Department of Mechanical Engineering

Faculty of Engineering, Computing, and the Environment

Thermodynamics and Fluid Mechanics

PRACTICAL BOOKLET

Key Information

- Bring this booklet with you when you are due in the lab for the practical session. Your rota appears on your timetable.
- You must read this booklet prior to attending the practical session.
- Attendance will be taken; note that no show implies a zero mark.
- Bring your health and safety kit for the practical session and wear it properly at all times while in the labs.
- Conduct the experiment using the lab sheet instructions. You may ask questions to lecturers if needed.
- After conducting the experiments, students will be grouped by the lecturer to produce a lab report. Solo reports will not be accepted.
- The report must be submitted electronically, via CANVAS, by one student only, using the template provided, and within two weeks after the session.
- Make sure you reference properly any material used in the report. Plagiarism will be checked using Turnitin software and similarities larger than 10% will be penalised.
- The file name should contain the surname of student submitting the report and module name (e.g., Williamson_Thermodynamics and Fluid Mechanics).
- Feedback will be given via CANVAS within twenty working days.

Assessment criteria

	Assessment criteria	Maximum mark
Content	**Front cover and Abstract, Table of Content & Contribution Page** Abstract (200 words maximum) should be well written, clearly, and succinct, summarise the aims, methods, results, and conclusions of the practical. Front cover, table of content and contribution page should be included.	**2**
	Introduction Clearly written, well structured, with evidence of relevant extra reading and background information. You should identify the main aims and objectives of the practical and explain the rationale for performing the study.	**2**
	Methods and Experimental Procedures Clearly describe the experiment, the apparatus used, the experimental procedures, and the methods.	**2**
	Theory Detail and explain the appropriate theory for the experiment you have carried out.	**2**
	Results Present clearly all calculation details, graphs, and tables. All figures and tables should be captioned correctly, with complete and descriptive captions. Provide references if applicable.	**42**
	Discussion Discuss in detail the results from the practical, compare the expected results to those obtained, analyse the experiment errors, relate the results to the objectives, provide your scientific opinion. Answer all questions from booklet	**42**
	Conclusions/Recommendations Brief summary of conclusions from the experiment and your recommendations.	**2**
Presentation	**Overall appearance and structure of report, effort** Report well structured, well written, clear, concise writing and well presented. Appropriate level of effort demonstrated. Report maximum 20 pages and word processed, minimum font size 11.	**2**
	Grammar/Spelling/Language Report is free of grammatical and spelling errors.	**2**
	Referencing All references corrected listed in “Reference” section and properly cited in the report following Harvard style.	**2**
Total		**100**

Level 4 grade criteria

CLASS	%	LETTER GRADE	OVERALL DESCRIPTION	GUIDELINE GRADE DESCRIPTIONS
FIRST	85-100	A+	Outstanding	Your work meets all of the criteria described below for the A and A- grades. On top of that, it shows that you have got an exceptional grasp of the skills and knowledge covered in this module. Your work also shows that you are able to analyse key concepts in a way that is unusually advanced for this level of study and that goes beyond the theories and models that we studied. Your work shows that you have followed good academic practice in terms of citation and referencing, presentation format and clear, accurate English.
1ST	75-85	A	Excellent	Your work shows a thorough grasp of the skills and knowledge required for this module. It is clear from your work that you have engaged in wide reading and study that goes well beyond the core areas needed to complete the assessment.
	70-74	A-	Very good	Your work shows a good ability to analyse key concepts using the models and theories that we covered in the course of the module. You have shown that you are able to define problems and/or practical issues clearly and to apply appropriate methods and tools covered in the module to tackle them. Your work shows that you have followed good academic practice in terms of citation and referencing, presentation format and clear, accurate English.
2.1	67-69	B+	Good	Your work shows a good knowledge and understanding of the material covered in this module.
	64-66	B		Your work also shows that you are able to analyse ideas using the principles, theories and approaches that we covered in the module.
	60-63	B-		Your work also shows that you are able to define problems and/or practical issues clearly and to apply appropriate methods and tools covered in the module. However, although your work does show that you recognise some of the complexities of this area of study, not all of your conclusions are based on sufficient evidence. Most of your work shows good academic practice in terms citation and referencing, presentation format and clear, accurate English
2.2	57-59	C+	Satisfactory	Your work shows some knowledge and understanding of the material covered in this module.
	54-56	C		Your work tends to be descriptive, with only limited analysis using the principles, theories and approaches that we covered in the module.

