BIRZEIT UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

MECHANICAL ENGINEERING DEPARTMENT AND MECHTRONICS PROGRAM

ENME 411
Mechanical Laboratory

Laboratory Manual

September 2014

Lab Safety Instructions and Rules
Mechanical Engineering department

General Behavior

- Never work in the laboratory alone, always have another qualified person in the area do not use any equipment unless you are trained and approved as a user by your instructor or staff. Ask questions if you are unsure of how to operate something.
- Perform only those experiments authorized by the instructor. Never do anything in the laboratory that is not called for in the laboratory procedures or by your instructor. Carefully follow all instructions, both written and oral. Unauthorized experiments are prohibited.

- Don't eat, drink, or smoke, in the laboratory
- Please don’t yell, scream, or make any sudden loud noises that could startle others who are concentrating on their work.
- When you are done with your experiment or project, all components must be dismantled and returned to proper locations.

- When operating high noise machines put on ear protection, those are available in the lab and will be given by the instructor.
- Shoes must completely cover the foot. No sandals are allowed.
- Dress properly during all laboratory activities. Long hair, dangling jewelry, and loose or baggy clothing are a hazard in the laboratory. Long hair must be tied back and dangling jewelry and loose or baggy clothing must be secured.
- Keep aisles clear and maintain unobstructed access to all exits, fire extinguishers, electrical panels, and eyewashes.

First Aid & fire

- First aid equipment is available in the lab, ask your instructor about the nearest kit.
- Fire extinguisher are available in the lab, ask your instructor about the nearest one to your lab.

Poisons

- Certain liquids used in our apparatus, for example refrigerants, manometer fluids, and mercury, are poisonous or can give off poisonous vapors.
- Avoid contact with such liquids, clean up any that is spilled and perform operations such as the filling of manometer in well ventilated conditions.

Electricity

- Do not handle electrical equipment while wearing damp clothing (particularly wet shoes) or while skin surfaces are damp.
- Never bend or kink the power cord on an instrument, as this can crack the insulation, thereby introducing the danger of electrical shocks or burns.
- Know where the stop button, main switch or other device for stopping the apparatus is located

Machines and moving parts

- In order to avoid the possibility of injuries, it is important that the students be aware of their surroundings and pay attention to all instructions.
- Deal with caution with rotating machines, fans pumps compressors, motors etc. don’t touch any of the rotating parts; shafts, or blades.
- Read and understand operation instructions before turning on the machines, do not turn machine till you instructed by the instructor or the technician.

High pressure cylinders

- Deal with caution with high pressure cylinders and systems.
- Turn such cylinders off after finishing the experiment.
- Close LPG cylinders safely after completing your experiment**.**

Hot surfaces and burns

- Do not touch hot surfaces; hot plates boilers, heating elements machines etc.

High flow streams

- When using compressed air, use only approved nozzles and never direct the air towards any person.
- Exercise care when working with or near hydraulically- or pneumatically-driven equipment.

Laboratory Report

General

The single most important requirement for a laboratory report is clarity. Imagine that your audience is one of your classmates who missed that experiment. The report should be understandable to someone who is not necessarily familiar with the specifics of the lab.

The report should be typewritten using a word processor. Use A4 white paper, one side of the paper only. Use double- spacing with 12 fonts. Also use the spelling and grammar checkers. However, grammar check will not assess clarity, and it will ignore simple errors. The quality of the writing will count for at least half of your grade.

All pages, equations, figures, graphs and tables must be numbered. Figures, tables, graphs, etc., must have titles and be introduced in a sentence in the text of the report. Figures must have axis labels that name the variable as well as giving its symbol and units if appropriate.

Figures, graphs, and tables must be neat and clear. Figures and graphs should be generated on the computer through drawing and plotting software (Excel or Mathlab are examples). Choose scales that are appropriate to the range of data and that can be easily read.

Many technical writers prefer to write sentences with passive verbs. A simple example: “The spring constant k was found from the slope to be 3.02 N/m.” If you run this sentence through the grammar check, it will tell you that “was found” is a verb in the passive voice. To change this to an active voice you could write: “The spring constant k is the slope, 3.02 N/m.” Not every sentence has to be in an active voice. What you want is a report that is readable.

Report Outline

The following format is required for the organization of the Technial Report:

- **Title Page**
- **Abstract**
- **Objectives**
- **Sample Calculation**
- **Results**
- **Discussion of Results**
- **Conclusion**
- **Appendices (Original data sheet, References)**

Lab Report Outline

Title Page or Cover Sheet

This **Title Page** has the title of the lab, title of the experiment, course number and assigned lab section, your name, your lab partner's names, the date that the lab was performed, the date of submition and your instructor's name. Please make this on a separate page.

Abstract

The purpose of an abstract in a scientific paper is to help a reader decide if your paper is of interest to him/her. (This section is the executive summary in a corporation or government report; it is often the only section that a manager reads.) The abstract should be able to stand by itself, and it should be brief. Generally, it consists of three parts which answer these questions:

- What did you do? – A statement of the purpose of the experiment, a concise description of the experiment and fluid mechnics principles investigated.
- What were your results? – Highlight the most significant results of the experiment.
- What do these results tell you? – Depending on the type of experiment, this is conclusions and implications of the results or it may be lessons learned form the experiment.

An abstract should be one paragraph of 100-200 words. Write the abstract after all the other sections are completed. (You need to know everything in the report before you can write a summary of it.)

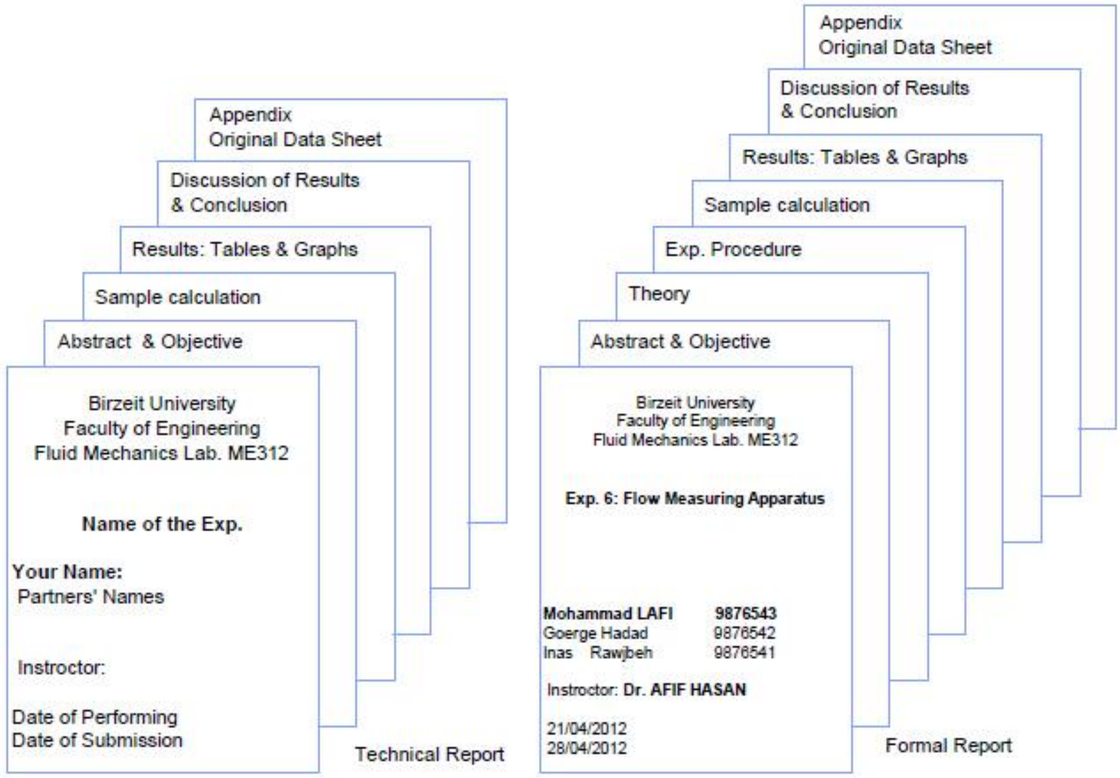


Fig. 1: Format for Technical reports (left) and Formal Reports

Objective

State the objective clearly in a concise manner in your own words. Describe the specific actions you are being asked to perform in the lab, such as measure something, analyze something, test something, etc. Objectives are the activities you are being asked to do in order to complete the lab experiment. Be sure to list them as such: to measure, to analyze, to determine something.

Theory

The theory section should contain a complete analytical development of all important equations pertinent to the experiment, and how these equations are used in the reduction of data. The theory section should be written textbook-style.

Experimental Procedure

A general description of the procedure should be given. This description should be comprehensive, but brief. It should include a generic list of equipment used and a sketch to show how the equipment items are related.Give a detailed description of how you accomplished the experiment. 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. Name all measured quantities and how they are measured. Use sketches, diagrams, or photos to describe the experimental set-up. Label the main components.

Sample Calculation

Show a sample of a complete calculation of each type involved in the determination of calculated data and the solution of problems. These sample calculations should be first shown in symbolic form (equations) with all variables & symbols properly defined.Then numerical data should be used with units shown in the actual calculations. Include a brief description of the calculation, the equation, numbers from your data substituted into the equation and the result. Do not include the intermediate steps. Numbers in the sample calculations must agree with what you recorded in your data sheet. For calculations repeated many times, you only include one sample calculation. Answers should have the proper number of significant figures and units. (It is not necessary to show the calculation for obtaining an average, unless your instructor requests that you do so.) Typing the equation into the lab report **is not required;** it is easier and faster to print these calculations neatly by hand. If you wish to type this section, then use the equation editor in Microsoft Word. Your lab instructor can give you information on using the equation editor.

Results

Include all tables and graphs that document your final results. Include all relevant information so that you can later refer to these number of tables and figures in the Discussion section to support your conclusions.

Tables: For each experiment, the lab manual has one or more tables for recording raw data, as well as, intermediate and final data values. All numerical results should be non-dimensional or reported in SI units, such as kg for kilograms, W for Watts. Record the original data neatly in pen. This original data sheet should be approved by instructor(s) during experiment day. Place the name of the table on the above side.

Graphs: You must follow the guidelines in the lab manual for all graphs. The first graphs of the semester must be made by hand, not computer software. After your lab instructor gives permission, you may use computer software to make graphs. Those graphs must also conform to the guidelines in the lab manual. Remember that when plotting data with units, both the slope and intercept of a graph also have units. Place the name of the graph below the graph.

Discussion of Results

This is the most important part of the lab report; it is where you analyze the data.Begin the discussion with the experimental purpose and briefly summarize the basic idea of the experiment with emphasis on the measurements you made and transition to discussing the results. State only the key results (with uncertainty and units) quantitatively with numerical values; do not provide intermediate quantities. Your discussion should address questions such as:

- What is the relationship between your measurements and your final results?
- What trends were observable?
- What can you conclude from the graphs that you made?
- How did the independent variables affect the dependent variables? (For example, did an increase in a given measured (independent) variable result in an increase or decrease in the associated calculated (dependent) variable?

Then describe how your experimental results substantiate/agree with the theory. When comparison values are available, discuss the agreement using either uncertainty and/or percent differences. This leads into the discussion of the sources of error. In your discussion of sources of error, you should discuss all those things that affect your measurement, but which you can't do anything about given the time and equipment constraints of this laboratory. Your discussion should address questions such as:

- Are the deviations due to error/uncertainty in the experimental method, or are they due to idealizations inherent in the theory (or both)?
- If the deviations are due to experimental uncertainties, can you think of ways to decrease the amount of uncertainty?
- If the deviations are due to idealizations in the theory, what factors has the theory neglected to consider? In either case, consider whether your results display systematic or random deviations.

Conclusion

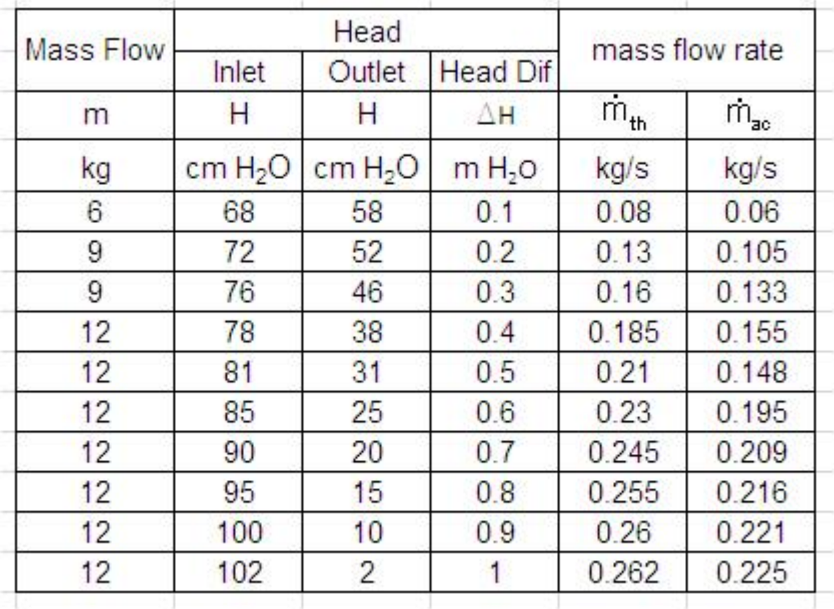
State your discoveries, judgments and opinions from the results of this experiment. Summarize your primary results in comparison with theory in two or three sentences. These should answer the objective of the experiment. Make recommendation for further study. Suggest ways to improve the experiment.

Appendices

- **Original Data Sheets:** Record the original data neatly in pen. 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. This original data sheet should be approved by instructor(s) during experiment day.
- **References:** List any book or publication that you have referenced in your report. Provide titles, authors, publisher, date of publication, page number, Website addresses etc.
  Book reference: Author last name, Author first name. Book's title. Publisher and city of publication, year of publication.
  Journal reference: Author last name, Author first name. Paper title, Name of journal, volume, pages, year.
  Internet reference: Site location (http://www.   ) and retrieved date.

Example of writing a Table and plotting a Graph Result

Table 1: The mass flow, in kg, inlet, outlet and difference head, in m H_2O, theoretical $\dot{m}_{th}$ and actual (measured), $\dot{m}_{ac}$ values of mass flow rate, in kg/s for the Venturi meter.



Mass Flow	Head			mass flow rate	
	Inlet	Outlet	Head Dif		
m	H	H	ΔH	$\dot{m}_{th}$	$\dot{m}_{ac}$
kg	cm H_2O	cm H_2O	m H_2O	kg/s	kg/s
6	68	58	0.1	0.08	0.06
9	72	52	0.2	0.13	0.105
9	76	46	0.3	0.16	0.133
12	78	38	0.4	0.185	0.155
12	81	31	0.5	0.21	0.148
12	85	25	0.6	0.23	0.195
12	90	20	0.7	0.245	0.209
12	95	15	0.8	0.255	0.216
12	100	10	0.9	0.26	0.221
12	102	2	1	0.262	0.225

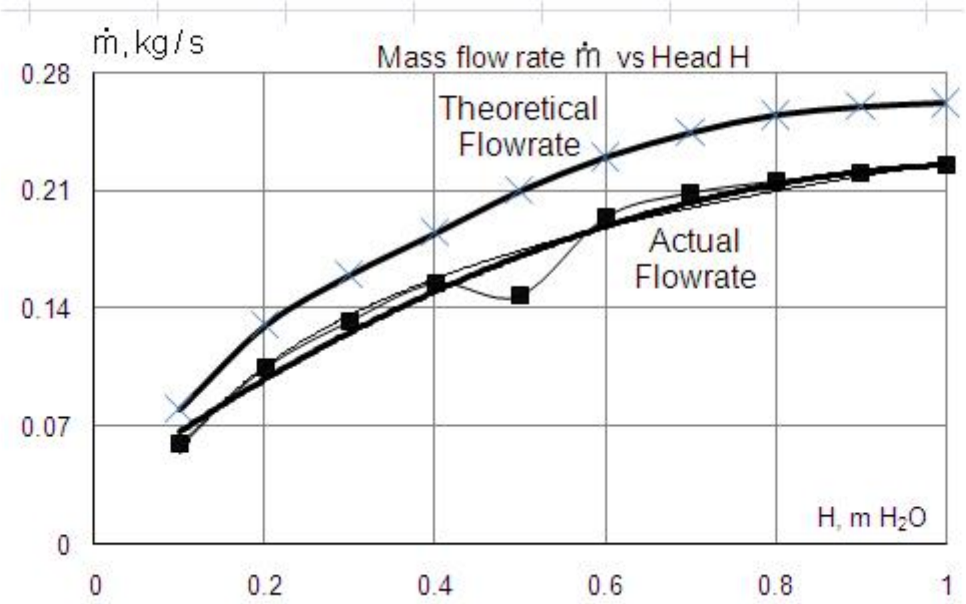


Fig. 2: The relationship between mass flow rate and head

EXPERIMENT No.(1)

STEAM RANKINE CYCLE

OBJECTIVE :

- To gain an understanding of the Rankine Cycler System as a whole and details of each component making up the system.
- Conduct start-up, operation, data gathering and shut down of Rankine Cycle Steam Turbine Power System.
- Graphically plot Rankine Cycler Run Data in preparation for system analysis and performance calculations.
- To perform system performance calculations using First Law Energy Conservation Equation for Steady State, Steady Flow Conditions **(SSSF)**.

