Thermal Fluid Laboratory

Instructor:

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Revised by Dr. Nashaat N. Nassar, August 25, 2013

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Prepared by Mr. Nashaat N. Nassar, April 18, 2004

Preface

The purpose of this manual is to make it easy for students to perform simple experiments in Fluid Mechanics and Heat Transfer.

The manual presents detailed descriptions of experiments. The arrangement and organization provide a convenient means of giving instruction on handling the equipments. The use of the equipments is not limited to the experiments described; the instructor can feel free to make variations. Moreover, the manual presents guidelines for preparation of laboratory reports.

The author is grateful to his students, namely: Mrs. Ola Arafat and Mrs. Deema Rabaya'a, at An-Najah National University, who helped in typing this manual.

For further information regarding any experiment, please contact me.

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Nablus, August 25, 2013

Table of Contents

I. Guidelines for Preparation of Laboratory Reports

The report should be typewritten with the graphs by a computer. Use double spacing with 12 fonts. Spelling and usage should be conventionally correct. Use A4 paper for the entire report. The following sections are to be included in this order:

1. TITLE PAGE

1. Student's name
2. Course and section Number
3. Number and title of the experiment
4. Date the experiment was performed
5. Names of group members
6. Date the report is presented

See attached sample cover page

2. ABSTRACT

This is a stand-alone summary of the report. It should include objective, what was done, results and conclusions. It should be clear, informative, and concise. It should not make any references to the body of the report or to the appendices. An abstract should never be longer than one page. Normally it is written after all other sections of the report have been completed.

3. INTRODUCTION

In this section, explain the purpose of the experiment. It puts the experimental work into perspective. Mention the relevance of the experiment to field of engineering. It can form a natural transition into the THEORY, METHODS, RESULTS, and CONCLUSIONS sections of the report.

4. THEORY

In this section state and explain any equations or theoretical principles and assumptions that were used in the experiment and the analysis. Define all parameters used. To find this information refer to textbooks, notes etc. Refer the reader to a numerical listing of sources in the appendix. Write equations using equation writer in the word processor.

5. EXPERIMENTAL METHODS

Give a detailed description of how you accomplished the experimentation. This should include equipment used in the experiment as well as how it was used. The description should have sufficient detail so that another experimenter could duplicate your efforts. Use sketches, diagrams, or photos to describe the experimental set-up. Label the main components. Provide dimensions and material of test samples where applicable. VISIO Technical, AutoCAD or another CAD package that is suitable can be used to develop and plot your sketches, and spreadsheet programs like EXCEL can be used for graphs. The equipment listing in the Appendices is the appropriate place for model numbers and serial numbers. In the methods section, use generic names for the equipment, e.g., the fluid network apparatus.

6. RESULTS and SAMPLE of CALCULATION

Summarize your results in an introductory sentence. Relate your results to your objective. Present the results in the easiest way for your reader to understand:
Graphs, tables, figures, etc. Spreadsheets are often a good approach. See section on preparation of graphs. All tables and figures must be referenced in the text, use a numbering system for identification of each one.
Explain the results of the experiment; comment on the shapes of the curves; compare results with expected results; give probable reasons for discrepancies from the theory; answer any questions outlined in the instructions and solve any problems that may have been presented. Tell why things happened, not only that they did happen. Comparisons should include numerical values and corresponding error percentages where relevant.
Do not present calculations and formulas in this section. Your calculations should be detailed in the Appendices under SAMPLE CALCULATIONS. Formulas should be discussed in the THEORY section.

7. DISCUSSION

Answer questions and separation of each question and answer from the other.

8. CONCLUSIONS

State your discoveries, judgments and opinions from the results of this experiment. Summarize your primary results in comparison with theory in two or three sentences. These should answer the objective of the experiment. Make recommendations for further study. Suggest ways to improve the experiment.
Consider that in the real world, information like that in the RESULTS and CONCLUSIONS will be all that upper management will want to receive. Beyond that, figures may be skimmed. Make the most of these sections.

9. APPENDICES

A. DATA TABLES

Data tables are for the convenience of the extremely interested reader. These tables may contain any additional comparisons or calculations that you have prepared and were not included in the RESULTS section which may contain only summaries of your work. Data Tables are the place to show everything that you did.

B. REST of CALCULATIONS

Demonstrate how you performed the calculation made in the experiment. Include tabular results of computations where such were made. Show the generic calculations to support all your work. Provide any computer or calculator program listings, along with sample input and output.

C. EQUIPMENT LIST

List every piece of equipment used in the experiment. Provide unique identification numbers, when possible. State the accuracy and/or the readability of the instruments.

D. RAW DATA SHEETS

Data sheets must be completed in ink and signed by the instructor at the completion of the laboratory period.
In the case of an error, line through the mistake, initial the mistake, and continue. Record the name of the recorder and the group members on the raw data sheets.

10. REFERENCES

List any books or publication that you referenced in compiling your report. Provide titles, authors, publisher, date of publication, page number, Website addresses etc.

II. Preparation of Graphs

ORIENTATION OF GRAPHS

Plan the graph in so that the binding margin of the graph paper is at the left or at the top.

COORDINATE AXES

Draw the axes of coordinates on the cross-sectioned part of the sheet, far enough in from the margin to leave room for inserting the scales and their identifications between the edges of the cross-sectioning and the axes, except when using log-log paper.

SCALES

Start all linear scales at (0,0) unless such a procedure would obscure the presentation of data. Of course, this is not possible when using log scales. The units on the major divisions of log scales should be powers of 10. Choose scales of 1, 2, 4, or 5 units per centimeter, or any decimal multiples, such as 0.1, .002, and 400. Proper choice of scales is important. Guiding principles are:

1. Utilize a good portion of the graph sheet area. DO not squeeze curves into one corner.
2. Do not unduly extend the scales. Have the scales readable to the precision of the instruments from which data was taken. Further extension of the scales only scatters the data points, emphasizing the experimental error.
3. Keep in mind the purpose of the graph. Avoid using scales that hide the real meaning or fail to show the intended relationships.
4. Letter in the scale numerals along the axes, putting the abscissa scale beneath the horizontal axis at appropriate intervals. Set all numerals on either axis in a vertical position as viewed from the bottom of the page.

SCALE LEGEND

Letter in the abscissa legend beneath the abscissa scale so as to be read from the bottom of the page. Letter in the ordinate legend to the left of the ordinate scale so as to be read from the right hand of the page. If more than one ordinate scale is used, place each ordinate legend immediately adjacent to the corresponding scale. Use descriptive titles followed by dimensional units, e.g., CAPACITOR CURRENT (MILLIAMPS).

OTHER LETTERING

Use capitals for all lettering on the graph paper. Arrange all except scale legends to be read from the bottom of the page and to run in horizontal lines.

TITLE

Letter in a concise descriptive title on each graph sheet, preferably in the bottom center. Do not list the legends in the title.

DATA POINTS

Indicate data points by small circles or appropriate geometric symbols, except in the case of correction curves for instruments where the plotted points are not emphasized.

CURVES

With EXCEL Software, draw smooth curves whose positions are governed by the plotted points. The curves should not necessarily pass through every point but should traverse the combined center of gravity of all the points. Only in the case of perfectly smooth data will all the points lie on the curve. One exception to the smooth curve rule: For instrument correction curves, join the plotted points by straight-line sections and break the curve where it reaches the data points. Draw curves with ink or with computer printer and software such as EXCEL.
When more than one curve is drawn on the same set axes, carefully identify each curve, preferable with a legend lettered immediately adjacent to the curve. Other (less desirable) methods are to use horizontal legends, each with an arrow pointing to the appropriate curve, or to number the curves and provide a table of titles. Data points for the different curves should use different geometric symbols.

INDEPENDENT VERSUS DEPENDENT VARIABLES

Plot the independent variable horizontally along bottom of the graph. Plot the dependent variable vertically. The dependent variable is usually mentioned first, e.g., "PRESSURE VERSUS TEMPERATURE" where pressure is the ordinate.

Sample Cover Page

Thermal Fluid Laboratory

Boiling Heat Transfer

(Experiment no. 1, Performed on: February 20, 2004)

Prepared by:
Naser Jaber

Group members:
N. Jaber
A. Daqa
M. Badran

Submitted to:
Dr. Nashaat N. Nassar

Chemical Engineering Department
An-Najah National University

February 26, 2004

III. Criteria for Evaluating Laboratory Reports and Grading Policy

Building Engineering Department
Thermal Fluid Lab (68308)
Report Grading Sheet

Instructor Name:	Experiment # :
Academic Year:	Performed on:
Semester:	Submitted on:
Students:	
1-	2-
3-	4-
5-	6-

Project's Outcomes

ILO 1 =64%	ILO 3 =33%	ILO 4 =3%

Evaluation Criterion	Grade	Points
Abstract Does it stand alone? Is it understandable? Does it include a summary of the following- objective, introduction, Theory, Methods and Conclusions?	15	
Introduction Does the introduction explain the relevance of the experiment to the field of engineering? Sufficient,Clear and complete statement of objectives.	10	
Theory Is the theory explained? ***Are all the necessary formulas stated and variables defined?***	10	
Procedure Can the experiment be reconstructed from the description given? Is there a diagram of the experimental set-up?	10	
Experimental Results and Calculations Is presentation clear and concise? Are all the relevant Tables, Graphs, explanations included? Are the pertinent Sample calculations, References, etc. included in the Appendices?	20	
Discussion and conclusion *Crisp explanation of experimental results. Comparison of theoretical predictions to experimental results, including discussion of accuracy and error analysis in some cases.* Are the conclusions derived from the results of the experiment? Were there any discrepancies from expected results? Is the objective of the experiment accomplished?	20	
Appendices Appropriate information, organized and annotated. Includes all calculations and raw data Sheet and Apparatus sufficiently described to enable another experimenter to identify the equipment needed to conduct the experiment.	10	
Appearance (writing quality) Title page is complete, page numbers applied, content is well organized, correct spelling, fonts are consistent, good visual appeal.	5	
Total	100	

IV. Laboratory Safety Requirements

اجراءات السلامة العامة في مختبر الموائع

يجب التقيد بمبادئ السلامة العامة التالية من قبل الطلبة ومشرفي المختبرات:

1) ضرورة الزام الطلبة بارتداء ارواب العمل لتأمين السلامة للجسم واليدين والملابس.
2) يمنع استخدام الهواتف النقالة داخل المختبر.
3) يمنع التواجد داخل المختبر لمن ليس له عمل رسمي.
4) التاكد من تعليمات التشغيل قبل تشغيل الاجهزة وضرورة تدريب الطلبة على الاستخدام الامن للاجهزة.
5) يجب الحفاظ على نظافة المختبر والادوات والارضيات وضمان جاهزية المختبر للعمل في اي وقت.
6) يمنع المزاح او الركض داخل المختبر منعا لوقوع اية حوادث ناتجة عن عدم الانتباه.
7) يمنع العمل في حالة التعب او المرض.
8) يمنع تنظيف الاجهزة وهي في حالة العمل.
9) يجب المحافظة على نظافة الارضيات والاجهزة وطاولات العمل.
10) التاكد من اطفاء المضخات في الاجهزة التي يتطلب فيها تشغيل المضخات بعد الانتهاء من التجارب وذلك لتامين سلامة الاجهزة.

وعلى المشرف او مهندس المختبر مراعاة ما يلي:

1) التاكد من فصل التيار الكهربائي عن سخانات المياه قبل مغادرة المختبر.
2) التاكد من اطفاء الكهرباء والماء والغاز قبل المغادرة.
3) يجب التحضير المسبق للاجهزة والتجارب المنوي اجراؤها والتاكد من صلاحية الاجهزة مسبقا.
4) يجب توفر صندوق للاسعاف الاولي في المختبر.
5) يجب توفر طفاية حريق مناسبة في المختبر ووضعها في مكان قريب من الباب الرئيسي للمختبر لتسهيل الوصول اليها. وابعادها عن مصادر الحرارة والطاقة واسطوانات الغاز.

LAB SAFETY

1) Wearing lab coat or a lab apron is required.
2) Using mobile in the lab is not prohibited.
3) Food and beverages are prohibited in the lab
4) Contact Mrs. Tbeileh if you need to use the lab during off-class hours.
5) Circulating areas must be free from obstructions.
6) Exits and fire extinguishers must be free from obstructions
7) Operation instruction must be clear for the student for each device.
8) Work stations and common areas are to be cleaned after each use.
9) Clean up a weigh scale every time after use with a damp paper towel and drying area once clean are requested.
10) Be sure after each experiment that all the pumps are off.
11) Be sure that the water sources are also off before leaving the lab.
12) First Aid box must be available

Any accident should be reported to the lab technician

1. CALIBRATION OF A PRESSURE GAUGE

1.1 Introduction

Many types of gauge are available for measurement of pressure. The simplest form is a manometer tube, in which the rise of level of a liquid indicates the static head, this being converted to pressure by multiplying by the liquid density. An example of a much more sophisticated instrument is a pressure transducer, in which the pressure is used to deflect a diaphragm. The deflection causes an electrical signal to be generated by some means such as an electric resistance strain gauge, and this signal is displayed, typically in digital form, as the corresponding pressure. The response is rapid, being typically 1 ms, and the display can be remote from the point of measurement. The Bourdon gauge (named after its inventor Eugene Bourdon) uses the deflection of a tube of oval cross-section to cause a pointer to move over a scale. Its response time is therefore long, being of the order of 1 s. Moreover, the distance between the measuring point and the gauge is limited by the practicable length of the capillary line connecting the gauge to the sensing point. Nevertheless, because of its simplicity and low cost, and the large selection of pressure ranges which are available, the Bourdon gauge is widely used in engineering practice.