	50-53	C-		There is some evidence in your work that you have applied the methods and tools covered in the module appropriately. You have recognised some, but not all, of the complexities of this area of study. Your work follows good academic practice to some extent in terms of citation and referencing, presentation format and clear, accurate English.
3RD	47-49 44-46 40-43	D+ D D-	Adequate	Your work shows that you have gained a basic knowledge and understanding of the material covered in this module. Your work is descriptive, rather than analytical, and you have made a number of assertions without any evidence to back up your arguments. There is some evidence in your work that you have applied the methods and tools covered in the module appropriately. Your work shows some evidence of good academic practice in terms of citation and referencing, presentation format and clear, accurate English, but this is not always consistent throughout.
MARGINAL FAIL	35-39	F5	Unsatisfactory	Your work shows only a limited knowledge and understanding of the material covered in this module. Your work is descriptive and shows no attempt to analyse ideas or arguments. There are some inaccuracies in your work and it is not always logical or coherent. Your work has not followed good academic practice in terms of citation and referencing, presentation format and clear, accurate English.
FAIL	34 OR BELOW	F4	Poor	Your work shows little knowledge or understanding of the material covered in the module. Your work is descriptive and shows no attempt to analyse ideas or arguments. Some of your work is irrelevant and it is not always logical or coherent. Your work suggests that you have not understood the methods and tools covered in the module. You work does not meet most of the Learning Outcomes for this module. Your work has not followed good academic practice in terms of citation and referencing, presentation format and clear, accurate English.