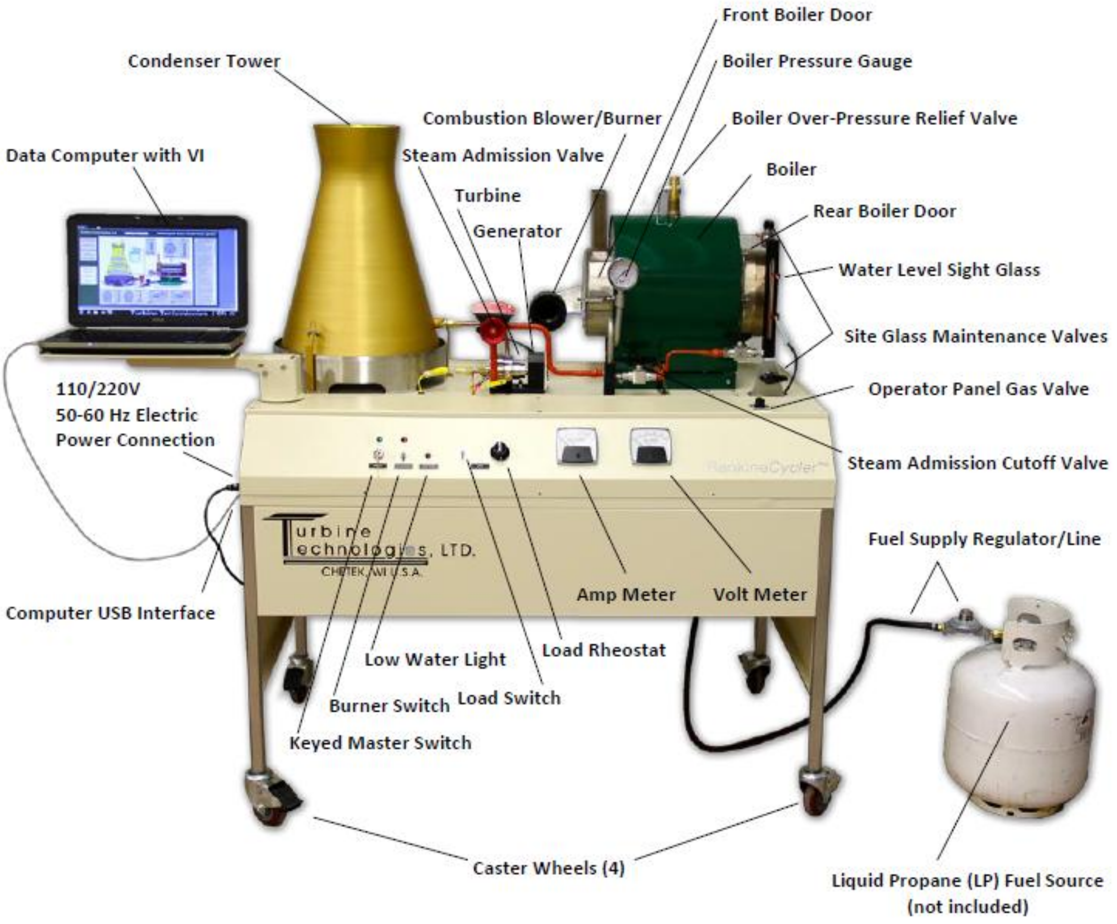


Figure (1) Steam Power cycle

SYSTEM DESCRIPTION:

The Rankine Cycler Steam Turbine Power System is representative of an actual steam power plant rendered in miniature. Each component faithfully models the full size component in purpose and function

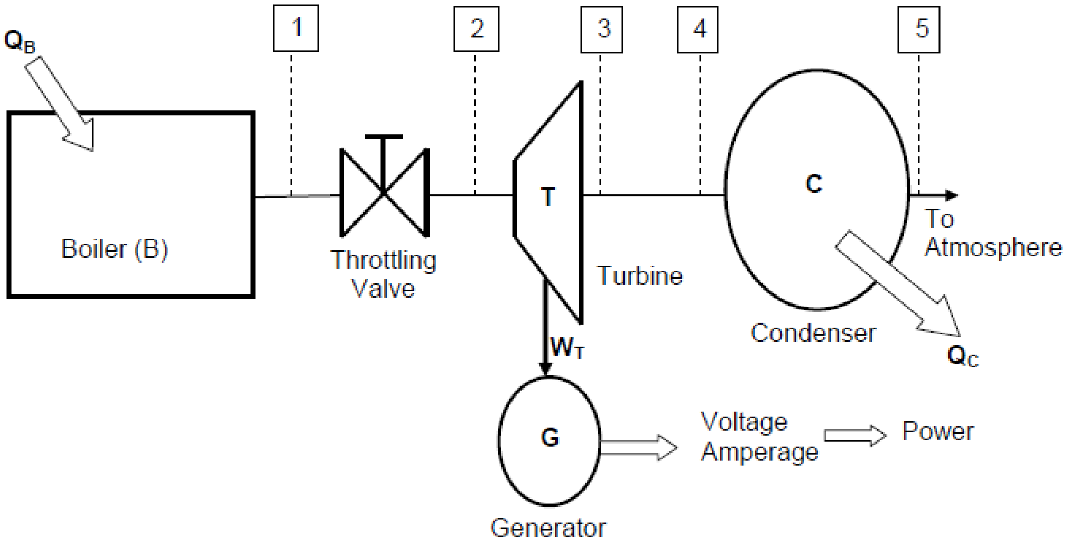


Figure (2) Schematic of the Steam Rankine as open cycle.

The Steam Rankine apparatus as shown in figure 2 consists of :

- Burner and Steam Generation Boiler
- Steam Admission Valve
- Steam Turbine
- Condenser Tower
- Electrical Generator
- Data Acquisition Computer

Details of each component are explained below.

Steam Generation Boiler

A forced air gas burner provides the necessary energy to vaporize the liquid working fluid as it passes through the boiler. An electrically driven centrifugal blower provides combustion air to the burner through a blower duct. A fuel line is routed through this duct, delivering fuel to a gas mixing nozzle. The fuel and air are further mixed by a vortex disk that introduces turbulence to the flow. A “hot surface" igniter located in the fixed rear boiler door and at the end of the primary flame tube provides the ignition source. Once combustion commences, the flame is self sustaining and the igniter will shut off.

The Rankine Cycle utilizes a fire tube or shell type boiler arrangement which is representative of over 80% of all boiler systems in use today. The shell of the boiler is an 8 in (20.3 cm) diameter by 11.5 in (29.2 cm) long stainless steel cylinder. The cylinder holds both the working fluid of the system as well as the high-pressure vapor prior to it exiting to the turbine. To allow heat transfer, 17 0.5 in diameter (1.3 cm) tubes pass through the cylinder allowing hot combustion gasses from the burner to “flow through" the boiler. Five of these boiler tubes lie above the full water line. A primary flame tube 2 in (5.1 cm) in diameter also passes through the boiler and holds the flame produced by the burner. The walls of the 17 tubes and the primary flame tube provide nearly 380 in2 (2,451.6 cm2) of surface area for heat transfer.

Boiler Sight Gage Indicates Water Level in Boiler Equipped with two adjustable position bezels for marking boiler water levels of interest during operation.

Main Shell External Length = 29.65 cm
Main Shell Wall Thickness = 0.64 cm
End Plate Outside Diameter = 20.70 cm
End Plate wall thickness = 0.64 cm
Main Flame Tube Outside Diameter = 5.08 cm
17 Return Pass Flame Tubes Outside Diameter = 1.90 cm
Boiler maximum operation conditions are;
Pressure = 120 psi (827 kPa)
Temperature = 608 ±F (320 ±C)
Boiler Volume = 203 oz (6,000 ml)

The sight glass provides an indication of the relative level of working fluid within the boiler. An upper and lower adjustable bezel allow the extents of working fluid to be marked

An analog **pressure gauge** is installed providing a direct read out of available boiler pressure. The gauge indicates the normal range of operation with a white background. The red area of the gauge indicates pressure conditions that exceed normal operating limitations.

Steam Admission Valve

The steam admission valve is a needle type valve that regulates the flow of steam vapor to the turbine. In the fully clockwise position, the valve is CLOSED preventing the flow of steam. In the fully counter-clockwise position, the valve is OPEN and the full flow of steam is available to the turbine. Intermediary positions regulate accordingly

Steam Turbine

High pressure steam is directed through a nozzle, forcing the steam to impinge directly on the blades of the turbine wheel causing it to rotate. This rotation is then used to derive useful work. High pressure steam, as regulated by the steam admission valve, enters the front housing through a fitting. Directed through the vane guide ring's six radially spaced nozzles, the steam causes the turbine to rotate by the steam's momentum reaction on the turbine blades. The steam now expands and diffuses in the rear housing, exiting through an exhaust fitting directing the steam to the condenser tower.

Maximum operating conditions for GENERATOR

Voltage	15.0 Volts
Current	1.0 Amps
Power	15 Watts
RPM	4500 RPM

The **electric generator** utilizes the rotational motion of the turbine to produce electrical energy. A four-pole, permanent magnet, brushless design, the generator is directly coupled to the output shaft of the turbine and supported on its own set of preloaded ball bearings. Both alternating current (AC) and direct current (DC) are available at the generator outputs.

Condenser Tower

The tower mantle, manufactured from aluminum, provides the heat transfer interface and a condensation surface. Steam enters the condenser tower through a distribution manifold that disperses the steam within the tower to maximize contact with the mantle. Four internal stainless steel baffles further direct the steam along the mantle, while allowing condensate to run back to a catchment basin at the bottom of the condenser tower. This basin can be drained, using the attached hose and pinch-clamp, to accurately measure the amount of condensation collected. Approximately 625 in2 (4,032 cm2) of area is available for heat transfer and condensation formation.

Operator Panel

Various controls and indicators are provided to assist the operator in using the Rankine Cycle.

Data Acquisition System

The RankineCycler comes equipped with a National Instruments 6218 precision data acquisition system permitting a full range of system parameter measurement. This system, comprising a suite of sensors, excitation power sources, signal conditioners, data acquisition hardware and user interface software, when used in conjunction with an appropriate computer, allows actual run-time data to be displayed and recorded for later analysis.

EXPERIMENTAL PROCEDURE :

First: Start and Operation

1. The COMPUTER DAQ SYSTEM (data acquisition computer) should be turned ON (See Section 4.2.5 DATA COLLECTION). This allows the computer adequate time to initialize prior to data collection.
2. The FUEL SOURCE regulator can be turned ON.
3. Turn the Rankine Cycle OPERATOR PANEL GAS VALVE to ON. This permits the flow of fuel to the fuel control system.
4. Select the MASTER SWITCH key to the ON position. Verify illumination of the GREEN panel light. Electrical power is now available to the system and the controls.
5. Select the BURNER SWITCH to the ON position. Verify illumination of the RED panel light. Electrical power is now available to the combustion blower.
6. Observe the COMBUSTION BLOWER and VERIFY ON. The COMBUSTION BLOWER motor will begin to rotate, drawing air into the burner and forcing it through the boiler.
7. Monitor BOILER PRESSURE. VERIFY POSITIVE PRESSURE within 3 MINUTES from BURNER start. If there is no positive indication of boiler pressure within three minutes of starting the BURNER, select the BURNER switch to OFF and investigate. Verify that the proper amount of water is in the boiler and the STEAM ADMISSION VALVE is fully CLOSED.
8. The system should now be PREHEATED. This allows the steam lines, valves and turbine to come up to the proper operating temperature. The turbine bearings are also lubricated at this time. The preheating process outlined below should take approximately 7 to 10 minutes to complete.
   a. Allow the indicated BOILER PRESSURE to rise to approximately 110 psi (758 kPa).
   b. The STEAM ADMISSION VALVE should be turned counter-clockwise to OPEN. This will allow steam to flow throughout the system. The turbine/generator may or may not rotate at this point.
   c. Monitor BOILER PRESSURE until it falls to approximately 40 psi (276 kPa).
   d. The STEAM ADMISSION VALVE should be turned clockwise to CLOSE. This will stop the flow of steam throughout the system and allow the boiler pressure to build again.
   e. Allow the indicated BOILER PRESSURE to rise to approximately 110 psi (758 kPa).
   f. The STEAM ADMISSION VALVE should again be turned counter-clockwise to OPEN. This will allow steam to flow throughout the system. The turbine/generator may or may not rotate at this point.
   g. Monitor BOILER PRESSURE until it falls to approximately 40 psi (276 kPa).

h. The STEAM ADMISSION VALVE should be turned clockwise to CLOSE. This will stop the flow of steam throughout the system and allow the boiler pressure to build again.
i. Allow the indicated BOILER PRESSURE to rise to approximately 110 psi (758 kPa0

9. While maintaining approximately 110 psi (758 kPa) of BOILER PRESSURE, the STEAM ADMISSION VALVE should be OPENED slowly. The rate at which the STEAM ADMISSION VALVE is OPENED should be just enough to maintain 110 psi (758 kPa) of BOILER PRESSURE and to counter any tendency for the BOILER PRESSURE to increase beyond this value. Once the turbine begins to rotate, the generator will produce electricity. Generator output will be directly indicated on the VOLT METER.
10. Continue opening the STEAM ADMISSION VALVE until the VOLT METER shows an approximate FULL SCALE DEFLECTION or an indicated 15.0 Volts.
11. The LOAD SWITCH should be selected to ON.
12. The LOAD RHEOSTAT should be ADJUSTED to MAINTAIN: 0.2A, 5.0 V
13. A BOILER PRESSURE of approximately 110 psi (758 kPa). This is nothing more than a starting point and the operator should not spend a great deal of time trying to achieve these values exactly.
14. In preparation of an experimental data run, the STEAM ADMISSION VALVE and the LOAD RHEOSTAT may now be adjusted to achieve a STEADY STATE CONDITION. Satisfactory run-time results can be achieved with the following STEADY STATE values:
    a. An AMP METER indication of approximately 0.2 Amps.
    b. A VOLT METER indication of approximately 6.0 Volts.
    c. A BOILER PRESSURE indication of approximately 110 psi (758 kPa).
    d. These values need not be matched exactly. When a
    reasonable STEADY STATE is ACHIEVED, RESUME CHECKLIST
15. To begin an experimental run, the TIME should be NOTED. This allows a steam rate calculation to be made at the conclusion of the experimental run.
16. SET the SIGHT GLASS UPPER BEZEL to the current, indicated WATER LEVEL. This allows measurement of the boiler water consumed during the experimental run. Confirm that all valves on lines into and out of sight glass are in the “open” position as shown.
17. Use the STEAM ADMISSION VALVE to make PERIODIC ADJUSTMENTS maintaining the STEADY STATE established in Step 17.
18. Allow time to CONDUCT THE EXPERIMENT AS REQUIRED. Once the STEADY STATE has been achieved, a sufficient amount of data should be collected with the DAQ system for later analysis. Steady state run time is approximately 10 -15 minutes. Boiler pressure will climb as water level drops.

While CONDUCTING THE EXPERIMENT, MONITOR WATER LEVEL in the BOILER using SIGHT GLASS. The WATER LEVEL must NOT fall to LESS THAN 1.0 in (2.5 cm) FROM BOTTOM OF SIGHT GLASS. Serious BOILER or BURNER damage may result if the BOILER is allowed to run out of water. An automatic low water level shut-off is built into the system to automatically shut off the unit if water level drops below the 25 mm level (1 inch) in the sight glass.

Second: Shutdown

The SHUTDOWN checklist ceases Rankine Cycle operation and places the system into a known, safe condition.

1. At the conclusion of the experimental run, the TIME should be NOTED for a steam rate calculation.

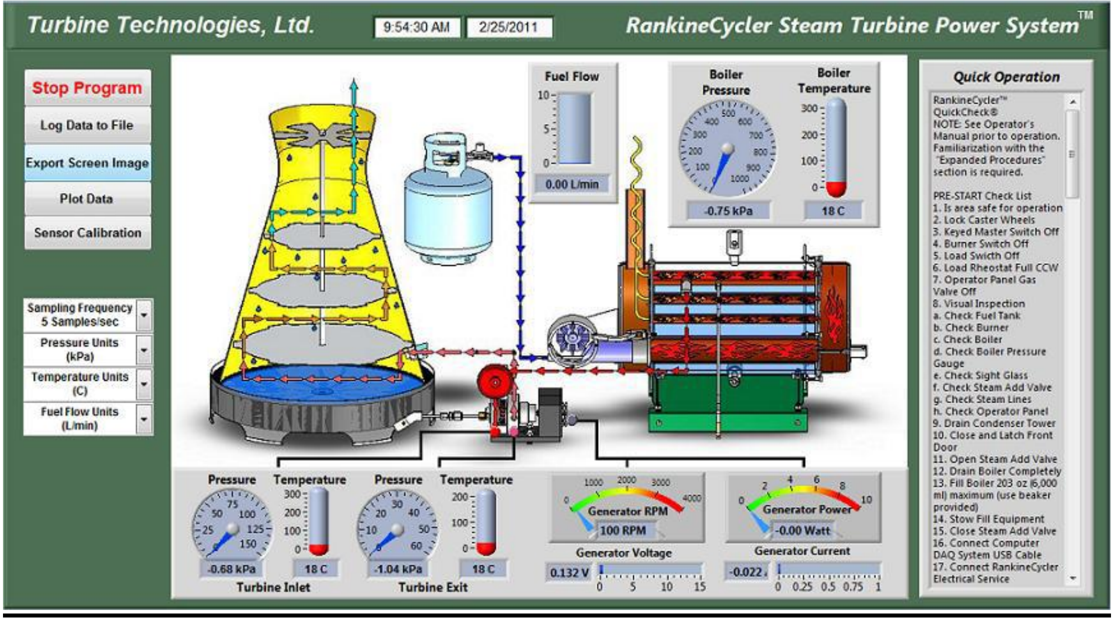
2. Turn the STEAM ADMISSION VALVE to the CLOSED position. SET the SIGHT GLASS LOWER BEZEL to the current, indicated WATER LEVEL. This allows measurement of the boiler water consumed during the experimental run.
3. Select the BURNER SWITCH to OFF. Verify that the RED light is extinguished indicating that no electrical power is available at the burner or the blower. The blower should immediately stop rotating.
4. The OPERATOR PANEL GAS VALVE should be selected OFF.
5. The LOAD RHEOSTAT should be turned FULL COUNTER-CLOCKWISE, resulting in MINIMAL LOAD.
6. The LOAD SWITCH should be selected OFF. And then The MASTER SWITCH should be selected OFF. Verify that the GREEN light is
7. The STEAM ADMISSION VALVE should be turned to the fully OPEN position. This relieves all remaining boiler pressure.
8. The FUEL SOURCE valve should now be turned OFF.

Third: Data ollection

Utilize the data acquisition system to capture the operational values from startup to shut down. Be sure to record the following data during the run:

Steady State Start Time: ________________
Steady State Stop Time: _________________
Initial Boiler Fill Amount: _____________________
Amount of Steady State Run Boiler Water Replaced: _________________
Amount of Condensate Collected from Condenser: __________________

From Windows, OPEN the Rankine Cycle Software by double-clicking on the Rankine cycle 1.0 shortcut icon located on the Windows Desktop. Rankine cycle 1.0 will start with the *Main Display/Control* and *Channel Configuration Window* displayed.



Sampling Frequency 5 Samples/sec
Pressure Units (kPa)
Temperature Units (C)
Fuel Flow Units (L/min)

RankineCycler™ QuickCheck®
NOTE: See Operator's Manual prior to operation. Familiarization with the "Expanded Procedures" section is required.

PRE-START Check List
1. Is area safe for operation
2. Lock Caster Wheels
3. Keyed Master Switch Off
4. Burner Switch Off
5. Load Swicth Off
6. Load Rheostat Full CCW
7. Operator Panel Gas Valve Off
8. Visual Inspection
a. Check Fuel Tank
b. Check Burner
c. Check Boiler
d. Check Boiler Pressure Gauge
e. Check Sight Glass
f. Check Steam Add Valve
g. Check Steam Lines
h. Check Operator Panel
9. Drain Condenser Tower
10. Close and Latch Front Door
11. Open Steam Add Valve
12. Drain Boiler Completely
13. Fill Boiler 203 oz (6,000 ml) maximum (use beaker provided)
14. Stow Fill Equipment
15. Close Steam Add Valve
16. Connect Computer DAQ System USB Cable
17. Connect RankineCycler Electrical Service

Importing Acquisition Data into MS-Excel Spreadsheet

A convenient way to analyze Rankine Cycle performance data is to graph the data points using MS-Excel Spreadsheet. To do this, the ASCII data captured during the lab data acquisition must be imported into Excel.

