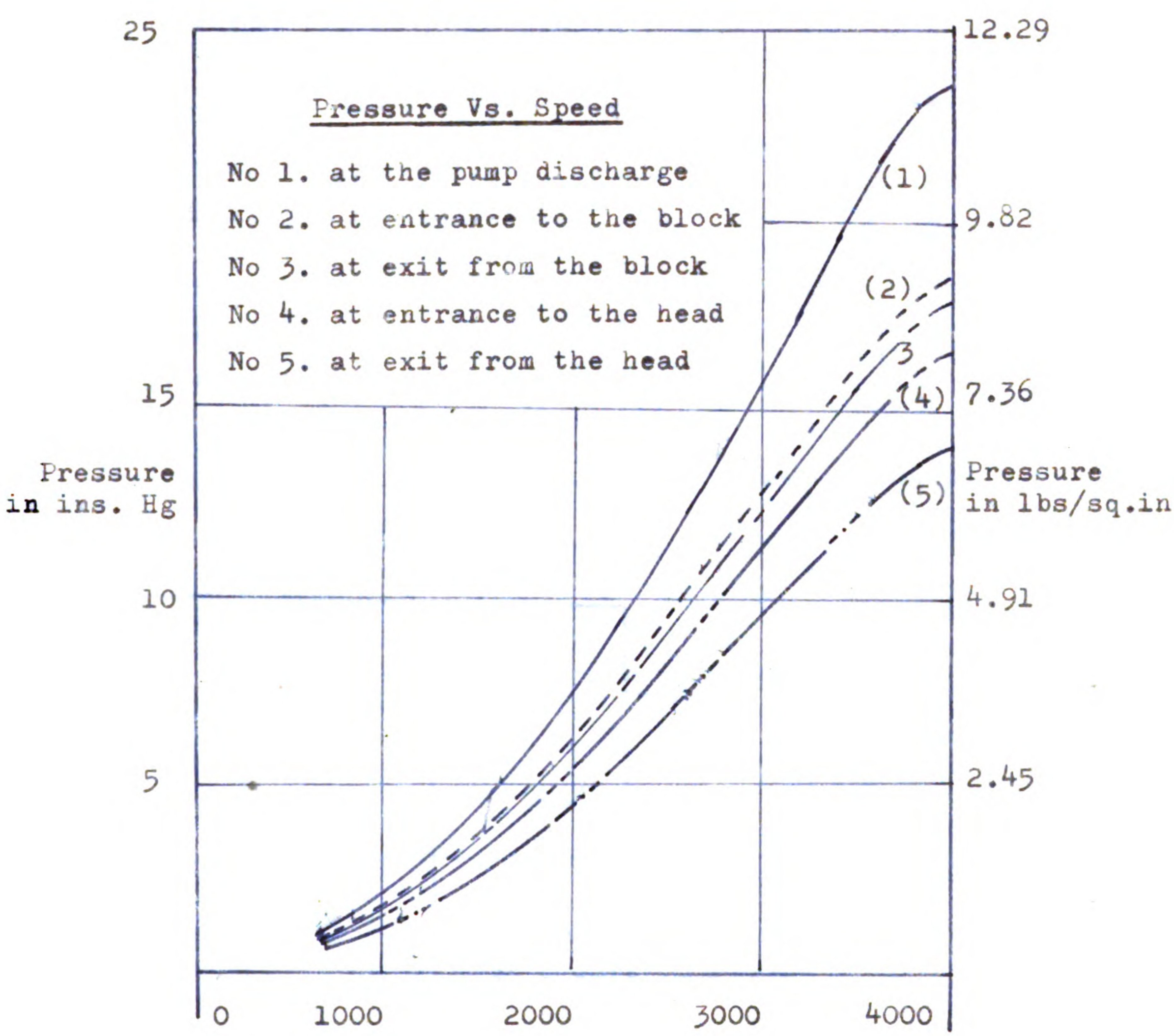
Case 2. :- U-tubes filled with mercury

Let the closed limb read H_m inches of Hg

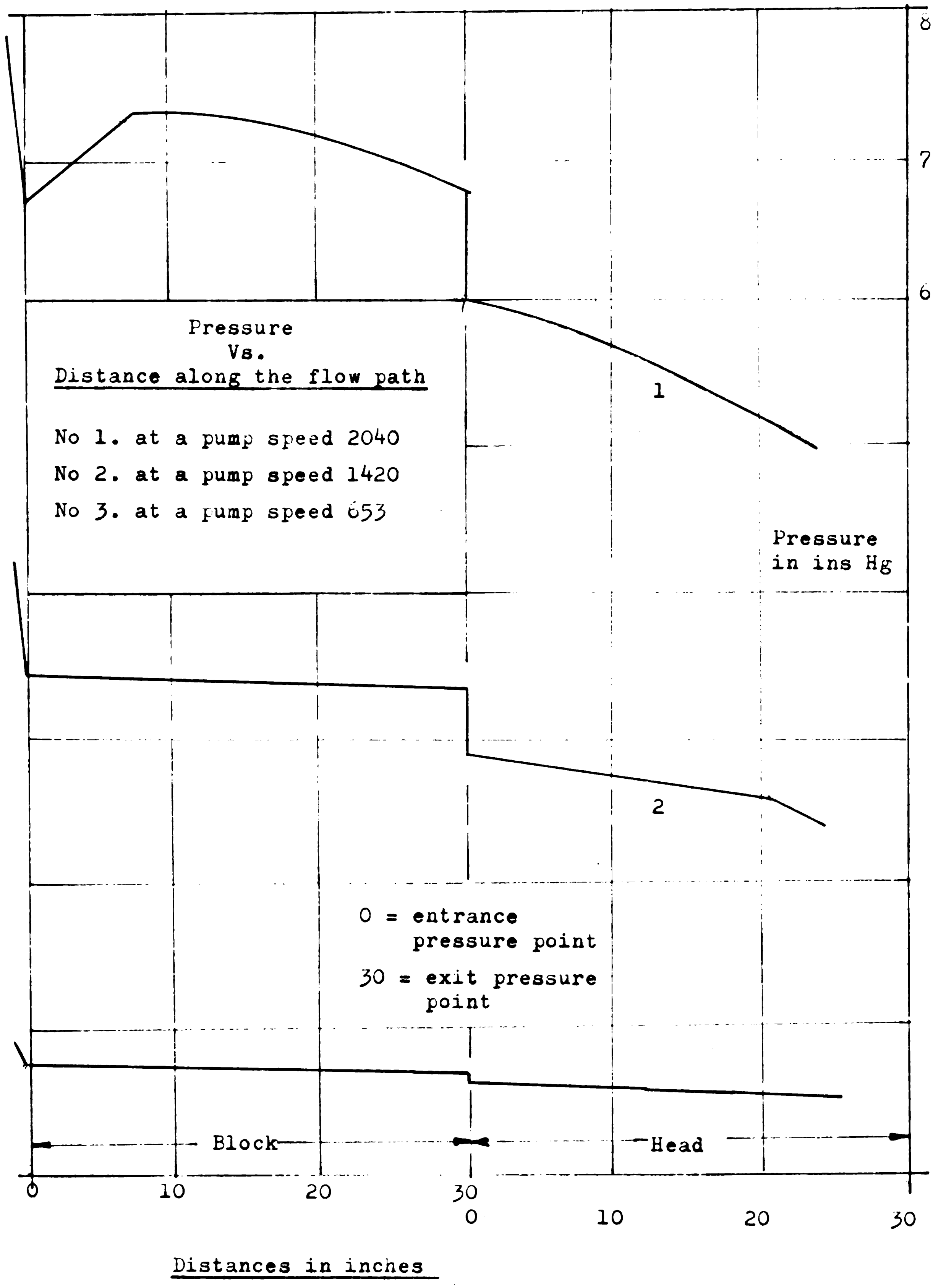
and the open limb read h_m inches of Hg

$$\text{Vacuum in inches of Hg} = H_m - h_m$$

Graph 1.



Speed of the pump in R.P.M.