Practical notes in this booklet

1. Fluid Mechanics Lab (RVMB 049)

Experiment: Pressure

2. Thermodynamics Lab (RVMB 049)

Experiment: Refrigeration

Experiment 1: Pressure

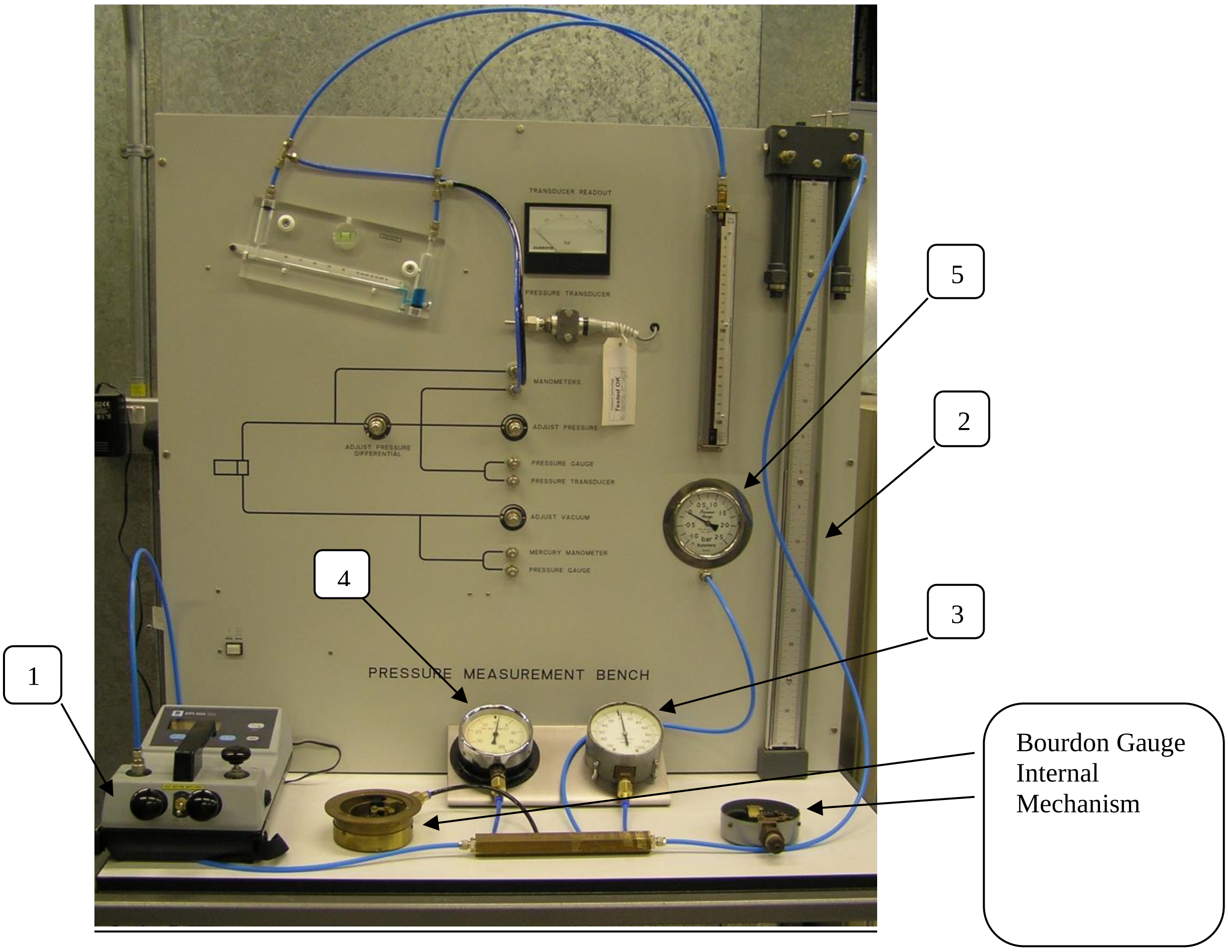
Introduction

The measurement of pressure is essential in establishing energy levels (in storage or transport) and in estimating forces for engineering design.

Instruments used for pressure measurements are either of the null balance or displacement type. In most applications, the instrument is also immersed in a fluid, the atmospheric air, and the fluid exerts a pressure, the “Barometric Pressure”. Since most gauges are open to atmosphere, they indicate the pressure above this ambient condition and known as the “gauge Pressure”.

Pressure instruments may be generally classified as manometers, dead-weight balances and elastic gauges, but a number are exceptions, for example the piezoelectric gauge and certain high vacuum gauges. The dead weight gauges and manometers (gravity-balance) are accurate enough for engineering purposes without correction for local gravity. All elastic gauges are calibrated.

There are two systems for applying pressure and vacuum to the test rig. There is a Portable Pressure calibrator The DPI-603 and a Rotary Vane Pump.



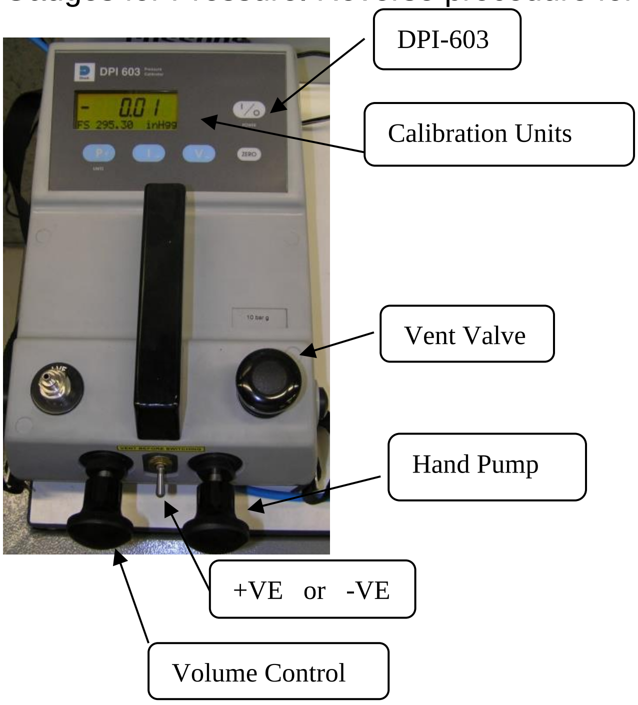
1. DPI-603 Portable Pressure calibrator

2. Mercury Glass Manometer
3. Bourdon Gauge 2
4. Bourdon Gauge 1
5. Pressure Gauge

<u>Pressure and Vacuum Measurement</u>

<u>Operating Procedure</u>

DPI-603
Visual check test rigs pneumatic connections.
Open the instruments vent valve.
Select between positive (+) or negative (–) as required. This is the selector on the front of the DPI-603, located between the hand pump and the volume adjuster.
Switch on Unit.
Select Calibration Units, i.e., in Hg or bar, etc.
Close Vent valve and zero instrument.
Using the hand pump pressurize the system to the required value using caution when reaching the extreme end of the Mercury scale. MAX 32 cm Hg. DO NOT exceed this area.
Vent air using vent valve and volume control. Obtain data from all of the relevant Gauges for Pressure. Reverse procedure for Vacuum.