Open: MS-Excel on computer desktop
Click: File
Click: Open
Click: C-Drive
Click: Users\Public\Public Documents\Rankine

Click: “All Files” under “Files of Type”
Select: The File Name You Assigned in “Log Data to File”
Click: Next (In Text Import Window, Step 1 of 3)
Click: Next (In Text Import Window, Step 2 of 3)
Click: Finish (In Text Import Window, Step 3 of 3)
Your data will now be in spreadsheet form.

Calculations and analysis :

Part I Transient analysis

Purpose: Graphically plot Rankine Cycle Run Data in preparation for system analysis and performance calculations to be conducted.

1. Plot the following, utilizing MS-Excel Spreadsheet Program:
    a. Fuel Flow vs. Time
    b. Boiler Temperature vs. Time
    c. Boiler Pressure vs. Time
    d. Turbine Inlet/Outlet Pressure vs. Time
    e. Turbine Inlet/Outlet Temperature vs. Time
    f. Generator DC Amps Output vs. Time
    g. Generator DC Voltage Output vs. Time
    h. Turbine RPM vs. Time

2. Print out plots and order them as listed.
Mark the steady state start and stop window on each of above plots.

3. Choose and mark an analysis point at a specific time somewhere within the steady state window. This will be the basis for your steady state, steady flow system performance analysis calculations.

Part II Steady State analysis

Purpose: To perform system performance calculations using First Law Energy Conservation Equation for Steady State, Steady Flow Conditions **(SSSF)**. The data for these calculations come from the information plotted and recorded in Lab.
Analyze each component listed (boiler, turbine and condenser) and perform the calculation requested.

1. From your plots (specific time mark) and data collected from system run, please record the following:
Atmospheric Pressure _________________
Initial Boiler Fill Amount _________________
Fuel Flow____________
Boiler Pressure ________________
Boiler Temperature _________________
Turbine Inlet Pressure ________________
Turbine Inlet Temperature _________________
Turbine Outlet Pressure __________________
Turbine Outlet Temperature __________________
Steady State Condensate Amount ________________
Steady State Boiler Water Use ________________

2. Using Steam Tables, gather state data for each point of interest in the system.
3. Show states and cycle on T-v and T-s diagrams, compare with ideal Rankine cycle?

Component	State		Properties			
	T ^{o}C	P	v	h	u	s
Boiler						
Turbine inlet						
Turbine outlet						
Condenser input						
Condenser output						

Component analysis

1. **Boiler (SSSF)**

Calculate heat flow out of boiler. How does this compare with measured LP gas flow to burner? *Assume: No condensate pumped back into boiler, Changes in Kinetic and Potential Energy are negligible.*

2. **Turbine / Generator (SSSF)**

Find the Work rate of the Turbine and Efficiency of Electric Generator.

3. **Condenser (SSSF)**

What is the total heat flow rate out of the system at the condenser?

Assume changes in Potential and Kinetic Energy are negligible.

What is the Condenser Efficiency during SSSF?

4. **Total System Efficiency (SSSF)**

What is the electrical power output verses the fossil-fuel energy input?

Useful equations

LP heating value = 2520 BTU/ft^3 = 43756 kJ/m^3 at 15 ^oC

Steam mass flow rate = boiler water volume consumptionX density/ time

Boiler energy balance

$$\dot{Q}_{BOILER} + \cancelto{0}{\dot{m}_{IN}}\,(h_{IN} + KE_{IN} + PE_{IN}) = \dot{m}_{OUT}\,(h_{OUT} + \cancelto{0}{KE_{OUT}} + \cancelto{0}{PE_{OUT}}) + \cancelto{0}{\dot{W}_{OUT}}$$

NO CONDENSATE RETURN PUMP, ∴ $m_{IN} = 0$

Turbine energy balance

$$\cancelto{0}{\dot{Q}_{turb}} + \dot{m}_{in}\,(h_{in} + \cancelto{0}{KE_{IN}} + \cancelto{0}{PE_{IN}}) = \dot{m}_{OUT}\,(h_{OUT} + \cancelto{0}{KE_{OUT}} + \cancelto{0}{PE_{OUT}}) + \dot{W}_{TURB}$$

- NO HEAT FLOW INTO TURBINE
- $\dot{m}_{IN} = \dot{m}_{OUT}$, Δ KE AND Δ PE ARE NEGLIGIBLE

Condenser energy balance

$$\dot{Q}_{COND} + \dot{m}_{IN}\,(h_{IN} + \cancelto{0}{KE_{IN}} + \cancelto{0}{PE_{IN}}) = \dot{m}_{OUT}\,(h_{OUT} + \cancelto{0}{KE_{OUT}} + \cancelto{0}{PE_{OUT}}) + \cancelto{0}{\dot{W}_{COND}}$$

- WORK IS NOT DONE BY WORKING FLUID IN CONDENSER
- $\dot{m}_{IN} = \dot{m}_{OUT}$

Total system efficiency

System efficiency= Electrical power output/ Thermal energy input

EXPERIMENT No.(2)

FAN TEST

OBJECTIVE :

The objective of this experiments is to test the performance of the fan and to examine the characteristics of different impellers such as radial, forward curved and backward curved blades.

INTRODUCTION :

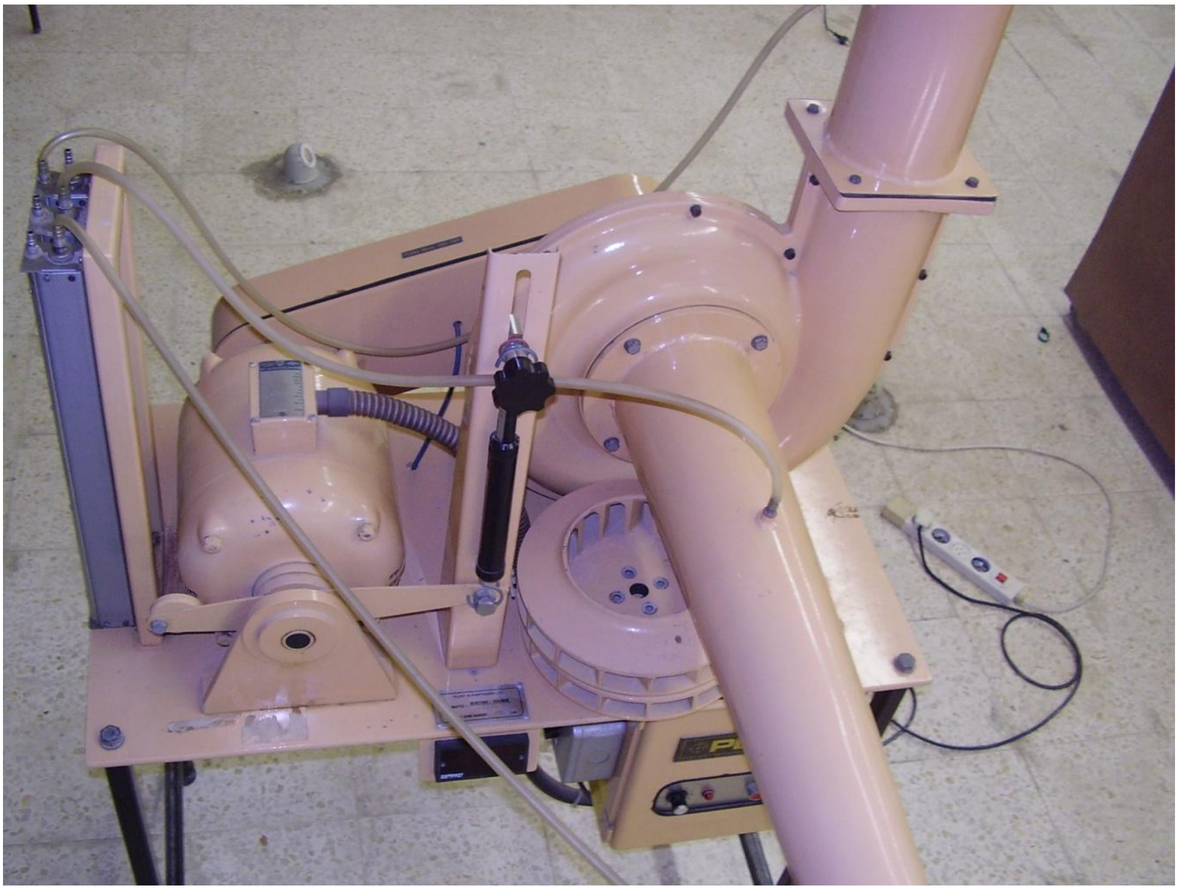


Figure (1) Fan Test Set

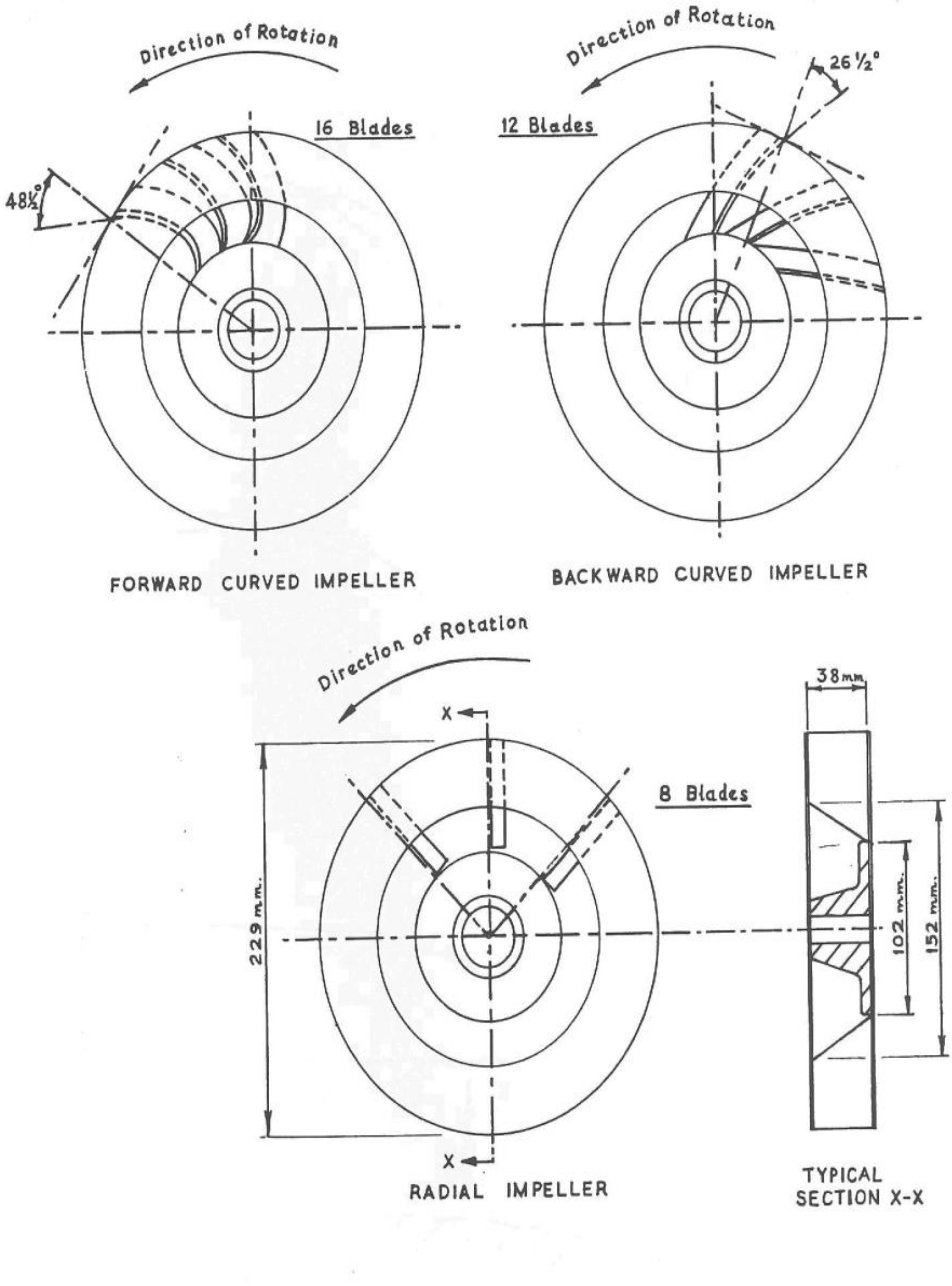


Figure 2: Schematic of impellers.

The fan is belt driven by a 1 hp AC motor. The fan is provided with three interchangeable impellers having respectively radial, forward curved and backward curved blades, (see Figure 2). By using the inlet nozzle as a flow meter the characteristics of the different impellers may be explored.

The fan test set up, shown in Figure 1, is supplied with three single column manometers for measuring the pressure at the throat of the measuring nozzle (h_1), the pressure before the fan (h_2), and the pressure after the fan (h_3).

Using the inlet nozzle in the present set-up as a flow meter, the volumetric flow rate, Q, and the mass flow rate, $\dot{m}$, can be obtained :

Volumetric flow rate :

$$Q = 1.006\sqrt{\frac{\Delta P T}{P_a}} \quad , m^3/s$$

Mass flow rate :

$$\dot{m} = 0.00351\sqrt{\frac{P_a \Delta P}{T}} \quad , kg/s$$

where : ΔP is in cm H_2O
$\Delta P = h_o - h_1$
h_o = atmospheric gage pressure, cm H_2O
h_1 = gage pressure at the throat of the nozzle, cm H_2O
T = absolute temp. of the air, ^oK
P_a = atmospheric pressure, N/m^2

The Fan Total Pressure, P_{fan}, is defined as the difference between the total pressures at the fan outlet, and the fan inlet. In the present apparatus the cross sectional areas at the fan inlet and outlet, at which inlet and outlet pressures are measured, are equal. Therefore, the velocity pressures at inlet and outlet are equal to the difference between the corresponding static pressures, h_3 at the outlet and h_2 at the inlet :

$$P_{fan} = h_3 - h_2 \quad , cm\ H_2O$$

$$P_{fan} = \gamma_{H2O}(h_3 - h_2) \quad , N/m^2$$

The Total Air Power of the fan, TAP_{fan}, or the useful work done, is equal to the product of the Fan Total Pressure, P_{fan}, and the volumetric flow rate; Q

$$TAP_{fan} = P_{fan}\, Q \quad , J/s \equiv Watt$$

The power input from the dynamometer to the shaft, SP, is given by :

$$\text{Shaft Power, } SP = \frac{2\pi r.F.N}{60} \quad , Watt$$

where : r = torque arm radius (m)
F = force (N)
N = speed (RPM)

The impeller Power, IP, is equal to the shaft power, SP, minus the losses in the driving belt and the bearings. These losses can be measured by driving the fan with the impeller removed.

The net fan total efficiency, η_{fan}, is defined as the ratio of the total air power of the fan, TAP_{fan}, to the impeller power, IP :

$$\eta_{fan} = \frac{TAP_{fan}}{IP}$$

EXPERIMENTAL PROCEDURE :

With the forward curved impeller installed.

1. Switch power ON.
2. Adjust the throttle opening at 100%.
3. Adjust the fan speed to a value of 2400 RPM.
4. Balance the motor case.
5. Read and record the following for the entire range of throttle openings: Throttle opening(%), The pressure at the throat of the nozzle (h_1), the fan inlet pressure (h_2), the fan outlet pressure (h_3), Force (F).
6. Switch the power off.
7. Remove the installed impeller (The instructor will show you the proper procedure).
8. With **NO** impeller installed, Adjust the fan speed to 2400 RPM and balance the motor case, Read the shaft force (F).
9. Repeat step 8 for a fan speed of 1200 RPM.
10. Install the radial impeller on the fan.
11. Repeat steps 1, 2, 3, 4, 5, 6 and 7 above.
12. Switch the power off. Remove the radial impeller and replace it with the backward curved impeller.
13. Repeat steps 1, 2, 3, 4, 5, 6 and 7 above.
14. Repeat step 13 for a fan speed of 1200 RPM.
15. Switch the power off.

CALCULATIONS :

A. The losses in the driving belt and the fan bearings.

B. For the three types of impellers :

1. The volumetric flow rate, Q, in m^3/s.
2. The mass flow rate, $\dot{m}$, in kg/s.
3. The fan total pressure, P_{fan}, in N/m^2
4. The total air power of the fan, TAP_{fan}, in Watts.
5. The shaft power, SP, in Watts.
6. The impeller power, IP, in Watts.
7. The net fan total efficiency, η_{fan}.

RESULTS :

A. For the three types of impellers at the fan speed of 2400 RPM.

1. Plot the fan total pressure, P_{fan}, vs. the volumetric flow rate, Q (on one graph). Also, include the theoretical values of the fan total pressure for comparison (see Figure 3).
2. Plot the impeller power, IP, vs. the mass flow rate, $\dot{m}$ (on one graph).
3. Plot the fan efficiency, η_{fan}, vs. the volumetric flow rate, Q (on one graph).

B. For the backward curved impeller blades :

1. On one graph, show the behavior of the total fan pressure, P_{fan}, vs. the volumetric flow rate, Q, for the two different speeds.
2. On one graph, show the impeller power, IP, vs. the mass flow rate, $\dot{m}$, for the different speeds.
3. On one graph, show the fan efficiency, η_{fan}, vs. the volumetric flow rate, Q, for the two different speeds.