All pressure gauges, of whatever type, need to be calibrated. If the required accuracy is low, then a standard calibration obtained from a sample of the particular model will suffice. For higher accuracy, a manufacturer will take special care, and will supply a calibration certificate for an individual gauge. As the calibration may change over a period, repeat calibrations may well be needed from time to time. For the highest accuracy, transducers and gauges are sometimes calibrated before each use. The normal calibration procedure is to load the gauge with known pressure, using a dead weight tester using oil. The pressure experiment, however, works satisfactorily with water instead of oil.

1.2 Description of Apparatus

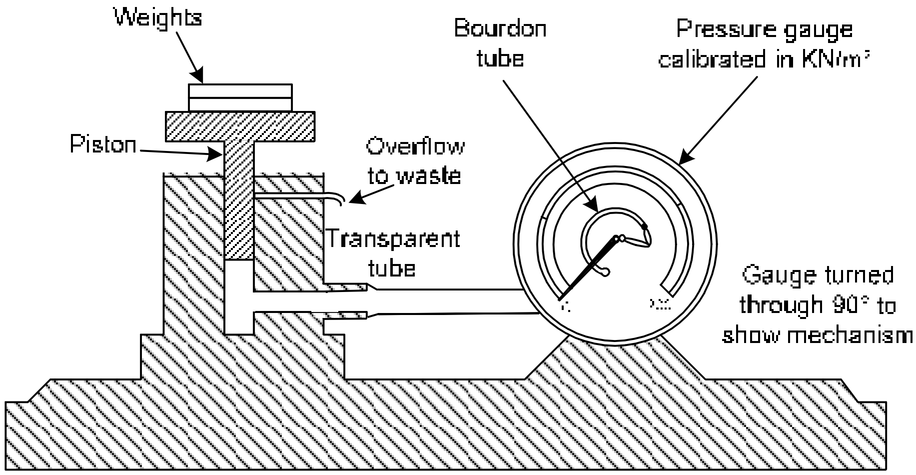


Figure 1.1 Apparatus for Calibration of Pressure Gauge.

The Bourdon pressure gauge shown in Figure 1.1 has a transparent dial through which the construction may be viewed. It consists essentially of a thin-walled tube of oval cross-section, which is bent to a circular arc encompassing about 270 degrees. It is rigidly held at one end, where the pressure is admitted. The other end is free to move and is sealed. When pressure is applied, the tube tends to straighten, so that the free end moves slightly. This movement operates a mechanism which drives a pointer round the graduated dial, the movement of the pointer being proportional to the applied pressure. The construction of the dead weight tester is also shown in Figure 1.1. A cylindrical piston, free to move vertically in a closely-fitting cylinder, is loaded with known weights. The space below the piston is filled with water, and the pressure is transmitted by the water to the gauge under test through a transparent hose. The pressure generated by the piston is easily found in terms of the total weight supported and the cross-sectional area of the piston.

1.3 Procedure

The weight of the piston, and its cross-sectional area, should be noted. To fill the cylinder, the piston is removed, and water is poured into the cylinder until it is full to the overflow level. Any air trapped in the tube may be cleared by tilting and gently tapping the apparatus.

In point of fact, a small amount of air left in the system will not affect the experiment, unless there is so much as to cause the piston to bottom on the base of the cylinder. The piston is then replaced in the cylinder and allowed to settle. A spirit level placed on the platform at the top of the piston may be used to ensure that the cylinder stands quite vertically.

Weights are now added in convenient increments, and at each increment the pressure gauge reading is observed. A similar set of results is then taken with decreasing weights. To guard against the piston sticking in the cylinder, it is advisable to rotate the piston gently while the pressure gauge is being read.

1.4 Results

Weight of piston = 9.81 N
Cross-sectional area = 333 mm^2 = 0.333 x 10^{-2} m^2

Table 1.1 True Pressures and Gauge Reading

Total load including piston weight		*True pressure* ***(kN/m^2)***	***Gauge reading***	
(kgf)	***(N)***		***Increasing pressure (kN/m^2)***	***Decreasing pressure (kN/m^2)***

1. Plot Gauge Reading (kN/m^2) vs. True Pressure (kN/m^2).
2. Plot Gauge Error (kN/m^2) vs. True Pressure (kN/m^2).

3. Comments on your results.

2. PRESSURE MEASUREMENT

2.1 Introduction:

In this experiment we will study very important property of fluid which is the pressure; in general we can define the pressure of fluid as the normal force exerted by the fluid per unit area(F/A) at some location within the fluid ,and it has the unit of (P_a = N/ $\mathbf{m^2}$ OR PSI=Ib/ $\mathbf{in^2}$ and mm (fluid) when it is measure as a head) we can find the pressure as gage pressure or absolute pressure ,where the absolute pressure = atmospheric pressure ± the gage pressure ,if the gage pressure is negative we can call it (vacuum pressure).

2.2 Objects

In this experiment, we will measure the pressure by using manometer and gages, and make comparison between them.

2.3 Theory:

Pressure = F/A =specific weight (γ) *height…...(1)
For vertical (U_tube) manometer :
$\Delta = P_1 - P_2$……..(2)
Δ (+ve for pressure and –ve for vacuum)
For inclined manometer:
$\Delta = p_1 - (p_2 * \sin 54)$……………………………………………(3)
Δ (+ve for pressure and –ve for vacuum)

2.4 Equipment:

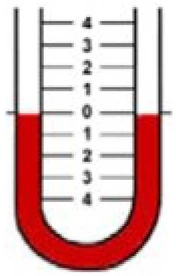
A. pressure measurement bench.

B. syringe.

2.5 <u>Procedure:</u>

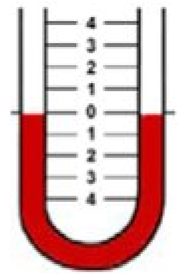
2.5.1 For vertical manometer:

1. Connect the small pipes with the device.

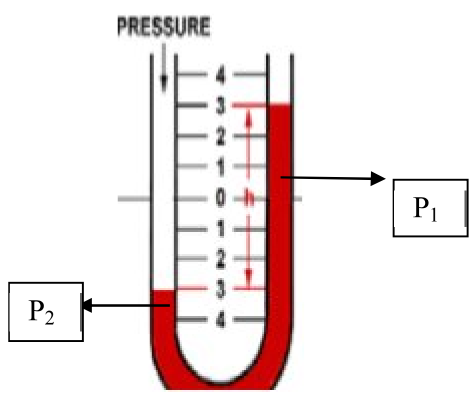


Read the elevation of fluid in the vertical manometer, and record the result in the table.

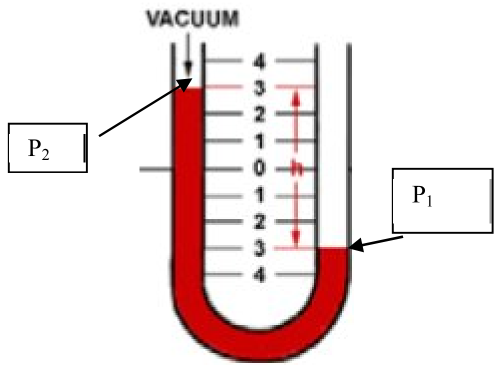
2. Close one leg of manometer.



3.fill the syringe with air and then connect it with the small pipes ,then press on the syringe to exit the air ,until it give the required pressure on the gage ,then record the elevation of



But if we want to read the vacuum pressure we will use the syringe to withdraw the air from the manometer:



2.5.2 For inclined manometer repeat the same procedures in both cases.

-Notes:
*The gages read from P=0 until p=550 mm_H_2o.
*The difference between two successive reading on the gage = 20mm_H_2o.
*The inclined manometer is inclined at angle 54^O.

2.6 Data sheet:

Pressure				Vacuum			
Pressure gauge	Inclined manometer			Vacuum gauge	Inclined manometer		
mm H2O	P1 mm H2O	P2 mm H2O	Δmm H2O	mm H2O	P1 mm H2O	P2 mm H2O	Δmm H2O
0				0			
50				-50			
100				-100			
150				-150			
200				-200			
250				-250			
300				-300			
350				-350			

Pressure				Vacuum			
Pressure gauge	Vertical manometer			Vacuum gauge	Vertical manometer		
mm H2O	P1 mm H2O	P2 mm H2O	Δmm H2O	mm H2O	P1 mm H2O	P2 mm H2O	Δmm H2O
0				0			
50				-50			
100				-100			
150				-150			
200				-200			
250				-250			
300				-300			
350				-350			

2.7 Discussion

Answer the following questions in the report:

1. **What degree of accuracy was achieved in the pressure case readings? Is it acceptable?**
2. **What are the sources of error in this experiment?**
3. **Which is better to use oil or water in calibration of pressure gauge experiment? Why?**
4. **Could the apparatus be improved? How?**
5. **What are the types of manometers?**
6. **When inclined manometer can be used?**
7. **Does the pressure gauge need calibration? Why?**

3. FLOW THROUGH ORIFICES AND NOZZLES

3.1 Introduction

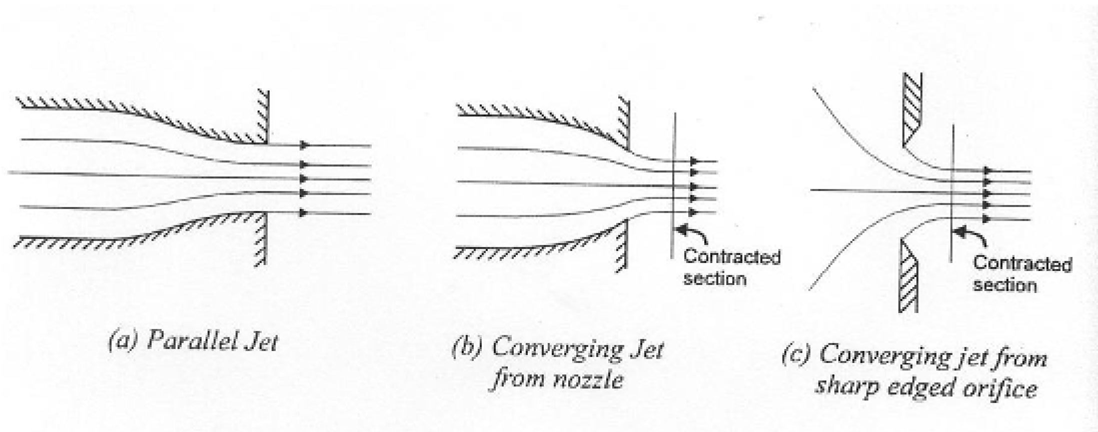


Figure 3.1 Examples of Jet Flows from Nozzles and Orifices.

Figure 3.1(a) shows fluid streaming through a smoothly contracting nozzle which produces a parallel jet. The overall increase in speed through the contraction reduces the effect of any non-uniformity which might exist in the approaching flow, so it is reasonable to assume that the fluid velocity is sensible uniform across the emerging jet. Since the cross-sectional area of the jet is the same as that of the nozzle, the rate of flow may be obtained simply by multiplying the nozzle area by the speed of the jet. In Figures 3.1(b) and 3.1(c) however, the fluid does not emerge in parallel fashion but as a convergent stream, so that the cross-sectional area of the jet reduces to a so-called **Contracted section** or **Vena contracta**. Over this section the streamlines are parallel. Moreover, the velocity is effectively uniform over the contracted section. The flow rate may now be obtained by multiplying the area of the contracted section by the fluid speed over it.

In each of these three examples, the emerging flow is shown as a **free jet**, i.e. a jet which does not mix with the surrounding fluid. This is the case, for example, for a water jet emerging into air. Such a jet will usually retain its identity for a considerable distance before disturbances cause it to break up, particularly if the approaching flow is free from turbulence. If, however, the flow does mix with the surrounding fluid, the result is a **submerged jet**. Such a jet normally becomes turbulent shortly downstream of the contracted section. It entrains flow from its surroundings and diffuses rapidly. Nevertheless, the rate of flow from the orifice may still be obtained as the product of cross-sectional area and speed at the contracted section.

The experiments described below relate exclusively to discharge of water into air through orifices and nozzles, i.e. to free jets. There is provision for measuring the

diameter of the contracted section and the velocity distribution across it, and for relating both velocity of flow and discharge rate to the head of water above the orifice or nozzle.