Experiment 2: Refrigeration

INTRODUCTION

The task of a refrigeration system is to cool materials and products, e.g. to protect food from being spoiled. Cooling can be described as a process in which heat is extracted from the environment. One widespread type of refrigeration system is known as the compression refrigeration system. In this system, refrigerant flows through four main components: Compressor, condenser, restrictor (or expansion valve) and evaporator.

The state of a fluid is identified from the direct measurement of two independent thermodynamic properties (e.g. temperature and pressure) and from these two properties, other properties in the process or cycle could be established using charts (e.g. pressure-enthalpy, P-h chart). The refrigerant used is R134a.

The experimental unit uses a vapour compression cycle operating as a refrigerator. From the refrigerant properties (temperature, pressure…), the aim is to investigate the thermodynamic cycle using both P-h chart and direct measurements.

OBJECTIVE

The objective is to study the thermodynamics of a vapour compression refrigeration cycle and the energy changes of the refrigerant at various stages of the cycle.

APPARATUS & DESCRIPTION OF REFRIGERATION CIRCUIT

Figures 1, 2 and 3 below show an overall view of the refrigeration system and the main components and connection points.
The key **function** of a **refrigeration system** is to **cool** the **material in question**. The task of the evaporator is to withdraw heat energy from the material to be cooled.

In the **ET 351C** trainer, the **evaporator** W2 (7) is indirectly electrically heated to simulate the cooling process. This is done by supplying the set electrical heating power to the evaporator via an intermediate heating circuit. This heating power is absorbed by the **refrigerant** in the evaporator. The value of this heating power is therefore a measure of the cooling effect.

In addition, the power of the **compressor** V1 (19) and the **condenser** W1 (5) is recorded, as well as the temperatures, pressures and flow rates at all relevant points in the refrigeration system. This enables the key figures for the refrigeration circuit to be calculated and the heat losses to be observed.

The **compressor** V1 (19) takes in cold, refrigerant vapour from the low pressure area. After the vapour has been taken in, it is compressed. This increases the vapour temperature to the final compression temperature.

The compressed refrigerant vapour is then fed to the **condenser** W1 (5), where it is isobarically (constant pressure) condensed and cooled. The condenser design is a **tubular heat exchanger**. The refrigerant flows through the shell, while the cooling water flows through the internal tube in a counter current. The heat transfer takes place from the refrigerant to the cooling water.

The cooling water mass flow rate is adjusted using the manual **control valve** V01 (4) and measured using the **rotameter** F02 (23). The temperatures of the incoming and outgoing cooling water are recorded at the measuring points T08 (24) and T09 (26).

After condensation, the refrigeration is fed to the **receiver** B1 (15). From here, it flows via the **filter/drier** F1 (11) and the **inspection glass with moisture indicator** G1 (10) to the **vane impeller flow meter** F01 (35).

In the **thermostatic expansion valve** (9), the refrigerant expands to a lower pressure level, which simultaneously involves a reduction in temperature.

After flowing through the thermostatic expansion valve, the refrigeration reaches the **evaporator** W2 (7), where it is isobarically evaporated.