8
7
6
Pressure
Vs.
Distance along the flow path
No 1. at a pump speed 2040
No 2. at a pump speed 1420
No 3. at a pump speed 653
1
Pressure
in ins Hg
2
0 = entrance pressure point
30 = exit pressure point
Block
Head
0
10
20
30
0
10
20
30
Distances in inches

Graph 2.

Relation between speed of the motor and speed of the pump

Speed of the motor in R.P.M. = N_3	280	395	470	610	840	880
Speed of the pump in R.P.M. = N_2	653	921	1090	1420	1953	2040

Speed of themotor in R.P.M.	1440	1640	1690
Speed of the pump in R.P.M.	3350	3800	3940

Sample Calculation

$$\frac{N_2}{N_3} \qquad \frac{D_3}{D_2}$$

Or $$N_2 = \frac{13.5 \times 280}{5.8}$$

$$= 653$$

The speed of the motor has been determined with a tachometer.

DATA SET UP

FOR

THE TEST TO KNOW RATE OF WATER FLOW AND

DRIVE POWER

The original levels of Hg in the U-tubes

(a) to adjust pressure = 16.3 inches

(b) to adjust vacuum = .45 "

(c) to record
venturimeter readings = 19.1 "

Pump Speed	The pressure should read in the U-manometer in open limb for	
	Vacuum	Pressure
1420	1.17	18
1953	2.48	20.54
2040	2.65	20.62
3350	5.15	24.65
3940	6.45	28.00

SAMPLE CALCULATION

TO SHOW "What the pressure should read " WAS OBTAINED

Speed of the pump = 3350

Pressure at the discharge point, point 2 = 17.2 ins of Hg

If there were no water pressure in the pressure limb of the manometer the pressure shoul show in the open limb

$$= 16.3 + \frac{17.2}{2}$$

24.9 ins

and in the closed limb

$$= 16.3 - \frac{17.2}{2}$$

$$= 7.7 \text{ ins}$$

So the pressure exerted by water (water was continous upto the Hg level in the closed limb)

= the height of 7.7 ins of H_2o

= .565 ins of Hg

So when the pressure shows 17.2 ins of Hg,

Actual pressure is 17.2 + .565 = 17.765 ins of Hg

And therefore when the pressure should be = 17.2 ins of Hg

the pressure should show $\dfrac{17.2 \text{ x} 17.2}{17.765} = 16.7$

Therefore the pressure should read in the open limb

$$= 16.3 + \frac{16.7}{2}$$

$$= 24.65 \text{ ins}$$

DATA OBTAINED
FROM
THE TEST TO KNOW RATE OF WATER FLOW AND DRIVE POWER AND
RESULTS

Table no 3

$$\text{Dynamometer H.P.} = \frac{\text{LB PULL X R.P.M.}}{5000}$$

Pump speed	Venturimeter Readings		Dynamometer Readings	Rate of Flow	H.P. Demanded
	P_1	P_2	Lbs	cft/sec	
1420	19.6	18.6	2.63	.056	.720
1953	20.84	1736	2.91	.088	1.136
2040	21.01	17.19	2.98	.094	1.216
3350	26.97	11.23	3.96	.191	2.656
3800	31.4	6.8	4.28	.238	3.264
3940	32.5	5.7	4.41	.249	3.48

SAMPLE CALCULATION

1. Rate of flow:-

Venturimeter equation $$\frac{V_2^2 - V_1^2}{2g} = \frac{P_1 - P_2}{w}$$

V = in ft./sec.

$\frac{P}{w}$ = in ft.of water

Example

Speed of the pump 3940

$$\frac{P_1 - P_2}{w} = 32.5 - 5.7 = 26.8 \text{ ins of Hg}$$

$$= \frac{26.8 \times 13.6}{12} \text{ ft of } H_2O$$

$$= 30.4 \text{ ft. of } H_2O$$

$$Q = A_1V_1 = A_2V_2$$

$$\text{Or } \frac{V_2}{V_1} = \frac{A_1}{A_2}$$

$$\text{Or } V_2 = \frac{.7854 \times D_1^2}{.7854 \times D_2^2} \times V_1$$

SAMPLE CALCULATION

1. Rate of flow:-

Venturimeter equation $$\frac{V_2^2 - V_1^2}{2g} = \frac{P_1 - P_2}{w}$$

V = in ft./sec.