3.2 Description of Apparatus

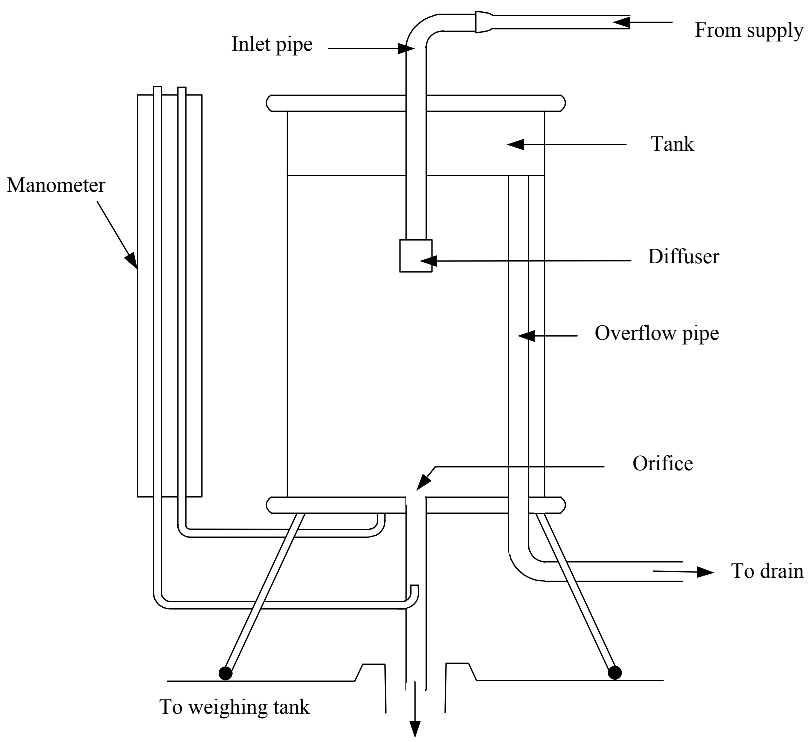


Figure 3.2 Arrangements of Apparatus

Figure 3.2 shows the arrangement, in which a water tank is fed from the bench supply valve, through an adjustable vertical pipe which terminates in a diffuser just below the water surface. An overflow pipe directs the surplus water to the drain outlet in the bench top. The orifice or nozzle under test is fitted into the base of the tank, and the emerging jet passes through the bench top the into the measuring tank of the bench. The fitting of the orifice is such that there is no unevenness along the inner surface of the tank. There is a tapping in the base which connects with a manometer tube, mounted in front of a vertical scale showing the level of water in the tank, measured above the plane of the orifice or nozzle exit. A second manometer tube is connected to a Pitot tube, which may be introduced into the discharging jet to measure the total head. It may be traversed across the jet revolving the graduated nut which works along a lead screw of 1mm pitch; each complete revolution of the nut moves the Pitot tube a distance of 1 mm. The diameter of the jet may thus be measured by traversing a sharp blade, supported in the Pitot tube, from one side of the jet to the other.

In some versions of the equipment, a further outlet is provided in the side of the tank, so the orifice may be mounted in the vertical plane. The jet then emerges horizontally. Traversing gear is provided to measure the shape of the jet trajectory, from which the horizontal component of velocity may be found.

3.3 Theory of Flow through an Orifice or Nozzle

Figure 3.3(a) shows the essential features of flow through an orifice or nozzle set in the base of the tank. Let the elevation of the water surface above the plane of the contracted section be H_o, as indicated by the water level in a piezometer tube which is connected to the base or wall of the tank, at any point where the velocity of flow is negligible. A typical streamline of the flow runs from some point S in the surface to the point *T* of the contracted section. Then, according to Bernoulli`s theorem, in the absence of loss along the streamline, the total head is constant from S to *T*, so

$$\frac{u_S^2}{2g} + \frac{P_S}{W} + Z_S = \frac{u_T^2}{2g} + \frac{P_T}{W} + Z_T \qquad (3.1)$$

If the surface area of the tank is large in comparison with that of the orifice, then u_s will be negligible. Also since the pressure is atmospheric at both *S* and *T*, $P_S = P_T$. So, noting that

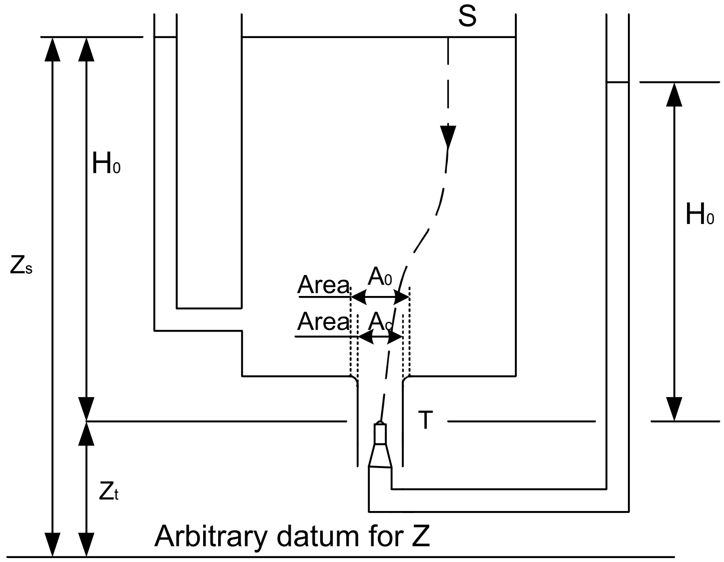
$$Z_T - Z_S = H_o \qquad (3.2)$$

by substituting in Bernoulli`s equation we find the velocity u_T at *T* to be

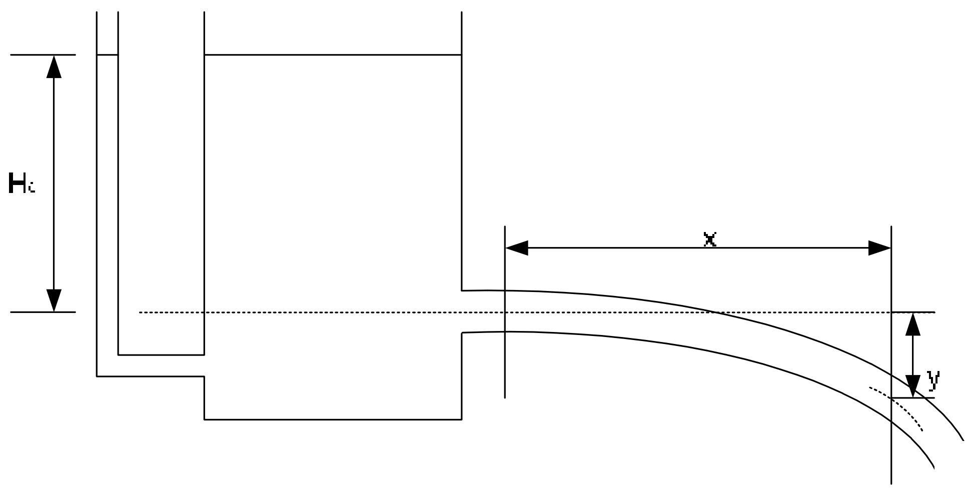
$$u_T = \sqrt{2gH_o} \qquad (3.3)$$

this is the **ideal** velocity at *T*, on the basis of constant total head along the streamline. The same result applies to all streamlines of the flow, so choosing the symbol u_o to denote this ideal velocity, we find

$$u_o = \sqrt{2gH_o} \qquad (3.4)$$



(a) Flow Through Orifice in Base of Tank



(b) Trajectory of Jet Issuing from Side

Figure 3.3 Diagrams Showing Notation

The **ideal** velocity u_o at the contracted section is seen to be that which is acquired by a body falling from rest under gravity thought a height H_o. This result is often referred to as **Torricelli`s theorem.** Because there is some loss of total head, the **actual** velocity u_c at the contracted section will be rather smaller than the ideal. A Pitot tube placed in the stream at the contracted section will record a value H_c, somewhat smaller than H_o, as indicated in Figure 3.2(a). The actual velocity u_c is given in terms of H_c by

$$u_c = \sqrt{2gH_c} \qquad (3.5)$$

Now making the simplifying assumption that u_c is uniform over the cross-section of the contracted section, we may define a **velocity coefficient C_u** as the ratio of actual velocity u_c to ideal velocity u_o, namely

$$C_u = u_c / u_o = \sqrt{H_c / H_o} \qquad (3.6)$$

In a similar sense, the **contraction coefficient C_c** is defined as the ratio of contracted area A_c to orifice area A_o

$$C_c = A_c / A_o \qquad (3.7)$$

Finally, the **discharge coefficient C_d** is defined as the ratio of the **actual** discharge Q to the **ideal** discharge Q_o, which would take place if the jet were to discharge at the ideal velocity without reduction of area. The **actual** discharge Q is

$$Q = u_c A_c \qquad (3.8)$$

Now, if the jet were to discharge at the ideal velocity u_o over the orifice area A_o the **ideal** discharge Q_o would be

$$Q_o = u_o A_o = \sqrt{2gH_o A_o} \qquad (3.9)$$

So the discharge coefficient may be written in the form

$$C_d = Q / Q_o = Q \Big/ \sqrt{2gH_o A_o} \qquad (3.10)$$

Substituting in this equation for Q from equation (3.8) and for Q_o from equation (3.9) gives

$$C_d = u_c A_c / u_o A_o \qquad (3.11)$$

And by using equations (3.6) and (3.7) we obtain the result

$$C_d = C_u C_c \qquad (3.12)$$

We may think of this equation as showing the discharge being reduced from its ideal value in the ratio C_d by two influences. *First*, fluid viscosity reduces the velocity from its ideal value in the ratio C_u. *Second*, the effective cross-sectional area of flow at the contracted section is less than that at the orifice in the ratio C_c. It is the product of these two effects which leads to flow reduction in the ratio C_d. In the experiment described below, values of each of the three coefficients are measured independently.

Another way of finding the velocity at the contracted section is indicated in Figure 3.3(b). Instead of using a Pitot tube to find u_c, the shape of the jet trajectory is used. The orifice or nozzle is set in the vertical side of the tank, so that the jet emerges in a perfectly horizontal direction. Provision is made for measuring the horizontal distance x and the vertical distance y (measured downwards) of the centerline of the jet from the center point of the contracted section. Assuming that the horizontal component of the jet velocity remains constant, then the horizontal distance covered in time *t* is

$$x = u_c \cdot t \qquad (3.13)$$

The vertical distance covered in the same time, as the motion accelerates downwards under the action of gravity, is

$$y = g \cdot t^2 / 2 \qquad (3.14)$$

Eliminating *t* between these two equations leads to

$$u_c = \sqrt{gx^2 / 2y} \qquad (3.15)$$

This equation may be used to establish u_c from a set of measurements of *x* and *y*. Alternatively, the measurements may be used to establish the value of C_u as follows. Equations (3.4),(3.5) and (3.6) are combined to give u_c in terms of C_u and h_o:

$$u_c = C_u u_o = C_u \sqrt{2gH_o} \qquad (3.16)$$

Equating this value of u_c to that given in equation (3.15) leads to

$$C_u = \sqrt{x^2 / 4H_o y} \qquad (3.17)$$

3.4 Experimental Procedure

The experiment on any chosen orifice or nozzle may be divided into two parts. First, the values of C_u, C_c and C_d are found at a single constant value of H_o. Second, the discharge Q is measured at a number of different values of H_o.

The equipment is set on the bench and leveled so that the base of the tank is horizontal, with the orifice in the base positioned so that it discharges directly into the measuring tank. The flexible supply pipe from the bench control value is connected to the inlet pipe of the apparatus. To obtain the steadiest reading, this inlet pipe should be set so that the diffuser is just submerged. The overflow from the tank is directed on to the bench top. The diameter of the orifice or nozzle should be noted.

In the first part of the experiment, water is admitted to the tank to allow it to fill to the height of the overflow pipe. The inflow is regulated so that a small steady discharge is obtained from the overflow, so ensuring that the level in the tank remains constant while the measurements are made. To measure C_d, the discharge rate is established by timing the collection of a known weight of water in the measuring tank, and noting the head H_o above the contracted section. To measure C_u, the Pitot tube is inserted into the jet at the contracted section, and the values of Pitot head H_c and of head H_o are noted. To measure C_c, it is necessary to measure the diameter of the jet at the contracted section. This is done by fixing the sharp-edged blade to the Pitot tube, the plane of the blade being normal to the direction of traverse of the tube. The blade is brought to each edge of the jet in turn, at the level of the contracted section, and the reading of positions, as read on the lead screw and graduated nut, are subtracted to give the diameter of the jet.

If the apparatus provides for discharge through an orifice mounted vertically in the side of the tank, C_u may be found by measuring the coordinates x and y of the jet as shown in Figure 3.3(b), particular care being taken to ensure that the orifice is set in a truly vertical plane.

In the second part of the experiment, the inflow rate to the tank is reduced in stages, to provide a set of values of head H_o and corresponding discharge rates Q. Care should be taken to allow the level in the tank to settle to a steady value after the inflow rate has been changed. It is advisable to read H_o several times while the discharge is being collected, and to record the mean value over the timed interval. About eight different flow rates should be sufficient to establish the relationship between discharge rate Q and head H_o.

3.5 Results and Calculations

Type of orifice	D_o-----------------
Cross-sectional area of orifice	A_o-----------------
Head above contracted section	H_o-----------------
Discharge rate	Q------------------
Pitot tube reading	H_c-----------------
Diameter of jet	D_c-----------------

Table 3.1 Raw Data for Part I

V ***(L)***	***t*** ***(s)***	H_o ***(mm)***	$H_o^{1/2}$ $(m^{1/2})$	***Q*** (m^3/s)

Table 3.2 Raw Data for Part II

V ***(L)***	***t*** ***(s)***	***Q*** (m^3/s)	***y*** ***(mm)***	$y^{1/2}$ $(m^{1/2})$	***x*** ***(mm)***

1. Plot Q (m^3/s) vs. $H_o^{1/2}$ $(m^{1/2})$.
2. Plot y (mm) vs. x (mm).
3. Plot $y^{1/2}$ $(m^{1/2})$ vs. x (mm).
4. Comment on your results.