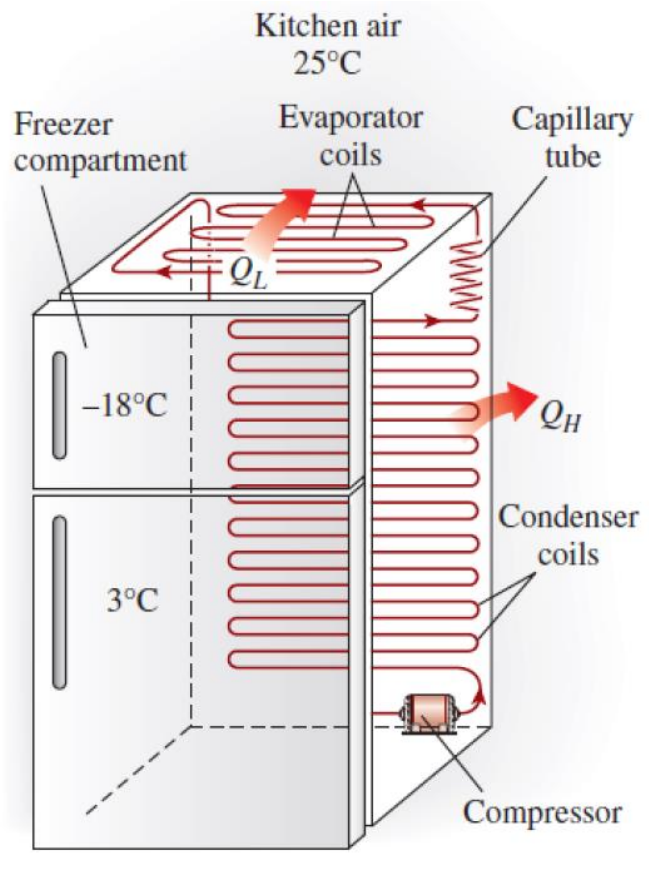
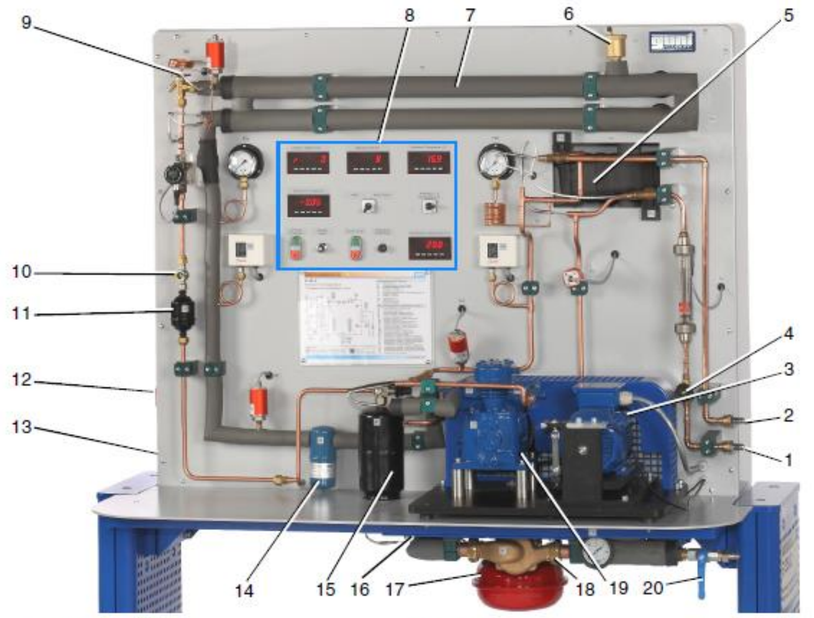


Figure 1. Ordinary household refrigerator (Cengel and Boles, 2011)



1 Cooling water, feed
2 Cooling water, return
3 Drive motor (M1)
4 Cooling water control valve (V01)
5 Condenser (W1)
6 Vent valve (V03)
7 Evaporator (W2)
8 Control and display panel
9 Thermostatic expansion valve (TEV)
10 Inspection glass with moisture indicator (G1)
11 Filter/drier (F1)
12 Master switch with emergency stop function
13 USB port (concealed)
14 Suction line receiver (B2)
15 Receiver (B1)
16 Heater (W3) (concealed)
17 Expansion vessel (B3)
18 Circulating Pump (P1)
19 Compressor (V1)
20 Fill / drain plug valve (V04)

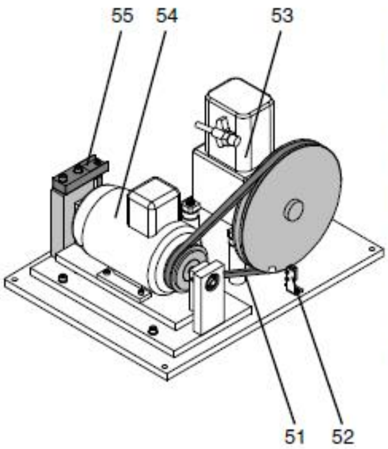
Figure 2. ET 351C, Overall view of refrigeration system, main components and connection points.

Figure 3. Overall view of refrigeration system, measuring points.

The most important components of this refrigeration system are: Compressor, Condenser, Thermostatic expansion valve and Evaporator. These are described below.

COMPRESSOR

51 Belt drive
52 Reflex photoelectric proximity switch
53 Piston compressor
54 Drive motor
55 Force transducer



Hermetic piston compressors are frequently used in refrigeration systems. Unlike these, however, the **ET 351C** contains an **open piston compressor**.

This open design allows the speed to be measured and the torque to be determined and therefore enables the mechanical power of the compressor to be calculated. Fig. 3.6 illustrates the construction of the compressor unit.

NOTICE

The piston compressor may only be operated with the refrigerant specified in Chapter 6.1, Page 93.

The belt driven (51) open piston compressor (53) and the suspended **drive motor** (54) make up the **compressor unit**.