$\frac{P}{w}$ = in ft.of water

Example

Speed of the pump 3940

$$\frac{P_1 - P_2}{w} = 32.5 - 5.7 = 26.8 \text{ ins of Hg}$$

$$= \frac{26.8 \times 13.6}{12} \text{ ft of } H_2O$$

$$= 30.4 \text{ ft. of } H_2O$$

$$Q = A_1V_1 = A_2V_2$$

$$\text{Or } \frac{V_2}{V_1} = \frac{A_1}{A_2}$$

$$\text{Or } V_2 = \frac{.7854 \times D_1^2}{.7854 \times D_2^2} \times V_1$$

or $V_2 = 4\ V_1$ ∮ D_1 = Dia at entrance = 2 inches
∮ D_2 = Dia at throat = 1 inch

Therefore
$$\frac{V_2^2 - V_1^2}{2g} = \frac{15\ V_1^2}{2g}$$

And
$$\frac{15\ V_1^2}{2g} = 30.4$$

$$V_1 = 11.4$$

So
$$Q = A_1 V_1 = .7854 \times \frac{4}{144} \times 11.4$$

$$= \underline{.249 \text{ cft/sec}}$$

2. For H.P. demanded

$$\text{H.P.} = \frac{\text{Lb Pull} \times \text{R.P.M.}}{5000}$$

$$= \frac{4.41 \times 3940}{5000}$$

$$= \underline{3.48}$$

PROCEDURE

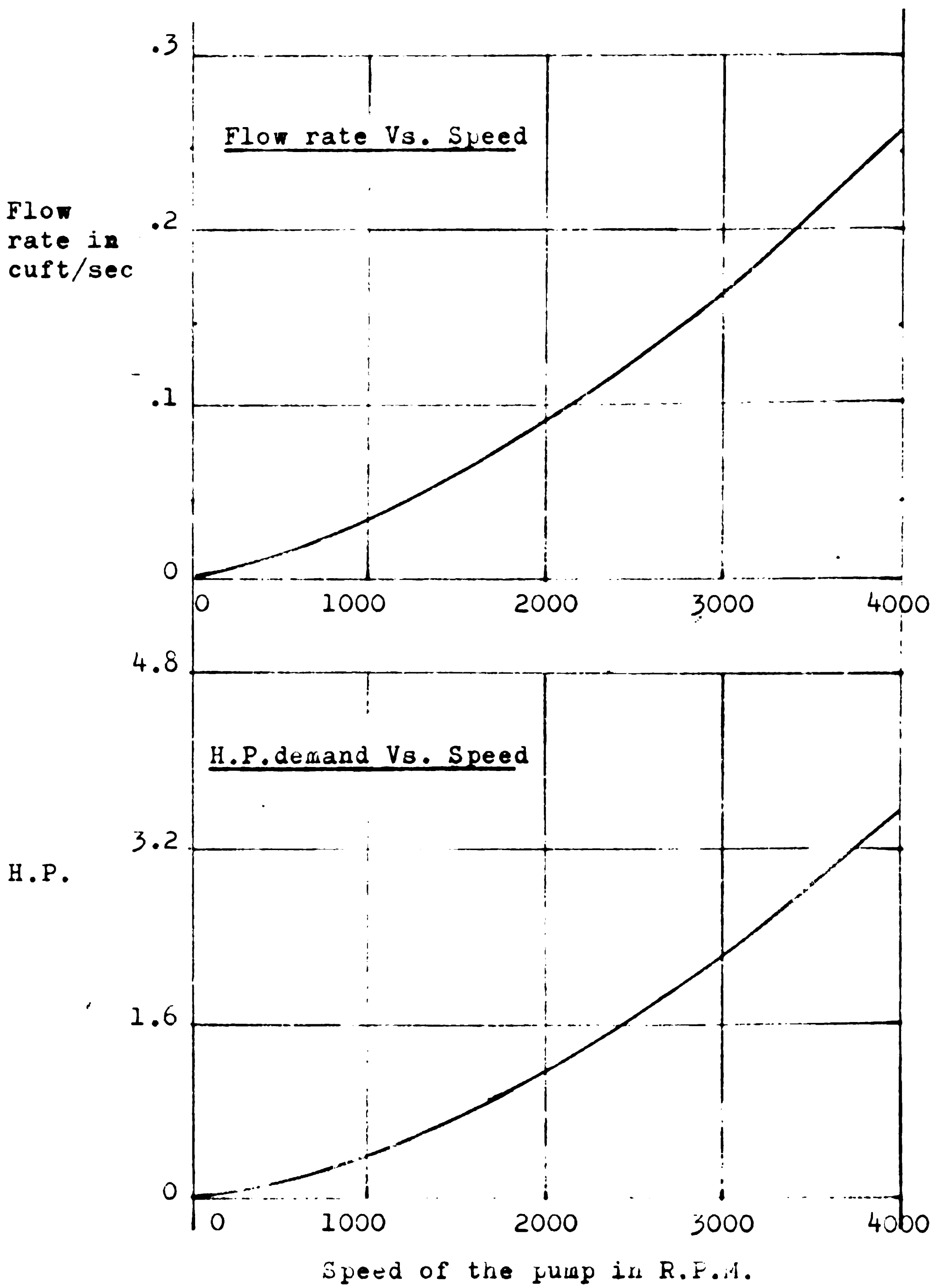
B. For finding rate of water circulation and power demand of the pump