3.6 Discussion of Results

1. Define pitot tube and piezometer tube? For what they used?
2. What is the difference between orifice and nozzle?
3. What is the purpose of using diffuser?
4. Which is better to use orifice and nozzle or venture meter to measure volumetric flow rate? Why?
5. Discuss your results

4. FLOW THROUGH A VENTURI METER

4.1 Introduction

The Venturi tube is a device which has been used over many years for measuring the rate of flow along a pipe. As may be seen from Figure 4.1, it consists essentially of a tapering contraction section, along which the fluid accelerates towards a short cylindrical throat, followed by a section which diverges gently back to the original diameter. (Such a slowly diverging section is frequently referred to as a diffuser). As the velocity increases from the inlet section to the throat, there is a fall in pressure, the magnitude of which depends on the rate of flow. The flow rate may therefore be inferred from the difference in pressure, as measured by piezometers placed up stream and at the throat .Such a unit is referred to as a Venturi flow meter.

Another way of metering the flow would be to insert a sharp edged orifice into the pipe; the differential pressure produced by flow through the orifice may similarly be used to infer the flow rate. Such an orifice meter has the advantage of simplicity and cheapness. In comparison with the Venturi tube, however, it causes a greater loss of total head than does a corresponding Venturi meter. This is because much of the velocity head at the throat is recovered as the fluid decelerates in the diffuser. Indeed, the differential piezometric head from inlet to the throat can be several times as great as the loss of total head across the whole device.

Although piezometer tappings are needed only at the up stream section and at the throat to infer the flow rate, it is instructive in a laboratory experiment to insert numerous further tapings to show the distribution of piezometric head along the whole length of the Venturi tube. As we shall see, it is possible to calculate the ideal distribution. Comparison with measurements will then show where the losses occur in the unit.

1.2 Description of Apparatus

Figure 4.1 shows the arrangement of the Venturi meter, which is manufactured in clear plastic material. Water is admitted from bench supply valve and passes through a flexible hose into the meter. Beyond the control valve, which is mounted just downstream of the meter, a further flexible hose leads to the measuring tank. The piezometer tapping in the wall of the Venturi tube are connected to vertical manometer tubes, mounted in front of a scale marked in millimeters. The manometer tubes are connected at their top ends to a common manifold, in which the amount of air may be controlled by a small air valve at one end. The whole assembly is supported on a base mounted on adjusting screws which serve to level the equipment.

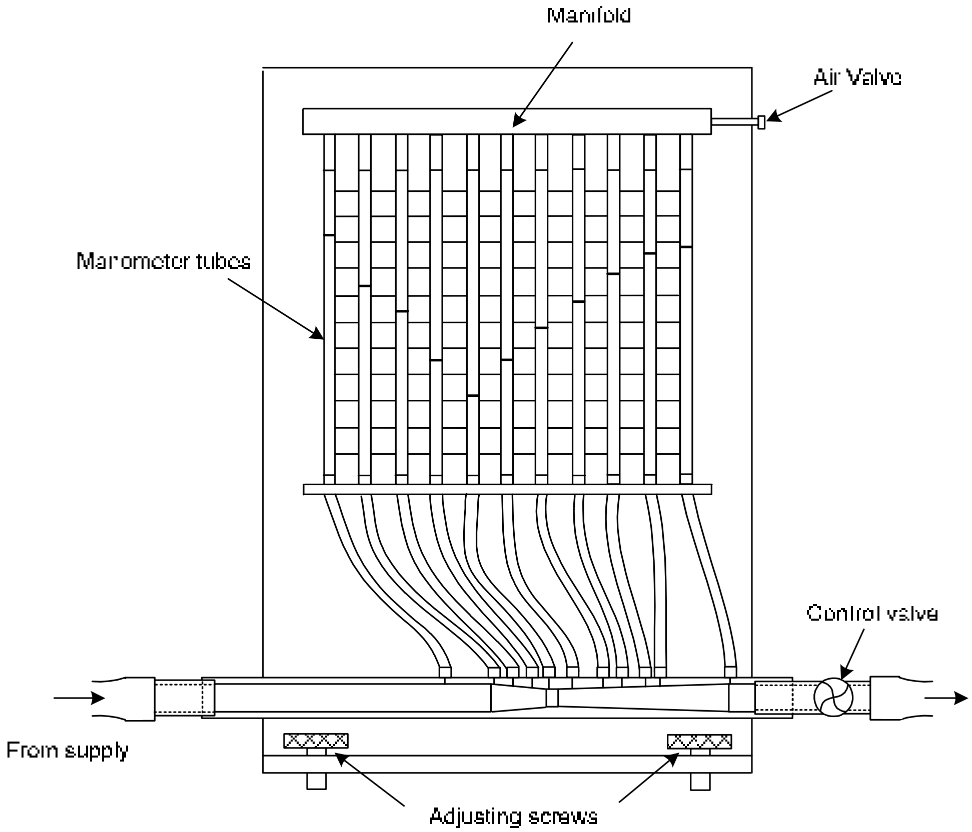


Figure 4.1 Arrangement of Venturi Meter Apparatus

4.3 <u>Theory of the Venturi Meter</u>

Consider flow of an incompressible, inviscid fluid through the convergent-divergent Venturi tube shown in Figure 4.2. The cross sectional area at the up stream section *1* is A_1 , at the throat section *2* is A_2 , and at any other arbitrary section *n* is A_n . Piezometer tubes at these sections register h_1**,** h_2 and h_n above the arbitrary datum shown. Note that, although the tube may have any inclination, the datum must of necessity be horizontal. Assume that both the velocity and the piezometric head are constant over each of the sections considered. This amounts to assuming the flow to be one Dimensional, so that the velocity and the piezometric head vary only in the direction of the tube length. We may then treat the convergent-divergent pipe as a stream tube, along which *Bernoulli`s theorem* states

$$\frac{u_1^2}{2g} + h_1 = \frac{u_2^2}{2g} + h_2 = \frac{u_n^2}{2g} + h_n \qquad (4.1)$$

in which u_1, u_2, and u_n are the flow velocities at sections *1, 2* and *n*.

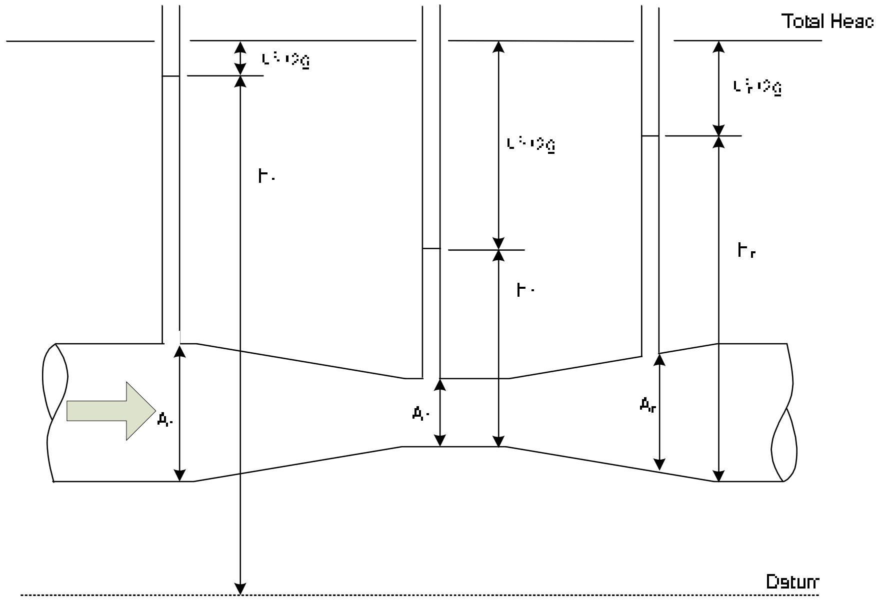


Figure 4.2 Ideal Conditions in a Venturi Meter

The equation of continuity is

$$u_1 A_1 = u_2 A_2 = u_n A_n = Q \qquad (4.2)$$

in which Q denotes the rate of volume flow or discharge. Substituting in equation (4.1) for u_1 from equation (4.2), gives

$$\frac{u_1^2}{2g}\left(\frac{A_2}{A_1}\right)^2 + h_1 = \frac{u_2^2}{2g} + h_2 \qquad (4.3)$$

and solving this for the velocity u_2 in the throat leads to

$$u_2 = \sqrt{\frac{2g(h_1 - h_2)}{1 - (A_2/A_1)^2}} \qquad (4.4)$$

The rate of flow Q is found by multiplying the throat velocity u_2 by the cross sectional area A_2 at the throat, giving

$$Q = A_2 \sqrt{\frac{2g(h_1 - h_2)}{1 - (A_2/A_1)^2}} \qquad (4.5)$$

This is the ideal discharge rate, obtained by assuming inviscid, one dimensional flow.

In practice, there is some loss of head between sections *1* and *2*. Also, the velocity is not absolutely constant across either of these sections. As a result, the actual values of Q fall a little short of those given by equation (4.5). It is customary to allow for this by writing

$$Q = C.A_2\sqrt{\frac{2g(h_1 - h_2)}{1-(A_2/A_1)^2}} \qquad (4.6)$$

in which C is known as the discharge coefficient or simply the coefficient of the Venturi meter. It's value, which usually lies between *0.92* and *0.99*, is established by experiment. It varies from one meter to another, and even for a given meter it may vary slightly with the flow rate.

Coming now to the distribution of piezometric head along the length of the meter, it is convenient to seek a dimensionless way of expressing the change in piezometric head between the inlet section *1* and any typical section *n*. This is conveniently done by use of the velocity head $u_2^2/2g$ at the throat. Accordingly, we define a piezometric head coefficient C_{ph} as

$$C_{ph} = \frac{h_n - h_1}{u_2^2/2g} \qquad (4.7)$$

Since $(h_n - h_1)$ and $u_2^2/2g$ both have the same dimensions of length, the piezometric head coefficient will be dimensionless. Suppose that, at some known flow rate, piezometric heads are read along the length of the Venturi tube. If these readings are then divided by the known value of velocity head at the throat, namely $u_2^2/2g$, the readings are thereby converted into dimensionless piezomeric head coefficients.

It is simple to find an expression for the ideal distribution of *Cph* along a Venturi meter, solely in terms of its geometry. From *Bernoulli`s* equation *(4.1),*

$$h_n - h_1 = \frac{u_1^2}{2g} - \frac{u_n^2}{2g} \qquad (4.8)$$

so dividing through by $\frac{u_2^2}{2g}$

$$\frac{h_n - h_1}{u_2^2/2g} = \left(\frac{u_1}{u_2}\right)^2 - \left(\frac{u_n}{u_2}\right)^2 \qquad (4.9)$$

Now the terms on the right may be substituted from the continuity equation:

$$\frac{u_1}{u_2} = \frac{A_2}{A_1} \text{ and } \frac{u_n}{u_2} = \frac{A_2}{A_n} \qquad (4.10)$$

and the expression on the left is the piezometric head coefficient C_{ph}. Making these substitutions, we obtain

$$C_{ph} = (A_2/A_1)^2 - (A_2/A_n)^2 \qquad (4.11)$$

as the ideal variation of dimensionless piezometric head along the tube. In terms of tube diameter D, since $A \alpha D^2$, the result is

$$C_{ph} = (D_2 / D_1)^4 - (D_2 / D_n)^4 \qquad (4.12)$$

4.4 Experimental Procedure

The apparatus is first leveled. This is done by opening both the bench supply valve and the control valve down stream of the meter, so as to allow water to flow for a few seconds to clear air pockets from the supply hose. The control valve is then gradually closed, so subjecting the Venturi tube to a gradually increasing pressure, which causes water to rise up the tubes of the manometer, thereby compressing the air contained in the manifold. When the water levels have risen to a convenient height, the bench valve is also closed gradually, so that, as both valves are finally shut off, the meter is left containing static water at moderate pressure, and the water level in the manometer tubes stands at a convenient height. The adjusting screws are then operated to give identical readings for all of the tubes across the whole width of the manometer board. The board should also be reasonably vertical when viewed from the end.

To establish the meter coefficient, measurements are made of a set of differential heads (h_2-h_1) and flow rates Q. The first reading should be taken with the maximum possible value of (h_2-h_1), i.e. with h_1 close to the top of the scale and h_2 near to the bottom. This condition is obtained by gradually opening both the bench valve and the control valve in turn.

Successive opening of either valve will increase both the flow and the difference between h_1 and h_2. Opening of the bench valve is accompanied by a general rise in levels in the manometer, while opening the control valve has the opposite effect. By judiciously balancing the setting of the two valves, the required condition may be obtained. If difficulty is experienced, air may be released from, or admitted to, the manifold through the small air valve at its end.

The rate of flow is found by timing the collection of a known amount of water in the weighing tank, in the meantime values of h_1 and h_2 being read from the manometer scale. Similar readings are then taken over a series of reducing values of (h_1-h_2), roughly equally spread over the available range from *250 mm* to zero. About *10* readings should suffice.

The distribution of piezometric head along the length of the Venturi tube may be established by taking the complete set of manometer readings at any of the flow rates used in the tests described above. If, however, this is done in every case, the reduction of the results becomes lengthy. It is therefore suggested that only one or two such comprehensive observations be made. For the sake of accuracy, these should be taken near the condition of maximum flow.

4.5 Results and Calculations

Figure 4.5 shows the profile of the Venturi meter, which has dimensions as follows:

Diameter at inlet	D_1	*26 mm*
Diameter at throat	D_2	*16 mm*
Cross sectional area at throat	$A_2 = \pi D_2^2 / 4 = 201.1 mm^2 = 2.011x10^{-4} m^2$	
Area ratio, throat to inlet	$A_2 / A_1 = (D_2 / D_1)^2 = (16/26)^2 = 0.379$	
Length of contraction section	*25 mm*	
Length of throat section	*16 mm*	
Length of diffuser	*89 mm*	
Length of over all	*130 mm*	

Positions of the piezometer tappings are indicated. At a typical tapping, lying at distance x_n downstream of the inlet section of the meter, the tube diameter is D_n.