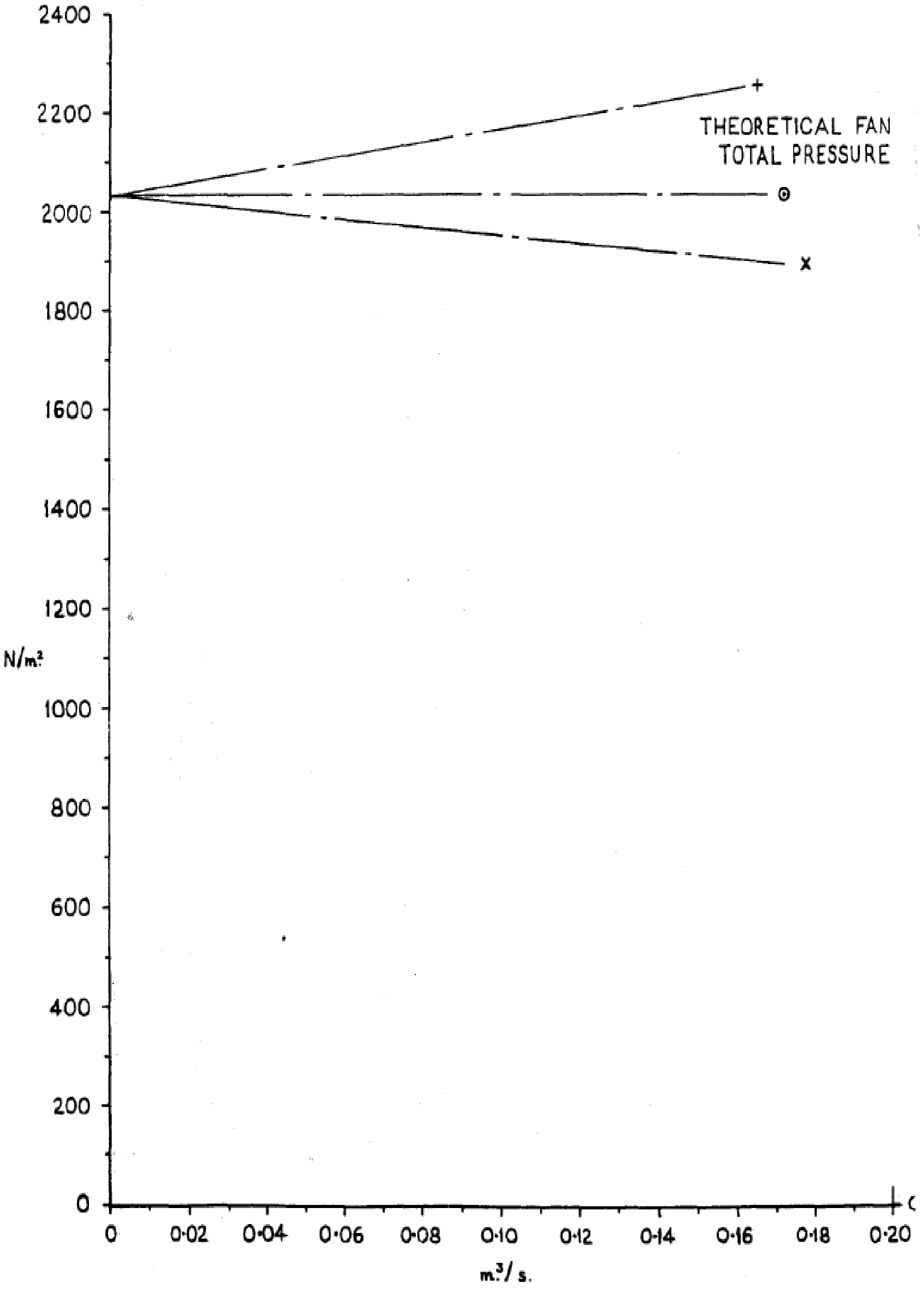


Figure (3) Theoretical Fan Total Pressure

Data Sheet

Forward curved impeller at 2400 RPM

Throttle Opening	**h_1 (mm H_2O)**	**(-) h_2 (mm H_2O)**	**h_3 (mm H_2O)**	**$F_{imp+shaft}$ (N)**
100 %				
90%				
80%				
70%				
60%				
50%				
40%				
30%				
20%				
10%				

Before installing the next impeller measure the Shaft force at;

2400 RPM = _____(N)

1200 RPM = _____(N)

Radial impeller at 2400 RPM

Throttle Opening	**h_1** (mm H_2O)	**(-) h_2** (mm H_2O)	**h_3** (mm H_2O)	**$F_{imp+shaft}$** (N)
100 %				
90%				
80%				
70%				
60%				
50%				
40%				
30%				
20%				
10%				

Backward curved impeller at 2400 RPM

Throttle Opening	h_1 (mm H_2O)	(-) h_2 (mm H_2O)	h_3 (mm H_2O)	$F_{imp+shaft}$ (N)
100 %				
90%				
80%				
70%				
60%				
50%				
40%				
30%				
20%				
10%				

Backward curved impeller at 1200 RPM

Throttle Opening	h_1 (mm H_2O)	(-) h_2 (mm H_2O)	h_3 (mm H_2O)	$F_{imp+shaft}$ (N)
100 %				
90%				
80%				
70%				
60%				
50%				
40%				
30%				
20%				
10%				

EXPERIMENT No.(3)

EXTEDED SURFACE HEAT TRANSFER (FINS)

OBJECTIVE :

- Verify Fourier law of conduction.
- Measure conductivity of metals
- Measure temperature profile along a rod.
- Apply fin theory
- Calculate heat losses from fin rod
- Calculate efficiency of fin
- Apply basic extended surface heat transfer.

APPARATUS DESCRIPTION :

The extended surface heat transfer apparatus comprises a long horizontal rod, which is heated at one end to provide an extended surface (cylindrical rod) for heat transfer measurements. Thermocouples at regular intervals along the rod allow the surface temperature profile to be measured. By making the diameter of the rod small in relation to the length, thermal conduction along the rod can be assumed to be one-dimensional and heat loss from the tip can be ignored.

The assembly consists of the control panel with read outs and control, and the extended surface or the cylindrical rod as shown in Figure (1).

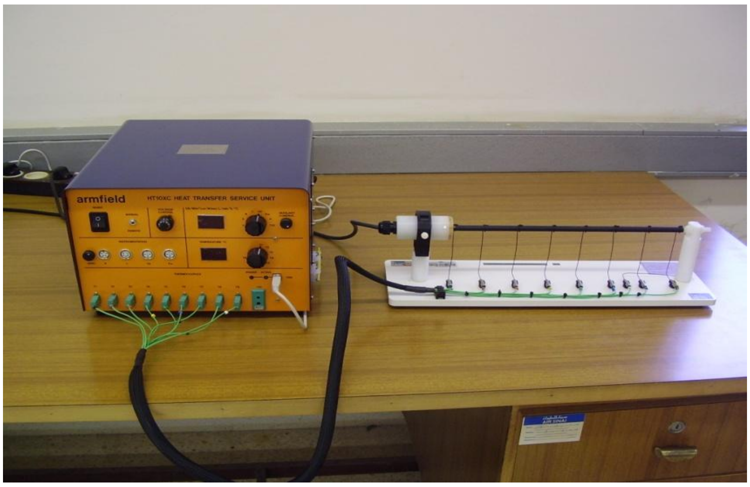


Figure (1) Extended heat transfer apparatus.

Heated rod

The bar is manufactured from a solid brass with a constant diameter of 10 mm and is mounted horizontally with support at the heated end. The bar is coated with black paint which provides a consistent emissivity close to one. The thermal conductivity of the bar is 121 W/m.K.

Heater

The rod is heated by a cartridge electric heating element operating at low voltage and is protected by a thermostat to prevent damage from overheating. The heating element is inserted co-axially into the end of the rod and is rated to produce 20 Watts nominally t 24 Volts DC. The power supplied to the heated rod can be varied and measured on the HT10X.

Thermocouples

Eight thermocouples are attached to the surface of the rod at equal intervals of 50 mm giving an overall instrumented length of 350 mm. Location of each thermocouple is shown in the apparatus. T1 measures the temperature at the hot end of the rod while T9 measures the ambient air temperature. All thermocouples are K type

The heater may be operated manually or remotely using the PC and the software.
For manual operation set the selector switch to the manual position. The voltage supplied to the heater is adjusted using the multi-turn potentiometer from 0 to 24 Volts DC.

The power supplied to the heater is the voltage times the current. Power = IxV Watts.

The temperatures can be read manually by the selecting switch set to the required position and read the value on the panel display. The temperature can be read by the Software and displayed on the mimic diagram of the HT15 software when on the REMOTE operation mode.

EXPERIMENTAL PROCEDURE :

Part one (Manual)

1. Operate on the manual mode
2. Set the voltage control to 20 Volts. When T1 reaches 80 ^{o}C reduce voltage to 9 volts.
3. Record the temperature of all thermocouples.
4. Repeat every five minutes till reaching steady state (when readings of temperatures remain constant).

Part two (Software)

1. Select REMOTE setting, and set the voltage to zero Volts using the control box.
2. From the PC and software click **load** to start the program. Then go into **view** and schematic of rod - temperature. Enter into computer control and click *power on*.
3. From heater control adjust the heater to give 10 volts.
4. Go to **view** then *tables* click **Go** *to* see the temperatures, repeat this every 5 minutes until reaching steady state. Clicking *sample* then *next results*.
5. To view the graph click **view** then **graph**, adjust the *temperature axis*
6. Repeat at another voltage 14 Volts.
7. You can save your results as excel files and copy to the USB

THEORY :

Refer to heat transfer book for convection –conduction systems.

Rectangular or pin (circular) fins have constant cross section area A_c=const=A

$$\Rightarrow \frac{dA_c}{dx} = 0$$

Base temperature T_b=T(x=0)
Fluid temperature T_p
Surface area $A_s = P_x$ or $dA_s = Pdx$
Where P: perimeter, then $\frac{dA_c}{dx} = 0$ and $\frac{dA_s}{dx} = P$ simplifying fin equation

$$\frac{d^2T}{dx^2} - \frac{h}{kA_c}P(T - T\infty) = 0$$

Let $\theta = T - T\infty = T(x) - t\infty \rightarrow \frac{d\theta}{dx} = \frac{dT}{dx}$

$$m^2 = \frac{hP}{A_c K}$$

$$\frac{d^2\theta}{dx^2} - m^2\theta = 0$$

General solution : $\theta(x) = c_1 e^{mx} + c_2 e^{-mx}$

constants c_1 and c_2 evaluated from first B.C at the base (x=0) where $T=T_b$

$T(x=0) = T_b$ and $\theta(x=0) = T_b - T_\infty = -\theta_b$

$$\theta_b = c_1 + c_2$$

Second B.C depends on physical condition at other end.

Case A: convection at the tip (x=0)

$$q_{conv} = q_{const_{x=L}} \Rightarrow hA_c(T_l - T_\infty) = -kA_c \left.\frac{dT}{dx}\right|_{x=L}$$

$$\text{or : } \quad h\theta(L) = -k \left.\frac{d\theta}{dx}\right|_{x=L}$$

Case B: Negligible convection (insulated) tip

$$\left.\frac{d\theta}{dx}\right|_{x=L} = 0$$

Case C: finite temperature at tip $T(x=L) = T_l$ or $\theta(L) = \theta L$

Case D: very long fin $L \to \infty$ $\quad T \to T_\infty \Rightarrow \theta L \to 0$

Apply B-C 2 for case D:

$$\theta_l = 0 = c_1 e^{-\infty} + c_2 e^{\infty} \to c_2 = 0$$

$$\text{B-C 1 : } \quad c_1 + c_2 = \theta_b \Rightarrow c_1 = \theta_b$$

$$\text{Then } \quad \theta = \theta_b e^{-mx}$$

Total heat transfer from fin for case D

$q_f = q_{constatbase}$ from energy balance over entire fin

$$q_f = -kA_c \left.\frac{dT}{dx}\right|_{x=0} = -kA_c \left.\frac{d\theta}{dx}\right|_{x=0}$$

$$q_f = -kA_c\left[-m\theta_b e^{-m(0)}\right] = kA_c m\theta_b = kA_c\sqrt{\frac{hP}{kA_c}}\theta_b$$

$$q_f = \sqrt{hPkA_c}\,\theta_b$$

$$\text{Fin efficiency} = \frac{q_f}{q_{\max}}$$

q_f : Heat lost from fin

$q_{\max}$: Maximum possible heat from fin.

Maximum heat transfer from fin could occur if entire fin is at base temperature, where maximum driving for ΔT exist. Actually $T_{(x)}$ decrease along the fin and $T_{(x)} - T_{\infty}$ is decreasing.

$$\gamma_f = \frac{q_f}{hA_f\theta_b}$$

A_f : is the fin surface area.

Case B: adiabatic fin (no convection at tip)

Temperature distribution along the fin is given as:

$$\frac{(Tx - T9)}{(T1 - T9)} = \frac{\cosh m(L - x)}{\cosh mL}$$

T1 = base temperature, and T9 is the ambient temperature.

The heat transfer from the fin is given as;

$$q_f = \sqrt{hPkA_c}\,\theta_b \tanh(ml)$$

The fin efficiency is given as;

$$\gamma_f = \frac{\sqrt{hPkA_c}\,\theta_b \tanh(ml)}{hA_f\theta_b} = \frac{\sqrt{hPkA_c}\tanh(ml)}{hLP}$$

since $A_f = LP$

$$\gamma_f = \frac{\tanh(ml)}{L\sqrt{\frac{hP}{kA_c}}} = \frac{\tanh(ml)}{mL}$$

Heat transfer from a cylindrical rod:

$$q_{tot} = hA_s(T_s - T_{\infty})$$

Where h is the combined convection and radiation heat transfer., T_{∞} is the ambient air temperature, Ts is the surface temperature. As, is the surface area and is given by πDL.

The combined heat transfer coefficient $h = h_c + h_r$.

Where h_c is the convection heat transfer coefficient and h_r is the radiation heat transfer coefficient.

The convection heat transfer coefficient can be calculated using a simple relationship ;

$$h = 1.32\left(\frac{(Ts - T\infty)}{D}\right)^{0.25}$$

The average heat radiation coefficient is estimated using the relationship;

$$hr = \sigma\varepsilon \frac{(Ts^4 - T\infty^4)}{(Ts - T\infty)}$$

σ= 56.7x10^{-9}W/m^2.K^4
ε = 0.95
D = 0.01 m
L = 0.35 m

ANALYSIS AND CALCULATIONS:

1. In a table list the temperature in all locations (T1 to T9)
2. Plot the values of temperature at the various locations of the rod (T1 to T8).
3. Find the value of **m** in the fin profile. You can find value of **m** for each location by solving the distribution in each location. Then calculate an average value. You may try different values to get closer to the measure profile (starting value m=7.4).
4. Show both experimental and theoretical curves on the same figure.
5. Comment on the shape of the curve.
6. Would doubling the length of the rod double the lost heat from it? Why?
7. Calculate the heat lost from the rod from the power supplied to the rod?
8. Calculate the heat lost from the rod by the conduction at the base (heated end).
9. Estimate the convection and radiation coefficients and the heat transfer from surface at each thermocouple location.
10. Calculate the heat transfer using the theoretical equations for fins given in theory.
11. Compare the value of total heat lost from rod calculated by different methods, and comment on the difference and which one you think gives the best answer? Why?
12. Calculate the fin efficiency and compare it with theoretical values.

Data Sheet

Manual Mode

Time min	T_1 °C at x= 0cm	T_2 °C at x= 5cm	T_3 °C at x= 10cm	T_4 °C at x= 15cm	T_5 °C at x= 20cm	T_6 °C at x= 25cm	T_7 °C at x= 30cm	T_8 °C at x= 35cm	T_9 °C Ambient Temp.	Voltage V	Current I
0											
5											
10											
15											
20											
25											

EXPERIMENT No.(4)

CROSS FLOW HEAT EXCHNAGER

OBJECTIVE :

The objective of this experiment is to determine experimentally the convective heat coefficient of cross flow heat exchanger.

INTRODUCTION :

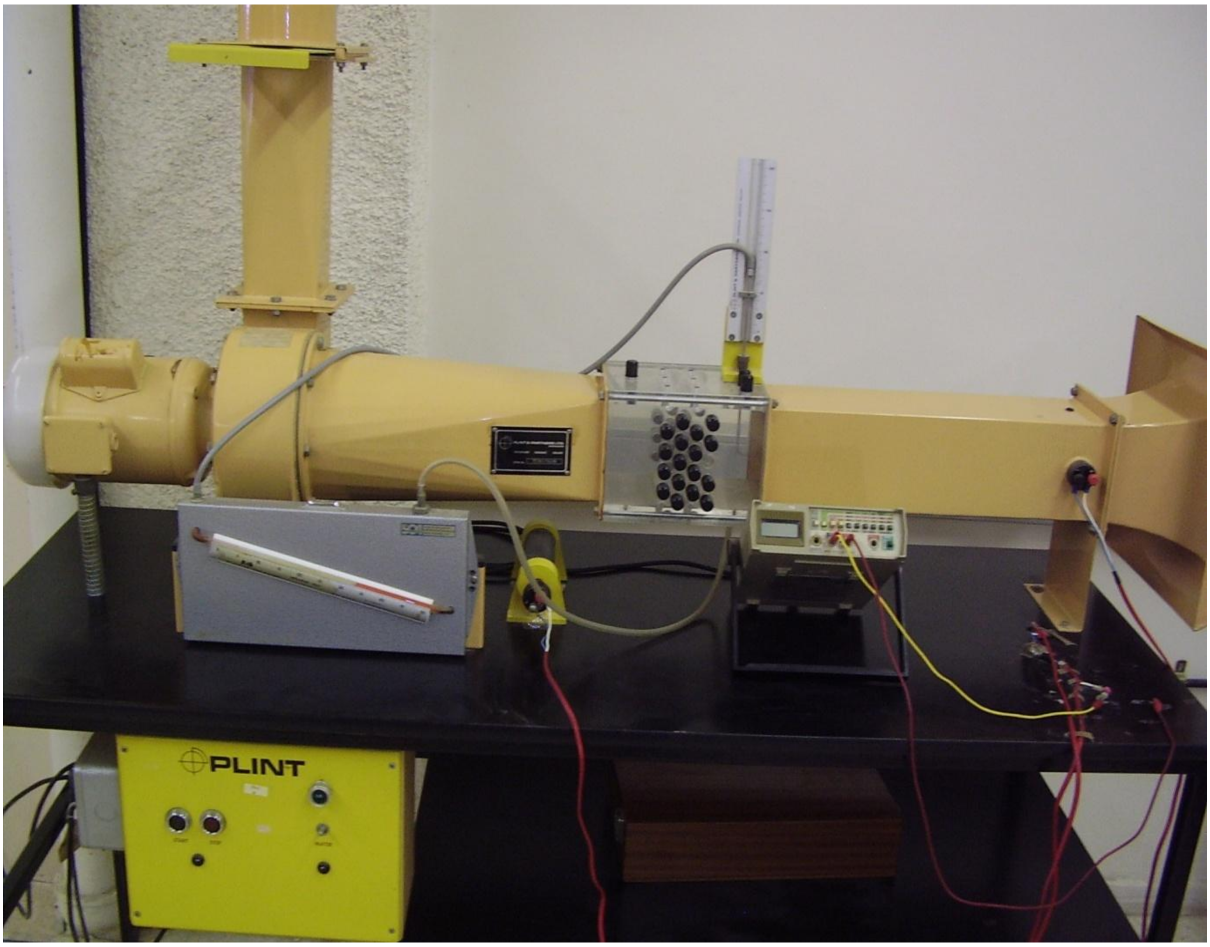


Figure (1) Cross flow heat transfer apparatus

The set-up for this experiment is shown in Figure (1). The apparatus consists of the following :

1. Perspex working section through which air may be drawn by a centrifugal fan.
2. Perspex rods, inserted into the working section with their axes at right angles to the direction of flow.
3. A pure copper rod, 10 cm in length.
4. A cylindrical electrical heater which raises the temperature of element to a maximum of 80°C.
5. Centrifugal fan driven by 1 hp electric motor.
6. The fan discharges to a graduated throttle valve by means of which the air velocity through the apparatus may be regulated.
7. A total head tube to permit exploration of the flow pattern upstream of the tube bank and this may be traversed in a direction perpendicular both to the air flow and to the axes of the element.
8. Static tapping so that the velocity head may be recorded by a manometer.
9. Inclined manometer for measurement of pressure drop and velocity heads.
10. Thermocouples in the element and at the air inlet are of copper and constantan for measurement of temperature difference.