The pump was disconnected from the engine and was fitted to a dynamometer for direct drive through a coupling. Necessry water connections were made and a venturimeter was put in the discharge line.

The dynamometer was run at various desired speeds. At every speed the pressures at the discharge point, point 1, were made equal to those for actual conditions by regulating the valve. The venturimeter leads were connected to an U-tube with plastic tubes.

Readings of venturimeter and dynamometer scale were taken every speed.

Graph 3


Flow rate Vs. Speed
Flow rate in cuft/sec
.3
.2
.1
0
0
1000
2000
3000
4000
4.8
H.P.demand Vs. Speed
H.P.
3.2
1.6
0
0
1000
2000
3000
4000
Speed of the pump in R.P.M.

VELOCITIES

Velocities were calculated for four sections in the flow passages of the cooling system. These four sections were critical sections in the sense described velow:-

The first section was the section at the pump discharge, it was a circular path of diameter 1.25 inches. The second section (Fig. 7) was the section of minimum area of water flow in the jacket around the engine block cut across the diameter of the cylinder. The area was calculated from the given dimensions. The third one was the section for the transfer of water from the block to the head of the engine. This consisted of five circular paths, one is of 1 inch diameter and the rest four are of diameter $\frac{1}{2}$ inch each. The last section was the section of flow of water through the water jacket of the head. This was also a section of minimum area and was found by cutting the head at various sections. The area at this section was irregular (Fig. 8) and it was found by making its impression on the graph paper.

RESULTS

Area of section 1 $A_1 = 17854 \times \dfrac{1.25^2}{144}$

$= .00856$ sq.ft

Area of section 2 $A_2 = \dfrac{4}{12} \times \dfrac{.5}{12} \times 2$

$= .028$ sq.ft

Area of section 3 $A_3 = .7854 \times \dfrac{1}{144} + 4 \times .7854 \times \dfrac{.5^2}{144}$