Table 4.1 presents values of x_n and D_n for each of the 11 tappings, shown as *A* to *L* in Figure 4.3.

We have seen that the ideal distribution of piezometric head coefficient C_{ph} depends solely on the geometry of the meter. Table 4.1 shows how this ideal distribution is computed. For each of the piezometer stations *n*, the diameter D_n is used to evaluate (D_2/D_n) and $(D_2 / D_n)^2$. The value of C_{ph} then follows from equation (4.12).

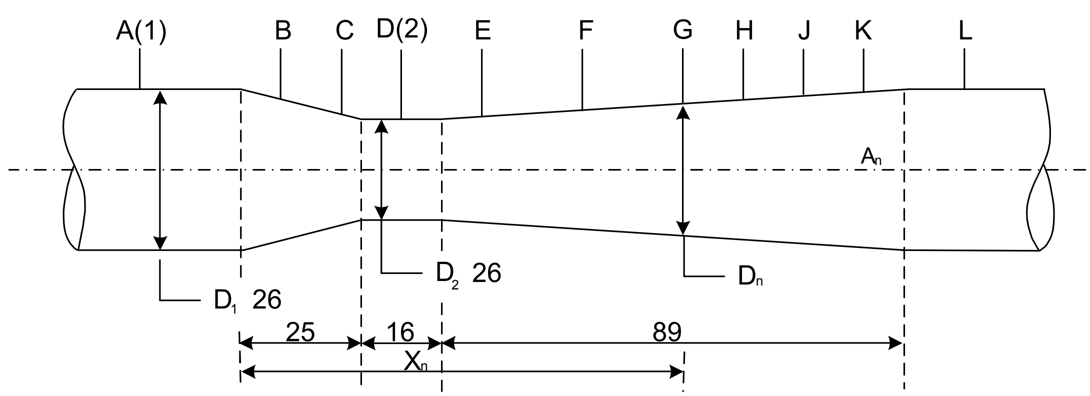


Figure 4.3 Dimensions of Venturi Meter and Locations of Piezometer Tubes

Table 4.1 Calculation of Ideal Values of Piezometric Head Coefficient C_{ph}.

Piez ref	***X_n (mm)***	***D_n (mm)***	***D_2/D_n***	$(D_2/D_n)^4$	***C_{ph}***
A(1)	-13	26.00	0.615	0.143	0.000
B	7	23.20	0.690	0.226	-0.083
C	19	18.40	0.870	0.572	-0.428
D(2)	33	16.00	1.000	1.000	-0.857
E	48	16.79	0.953	0.825	-0.682
F	63	18.47	0.866	0.563	-0.419
G	78	20.16	0.794	0.397	-0.254
H	93	21.84	0.733	0.288	-0.144
J	108	23.53	0.680	0.214	-0.070
K	123	25.21	0.635	0.162	-0.019
L	143	26.00	0.615	0.143	-0.000

Table 4.2 Measurements of (h_1-h_2) and Q

Q (m^3/s)	***T (s)***	***h_1 (mm)***	***h_2 (mm)***	***(h_1-h_2) (mm)***	$(h_1 - h_2)^{1/2}$ $(m^{1/2})$	***C***

1. Plot $(h_1 - h_2)^{1/2}(m)^{1/2}$ vs. $Q\,(m^3/s)$
2. Plot C vs. $Q\ (m^3/s)$.
3. Plot C_{ph} vs. x (mm).
4. Comment on your results.

4.6 Discussion of Results

1. What suggestions have you for improving the apparatus?
2. If the venture meter were not horizontal what will be the results? How it affect the result?
3. If outlet valve is used instead of inlet, what will be the effect?
4. Mention at least 3 other methods used to measure the volumetric flow rate?
5. Discuss your results? (The value of coefficients'?

FLOW MEASUREMENT

5.1 Introduction

In this experiment we will measure the flow in (m^3/s) by using four ways, Venturi meter, Orifice meter, Rotameter and volumetric bench. We will show later at the experiment that the Venturi is the most accurate method to measure the flow. This experiment also giving application of the steady flow Energy Equation and Bernoulli's Equation. Hydraulic Benches will provide the three systems with flow water.

5.2 Objective

-To measure water flow using four methods, Venturi meters, Orifice meter, Rotameter and bench.
- To array the equipments according to its accuracy.

5.3 Theory

5.4 Instrument:

1- Water
2- Hydraulics Benches
3- Rota-meter
4- Orifice meter
5- Venturi meter
6- Stopwatches
7- Scales

5.5 Procedure

Venturi meter:

1- Open the valve to get a flow from the bench to enter the Venturi meter device.
2- After the water flow through the Venturi meter read the height of the fluid of the manometer at points A & B (Shown in Figure 1)

Orifice meter:

3- After the water flow through Venturi meter, it's entering the orifice meter. Read the manometer at the points E & F (Shown in Figure 2)

Rota-meter

4- The same flow which moves in the Venturi meter and orifice meter will enter the Rota-meter. Read the height of the plump float.

Volumetric bench

5- Close the water drainage hole and notes the water scale until it reaches zero level at the level gage and measure the time for the water flow to reach a specific level.

(Note: The same flow move at the four devices, so don’t change the valve opening until you finish reading all data.)

6- Change the tap opening and do the pervious steps for more two trials.

5.6 Results and Data sheet:

A_A = mm^2 A_B = mm^2

A_E= mm^2 A_F = mm^2

h_A (mm)	h_B (mm)	h_E (mm)	h_F (mm)	Rotameter reading (mm)	Volume (L)	Time (sec)

5.7 Discussion

Answer the following question in the report:

1- The advantages of the Venturi meter device?

2- Are the results accepted?

3- Do all the calibration document for one of the devices?

6. IMPACT OF A JET

6.1 Introduction

Water turbines are widely used throughout the world to generate power. In the type of water turbine referred to as a Pelton wheel, one or more water jets are directed tangentially on to vanes or buckets that are fastened on the rim of the turbine disc.

The impact of the water on the vanes generates a torque on the wheel, causing it to rotate and to develop power. Although the concept is essentially simple, such turbines can generate considerable output at high efficiency. Powers in excess of *100 MW*, and hydraulic efficiencies greater than 95%, are not uncommon. It may be noted that the Pelton wheel is best suited to conditions where the available head of water is great, and the flow rate is comparatively small. For example, with a head of *100 m* and a flow rate of 1 m^3/s, a Pelton wheel running at some 250 rev/min could be used to develop about *900 kW*. The same water power would be available if the head were only 10m and the flow rate were 10 m^3/s, but a different type of turbine would then be needed.

To predict the output of a Pelton wheel, and to determine its optimum rotational speed, we need to understand how the deflection of the jet generates a force on the buckets, and how the force is related to the rate of momentum flow in the jet. In this experiment, we measure the force generated by a jet of water striking a flat plate or a hemispherical cup, and compare the results with the computed momentum flow rate in the jet.

6.2 Description of Apparatus

Figure 5.1 shows the arrangement, in which water supplied from the Hydraulic Bench is fed to a vertical pipe terminating in a tapered nozzle. This produces a jet of water which impinges on a vane, in the form of a flat plate or a hemispherical cup.

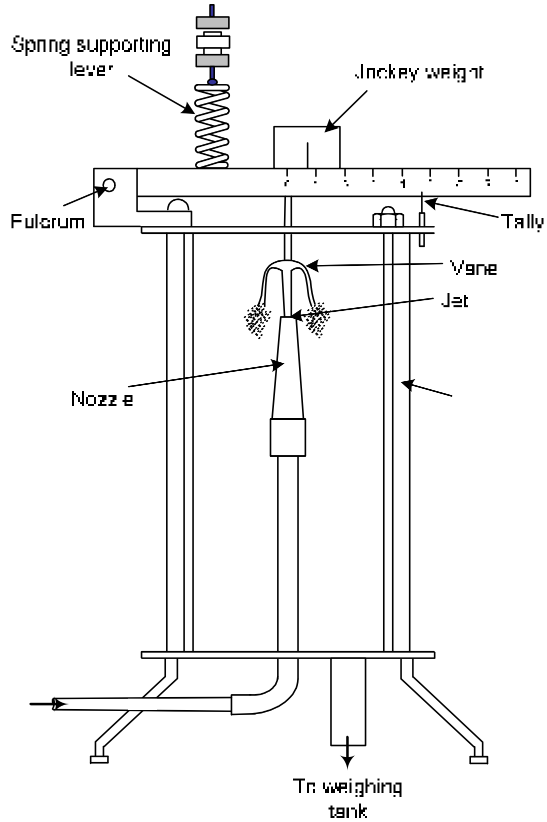


Figure 6.1 Arrangement of Apparatus

The nozzle and vane are contained within a transparent cylinder, and at the base of the cylinder there is an outlet from which the flow is directed to the measuring tank of the bench. As indicated in Figure 6.1, the vane is supported by a lever which carries a jockey weight, and which is restrained by a light spring. The lever may be set to a balanced position (as indicated by a tally supported from it) by placing the jockey weight at its zero position, and then adjusting the knurled nut above the spring. Any force generated by impact of the jet on the vane may now be measured by moving the jockey weight along the lever until the tally shows that it has been restored to its original balanced position.

6.3 Theory of the Experiment

The equation of momentum is discussed in early chapter. Consider how it applies to the case shown schematically in Figure 6.2, which shows a jet of fluid impinging on a symmetrical vane. Let the mass flow rate in the jet be $\dot{m}$. Imagine a control volume *V*, bounded by a control surface *S* which encloses the vane as shown. The velocity with which the jet enters the control volume is u_1, in the x-direction. The jet is deflected by its impingement on the vane, so that it leaves the control volume with velocity u_2, inclined at an angle β_2 to the *x*-direction.

Now the pressure over the whole surface of the jet, apart from that part where it flows over the surface of the vane .is atmospheric. Therefore neglecting the effect of gravity, the changed direction of the jet is due solely the force generated by pressure and shear stress at the vane's surface. If this force on the jet in the direction of x be denoted by F_j, then the momentum equation in the x-direction is

$$F_1 = \dot{m}(u_2 \cos \beta_2 - u_1) \qquad (5.1)$$

The force F on the vane is equal and opposite to this, namely

$$F = \dot{m}(u_1 - u_2 \cos \beta_2) \qquad (5.2)$$

For the case of a flat plate $\beta_2 = 90$, so that $cos\, \beta_2 = 0$. It follows that

$$F = \dot{m}u \qquad (5.3)$$

Is the force on the flat plate, irrespective of the value of u_2.

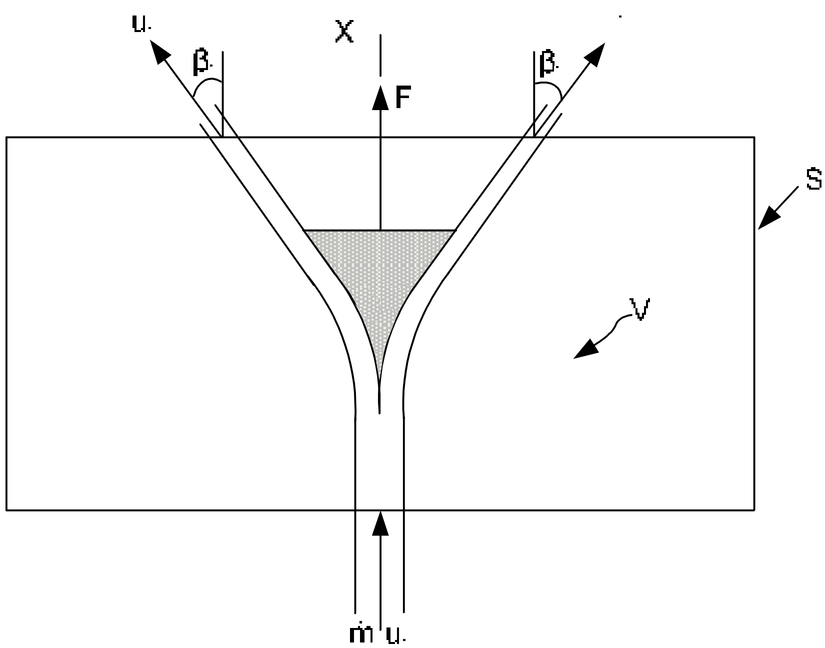


Figure 6.2 Sketch of Jet Impinging on A Vane

For the case of a hemispherical cup, we assume that $\beta_2 = 180^o$, so that $\cos \beta_2 = -1$, and

$$F = \dot{m}(u_1 + u_2) \qquad (6.4)$$

If we neglect the effect of change of elevation on jet speed, and the loss of speed due to friction over the surface of the vane, then $u_1 = u_2$, so

$$F = 2\dot{m}u_1 \qquad (6.5)$$

is the maximum possible value of force on the hemispherical cup. This is just twice the force on the flat plate.

Returning now to Figure 6.2, the rate at which momentum is entering the control volume is $\dot{m}u_1$**. We may think of this as a rate of flow of momentum in the jet, and denote this by the symbol *J*, where**

$$J = \dot{m}u_1 \qquad \textbf{(6.6)}$$

For the flat plate, therefore, we see from equation (5.3) that

$$F = J \qquad \textbf{(6.7)}$$

and for the hemispherical cup the maximum possible value of force is, from equation (6.5)

$$F = 2J \qquad \textbf{(6.8)}$$

In the SI system the units of $\dot{m}_1$ **and *u* are**

$$\dot{m}[Kg/s] \text{ and } u[m/s]$$

In an equation such as (6.3), then, the units of force F are

$$F[N] \text{ or } [Kg.m/s^2]$$

6.4 Experimental Procedure

The apparatus is first leveled and the lever brought to the balanced position (as indicated by the tally), with the jockey weight at its zero setting. Note the weight of the jockey, and the following dimensions: diameter of the nozzle, height of the vane above the tip of the nozzle when the lever is balanced, and distance from the pivot of the lever to the centre of the vane.