The suspended drive motor is held by a torque bracket. The holding force is measured using a **force transducer** (55).

The speed is measured with the **reflex photoelectric proximity switch** (52) on the belt pulley of the piston compressor.

A **frequency converter** is connected upstream of the drive motor. This frequency converter allows:

- Adjustment of the compressor speed
- Display of the electric power consumption (P_{el1}) of the drive motor

CONDENSER, WATER COOLED

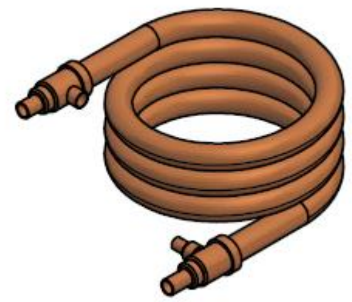


Fig. 3.7 Condenser W1, shown without insulation

The water cooled **condenser** W1 (5) is a **tubular heat exchanger**. The cooling water and refrigerant flow through the condenser in a **counter current**. The cooling water flows from bottom to top in the **internal tube**. The refrigerant flows from top to bottom through the **shell**.

The double tube of the condenser is in a spiral shape. This results in a compact construction. The condenser is largely insulated to minimise heat losses from the refrigerant to the environment.

Fig. 3.7 shows the condenser without insulation.

Fig. 3.8 shows a photo of the insulated condenser with indication of the material flows.

For both the refrigerant and the cooling water flow, the flow rate and the inlet and outlet temperatures are continuously recorded. This enables the corresponding heat flows in the condenser to be determined.

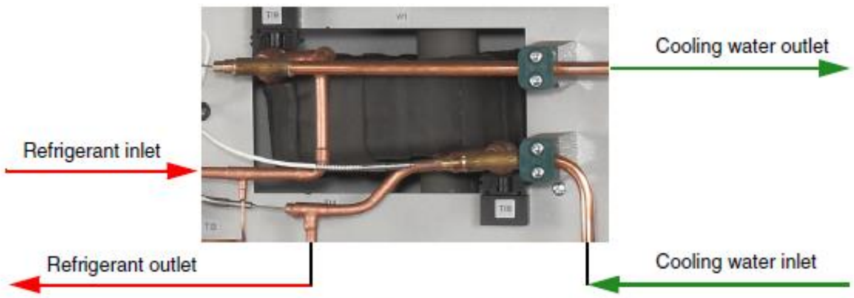


Fig. 3.8 Condenser W1, photo, with indication of material flows

THERMOSTATIC EXPANSION VALVE

The photo below shows the **thermostatic expansion valve** TEV (9), referred to below as the expansion valve for short. The expansion valve is located directly before the evaporator. The task of the expansion valve is to expand the liquid refrigerant and inject it into the evaporator.

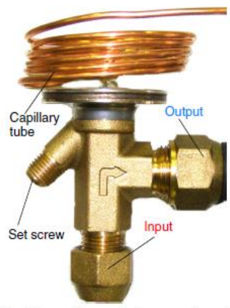


Fig. 3.9 Thermostatic expansion valve (TEV)

EVAPORATOR

The indirectly electrically heated **evaporator** W2 consists of two **tubular heat exchangers** through which the refrigerant and brine (in the counter cur- rent) flow. The evaporator is largely insulated to minimise the unwanted entry of ambient heat into the refrigerant in this case.

The entire heating circuit is also largely insulated to reduce the unwanted exchange of heat between the environment and the heating circuit to a minimum.

The low losses in this process ensure that the entire heat energy of the heater in the heating circuit is available to the evaporator. Together with the insulation of the evaporator against the entry of ambient heat, it can be determined that the heating power of the heater corresponds to the refrigerating capacity of the evaporator.