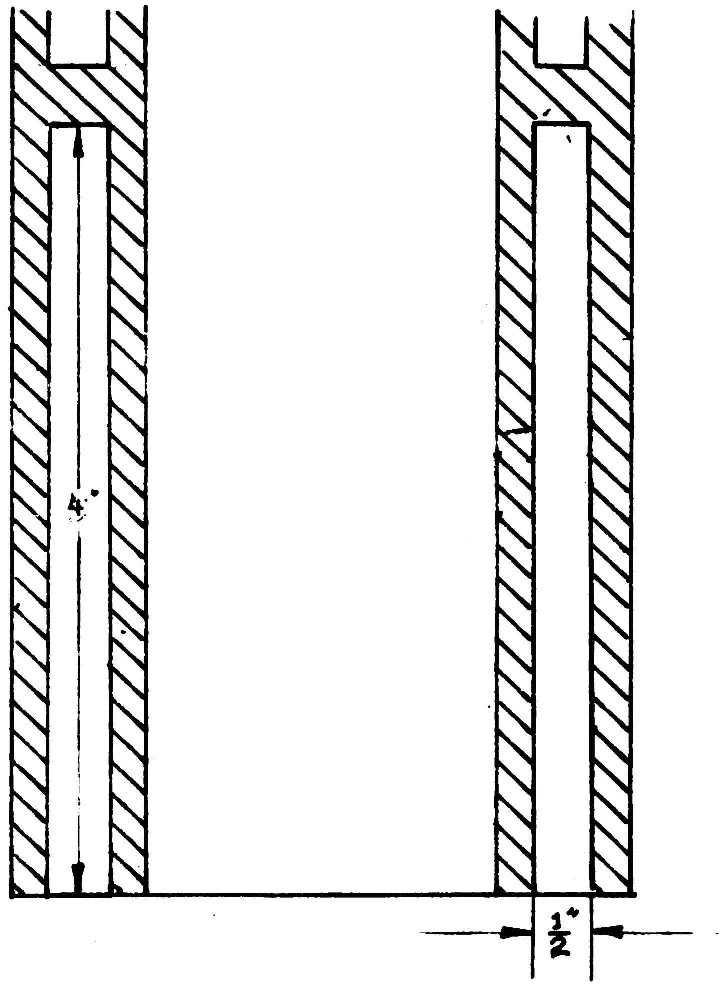
$= 0.0109$ sq.ft

Area at section 4 $A_4 = .03$ (calculated from the graph)

Pump speed	Rate of Flow	Velocities of water			
		Sec. 1	Sec. 2	Sec. 3	Sec. 4
1420	.056	6.54	2.0	5.14	1.866
1953	.088	10.32	3.14	8.075	2.94
2040	.094	10.98	3.36	8.63	3.13
3350	.191	22.3	6.83	17.5	6.38
3800	.238	27.8	8.5	21.8	7.94
3940	.249	29.1	8.9	22.8	8.3