Water is then admitted through the bench supply valve, and the flow rate increased to the maximum. The force on the vane displaces the lever, which is then restored to its balanced position by sliding the jockey weight along the lever. The mass flow rate is established by collection of water over a timed interval. Further observations are then made at a number reducing flow rates. A bout eight readings should suffice.

The best way to set the conditions for reduced flow rate is to place the jockey weight exactly at the desired position, and then to adjust the flow control valve to bring the lever to the balanced position. The condition of balance is thereby found without touching the lever, which is much easier than finding the point of balance by sliding the jockey weight. Moreover, the range of settings of the jockey position may be divided neatly into equal steps.

The experiment should be run twice, first with the flat plate and then with the hemispherical cup.

6.5 Results and Calculations

Diameter of nozzle $D = 10.0\ mm$

Cross sectional area of nozzle $A = \pi D^2 / 4 = 78.5 mm^2 = 7.85 x 10^{-5} m^2$

Height of vane above nozzle tips $H = 35\ mm = 0.035\ m$

Distance from centre of vane to pivot of lever $L = 150\ mm$

Mass of jockey weight $M = 0.600\ kg$

Weight of jockey weight $W = Mg = 0.600 x 9.81 = 5.89 N$

Table 6.1 Results for Flat Plate

V ***(L)***	***t*** ***(s)***	***y*** ***(mm)***	***Q*** (m^3/s)	u_1 ***(m/s)***	u_o ***(m/s)***	***J*** ***(N)***	***F*** ***(N)***

Table 6.2 Results for Hemispherical Cup

V ***(L)***	***t*** ***(s)***	***y*** ***(mm)***	***Q*** (m^3/s)	u_1 ***(m/s)***	u_o ***(m/s)***	***J*** ***(N)***	***F*** ***(N)***

1. **Plot force on vane *F(N)* vs. the rate of momentum flow in jet *J(N)* for both flat plate and a hemispherical cup.**
2. **Comments on your results.**

6.6 Discussion of Results

1. What suggestions have you for improving the apparatus?
2. What would be the effect on the calculated value of the vane efficiency of the following systematic errors of measurement:
   a) Mass of jockey weight in error by 0.001 kg
   b) Distance L from centre of vane to pivot of lever in error by 1 mm
3. What would be the effect on the calculated force on the flat plate if the jet were to leave the plate not absolutely horizontal, but inclined upwards at an angle of 1^{o}?
4. If the experiment were to be repeated with the vane in the form of a cone with an included angle of 60^{0}(half angle 30^{0}), how would you expect the results to appear?

7. Linear and Radial Heat Conduction

7.1 Objective

The primary aim of this experiment is to study the Fourier's Law on linear and radial conduction heat transfer.

7.2 Introduction

Generally, heat is defined as energy transfer due to the temperature gradients or difference between two points. Heat energy can be transferred in three modes, which are conduction, convection, and radiation. One of the most common heat transfer modes, which is conduction heat transfer, is defined as heat transferred by molecules that travel a very short distance (~0.65μm) before colliding with another molecule and exchanging energy.

In this experiment, both *linear* and *radial* conduction heat transfer methods are studied. The entire system (insulated heater/specimen, air and laboratory enclosure) are at room temperature initially (t = 0). The heater generates uniform heat flux as switched on.

7.2.1 Linear Conduction

For linear conduction, an electrical heating element is bonded to one end of a metal rod (heat source). Another end of the rod is exposed to heat discharge (heat sink). The outer surface of the cylindrical rod is well insulated; thus yielding one-dimensional linear heat conduction in the rod once the heating element is switched on. Thermocouples are embedded in the rod, along its centerline, at x = 0, 10, and 20 mm from the heating element. A simple sketch for heat conduction along a well-insulated cylindrical rod is shown on Figure 7.1.

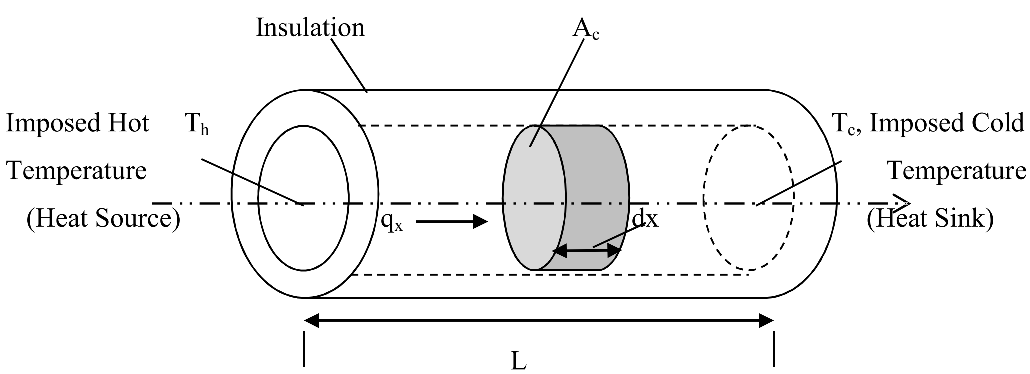


Figure 7.1 A simple sketch for heat conduction along a well-insulated cylindrical rod

7.2.2 Radial Conduction

For radial conduction, the electrical heating element is bonded to the center part of a circular brass plate (heat source). The cooling water flows through the edge of the plate that acts as a heat sink for heat discharge. The other surfaces of the plate are well insulated to simulate radial heat conduction from the plate center to its edge when the heating element is switched on. The brass plate has a radius, r_{plate} = 55 mm and thickness, t = 3.2 mm. Thermocouples are embedded in the circular plate, at r = 0, 10, 20, 30, 40, and 50 mm. A simple sketch for heat conduction along a well-insulated cylindrical rod is shown in Figure 7.2.

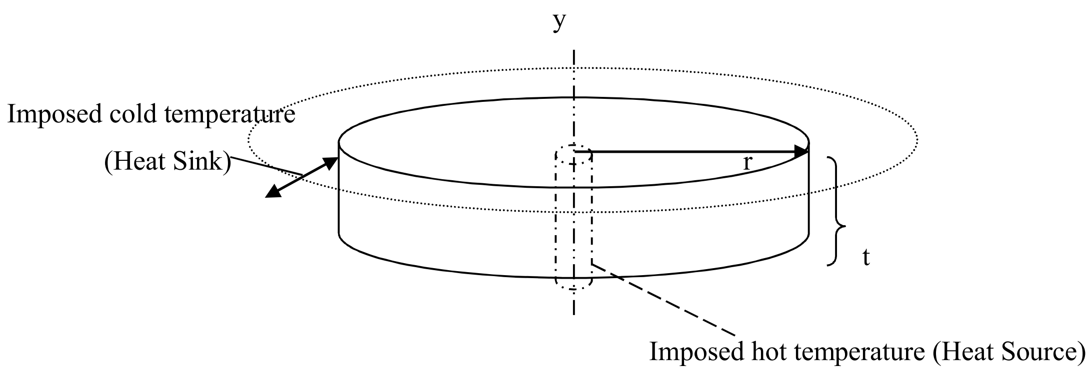


Figure 7.2 A simple sketch for heat conduction along a well-insulated cylindrical rod

7.3 Apparatus

The apparatus that will be using in this experiment is the H940 Heat Conduction Unit. There are four items to this unit.

7.3.1 The First Item

It is the transformer with a circuit breaker attached. The transformer consists of two cords, one of which plugs into an AC outlet and the other into the calibration unit (Figure 7.3).

7.3.2 The Second Item

It is the calibration unit. The calibration unit has two basic functions.

1. It delivers heater power to the heater element within the test unit,
2. It calibrates the temperatures at each of the nine positions so they can be read by the digital meter.

The far right knob adjusts the amount of power delivered to the heater. The knob to the left is the temperature selector switch, which will give the temperature at any of the nine positions (Figure 7.4).

7.3.3 The Third Item

This is the test unit. The test unit consists two test geometries:

1. An insulated brass bar for which samples can be placed between the two ends.
2. An insulated disk.

Both of these test geometries have a hose running through the cold end for which cold water from the sink can be passed through (Figure 7.4). *The purpose of having cold water running through the end of the bar or disk is to remove heat that is produced form the other end*. Once the rate at which heat is generated is equal to the rate at which heat is removed, *steady state equilibrium conditions* will exist. At this point the temperatures will be constant throughout the bar or disk and readings can be taken. There are two heater cords, one from the test bar and the other from the test disk. The cord for the desired test connects into the heater plug located in the lower right hand corner of the calibration unit.

7.3.4 The Sample Box

The last item of the conduction unit is a box that contains the samples, thermocouples, and conducting paste. The samples can be placed in the bar test unit by releasing the clamps and sliding the cold bar end out. The samples fit in only one way. The thermocouples must be placed in order from 1 to 9 as shown in Figure 1.4. There is a label on both the calibration unit and the test unit letting you know were the number 1 thermocouple starts. The conducting paste is a highly conductive compound which is designed to decrease contact resistance when applied to the ends of the connecting bars.

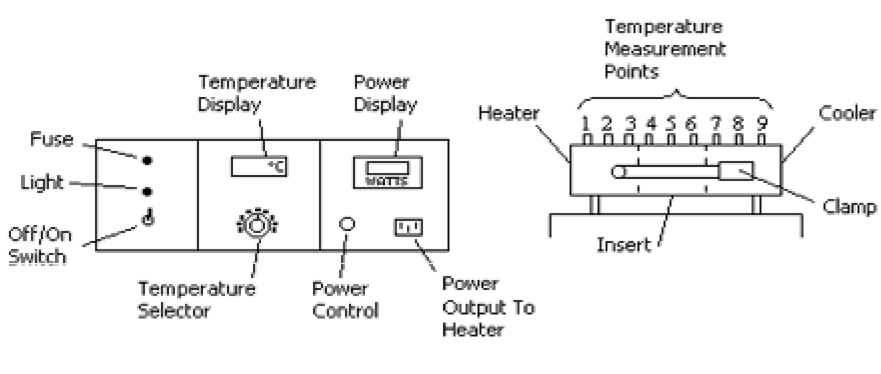


Figure 7.3 Front view of the calibration and test units

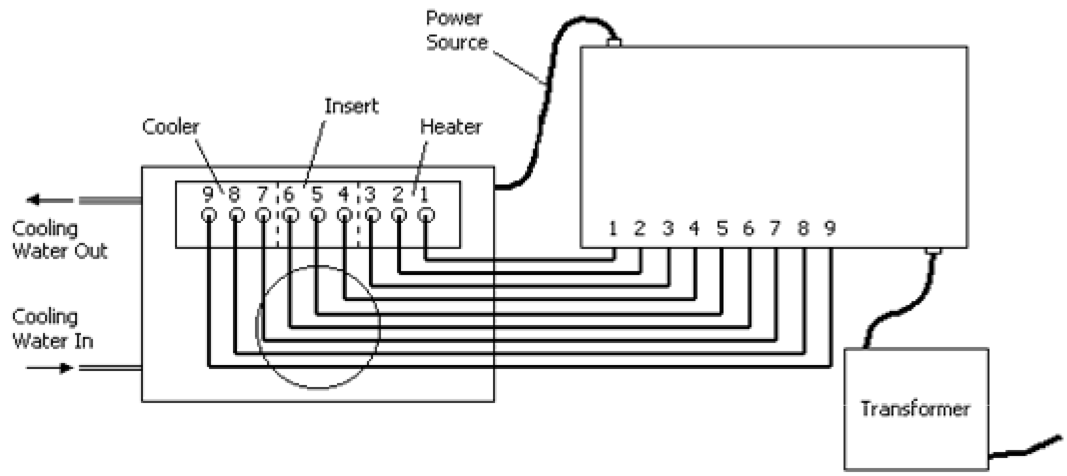


Figure 7.4 Top view of the calibration and test units

7.4 <u>Procedures</u>

7.4.1 Linear conduction along cylindrical metal rod

1. Install the brass specimen to the test unit.
2. Insert the probe in the holes provided along the specimen, making sure that each one is touching the rod. Take note of the distance for each thermocouple (x values).
3. Make sure there is water supply to the unit for simulating heat sink.
4. Turn on the heater with 10-Watt power input and record the temperatures after the readings reach steady state, which is about 20 to 30, minutes. Also, record the corresponding heater power input.
5. Record the measured temperature at each point.

7.4.2 Radial conduction along circular metal plate

1. Insert the thermocouples in the holes provided on the specimen, making sure that each one is operating properly. Take note of the distance for each thermocouple (r-values).
2. Make sure there is water supply to the unit for simulating heat sink.
3. Turn on the heater with 20 W power input and record the temperatures after the readings reach steady state, which is about 20 to 30, minutes. Also, record the corresponding heater power input.
4. Record the measured temperature at each point.