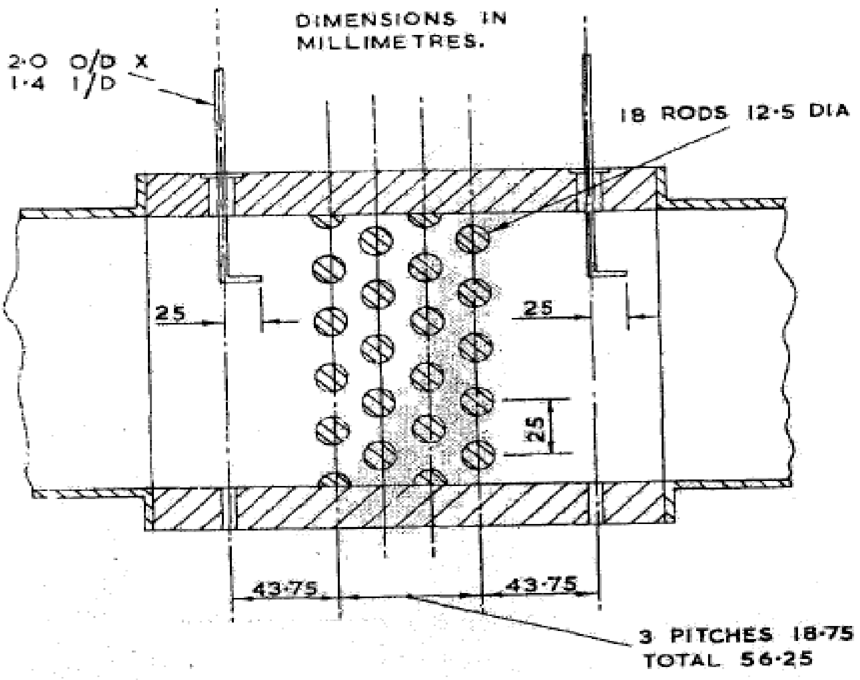


Figure (2) Working section of the cross flow heat exchanger

THEORY :

Assumptions :

1. All of the heat from the cylindrical copper heated element is transferred to the air flowing past it.
2. The temperature gradients within the heated element are negligible, and the thermocouple embedded at the center gives a true indication of the effective surface temperature.

A certain amount of heat is conducted from the heated copper element into the plastic extension pieces. Due to this an addition to the true length of the heated element to give an effective length to be used in the calculations.

$$l_e = l + 0.0084$$

Where : l : length of the copper heated element in m.

l_e : effective length of heated element in m.

Using the lumped capacity system, the following relation can be derived :

$$\ln\left[\frac{T - T_\infty}{T_o - T_\infty}\right] = -mt \quad ----(1)$$

$$where, m = \frac{hA_e}{\rho C V_e}$$

$$m = \frac{h}{\rho C L_s} \quad -----(2)$$

$$where, L_s = \frac{V}{A_e}$$

T : the temp. of the heated element, ^oC.

T_∞ : air temp., ^oC.

T_o : initial temp., ^oC.

t : time, seconds.

h : convective heat transfer coefficient, $\frac{W}{m^2.^o C}$

A_e : effective surface area of heated element, m^2.

r : density of heated element, kg/m^3.

C : specific heat, $J/kg.^oC$

V_e : effective volume of heated element, m^3.

L_s : characteristic length, m

For the lumped capacity system analysis to be valid, the value of the Biot number, Bi : Bi < 0.1

where $Bi = \frac{hL_s}{K}$

K : thermal conductivity of the heated element, W/m. ^oC

Equation (1) represent the equation of a straight line, with a slope of -m. Plotting $\ln\left[\frac{T - T_\infty}{T_o - T_\infty}\right]$ vs. t, the slope of the line can be determined. Once the value of m is known, the convective heat transfer coefficient , h, may be calculated from equation (2).

The velocity, V, in the test section may be determined from the following relation :

$$V = 237.3\sqrt{\frac{H_1 T_\infty}{P_a}} \quad ----(3)$$

Where, H_1 : upstream velocity head, cm H_2O
P_a : atmospheric pressure, N/m^2
T_∞ : absolute temp.

To determine the velocity of the flow in the transverse plane where the heated element is located, the conservation of mass is used :

$$\dot{m}_1 = \dot{m}_2$$
$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$
$$but\, \rho_1 \rho_2$$
$$\therefore V_2 = \frac{A_1}{A_2} V_1$$

Note that, the diameter of the heated element and the Perspex rods is 1.25cm, and the height of the working section is 12.5cm.

Nusselt number, Nu, is a nondimensional heat transfer number and it is defined as :

$$Nu = \frac{hd}{K}$$

Where : h : convective heat transfer coefficient
d : diameter of the heated element
K : thermal conductivity of air

Nusselt number is a function of parameters :

Reynolds number, Re and Prandtl number, Pr

$$\mathrm{Re} = \frac{Vd}{\nu}$$

$$\mathrm{Pr} = \frac{C_p \mu}{K}$$

Where : V : air velocity
d : heated element diameter
ν : kinematic viscosity of air
C_p : specific heat of air
K : thermal conductivity of air
μ : dynamic viscosity of air

EXPERIMENTAL PROCEDURE :

Part A : The heated element in isolation in the center of the front rank :

1. Make sure there is no Perspex rods in the working station.
2. Make sure the throttle opening is closed (0%).
3. Switch the fan on.
4. Insert the copper rod into the cylindrical heater.
5. Switch the cylindrical heater on.
6. When the temp. difference between the copper rod and the air temp. is in between 2.2 ~ 2.4 mV, remove the copper rod from the heater and place it in the center of the front rank.
7. Once the copper rod is in place, read and record the following every 10 seconds until the temp. difference reaches about 0.4 mV : time, t, temp. difference, $\Delta T = T - T_\infty$, air temp., T_∞, the velocity head, H_1.
8. Adjust the throttle opening to 10%.
9. Repeat steps 4, 5, 6 and 7 above.
10. Repeat steps 8 and 9 for throttle openings of 20%, 40%, 60%, 80% and 100%.
11. Switch the fan off.
12. Repeat step 9 above.

Part B : The heated element occupies the center position in the third row of tubes :

1. Fill the first and second ranks with Perspex rods.
2. Fill the third row with Perspex rods except the center position.
3. Repeat steps 4 to 10 from Part A.
4. Switch the heater off.
5. Switch the fan off.
6. Remove the Perspex rods from the working section.

CALCULATION :

For both cases calculate :

1. The slope of the straight line, m, using least square method.
2. Reynolds number, Re.
3. Nusselt number, Nu.
4. The transient heat flow, $\dot{Q}$.
5. Check for lumped capacity system analysis, validity.

RESULTS:

1. For both cases plot $\ln\left[\frac{T-T_\infty}{T_o-T_\infty}\right]$ vs. time. (For the condition of throttle opening of 80% and natural convection).
2. Plot Nusselt number vs. Reynolds number. Both cases on the same graph.
   Note : Include the curves of the following empirical relations for the two cases : case (1) the heated element in isolation in first rank:
   $Nu = 0.24\ (Re)^{0.6}$
   case (2), the heated element in the third row :
   $Nu = 0.3\ (Re)^{0.6}$
3. Plot the transient heat flow vs. time. Both cases on the same graph. (For natural and 80% throttle opening).

Data Sheet

Part 1

Without Perspex rods

	Throttle Opening 100%	Throttle Opening 80%	Throttle Opening 60%	Throttle Opening 40%	Throttle Opening 20%
	Air flow rate ( )mmH_2O	Air flow rate ( )mmH_2O	Air flow rate ( )mmH_2O	Air flow rate ( )mmH_2O	Air flow rate ( )mmH_2O
Time (sec)	**Thermocouple (mV)**	**Thermocouple (mV)**	**Thermocouple (mV)**	**Thermocouple (mV)**	**Thermocouple (mV)**
0					
10					
20					
30					
40					
50					
60					
70					
80					
90					
100					
110					
120					
130					
140					
150					
160					
170					
180					
190					
200					
210					
220					
230					
240					

Part 2

With Perspex rods

	Throttle Opening 100%	**Throttle Opening 80%**	**Throttle Opening 60%**	**Throttle Opening 40%**	**Throttle Opening 20%**
	Air flow rate ( )mmH_2O	**Air flow rate ( )mmH_2O**	**Air flow rate ( )mmH_2O**	**Air flow rate ( )mmH_2O**	**Air flow rate ( )mmH_2O**
Time (sec)	**Thermocouple (mV)**	**Thermocouple (mV)**	**Thermocouple (mV)**	**Thermocouple (mV)**	**Thermocouple (mV)**
0					
10					
20					
30					
40					
50					
60					
70					
80					
90					
100					
110					
120					
130					
140					
150					
160					
170					
180					
190					
200					
210					
220					
230					
240					

Atmospheric Pressure =_______kN/m^2

Ambient Temperature = ______^{o}C

EXPERIMENT No.(5)

HEAT PUMP

OBJECTIVES :

The objective of this experiment is to test the performance of an experimental heat pump, this includes;

- Know components of a vapor compression cycle
- Distinguish cooling and heating modes of heat pump
- Measuring cooling/ heating capacity of the unit
- Measuring COP of the unit
- Investigate effect of heat removal on unit performance
- Determining air properties and the use of psychrometric chart

APPARATUS DESCRIPTION :

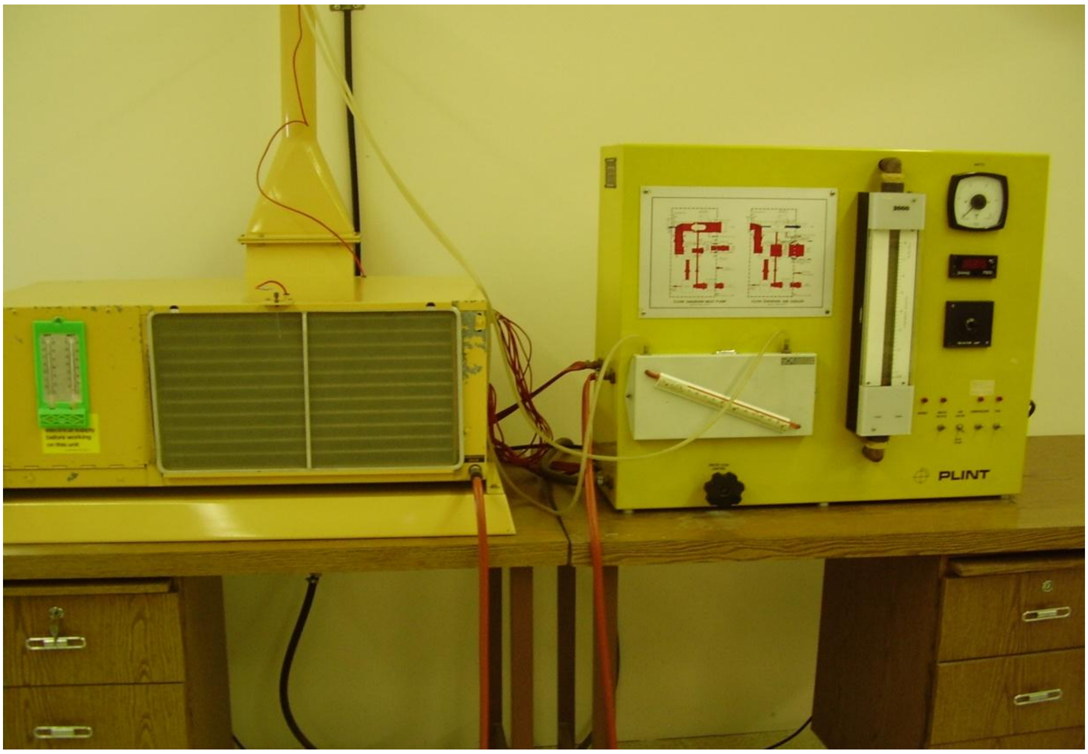


Figure (1) Heat pump unit

EXPERIMENTAL PROCEDURE :

1. Turn on the circulating water and adjust the flow rate to a value of 4 liter/min using Rotameter.
2. Read the inlet circulating water, T_3.
3. If T_3 is less than 10^oC, switch the water heater on.
4. Choose heating to operator as a heat pump.
5. Switch on the compressor and the fan.
6. Note : The wattmeter reading is the total electrical power input to both the fan and the compressor. To get the input power to the individual units, switch off the fan momentarily at which the wattmeter reading is the input power to the compressor.
7. Every 5 minutes, read and record the following : The temperatures T_1, T_2,...,T_{10}, Pitot tube velocity head, H_1, the total input power to the compressor and the fan, E_{total}, the input power to the compressor, E_c.
8. Measure the relative humidity Φ of air entering the unit using the sling hygrometer.
9. When steady state condition is recorded (i.e., the temp. is not changing any more).
10. Adjust the circulating water flow rate to 5 liter/min and wait approximately 5 minutes and then read and record only once all the values you recorded in step 6.
11. Repeat step 9 for circulating water flow rates of 6, 3 and 2.

THEORY :

The notation below is used in the theory explained in this experiment.

Temperatures

T_1	Air at inlet
T_2	Air at discharge
T_3	Circulating water at inlet
T_4	Circulating water at discharge
T_5	Compressor discharge
T_6	Compressor inlet
T_7	Refrigerant-to-water heat exchanger discharge
T_8	Refrigerant-to-water heat exchanger inlet
T_9	Refrigerant-to-air heat exchanger inlet
T_{10}	Refrigerant-to-air heat exchanger discharge

Mass Flow Rates

Dry air	m_1 kg/s
Circulating water	m_3 kg/s

Thermal Quantities

Specific heat of water	C_w J/kg ^oC
Specific heat of air at constant pressure	C_p J/kg ^oC
Specific enthalpy of water vapor	h_v J/kg

Enthalpy Flow Rates

Dry air entering conditioner	Q_1 J/s
Water vapor entering conditioner	Q_2 J/s
Dry air leaving conditioner	Q_3 J/s
Water vapor leaving conditioner	Q_4 J/s
Circulating water at inlet	Q_6 J/s
Circulating water at outlet	Q_7 J/s
Radiation and stray losses	Q_8 J/s

Electrical Input

Refrigerator compressor	E_c W
Fan	E_F W

Psychrometer Data

Relative humidity at inlet	Φ
Density of saturated water vapor at inlet	ρ_W kg/m^3
Density of dry air at inlet	ρ_a kg/m^3
Specific humidity at inlet	γ

Ideal Heat Pump

Power input	W J/s
Input from cold source	q_2 J/s
Output to hot sink	q_1 J/s

The machine is shown schematically in Fig.3, which shows the various energy flows through the system boundary. They are defined as below :
Enthalpy of dry air entering conditioner

$Q_1 = m_1 C_p T_1$

Enthalpy of water vapor entering conditioner

$Q_2 = \gamma m_1 h_v$

Enthalpy of dry air leaving conditioner

$Q_3 = m_1 C_p T_2$

Enthalpy of water vapor leaving conditioner

$Q_4 = \gamma m_1 h_v$

Enthalpy of circulating water at inlet

$Q_6 = m_3 T_3 C_w$

Enthalpy of circulating water at outlet

$Q_7 = m_3 T_4 C_w$

Radiation and stray losses

Q_8

Electrical input to fan

E_F

The Steady flow energy balance for the system :

$$(Q_6 - Q_7) + (E_c + E_F) = (Q_3 + Q_4) - (Q_1 + Q_2) + Q_8$$

The coefficient of performance, COP, may be defined in two different ways :

1. The overall of external coefficient

$$COP_{external} = \frac{(Q_3 + Q_4) - (Q_1 + Q_2)}{(E_c + E_F)}$$

The corresponding ideal value,

$$COP_{external)ideal} = \frac{\frac{1}{2}(T_1 + T_2)}{\frac{1}{2}(T_1 + T_2) - \frac{1}{2}(T_3 + T_4)}$$

2. The internal coefficient :

$$COP_{internal} = \frac{(Q_3 + Q_4) - E_F - (Q_1 + Q_2)}{E_c}$$

The corresponding ideal value,

$$COP_{internal)ideal} = \frac{T_{10}}{T_{10} - T_8}$$

The air flow through the unit is measured using a Pitot-static tube mounted in the center of the discharge duct.

The volumetric flow rate, $\dot{V}$, of air in the duct :

$$\dot{V}=0.3014\sqrt{\frac{H_1T_2}{P_a}}\ m^3/s$$

Where :

H_1 : velocity head in mm H_2O

T_2 : absolute air temp. at discharge

P_a : atmospheric pressure, N/m^2

The mass flow rate, m_1, of air in the duct :

$$m_1=0.00105\sqrt{\frac{H_1P_a}{T_2}}\ kg/s$$

The specific humidity of the air entering the unit :

$$\phi=\frac{\Phi\,\rho_w}{\rho_a}$$

Where :

Φ : relative humidity

ρ_W : density of saturated water vapor entering the unit

ρ_a : density of air entering the unit

When the device is reversible (i.e. operating in Carnot cycle) as shown in Fig.4, which is considered the ideal cycle.

The coefficient of performance of a heat pump, COP_{hp}, is defined as :

$$COP_{hp}=\frac{q_2}{W}$$

Where :

q_2 : is the input from a cold source

W : power input

$$q_2 = (Q_3 + Q_4) - (Q_1 + Q_2)$$

$$W = (W_c + W_F)$$

When the unit is operating in a Carnot cycle (i.e., ideal), the ideal coefficient of performance for heat pump is defined as:

$$COP_{hp)ideal}=\frac{T_2}{T_2-T_3}$$

ANALYSIS AND CALCULATIONS :

1. Plot T2, compressor power versus time, and comment on the curve.
2. Find inlet and exit air specific humidity using equations and psychrometric chart, also find for inlet air the specific volume, and enthalpy.
3. Calculate the volumetric flow rate of air in the duct.
4. Calculate the mass flow rate of air in the duct.
5. Calculate the heat added or removed from air.
6. Calculate the heat from circulating water.
7. Calculate the heat lost to surroundings.
8. Find the actual and ideal of both the overall external and the internal coefficients of performance.