Fig. 7

Section showing the
area of water flow through jacket
of the block



Not to scale

Section of minimum area of flow of water
through the water jacket of the head

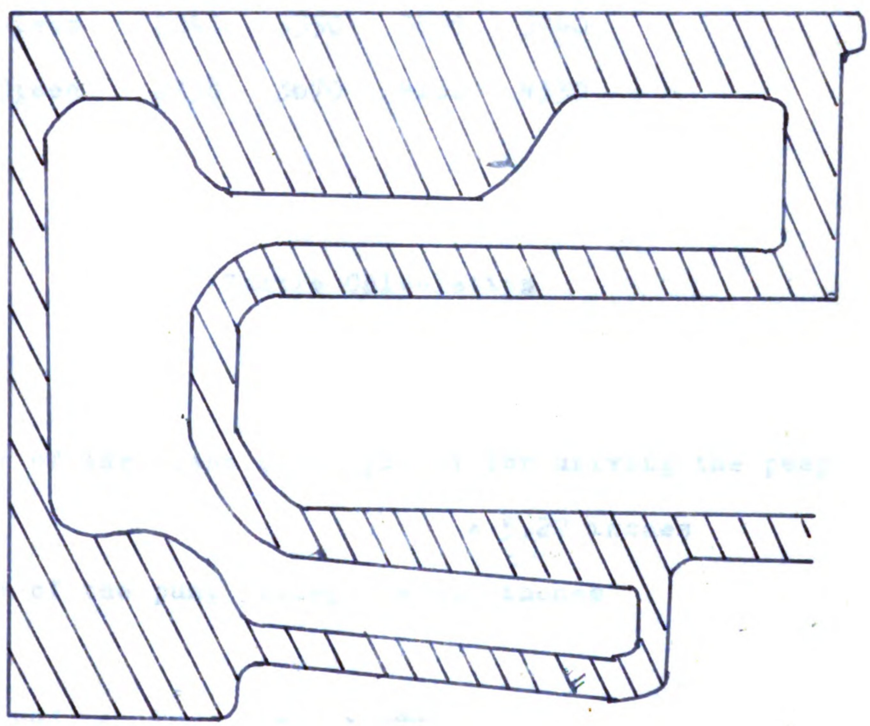


Fig. 8

Relation between Pump Speed and Engine Speed

Pump Speed	653	921	1090	1420	1953
Engine Speed	715	1010	1195	1564	2140

Pump Speed	2040	3350	3800	3940
Engine Speed	2238	3670	4160	4330

Sample Calculation

Diameter of the crank shaft pulley for driving the pump

= 5.27 inches

Diameter of the pump pulley = 5.8 inches

$$\text{Engine Speed} = \text{Pump Speed} \times \frac{5.8}{5.27}$$

$$= 653 \times \frac{5.8}{5.27}$$ (when pump speed = 653)

$$= 715$$

CONCLUSION

This investigation reveals some informations about " FLUID FLOW PATTERNS IN THE HEAT TRANSFER PASSAGES OF AN INTERNAL COMBUSTION ENGINE " which were before unknown to the students and teachers of Internal Combustion Engines. These may now fill up the vacant place in the literature.

A look to the graphs Pressure Vs. Speed and Pressure Vs. Distance of pressure points in the system from the pump outlet shows that maximum pressure drops take place at exit from the pump to the entrance of the block, and at the exit from the block to the entrance of the head. This is because of entrance and exit losses. The pressure drop along the block is negligible compared to the drops described above, while there is a considerable amount of drop along the head. The reasons are that the flow path along the head offers large resistance due to its zigzag course, and the plain path along the block offers a very small resistance. The velocity of water through the water jacket must be turbulent, this is necessary for high rate of heat transfer through the heat transfer surfaces of the head.

From the graph 1 it is seen that the pressure has the steepest gradient at a pump speed between 2000 to 3500 R.P.M., this is because with the increase of rate of water circulation pressure increases. But after that, gradient changes and tends to become less and less steep, this indicates some hindrance wich may be a larger friction factor at high speed.

The maximum vacuum in the cooling system is 12 inches of Hg or the minimum absolute pressure is 18 inches of Hg when the barometer reads 30 inches of Hg. At this pressure the boiling point of water is 187.45° F. So if the thermostat is designed for 160° F or 180° F there is no chance for cavitation.

The graph No 3 , rate of water circulation Vs. Speed can be used to check for correct rate of water circulation through the cooling system, Horse Power demanded by the Pump Vs. Speed can be used to figure out Mechanical Efficiency. The loss of power to drive the pump is an important factor for small cars which are designe for 30 Or 40 H.P.

The future designers of water pump and heat transfer passages may be benefited by this investigation.

BIBLIOGRAPHY

1. P. M. Heldt, Water Cooling, page 507, Automotive Engines Ninth edition. P.M. Heldt, Nyack, N.Y. 1935
2. Ben G. Elliot, Engine Cooling, page 208, Automobile Power Plants, First edition McGraw-Hill Book Company, Inc.,
3. S. Goldstein, Velocity and pressure measurements, page 248, Modern Developments in Fluid Mechanics, Vol 1 Clarendon Press, Oxford.
4. Hunter Rouse, Elementary Mechanics of Fluids, John Wiley & Sons, Inc. New York.
5. L.C. Lichty, Engine Cooling, page 428, Internal Combustion Engines. McGraw-Hill Book Company, Inc. New York.
6. King, Wisler, Woodburn, Hydraulics, John Wiley & Sons Inc. New York.
7. F. T. Morse, Power Plsnt Engineering and Design, D. Van Nostrand Company, Inc. New York.