7.5 Report Requirement

1. Plot the temperature profile for both models as a function of distance for the both method of data collected. Select the best method and comment.
2. For the radial and linear conduction model, derive a general equation for the temperature reading as a function of distance, *x* for linear conduction, *T(x),* and *r* for radial conduction, *T(r),* using the parameters of k, *t*, *A*, T_1, *L*, and *R*. State the boundary conditions applied.
3. Plot the temperature profile for both models as a function of distance and obtain the slope *dT/dx* for linear conduction and *dT/dr* for radial conduction.
4. By using the slope of the graph plotted, calculate the thermal conductivity for each specimen used.
5. Compare and discuss the thermal conductivity obtained from the two methods and the typical values contained in tables of published data/Literature.
6. Discuss the characteristics of your plots and compare against the expected profile by the theory. Also discuss the validity of the Fourier Law and all the assumptions made as well as the source of errors.

7.6 Raw Data and Result Tables

PART I

Record your reading as follows:

Table 7.1 Raw Data for Experiment #1 (Part I)

Test	*Wattmeter Q (W)*	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)	T_9 (°C)
A										
B										
C										

The final results should be reported in the following format

Table 7.2 Processed Data for Experiment #1 (Part I)

Test	*Wattmeter Q (W)*	*A* (mm^2)	*dT/dx* (°C/mm)	*dx/dT* (mm/°C)
A				
B				
C				

k_{exp}= W/mm.K,
k_{ref} = W/mm.K,
% diff.= %

Part II

Record your reading as follows:

Table 7.3 Raw Data for Experiment #1 (Part II)

Wattmeter Q (W)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)	T_9 (°C)

8. Conduction Along a Composite Bar

8.1 Objectives

The objective of this experiment is to study the conduction of heat along a composite bar, as well as to evaluate the overall heat transfer coefficient.

8.2 Introduction

Experiment 7 has indicated how heat is transferred through a simple bar. Now this experiment must extend our knowledge to a bar made up of different materials. As stated in Experiment 7, there is an analogy between the conduction of electricity and the conduction of heat. Since electrical resistance is associated with the conductance of electricity, there is also a thermal resistance associated with the conductance of heat. Composite fluids and solids behave much like series and parallel combination of resistors in an electrical circuit. Using this approach one can add up the thermal resistances to find the overall resistance and heat transfer coefficient.

8.3 Theory

Assume that we have a combination of different materials put together to form a composite structure like the composite wall in Figure 8.1. Also assume that the cross sectional area normal to the flow of heat transfer is constant and that heat flows in a one dimensional direction. Taking only one of the slabs for now, we learned from Experiment 1 that the heat transfer is governed by Fourier's Law, given by

$$q_x = -kA\frac{dT}{dx} = \frac{kA}{L}(T_{s,1} - T_{s,2}) \tag{8.1}$$

Regarding the concept of thermal resistance for conduction. Resistance in general is defined as the ratio of driving potential over the transfer rate. As transfer rate goes to zero, the resistance becomes infinite and, similarly, as the driving potential goes to zero, resistance fails to exist. By using Fourier's Law and the definition of resistance, one can derive the thermal resistance for all the modes of heat transfer:

$$R_{t,cond} = \frac{T_{s,1} - T_{s,2}}{q_x} = \frac{L}{kA} \quad (8.2)$$

$$R_{t,conv} = \frac{T_S - T_{Fluid}}{q} = \frac{1}{hA} \quad (8.3)$$

$$R_{t,rad} = \frac{T_S - T_{sur}}{q_{rad}} = \frac{1}{h_r A} \quad (8.4)$$

where R is the resistance for each mode. Symbols T_s, T_{Fluid}, and T_{sur} are the temperatures for the surface, fluid, and surroundings, respectively. The symbols h_r and h are the heat transfer coefficients for radiation and convection, respectively.

If we sum up all the individual heat transfers, the intermediate temperatures cancel and we get:

$$q_x = \frac{T_{s,1} - T_{s,n}}{\sum R_t} = \frac{T_{s,1} - T_{s,2}}{\left(\frac{L_1}{k_1 A}\right) + \left(\frac{L_2}{k_2 A}\right) + \left(\frac{L_n}{k_n A}\right)} \quad (8.5)$$

To simplify Equation 2.5, combine everything that does not change across the composite, like the initial and final temperature and the area A, and call the rest that does change from material to material the overall heat transfer coefficient U. Therefore

$$q_x = UA\Delta T \quad (8.6)$$

and the overall heat transfer coefficient is:

$$U = \frac{1}{R_{tot} A} = \frac{1}{\left(\frac{L_1}{k_1}\right) + \left(\frac{L_2}{k_2}\right) + \left(\frac{L_n}{k_n}\right)} \quad (8.7)$$

There are two ways to find the overall heat transfer coefficient by finding R_{tot}.

1. The first way is to find all the individual k's using Equation 8.1 for each section of bar, and using these values in Equation 8.7.

2. The second way is to use Equation 8.6 with the *ΔT* of the entire bar.

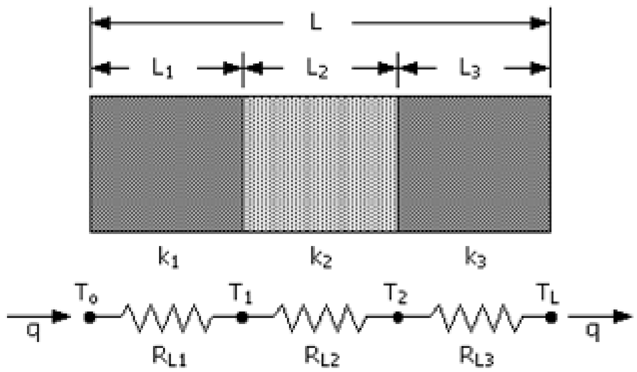


Figure 8.1 Composite Wall

8.4 Apparatus

H940 Heat Conduction Unit

8.5 Procedures

1. Take a stainless steel sample (30 mm long) and insert the steel sample to the test unit.
2. Allow cold water to flow through the test unit.
3. Select an intermediate position for the heater power control and allow sufficient time for a steady state condition to be achieved.
4. Record the temperature (*T*) at all six sensor points and the input power reading on the wattmeter (*Q*) in Table 2.1.
5. Repeat the procedure, for other input powers up the maximum setting of the control. After each change, allow sufficient time to achieve steady state conditions (Up to 10 min).

8.6 Report Requirement

1. Plot the temperature profile along the length of the core as in Figure 8.2, and obtain the outer surface temperature T_{hs} and T_{cs}.
2. Calculate the overall heat transfer coefficient (*U*) using both methods. For the first method, use Equation 8.7 and the individual *k's* found from Equation 8.1. For the second method, use Equation 8.6 and the extreme temperatures. Record the results in Table 8.2.
3. Compare the two experimental values of (*U*). If they disagree significantly, explain why.

4. Calculate (U) using Equation 8.7 and *k's* values from literature (published data).
5. Compare the experimental (U) by the second method with the (U) calculated from Equation 8.7 and using the *k's* from the literature.
6. Discuss sources of error from equipment and assumptions.

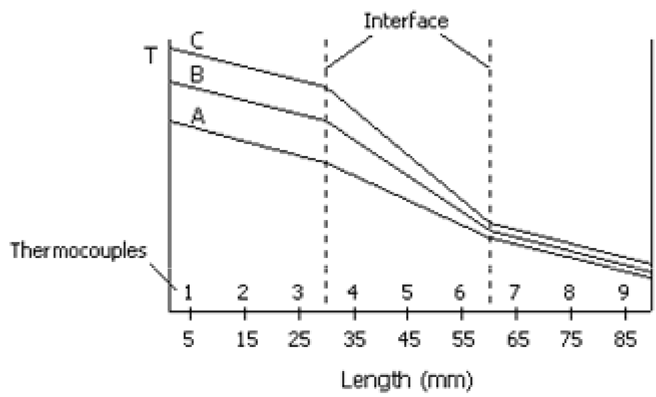


Figure 8.2 Temperature Distributions Along the Composite Bar

8.7 Raw Data and Result Tables

Record your reading as follows:

Table 8.1 Raw Data for Experiment #2

Test	***Wattmeter Q (Watts)***	***T_1 (^oC)***	***T_2 (^oC)***	***T_3 (^oC)***	***T_7 (^oC)***	***T_8 (^oC)***	***T_9 (^oC)***
A							
B							
C							

The final results should be reported in the following format

Table 8.2 Processed Data for Experiment #2

Test	***A (mm^2)***	***$(dx/dT)_h$ ($mm/^oC$)***	***$(dx/dT)_s$ ($mm/^oC$)***	***$(dx/dT)_c$ ($mm/^oC$)***	***k_{hot}***	***$k_{specimen}$***	***k_{cold}***
A							
B							
C							
Average	---------						

Table 8.3 Processed Data for Experiment #2

Test	***T_{hot} (^oC)***	***T_{cold} (^oC)***	***U_{exp1} ($W/mm\cdot K$)***	***U_{exp2} ($W/mm\cdot K$)***	***$U_{reference}$ ($W/mm\cdot K$)***	***% diff. 1 vs. 2***	***% diff. exp. vs. ref.***
Average							

9. Effect of Cross-Sectional Area

9.1 Objectives

The objective of this experiment is to understand how variable cross-section affects heat transfer.

9.2 Introduction

Experiment #2 showed how different materials affect heat flow, now this experiment shows how changes in cross-sectional area affect heat flow. In this experiment the same brass bar will be used, but instead of using the 25 mm diameter cross-section sample, a sample with a much smaller cross-section with a diameter of 13 mm will be used.

9.3 Theory

Fourier's Law states that,

$$q = -kA\frac{dT}{dx} \qquad (9.1)$$

The heat flow rate (q) is the same for each section of the conductor. Also the thermal conductivity (k) is assumed to be constant. If this is the case then,

$$A_h\left(\frac{dT}{dx}\right)_h = A_s\left(\frac{dT}{dx}\right)_s = A_c\left(\frac{dT}{dx}\right)_c \qquad (9.2)$$

In other words, the temperature gradient is inversely proportional to the cross-sectional area. Take Equation 9.2 and solve for the temperature gradient ratio, which is the ratio of the sample temperature gradient over the hot or cold temperature gradient, it can be seen that it is equal to the inverse of the ratio of the two different cross-sectional areas.

$$\frac{\left({dT}/{dx}\right)_s}{\left({dT}/{dx}\right)_{h/c}} = \frac{A_{h/c}}{A_s} \qquad (9.3)$$

In this experiment you are to compare the gradient ratio obtained from the plot of temperature versus distance with the inverse ratio of the two different areas.

9.4 Apparatus

H940 Heat Conduction Unit

9.5 Procedures

1. Take the brass sample (30 mm long) with 15 mm.
2. Insert the brass sample to the test unit.
3. Allow cold water to flow through the test unit.
4. Select between 5-10 Watts for the heater power control and allow sufficient time (20 min) for a steady state condition to be achieved (no more than 20 minutes).
5. Record the temperature (*T*) at all six sensor points and the input power reading on the wattmeter (*Q*) in Table 9.1.

9.6 Report Requirement

1. Plot the temperature profile along the length of the core as in Figure 9.1, and obtain the temperature gradient ratio. Compare this value with the theoretical value.
2. Discuss possible sources of error within the equipment or the assumptions made in the theory.

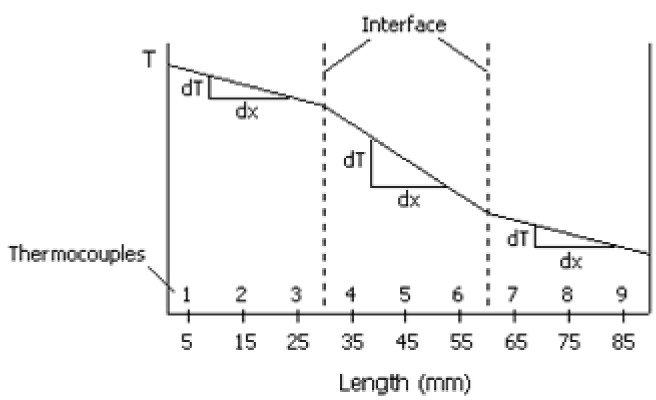


Figure 9.1 Typical Temperature Distributions

9.7 Raw Data and Result Tables

Table 9.1 Data for Experiment #3

Wattmeter Q (W)	***T_1 (^oC)***	***T_2 (^oC)***	***T_3 (^oC)***	***T_7 (^oC)***	***T_8 (^oC)***	***T_9 (^oC)***

Table 9.2 Processed Data for Experiment #3

Area sample (mm^2)	***Area h/c (mm^2)***	***$(dx/dT)_h$ ($mm/^oC$)***	***$(dx/dT)_s$ ($mm/^oC$)***	***$(dx/dT)_c$ ($mm/^oC$)***	***Area ratio (h/c)/s***	***Gradient ratio exp.***	***% error***

10. Effect of Insulation

10.1 Objective

The objective of this experiment is to study the effects of an insulating material such as paper by finding the thermal conduction coefficient (*k*) for that material.

10.2 Introduction

It is very important today in certain engineering applications, such as heating and air conditioning, to limit heat transfer to a minimum. In that respect engineers look for materials that do not conduct heat well or have a very small heat transfer conduction coefficient.

In this experiment you will calculate the conduction coefficient for paper or any other materials and compare it with values from the literature.

10.3 Theory

Using Fouier's Law and solving for the conduction coefficient,

$$k = \frac{q}{A}\left(\frac{\Delta x}{\Delta T}\right)_{Insulator} \qquad (4.1)$$

10.4 Apparatus

H940 Heat Conduction Unit

10.5 Procedures

1. Measure and record the paper thickness.
2. Insert the paper concentrically within the two metal bars of the apparatus and clamp (if possible). Do not use conducting compound.
3. Control the input power to approximately 10-15 Watts and allow around 20 min. to reach steady state making sure T_1 does not exceed 100^oC.
4. Record temperatures at all six sensor points and record in Table 4.1.