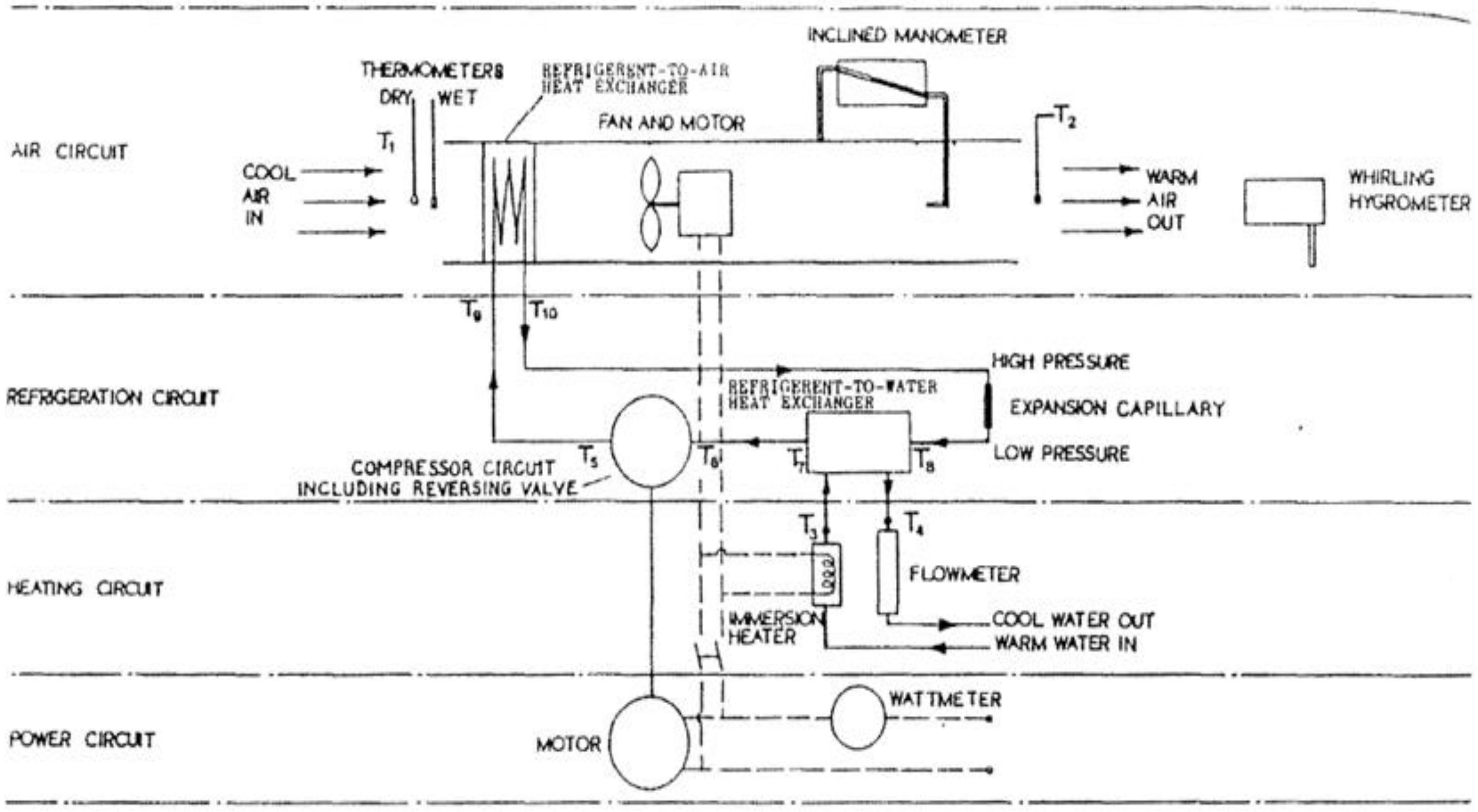


Fig. 2 FLOW DIAGRAM, HEAT PUMP

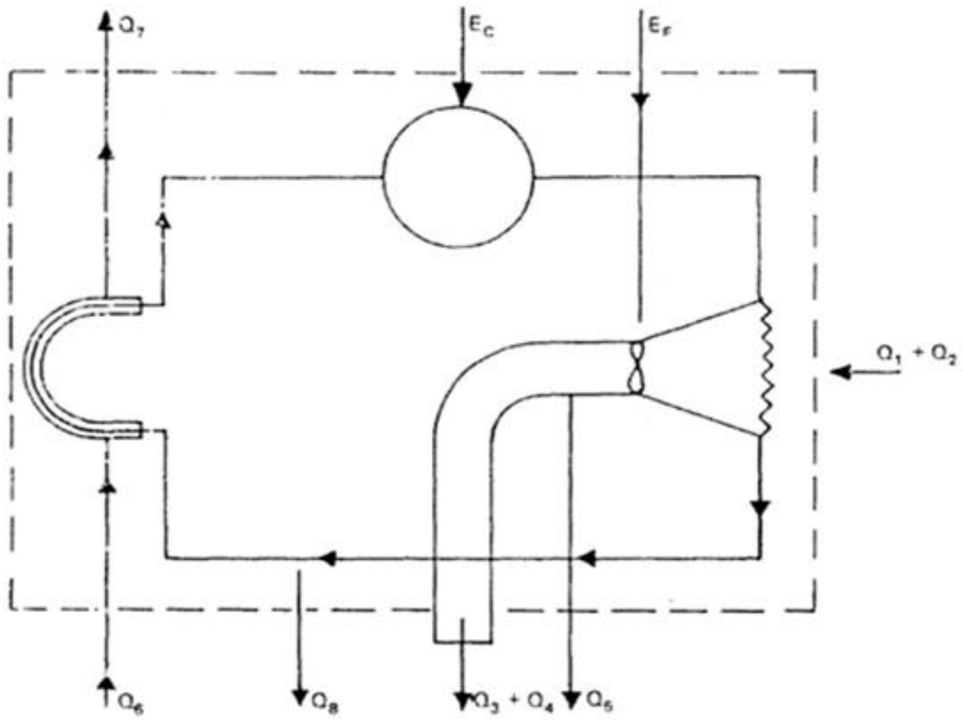


Fig. 3 ENERGY FLOW DIAGRAM

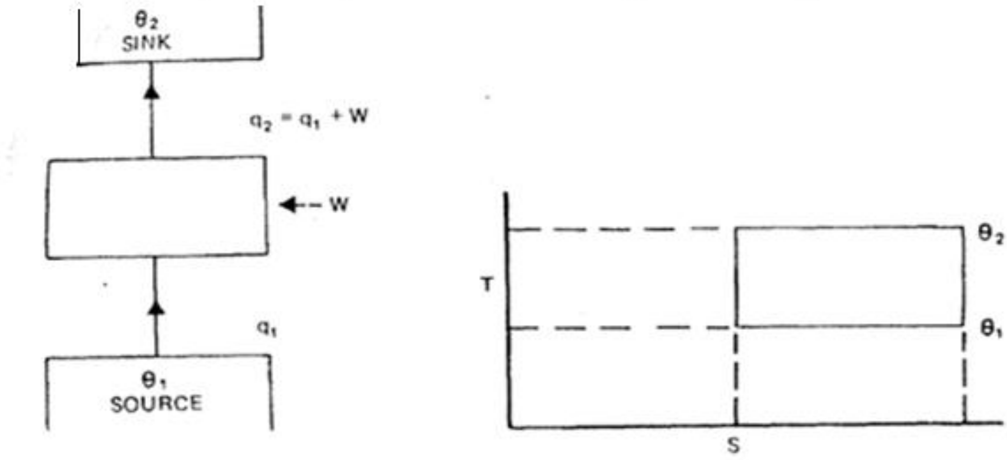


Fig. 4 IDEAL REVERSIBLE ENGINE

DEPRESSION OF WET BULB

DRY BULB READINGS

°C	·5	1·0	1·5	2·0	2·5	3·0	3·5	4·0	4·5	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5	9·0	9·5	10·0	10·5	11·0	11·5	12·0	12·5	13·0	13·5	14·0	14·5	15·0	15·5	16·0	16·5	17·0	17·5	18·0	18·5	19·0	19·5	20·0
+20	96	91	87	83	78	74	70	66	63	59	55	51	48	44	41	37	34	30	27	24	21	18	15	12	9	6	3	0												
21	96	91	87	83	79	75	71	67	64	60	56	52	49	46	42	39	36	32	29	26	23	20	17	14	11	8	6	3	0											
22	96	92	88	83	80	76	72	68	64	61	57	54	50	47	44	40	37	34	31	28	25	22	19	16	13	11	8	5	3	0										
23	96	92	88	84	80	76	72	69	65	62	58	55	51	48	45	42	39	36	33	30	27	24	21	18	16	13	10	8	5	3	0									
24	96	92	88	84	80	77	73	69	66	63	59	56	53	49	46	43	40	37	34	31	28	26	23	20	18	15	12	10	7	5	3	0								
25	96	92	88	84	81	77	74	70	67	63	60	57	54	50	47	44	41	38	36	33	30	27	25	22	19	17	14	12	10	7	5	3	0							
26	96	92	88	85	81	78	74	71	67	64	61	58	55	52	48	46	43	40	37	34	32	29	26	24	21	19	16	14	12	9	7	5	3	0						
27	96	92	89	85	81	78	75	71	68	65	62	59	55	52	50	47	44	41	38	36	33	30	28	25	23	21	18	16	14	11	9	7	5	3	0					
28	96	93	89	85	82	78	75	72	68	65	62	59	56	53	50	48	45	42	40	37	34	32	29	27	25	22	20	18	15	13	11	9	7	5	3	1				
29	96	93	89	86	82	79	76	72	69	66	63	60	57	54	51	49	46	43	41	38	36	33	31	28	26	24	21	19	17	15	13	11	9	7	5	3	0			
30	97	93	89	86	83	79	76	73	70	67	64	61	58	55	52	50	47	44	42	39	37	34	32	30	27	25	23	21	19	17	15	13	11	9	7	5	3	1		
31	97	93	89	86	83	79	77	73	70	67	64	61	59	55	53	50	48	45	43	40	38	35	33	31	29	27	24	22	20	18	16	14	12	10	8	7	5	3	0	
32	97	93	89	86	83	80	77	74	71	68	65	62	60	56	54	51	49	46	44	41	39	37	34	32	30	28	26	24	22	20	18	16	14	12	10	8	7	5	3	1
33	97	93	90	86	84	80	77	74	71	68	66	63	60	58	55	52	50	47	45	42	40	38	36	33	31	29	27	25	23	21	19	17	15	14	12	10	8	7	5	3
34	97	93	90	87	84	80	77	74	71	68	66	64	61	58	56	53	51	47	46	42	41	38	37	34	32	30	28	26	24	22	21	19	17	15	13	12	10	8	7	5
35	97	93	90	87	85	81	78	75	72	69	66	64	61	59	56	54	51	49	47	44	42	40	38	36	33	31	29	27	26	24	22	20	18	16	15	13	11	10	8	7
36	97	93	90	87	85	81	78	75	72	69	67	64	61	59	57	55	52	50	48	45	43	41	39	37	34	32	30	29	27	25	23	21	20	18	16	14	13	11	10	8
37	98	93	91	87	86	82	79	76	73	70	67	65	62	60	58	55	53	51	48	46	44	42	40	38	35	34	32	30	28	26	24	22	21	19	17	16	14	13	11	10
38	98	93	91	88	86	82	79	76	73	70	67	65	62	60	58	56	53	51	48	46	44	42	40	39	37	35	33	31	29	27	25	24	22	20	19	17	16	14	13	11
39	98	94	91	88	86	82	79	76	74	71	68	66	63	61	58	57	54	52	50	48	46	44	42	40	37	35	33	31	30	28	26	25	23	21	20	18	17	15	14	12
40	98	94	91	88	86	82	79	77	74	71	68	66	63	61	59	57	54	52	50	48	46	44	42	40	38	36	34	31	29	28	27	26	24	22	21	20	18	17	15	14
41	98	94	91	88	86	83	79	77	74	72	69	67	64	62	59	57	55	53	51	49	47	45	43	41	38	36	34	32	30	29	28	26	25	23	22	20	19	18	16	15
42	98	94	92	88	86	83	80	78	75	72	69	67	64	62	60	58	56	54	51	49	47	45	44	42	39	37	35	33	31	29	28	27	26	24	22	21	20	19	18	16
43	98	94	92	88	86	83	80	78	75	73	69	68	65	63	60	58	56	54	52	50	48	46	44	43	40	38	36	34	32	30	29	27	27	25	23	22	21	20	19	17
44	98	94	92	88	87	83	80	78	75	73	70	68	65	63	61	59	57	55	53	51	49	47	45	44	41	39	37	35	33	30	29	28	27	25	24	22	22	20	19	18
45	98	94	92	89	87	83	80	78	75	73	70	68	65	64	62	59	57	55	53	51	49	47	45	44	41	39	37	35	33	31	30	28	27	25	24	23	22	21	20	19
46	98	94	92	89	87	84	80	78	75	73	70	68	66	64	62	60	57	56	54	52	50	48	46	44	42	39	37	35	34	31	30	28	27	26	25	24	23	22	21	20
47	98	94	92	89	87	84	81	79	76	74	71	69	66	65	62	60	58	56	54	52	50	49	47	45	42	40	38	36	34	32	31	29	28	27	26	25	24	23	22	21
48	98	94	92	89	87	84	81	79	76	74	71	69	66	65	62	61	58	57	55	53	51	49	47	45	42	40	38	36	34	32	31	30	29	28	27	26	25	24	23	22
49	98	94	92	89	87	84	81	79	76	74	71	70	67	66	63	61	58	57	55	53	51	49	47	45	42	40	38	36	35	34	32	31	30	29	28	27	26	25	24	23
50	99	94	92	89	87	84	81	79	76	74	71	70	67	66	63	62	59	58	56	54	52	50	48	46	43	41	39	37	36	35	34	32	31	30	29	28	27	26	25	24

DEPRESSION OF WET BUL

DRY BULB READINGS

°C	·25	·5	·75	1·0	1·25	1·5	1·75	2·0	2·25	2·5	2·75	3·0	3·25	3·5	3·75	4·0	4·25	4·5	4·75	5·0	5·25	5·5	5·75	6·0	6·25	6·5	6·75	7·0	7·25	7·5	7·75	8·0	8·25	8·5	8·75	9·0	9·25	9·5	9·75	10·0	10·25	10·5	10·75
−5	94	88	83	77	71	66	60	54	49	43	38	32	29	26	23	20																											
4	95	89	84	78	73	67	62	57	51	46	41	36	31	27	24	22	20																										
3	95	89	84	79	74	69	64	59	54	49	44	39	34	29	25	23	21	19																									
2	95	90	85	80	75	70	66	61	56	52	47	42	37	33	28	24	22	19	17																								
1	96	91	86	81	76	72	67	63	58	54	49	45	40	36	32	27	24	21	19	17																							
0	96	91	86	82	78	73	69	65	60	56	52	48	43	39	35	31	27	24	20	18	16																						
+1	96	91	87	83	79	75	71	66	62	58	54	50	46	42	38	34	30	26	22	19	17	15																					
2	96	92	88	84	80	76	72	68	64	60	56	52	49	45	41	37	33	30	26	22	20	17	15																				
3	96	92	88	84	81	77	73	69	66	62	58	54	51	47	44	40	36	33	30	26	23	20	17	15																			
4	96	92	89	85	82	78	74	70	67	63	60	56	53	49	46	42	39	35	32	29	26	23	20	17	15																		
5	97	93	89	86	83	79	75	72	69	65	62	58	55	51	48	45	42	38	35	32	28	24	21	19	17	15	12	10															
6	97	93	90	86	83	79	76	73	70	66	63	60	57	53	50	47	44	41	37	35	32	29	25	23	20	18	16	12	10														
7	97	93	90	87	84	80	77	74	71	67	64	61	59	55	53	49	46	43	40	37	35	31	28	26	23	20	17	14	12	10													
8	97	94	91	87	85	81	78	75	72	69	66	63	60	57	54	51	48	45	42	40	37	34	31	29	26	23	20	18	16	13	11												
9	97	94	91	88	85	82	79	76	73	70	67	64	62	58	56	53	50	47	44	42	39	36	33	31	29	26	23	21	18	16	13	11											
10	97	94	91	88	86	82	79	76	74	71	68	65	63	60	58	54	52	49	46	44	41	39	36	34	31	29	26	24	22	19	16	14	12	10									
11	98	94	91	88	86	83	80	77	75	72	69	66	64	61	58	56	54	51	48	46	43	41	38	36	33	31	28	26	24	22	19	17	15	12	10								
12	98	94	91	89	87	83	80	78	75	73	70	68	65	62	59	57	55	53	50	48	45	43	40	38	35	33	31	29	26	24	22	20	18	16	14	11							
13	98	95	91	89	87	84	81	79	76	74	71	69	66	64	61	59	56	54	51	49	47	45	42	40	37	36	33	31	29	27	24	23	21	18	16	14	12						
14	98	95	92	90	87	84	81	79	77	74	72	70	67	65	62	60	57	56	53	51	49	46	44	42	39	38	35	33	31	29	27	25	23	21	19	17	15	12					
15	98	95	92	90	88	85	82	80	77	75	72	71	68	66	63	61	59	58	54	52	50	48	46	44	41	40	38	36	34	42	29	27	25	23	21	20	18	16	14	12			
16	98	95	92	90	88	85	83	81	78	76	73	71	69	67	65	63	61	58	56	54	52	50	47	46	43	42	39	37	36	34	32	30	28	26	24	22	20	18	16	15	13	11	9
17	98	95	92	90	88	86	83	81	78	77	74	72	70	68	66	64	62	59	57	55	53	51	49	47	45	43	41	39	38	36	33	32	30	28	26	24	22	21	19	17	16	14	12
18	98	95	93	91	89	86	83	82	79	77	75	73	71	69	67	65	63	61	58	56	54	53	50	49	47	45	43	41	39	37	35	34	32	30	28	27	25	23	21	20	18	16	14
19	98	95	93	91	89	86	84	82	80	78	76	74	72	70	67	65	64	62	59	58	56	54	52	50	48	46	44	43	41	39	37	36	34	32	30	29	27	25	23	22	20	19	17

RELATIVE HUMIDITY TABLE

INSTRUCTIONS FOR OBTAINING RELATIVE HUMIDITY WITH WHIRLING PSYCHROMETER

The psychrometer is whirled rapidly for 15 or 20 seconds while held well in front of the body facing into the wind, and shaded in bright sunshine. Then it is stopped and the wet bulb quickly read first. This is repeated until at least two successive readings are within 0.1°. The wet bulb reading is subtracted from the dry bulb reading giving the depression of the wet bulb and the relative humidity obtained from the tables.

DISTILLED WATER ONLY should be used and the muslin wick renewed as soon as it becomes dirty or greasy; as a rough guide: in a smoky town atmosphere after 1 hour's use; in clean air, after 50 hours' use.

TEMPERATURES BELOW FREEZING. If the wet bulb temperature falls below freezing point, but the water remains in the liquid state, no error is caused if the minimum temperature is reached. If, however, ice forms during whirling extra whirling is necessary to lower the temperature to the minimum since on freezing the temperature of the wet bulb is temporarily raised to O°C.

Data Sheet

Transient, ***Water flow rate = 4 L.P.M***

Air flow rate = (   ) mmH$_2$O

Time (min)	Water Flowrate (L.P.M)	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	T_{10} °C	Total Power (KW)	Compressor Power (KW)	Wet Bulb Temp.	Dry Bulb Temp.	Φ
0	4															
5	4															
10	4															
15	4															
20	4															
25	4															
30	4															
35	4															

Steady State,

Air flow rate = (   ) mmH$_2$O

Time (min)	Water Flowrate (L.P.M)	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	T_{10} °C	Total Power (KW)	Compressor Power (KW)	Wet Bulb Temp.	Dry Bulb Temp.	Φ
	5															
	6															
	3															
	2															

EXPERIMENT No.(6)

BOUNDARY LAYER

INTRODUCTION :

It is a fact well established by experiment that when a fluid flows over a solid surface there is no slip at the surface. The fluid in immediate contact with a surface moves with it, the relative velocity increases from zero at the surface to the velocity in the free stream through a layer of fluid which is called the ***Boundary layer.*** see Figure 1.1.

Figure (1) Boundary Layer

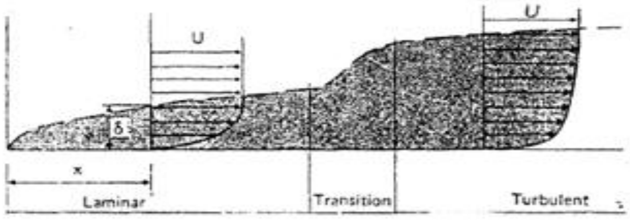


Fig 1.1

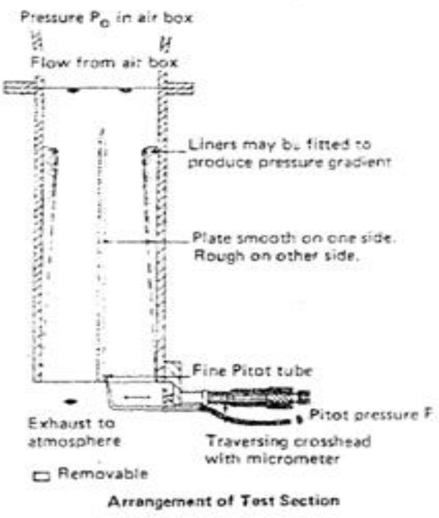


Fig 1.2

THEORY AND DEFINITIONS :

1. Boundary layer thickness (δ) is the thickness where velocity reaches 0.99 of the free stream value .

2. Displacement thickness (δ*) is the thickness by which fluid outside the layer is displaced away from the boundary layer by the existence of the layer.

$$\delta^* = \int_0^\infty (1 - \frac{u}{U})\,dy$$

   Where u is the velocity in the boundary layer, at distance y from the wall. U the free steam velocity.

3. Momentum thickness Θ

$$\Theta = \int_0^\infty \frac{u}{U}(1 - \frac{u}{U})\,dy$$

4. Skin friction coefficient C_f

$$C_f = \frac{\tau_w}{\frac{1}{2}\rho U^2}$$

where τ_w is the surface shear stress.

5. Shape factor H

$$H = \frac{\delta^*}{\Theta}$$

DESCRIPTION OF APPARATUS :

Fig. 1.2 shows the arrangement of the test section attached to the outlet of the contraction of the air flow bench. A flat plate is placed at mid height in the section, with a sharpened edge facing the oncoming flow. One side of the plate is smooth and the other is rough so that by turning the plate over results may be obtained on both types of surfaces.

A fine and a delicate Pitot tube may be traversed through the boundary layer at a section near the downstream edge of the plate. Liners may be placed on the walls of the working section so that either a generally accelerating or generally decelerating free stream may be produced along the length of the plate, depending on which way round they are fitted.

EXPERIMENTAL PROCEDURE :

1. To obtain a boundary layer velocity profile the Pitot tube is set up at enough distance from the surface (where $u = U$) and the desired wind speed is established by bringing the pressure P_o in the air box to the required value.

2. The distance y can be calculated from the micrometer reading, for smooth surface $y = 0.2$ mm for the reading of 15.14 mm and $y = 0.2$ mm for the reading of 16.10 mm on the micrometer for the rough surface. Find δ^*, Θ, H and C_f.

3. Repeat the above procedure with the rough surface. With and without the present of the liner.

- Compare between the results obtained.

DIMENSIONS :

Length of plate from leading edge to traverse section,

$L = 0.265$ m

Thickness of pitot tube at tip,

$2t = 0.4$ mm

Data Sheet

Smooth Surface

y mm	P_{airbox} (P_t) mbar	$P_{Pitottube}$ (P_p) mbar

Rough Surface

y mm	P_{airbox} (P_t) mbar	$P_{Pitottube}$ (P_p) mbar

EXPERIMENT No.(7)

DRAG MEAUSREMENT ON CYLINDRICAL BODIES

INTRODUCTION :

The resistance of a body as it moves through a fluid is of obvious technical importance in hydrodynamics and aerodynamics. This resistance is known as Drag Force (D).

Figure (1) Drag Measurements

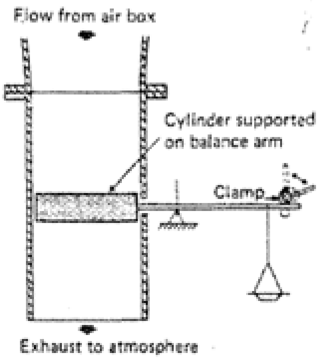


Fig 2.1

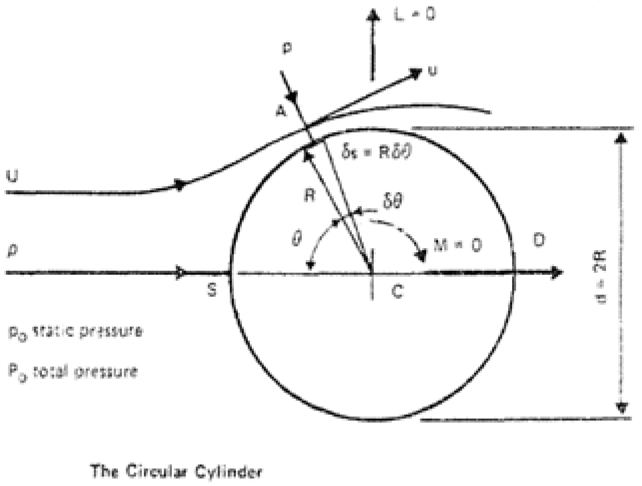


Fig 2.2

In this experiment we place a circular cylinder in an air stream and measure its drag coefficient (C_d)

$$C_d = \frac{D}{\frac{1}{2}\rho U^2 d.L}$$

Where

$$\frac{1}{2}\rho\, U^2 = P_t - P_s = P$$

P_t is the total pressure
P_s is the static pressure
d is the cylinder diameter

Two methods to measure the drag shall be used :-

(A) - Direct Method (Weighing)

A.1 EXPERIEMNTAL PROCEDURE :

1. The equipment is set up with the circular cylinder affixed to the balance and the zero adjusted.
2. The wind speed brought up to the maximum.
3. Weights are added to the scale pan to measure the drag force(It is recommended that the exact balance is found by suitably trimming the wind speed rather than by making slight adjustment to the weight in the weight in the scale pan). see Fig. 2.1.
4. In this way, readings may be obtained at convenient points over the whole range of speed
5. At each wind speed the total pressure P_t and the static pressure P_s at the inlet are recorded.

A.2 QUESTIONS :

- Plot the drag force vs dynamic pressure for circular cylinder.
- Find C_D

(B) Pressure Distribution around the surface

The element of drag force per unit cylinder length, due to normal pressure (P) and the shear stress (τ) is

$$\delta D = (P\cos\theta + \tau\sin\theta)ds$$

Then

$$D = \oint (P\cos\theta + \tau\sin\theta)ds$$

Under the experimental conditions, the shear stress contribution to the drag force is very small compared to that from normal pressure. Hence the drag relation is simplified. In our case the shear stress is very small compared with the normal pressure P and the drag relation comes to the form

$$D = \oint (P\cos\theta)\frac{d}{2}d\theta$$

Where

$$ds = \frac{d}{2}d\theta$$

B.1 EXPERIEMNTAL PROCEDURE :

1. The cylinder is mounted with protractor in place.
2. The wind speed is set at some convenient value near the maximum.
3. The surface pressure P is measured at various settings at the protractor (It is recommended that 5 degrees intervals be used for readings over the front half and 10 degrees intervals for readings over the rear). see fig 2.2
4. The total pressure P_t and static pressure P_S at inlet are observed from time to time and the wind speed readjusted if necessary so that they are kept constant throughout.
5. Calculate the drag coefficient (C_D).

B.2 QUESTIONS :

- Plot C_p vs θ θ ={ $0^o \pm 180^o$ }
- Find C_D

where C_p is the pressure coefficient defined as :

$$C_p = \frac{P}{\frac{1}{2}\rho U^2}$$

\

Data Sheet

Part 1

Direct weighing

Mass (g)	P_{total} (airbox) mbar	P_{in} (inlet) mbar

Part 2

Pressure distribution round cylinder

Angle θ	**P_{total} (airbox) mbar**	**P_{in} (inlet) mbar**	**P_{tube} mbar**
0			
10			
20			
30			
40			
50			
60			
70			
80			
90			
100			
110			
120			
130			
140			
150			
160			
170			
180			
190			
200			
210			
220			
230			
240			
250			
260			
270			
280			
290			
300			
310			
320			
330			
340			
350			
360			

EXPERIEMNT No.(8)

PLATE HEAT EXCHANGER

OBJECTIVE :

- Distinguish types of heat exchangers
- Apply basic heat exchanger theory
- Investigate flow arrangement (co and counter flows)
- Measuring log-mean- temperature difference
- Measuring the overall heat transfer coefficient U -value
- Effect of flow rate on the U-value
- Investigating heat exchanger efficiency.

APPARATUS DESCRIPTION :

The heat exchanger unit consists of a plate heat exchanger, heating reservoir, thermostat to control the hot water temperature, thermocouples that measure temperature of flowing liquid, a flow meter sensors and the data acquisition system, Figure (1) shows the unit.

The connecting hoses can be easily unlocked and connected to the exchanger allowing easy change of flow arrangement form co current to counter current flow.

Figure (1) Plate Heat Exchanger

EXPERIEMNTAL PROCEDURE :

Priming:

1. To prime the hot and cold water circuits connect the heat exchanger hot water inlet (appropriate flexible tube with red collar) to the quick release cold water outlet connector (blue collar with arrow pointing left) at the rear of HT30X.
2. Connect the heat exchanger hot water outlet (appropriate flexible tube with red collar) to the quick release hot water inlet connector on HT30X (red collar with arrow pointing right at the front of HT30X.
3. To prime the hot water circuit first ensure the bypass valve in the hot water circuit is fully closed (right-hand valve with black handle 90 degree to valve body).
4. Ensure that the cold water pressure regulator is set to minimum pressure (pull the grey knob upwards – towards the right – the turn the knob fully anticlockwise, looking at the end of the knob).
5. Open the cold water pressure regulator valve fully (left-hand valve with black handle in line with valve body). Gradually adjust the pressure regulator by turning the grey knob clockwise until cold water is heard / seen to flow steadily through the flexible tubing of the hot water circuit.
6. wait until water flows in to the clear plastic priming vessel and all air bubbles have been expelled from flexible tubing. ***Note:*** water will flow from the hot water outlet connector at the front of HT30X before priming is complete, this is normal and the water will drain in the central canal.
7. When the system has primed, close the cold water flow control valve (left hand valve with black handle at 90 degrees to valve body).
8. Disconnect the flexible tube (to the heat exchanger) from the cold water outlet connector (blue collar with arrow pointing left) then reconnect the same flexible tube to the hot water outlet connector (red collar with arrow pointing left).
9. Fill the clear plastic priming vessel with clean water to the level of over flow the replace the lid on vessel.
10. Switch on the hot water circulating pump. Any remaining air bubbles will be expelled via the priming vessel. Open and close the hot water bypass valve (right-hand valve with black handle) several times until no air bubbles are seen traveling along the flexible tubing. If the level falls below mid height in priming vessel the it will be necessary to top it up with clean water.
11. Reconnect as in Figure (1).

Cocurrent

1. Close the cold water flow control valve V_{cold} the reverse the cold water connections to the shell of the heat exchanger. Note : the connection to the heat exchanger are now configured for cocurrent operation where the hot and cold water fluid streams flow in the same direction across the heat transfer surface (the two fluid streams enter the heat exchanger at the same end). See figure 2.
2. Open the cold water control valve V_{cold} and adjust it to give a reading of 1 liter/min (hot and cold water flow rates the same as before).
3. when the temperature are stable record the following: T_1,T_2, T_3, T_4, F_{hot}, F_{cold}.
4. Check the cold fluid flow rate by collecting certain amount of water in graduated cylinder and dividing by the time it took to collect this amount of water.
5. Repeat for another 4 flow rates of the hot/cold water.

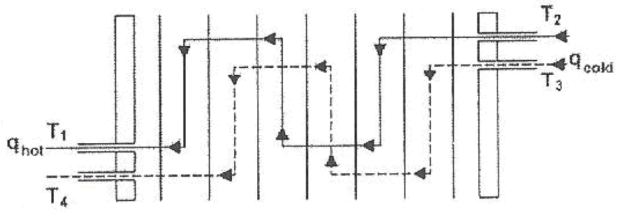
Counter current

1. Set the temperature controller to a set point approximately 45°C above the cold water inlet temperature (T_4) . (e.g If T_3 = 15°C the set controller to 60°C, then switch the hot water circulator.
2. Set the flow indicator switch to F_{cold} then adjust the cold control valve V_{cold} (not the pressure regulator $V_{reg)}$ to give 1 liter/min.
3. Set the flow water indictor switch to F_{hot} then adjust the hot water control valve V_{hot} to give 2 liters/min.
4. Allow the temperature to stabilize (monitor the temperature using the switch / temperature meter).
5. When the temperature are stable record the following: T_1, T_2, T_3, T_4, F_{hot}, F_{cold}.
6. Repeat experiment for another 4 flow rates of hot/cold water.

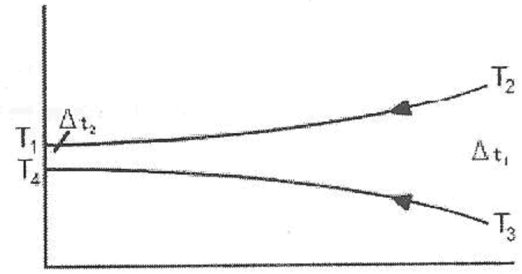
THEORY :

When the heat exchanger is connected for countercurrent operation the hot cold fluid streams flow in opposite directions across the heat transfer surface (the two fluid streams enter the heat exchanger at opposite ends). Figures 2 and 3 are showing the co-current and counter-current arrangements and their temperature profiles.

The hot fluid passes through the seven tubes in parallel, the cold fluid passes across the tubes three times, directed by the baffles inside the shell.

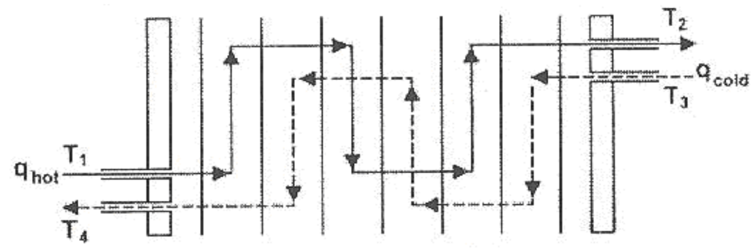


Cocurrent diagram

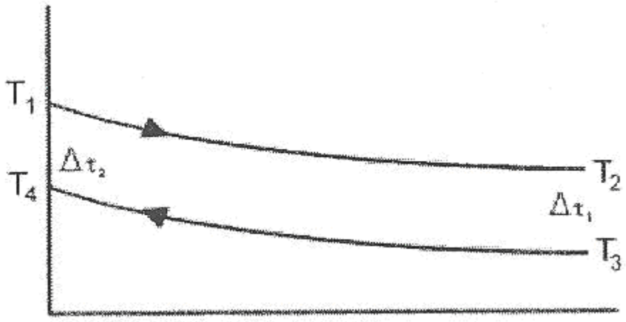


Cocurrent

Figure 2: Co-current arrangement and its temperature profile.



Countercurrent Diagram



Countercurrent

Figure 3: Countercurrent arrangement and its temperature profiles.

Because the temperature difference between the hot and the cold fluid streams varies along the length of the heat exchanger it is necessary to derive an average temperature difference (driving force) from which the heat transfer calculations can be performed. This average temperature difference is called the Logarithmic Mean Temperature Difference (LMTD) Δt_{1m}

Where
(LMTD) $\Delta t_{1m} = [(\Delta t_1 - \Delta t_2) / \ln (\Delta t_1 / \Delta t_2)]$
And
$\Delta t_1 = (T_1 - T_4)$, $\Delta t_2 = (T_2 - T_3)$ (^oC)

Note this equation cannot produce any results for the case where $\Delta t_1 = \Delta t_2$

(LMTD)

$$\Delta t_{1m} = [(T_1 - T_4) - (T_2 - T_3)] / \ln[(T_1 - T_4) / (T_2 - T_3)] \quad (^oC)$$

In this experiment the equation for LMTD is the same for both countercurrent and cocurrent operation because the temperature measurement points are fixed on the exchanger. Two different equations will result if the temperature points are related to the fluid inlets and outlets.

Heat transfer in the exchanger is given by the equation;

$$Q = UA\,F\,\Delta t_{1m}$$

Where U is the overall heat transfer coefficient
A area of heat exchange
F correction factor for shell in tube equals 0.95
Δt_{1m} is the log –mean temperature – difference.

The heat exchange area for the shell and tube exchanger must be calculated using the arithmetic mean diameter of the inner tubes.