10.6 Report Requirement

1. Plot temperature vs. distance as in Figure 10.1.
2. Calculate the heat transfer coefficient. Record the results in Table 10.2.
3. Compare experimental value with values from the literature.
4. Discuss sources of error that might cause discrepancy.
5. Is this a good experiment to find the thermal conductivity of unknown material such as a circuit board?

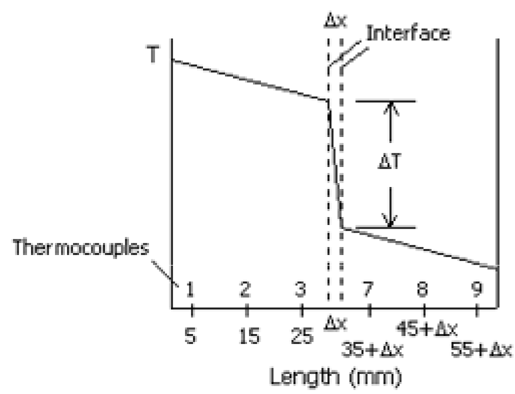


Figure 10.1 Temperature distribution along the cork

10.7 Raw Data and Result Tables

Record your reading as follows:

Table 10.1 Raw Data for Experiment #4.

Wattmeter Q (W)	***T_1 (°C)***	***T_2 (°C)***	***T_3 (°C)***	***T_7 (°C)***	***T_8 (°C)***	***T_9 (°C)***

The final results should be reported in the following format:

Table 10.2 Processed Data for Experiment #4

Sample	***Area (mm^2)***	***Width (mm)***	***Q (W)***	***ΔT (^oC)***	***k_{exp} (W/mm·K)***	***k_{ref} (W/mm·K)***	***% error***

11. Heat Conduction in Fluids

11.1 Objective

The objective of this experiment is to study heat conduction in fluids by using Fourier's law. In this experiment the thermal conductivity of water will be determined and the results will be compared with known values.

11.2 Introduction

Conduction does take place in fluids as well as solids. Usually the most common mode of heat transferred in a fluid is convection because of the bulk motion created by buoyancy forces due to density gradients throughout the liquid. However, as the space occupied by the fluid becomes very small, density gradients become negligible. Since there is negligible bulk motion, heat transfer is primarily due to conduction. In this experiment we will use an apparatus, shown in Figure 5.1 that will enable us to neglect density gradients and allow us to study conduction in the fluids air and water.

11.3 Theory

To find the thermal conduction coefficient we must use Fourier's Law. Solving for k we get,

$$k = \frac{q_c}{A}\frac{dx}{dT} \qquad (5.1)$$

For radial heat conduction in a cylinder, *dx* becomes *dr* and area *A* is the cross sectional area of the conducting path. Now for measurements made at steady state conditions across the small radial gap, *dr* becomes Δr, and *dT* becomes ΔT so we can obtain,

$$k = \frac{q_c}{A}\frac{\Delta x}{\Delta T} \qquad (5.2)$$

In order to find the heat by conduction (q_c) we must make use of conservation of energy. When applied to this system we get,

$$q_c = q_{gen} - q_{lost} = \frac{V^2}{R} - q_{lost} \qquad (5.3)$$

Substituting Equation 5.2 into Equation 5.3 we get the following expression for q_{lost}.

$$q_{lost} = q_{gen} - q_c = \left(\frac{V^2}{R}\right) - kA\frac{\Delta T}{\Delta r} \qquad (5.4)$$

The symbols V and R are the voltage and resistance of the heater element which generates electrical heat (Figure 5.1). In this mechanism there are heat transfers other than that transferred by conduction through the fluid under test. These heat "*losses*" are defined as *incidental* heat transfer. The heat losses can be a result of:

1. Heat conduction through the O-ring seals
2. Heat radiated from the plug
3. Heat losses to the surroundings by radiation and convection from the exposed ends of the plug.

From a simple understanding of heat transfer, we may assume q_{lost} to be proportional to the temperature difference between the plug and the jacket. q_{lost} can be estimated from the calibration graph of incidental heat transfer versus the plug and jacket temperature difference (see Figure 5.2). For this analysis you will use the known thermal conductivity of air *(Figure 5.3)*. The thermal conduction coefficient can then be calculated for other fluids by the temperature difference across the fluid.

In other words, the data from the air calibration test is used to calculate q_c from Equation 5.2, using the known tabulated thermal conductivity of air, k_{air}. The value for q_{gen} is then calculated and Equation 5.3 solved for q_{lost}. The graph of the three q_{lost} vs. ΔT values is the calibration curve, from which the values of q_{lost} for the water test will be found (it is assumed that heat loss is directly related to temperature difference). The q_{lost} from the graph and the calculated value of q_{gen} for the water tests are then put into Equation 5.3 to find q_c. Finally, the value of q_c is put into Equation 5.2 to give the experimental thermal conductivity of water.

11.4 Apparatus

H470 Heat Conduction Unit, the apparatus used in this experiment consists of three items.

11.4.1 The first item

Is the transformer used to convert 110 to 220 volts.

11.4.2 The second item

Is the plug jacket assembly, which consists of two cylinders. *The smaller cylinder* or plug is machined from aluminum (to reduce thermal inertial and temperature variation) and contains a cylindrical heating element whose resistance at the working temperature is accurately measured. A thermocouple is inserted into the plug close to its external surface, and the plug also has ports for the introduction and venting of the fluid under test.

The second cylinder or water cooled jacket fits concentricity around the plug. The fluid whose thermal conductivity is to be determined fills the small radial clearance between the heated plug and the water cooled jacket. The clearance is small enough to prevent natural convection in the fluid. Due to the positioning of the thermocouples and the high thermal conductivities of the materials involved, the temperatures measured are effectively the temperatures of the hot and cold faces of the fluid surface.

11.4.3 The Third Item

The console, which is connected by flexible cables to the plug/jacket assembly and provides for the control of the voltage supplied to the heating element. An analog voltmeter enables the power input to be determined and a digital temperature indicator with 0.1K resolution displays the temperatures of the plug and jacket surfaces. The features of the console are shown in Figure 5.1.

The following are specifications of the apparatus needed for calculations.

1. Nominal resistance of heating element, R = 55 Ω
2. Nominal radial clearance between plug and jacket, Δr = 0.30 mm *
3. Effective area of conducting path through fluid, A = 0.0133 m^2

*The values to be used are engraved on the head of the plug!

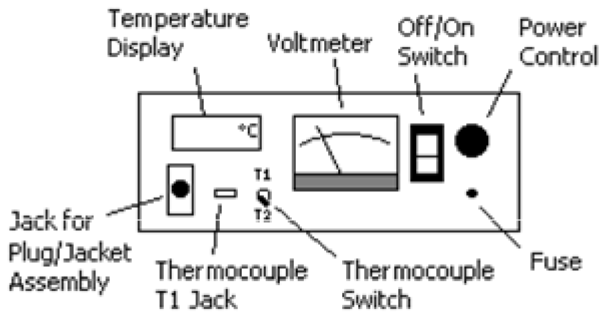


Figure 11.1 Schematic of Console Unit

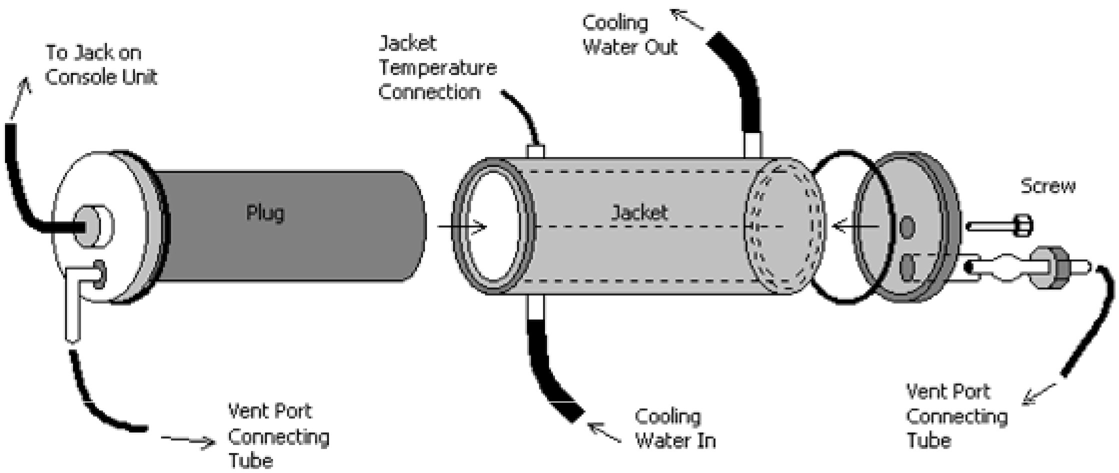


Figure 11.2a Schematic of Plug/Jacket Assembly

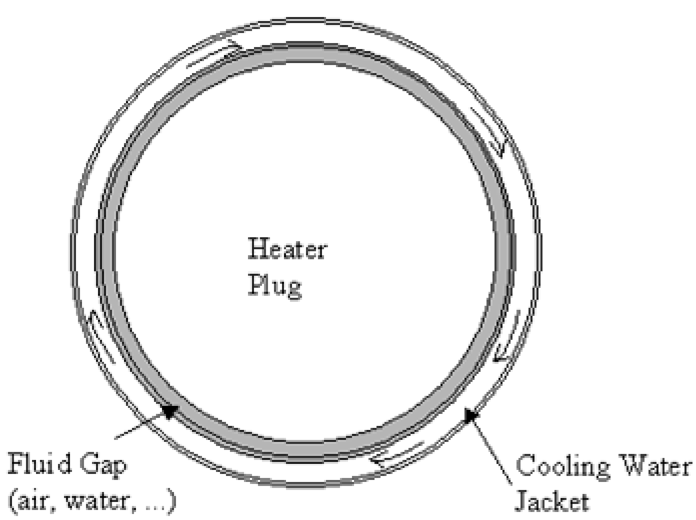


Figure 11.2b Cross-Sectional View of Plug/Jacket Assembly

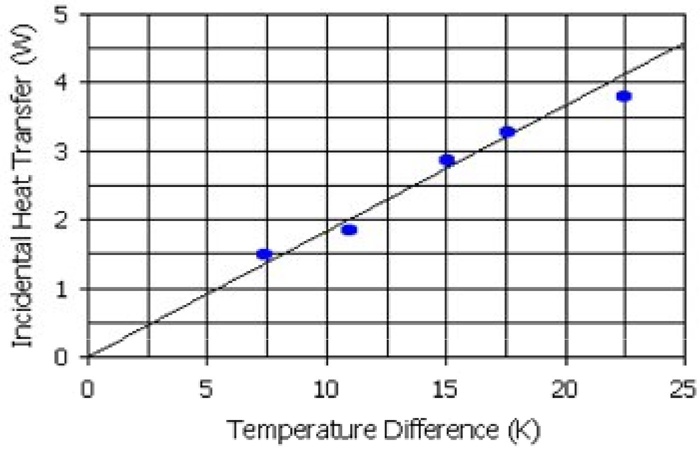


Figure 11.3 Example Graph of Incidental Heat Transfer

11.5 <u>Procedure</u>

11.1 Preparation

1. Ensure the main switch is off.
2. Connect the thermocouple from the jacket to the hand held thermocouple measuring device. Connect the main power cord from the test apparatus to the main control box. Note that the core temperature can be taken from the main control box, and the water jacket temperature is taken from the hand held thermocouple meter. Make sure that the toggle switch is in the down (T_2) position. Please leave the switch alone during the remainder of the experiment.
3. Pass water through the jacket at about 3 liters per minute (the actual quantity is unimportant but a copious supply is necessary so the jacket will operate at a sensibly constant temperature). The space between the plug and the jacket will remain occupied by air.

11.2 Calibrating the device by heat loss estimation with air in the gap

1. Connect the small flexible tubes to the charging and vent unions at either end of the plug and jacket to close off the chamber. Note: Air is now trapped in the radial chamber.
2. Switch on the electrical supply.
3. Adjust the variable transformer to about 15 V.
4. Observe the plug and jacket temperatures and when they are stable, enter their values and the voltage in Table 11.1.
5. Increase the electrical input to about 30 V and when stable repeat the step above.
6. Repeat again for 45 V.

7. Calculate the incidental heat loss and plot the heat loss as a function of the temperature difference. Calculate the best fit line using linear regression. This will be your preliminary calibration curve for estimating heat loss (see Figure 11.3)
8. Repeat the experiment three more times to improve the heat loss estimate and study the error in the estimate of heat loss. Adjust the transformer to about 40 V, and measure the temperatures and voltage when stable.

9. Repeat again for 25 V, and 10 V.

10. Calculate and plot the heat loss for all six data measurements together on the graph and repeat the linear regression analysis. This will be your final calibration curve for heat loss.

11.6 Raw Data and Result Tables

Table 11.1 Raw Data for Air

Voltage (V)	T_p (°C)	T_j (°C)	ΔT (°C)	q_{gen} (W)	q_c (W)	q_{lost} (W)	k_{air} (ref.)

Table 11.2 Raw Data for Water

Voltage (V)	T_p (°C)	T_j (°C)	ΔT (°C)	q_{gen} (W)	q_{lost} (W)	q_c (W)

k_{exp}= W/mm.K,

k_{ref} = W/mm.K,

% diff.= %