Arithmetic mean diameter (m) $d_m = (d_o + d_i) / 2$
Heat transmission length (m) $L = n \,.\, s$

Where
n = number of tubes = 7
s = heat transmission length of each tube (m) = 0.144
L = 1.008

Heat transmission area $A = \pi \,.\, d_m \,.\, L$ (m^2)

For plate heat exchanger the total area of all plates is 0.4 m^2

Also the heat exchanged can be calculated based on the heat lost by the hot fluid or the heat gained by cold fluid as

$$Q = mC(Tout - Tin)$$

It is known that's the reduction in the hot fluid temperature

$$T_{hot} = T_1 - T_2 \ (^oC)$$

And the increase in the cold fluid temperature

$$T_{cold} = T_4 - T_3 \ (^oC)$$

And the heat power emitted from fluid

$$Q_e = m_h \ . \ (Cp)_h \ (T_1 - T_2) \ \text{(in Watt)}$$

Where:

Hot fluid inlet temperature	T_1	(^oC)
Hot fluid outlet temperature	T_2	(^oC)
Cold fluid inlet temperature	T_3	(^oC)
Cold fluid outlet temperature	T_4	(^oC)
Hot fluid volume flow rate	V_{ho}	
Specific heat for hot fluid		$(Cp)_h$ (kJ/kg ^oK) from table 1
Mass flow rate (hot fluid)		m_h (kg/s)

A useful measure of the heat exchanger performance is temperature efficiency of each fluid stream, the temperature change in each fluid stream is compared with the maximum temperature difference between the two fluid streams given a comparison with an exchanger of infinity size.

Temperature efficiency for hot fluid

$$\eta_h = [(T_1 - T_2) / (T_1 - T_3)] \times 100 \qquad (\%)$$

Temperature efficiency for cold fluid

$$\eta_c = [(T_4 - T_3) / (T_1 - T_3)] \times 100 \qquad (\%)$$

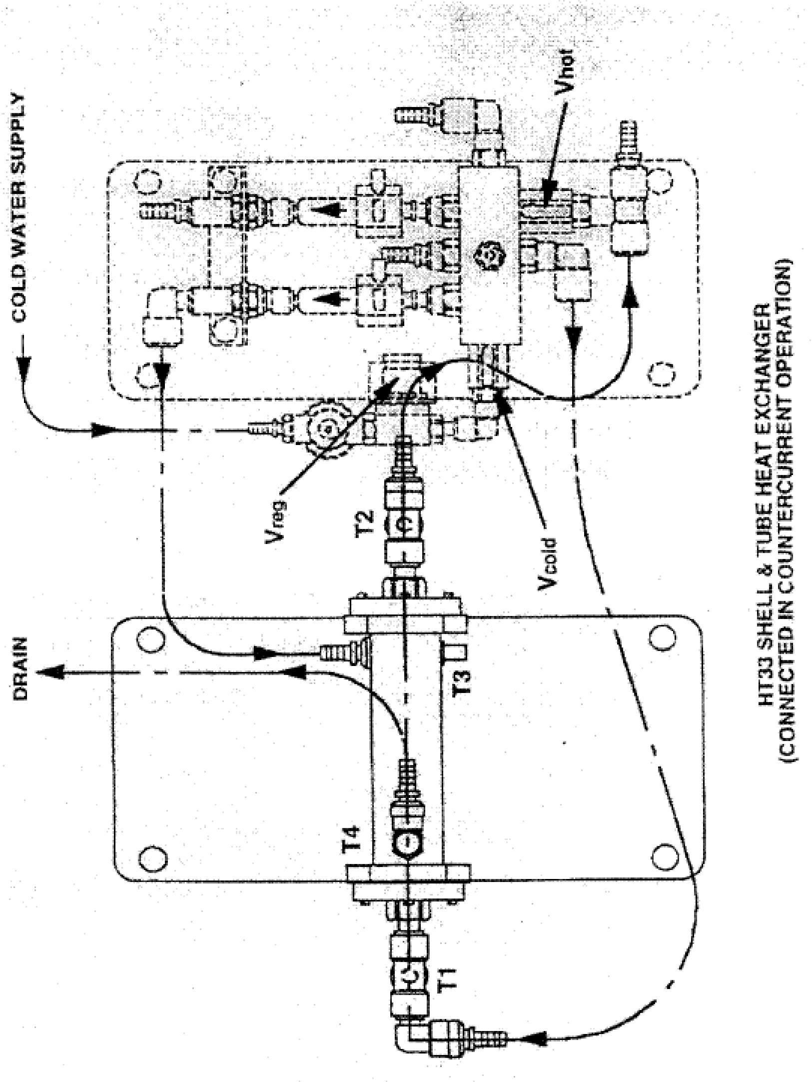
Mean temperature efficiency

$$\eta_m = (\eta_h + \eta_c) / 2 \qquad (\%)$$

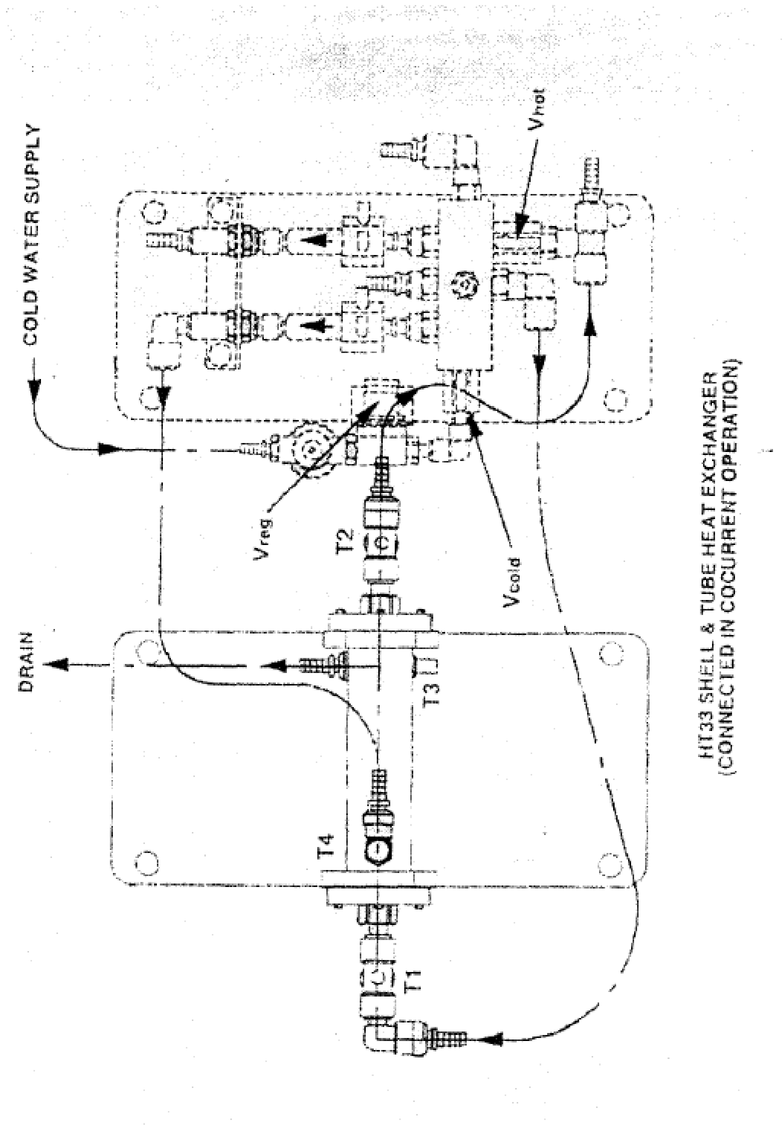
ANALYSIS AND CALCULATIONS :

1. In a table present your results as flow rates of hot and cold fluids, temperatures of all streams, for both cases co and counter current arrangements.
2. Calculate the log mean temperature differences, the overall heat transfer coefficient, U.
3. Calculate the hot fluid, cold fluid, and average efficiencies for all runs.
4. Plot efficiencies versus cold /hot fluid flow rates, comment on results.
5. Plot U –value versus cold/hot fluid flow rates, comment on results.
6. Discuss the difference between the co and the counter current arrangements.

Appendix :



fig(1)



HT33 SHELL & TUBE HEAT EXCHANGER
(CONNECTED IN COCURRENT OPERATION)

fig (2)

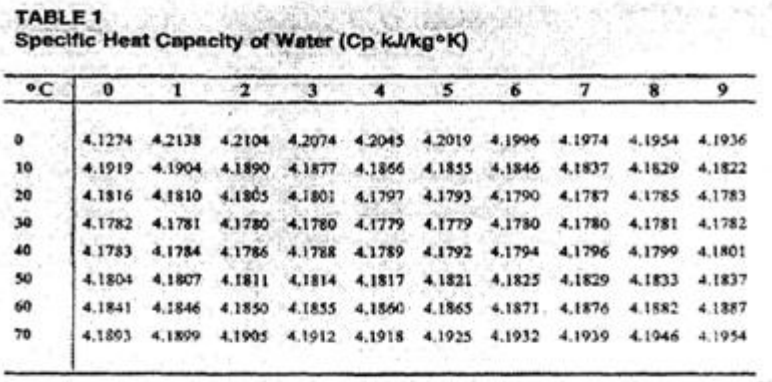


TABLE 1
Specific Heat Capacity of Water (Cp kJ/kg°K)

°C	0	1	2	3	4	5	6	7	8	9
0	4.1274	4.2138	4.2104	4.2074	4.2045	4.2019	4.1996	4.1974	4.1954	4.1936
10	4.1919	4.1904	4.1890	4.1877	4.1866	4.1855	4.1846	4.1837	4.1829	4.1822
20	4.1816	4.1810	4.1805	4.1801	4.1797	4.1793	4.1790	4.1787	4.1785	4.1783
30	4.1782	4.1781	4.1780	4.1780	4.1779	4.1779	4.1780	4.1780	4.1781	4.1782
40	4.1783	4.1784	4.1786	4.1788	4.1789	4.1792	4.1794	4.1796	4.1799	4.1801
50	4.1804	4.1807	4.1811	4.1814	4.1817	4.1821	4.1825	4.1829	4.1833	4.1837
60	4.1841	4.1846	4.1850	4.1855	4.1860	4.1865	4.1871	4.1876	4.1882	4.1887
70	4.1893	4.1899	4.1905	4.1912	4.1918	4.1925	4.1932	4.1939	4.1946	4.1954

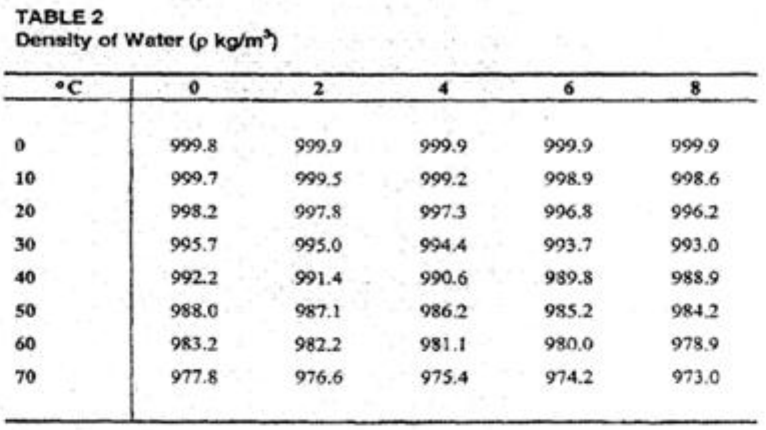


TABLE 2
Density of Water (ρ kg/m³)

°C	0	2	4	6	8
0	999.8	999.9	999.9	999.9	999.9
10	999.7	999.5	999.2	998.9	998.6
20	998.2	997.8	997.3	996.8	996.2
30	995.7	995.0	994.4	993.7	993.0
40	992.2	991.4	990.6	989.8	988.9
50	988.0	987.1	986.2	985.2	984.2
60	983.2	982.2	981.1	980.0	978.9
70	977.8	976.6	975.4	974.2	973.0

Data Sheet

Counter-Current

Hot Water Flow rate	T_1 Hot IN	T_2 Hot OUT	T_3 Cold IN	T_4 Cold OUT

Co-Current

Hot Water Flow rate	T_1 Hot OUT	T_2 Hot IN	T_3 Cold IN	T_4 Cold OUT

For both Counter-Current and Co-Current,
Cold Water Flow rate, ***1L = ____sec.***

EXPERIMENT No.(9)

CHARACTERISTICS OF RADIAL MACHINES PARALLEL AND SERIES

INTRODUCTION :

Pumps are mechanical devices that impart energy to fluid . Pumps lift water from one elevation to a highest level, overcome friction and minor losses during the conveyance and add pressure head to the outlet. Pumps use mechanical energy generated from diesel, gasoline or electric motors to increase the pressure and the velocity head of water.

Centrifugal pumps use centrifugal force imparted to the fluid by one or more rotating elements called impellers to increase the kinetic energy and the pressure energy of the fluid. these pumps have low specific speeds and are normally used in pumping domestic and irrigation water.

A centrifugal pump consists basically of three components : an inlet duct, a set of rotating vanes called impellers, enclosed within a stationary housing called casing.

Figure (1) Radial Pumps

Water is forced through the center of the impeller by atmospheric or other pressure and set into rotation by impeller vanes. The resulting force accelerates the fluid outward between the vanes until its thrown from the periphery of the impeller into the casing. The casing collects the fluid, converts part of its velocity head into pressure head by increasing the cross sectional area of flow and directs the flow to the pump outlet.

EXPERIMENTAL PROCEDURE :

The system consists of Pump(1)(The large pump), Pump(2)(The small pump), Piping and a system of valves to control the path of flow : i.e. To operate a single pump or two pumps in parallel or in series according to the following table:

Valve No.

Operation	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Pump (1) only	o	o*	●	●	●	●	●
Pump (2) only	●	●	o	o*	●	●	●
Parallel operation	o	o*	o	●	●	●	o
Series operation	o	●	●	o*	o	●	●

o = valve open
● = valve closed
o* = controlling valve

Pressures:

P_1	Pump (1) Inlet Pressure	m H_2O	
P_2	Pump (1) Outlet Pressure	m H_2O	
P_3	Combined Outlet Pressure	m H_2O	(Parallel)
P_4	Pump (2) Inlet Pressure	m H_2O	
P_5	Pump (2) Outlet Pressure	m H_2O	
P_6	Combined Outlet Pressure	m H_2O	(Series)

Speeds:

N_1	Pump (1) speed rpm
N_2	Pump (2) speed rpm

Torque arm force:

F_1	Pump (1) N.
F_2	Pump (2) N.

Heads:

$H_1 = P_2 - P_1$ m H_2O (Pump (1))

$H_2 = P_5 - P_4$ m H_2O (Pump (2))

H parallel = P_3 m H_2O
H series = P_6 m H_2O

1 bar = 10.194 m H_2O

1. Operate the system parallel or series at speed N_1 rpm. Record the Torque arm Force F_1, F_2 of the spring after balancing it with the motor Torque, P_1, P_2, P_3, Q_1, Q_2, P_4, P_5, P_6, Voltage and current.

2. Change the flow rate by the control valve, and by using the speed controller keeping the same N_1 rpm.

3. Repeat this several times by changing Q and maintaining the same N_1.

4. Repeat the previous procedure using another speed N_2, four times increasing (decreasing) for the same mode of operation.

RESULTS :

1. Draw Pump pressure rise vs Q [H-Q]

$P_2 - P_1$ vs Q_1
$P_5 - P_4$ vs Q_2
for 2 RPM

3. Draw the efficiency curve on the same H-Q graph and show the design point comment on the efficiency variation.

For ***Parallel operation*** the efficiency of Pump (1),

$$\eta_1 = \frac{\rho g Q_1 \Delta H}{T_1 \omega} \qquad \Delta H = (P_2 - P_1)$$

and for Pump (2)

$$\eta_2 = \frac{\rho g Q_2 \Delta H}{T_2 \omega} \qquad \Delta H = (P_5 - P_4)$$

For ***Series operation*** the efficiency of Pump (1),

$$\eta_1 = \frac{\rho g Q_2 \Delta H}{T_1 \omega} \qquad \Delta H = (P_2 - P_1)$$

and for Pump (2)

$$\eta_2 = \frac{\rho g Q_2 \Delta H}{T_2 \omega} \qquad \Delta H = (P_5 - P_4)$$

T = Torque = F × L (Nm).
L , being the force arm = 0.165 m.
ω , the angular velocity = 2π N / 60 (rad/s).

3. Draw system pressure P_3 for parallel and P_6 for series vs Q

Q parallel = $Q_1 + Q_2$
Q series = Q_2

4. Calculate the value of the specific speed

$$N_s = \frac{N\sqrt{Q}}{(gH)^{3/4}}$$

5. Draw the mechanical and electrical power vs. RPM for each pump.

Mechanical power = $T.\omega$
Electrical power = V.A

Data Sheet

Radial Pumps

Parallel Operation

Pump 1

RPM = 3000

Run	**P_1 (bar)**	**P_2 (bar)**	**P_3 (bar)**	**Q_1 (L.P.S)**	**V_1**	**A_1**	**F_1 (N)**
1							
2							
3							
4							
5							

RPM = 2500

Run	**P_1 (bar)**	**P_2 (bar)**	**P_3 (bar)**	**Q_1 (L.P.S)**	**V_1**	**A_1**	**F_1 (N)**
1							
2							
3							
4							
5							

Radial Pumps

Parallel Operation

Pump 2

RPM = 3000

Run	P_4 (bar)	P_5 (bar)	P_6 (bar)	Q_2 (L.P.S)	V_2	A_2	F_2 (N)	F_3 (N)
1								
2								
3								
4								
5								

RPM = 2500

Run	P_4 (bar)	P_5 (bar)	P_6 (bar)	Q_2 (L.P.S)	V_2	A_2	F_2 (N)	F_3 (N)
1								
2								
3								
4								
5								

Radial Pumps

Series Operation

Pump 1

RPM = 3000

Run	**P_1 (bar)**	**P_2 (bar)**	**P_3 (bar)**	**Q_1 (L.P.S)**	**V_1**	**A_1**	**F_1 (N)**
1							
2							
3							
4							
5							

RPM = 2500

Run	**P_1 (bar)**	**P_2 (bar)**	**P_3 (bar)**	**Q_1 (L.P.S)**	**V_1**	**A_1**	**F_1 (N)**
1							
2							
3							
4							
5							

Radial Pumps

Series Operation

Pump 2

RPM = 3000

Run	**P_4 (bar)**	**P_5 (bar)**	**P_6 (bar)**	**Q_2 (L.P.S)**	**V_2**	**A_2**	**F_2 (N)**	**F_3 (N)**
1								
2								
3								
4								
5								

RPM = 2500

Run	**P_4 (bar)**	**P_5 (bar)**	**P_6 (bar)**	**Q_2 (L.P.S)**	**V_2**	**A_2**	**F_2 (N)**	**F_3 (N)**
1								
2								
3								
4								
5								