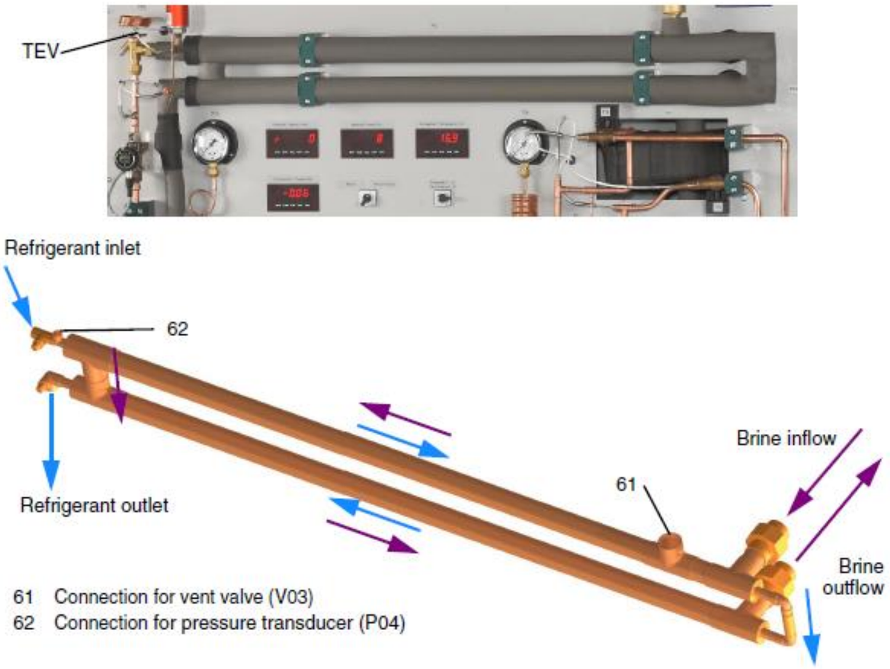


Fig. 3.11 Evaporator W2, photo and sketch

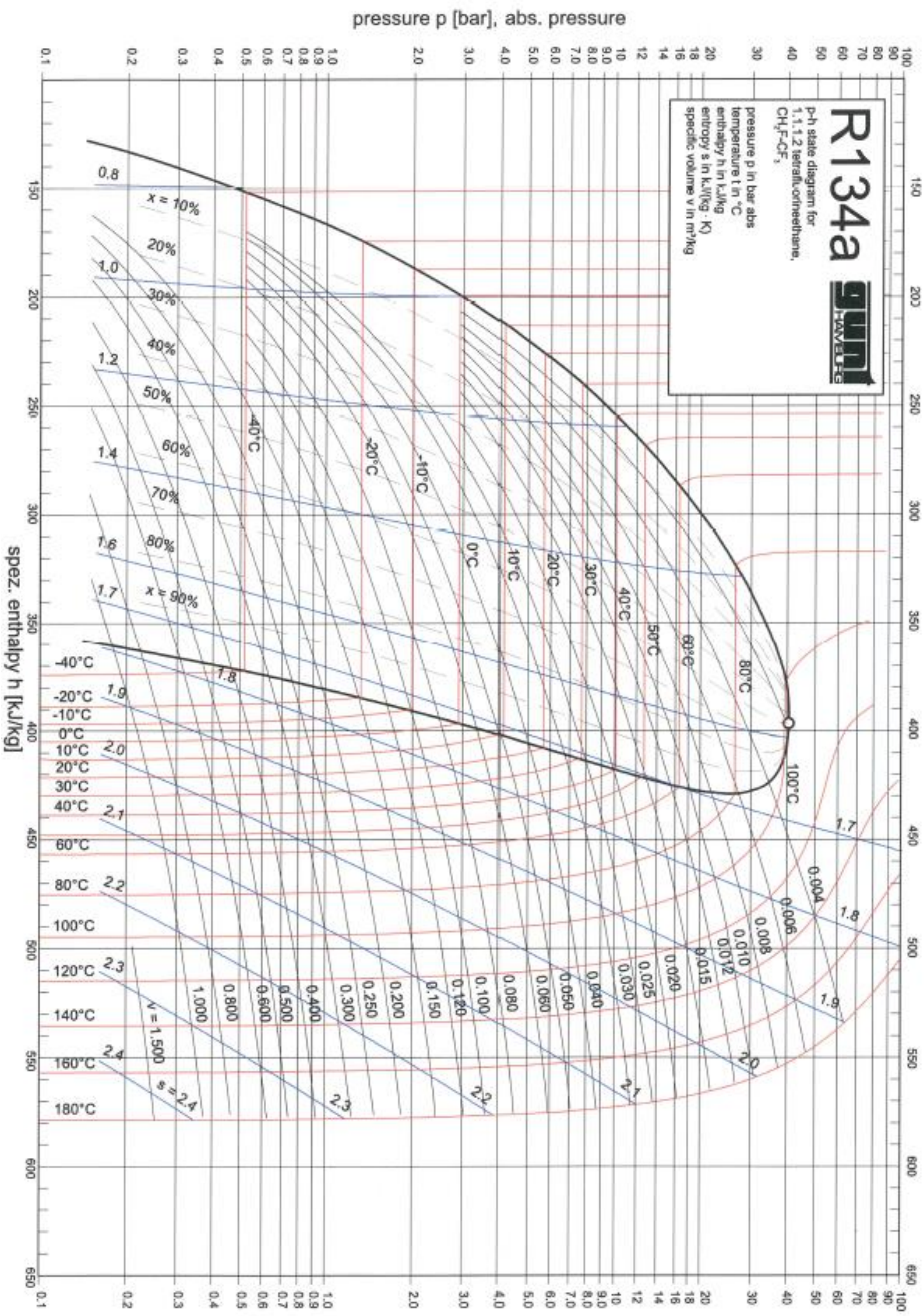
Each group needs to complete the following Data sheet by taking the readings from the rig. The **dial manometers** used has a Bourdon gauge construction. Please note that the reading will be gauge pressures, which should be converted into absolute pressure to use the p-h chart for R134a:

$P_{absolute} = P_{Gauge} + P_{atmospheric}$

REFRIGERATION EXPERIMENT – DATA SHEET

Atmospheric Pressure:.......................mbar

Parameter Measured	Symbol	Unit	Values
Compressor inlet temperature	T_1	°C	
Compressor outlet temperature	T_2	°C	
Condenser inlet temperature	T_3	°C	
Condenser outlet temperature	T_4	°C	
TEV(expansion valve) inlet temperature	T_5	°C	
Evaporator inlet temperature	T_6	°C	
Evaporator outlet temperature	T_7	°C	
Cooling water inlet temperature	T_8	°C	
Cooling water outlet temperature	T_9	°C	
Brine temperature	T_{10}	°C	
Heater power	P_{el2}	W	
Evaporator outlet pressure	P_1	bar, gauge	
Condenser inlet pressure	P_2	bar, gauge	
Condenser outlet pressure	$P_3=P_2$	bar, gauge	
Evaporator inlet pressure	$P_4=P_1$	bar, gauge	
Compressor speed	N	rpm (rev/min)	
Compressor torque	T_{comp}	Nm	
Refrigerant volume flow rate	$\dot{V}_R$	L/min	
Cooling water mass flow rate	$\dot{m}_W$	g/s	



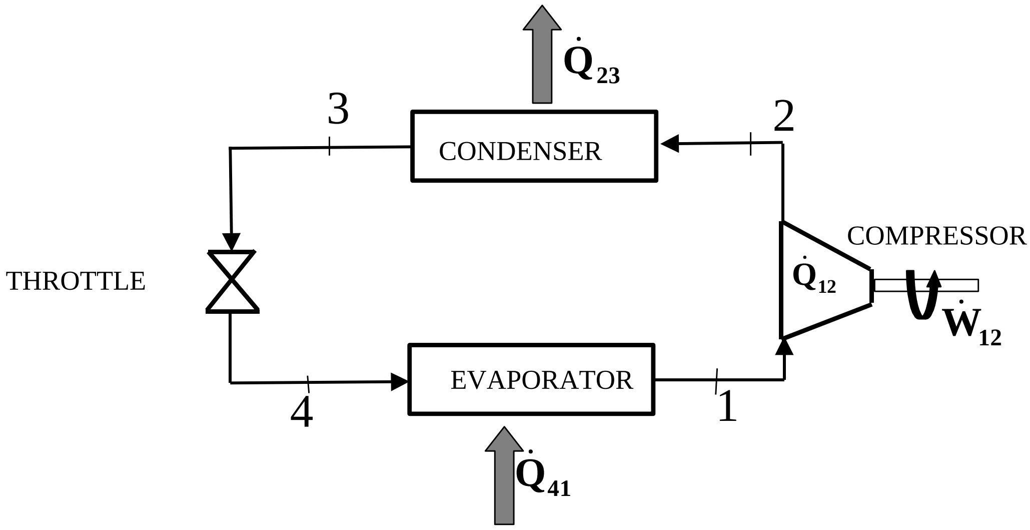
Pressure (P) – specific enthalpy (h) chart for R134a

THEORY

For a pure substance once two independent thermodynamic properties have been established then the other properties may be obtained. In this instance the properties of pressure and temperature are observed directly, and some others established using a chart.

Essentially, there are four steady flow processes making up the cycle:

(1) Compression of the refrigerant in the compressor from state 1 to state 2
(2) Condensing at ***constant pressure*** from state 2 to state 3
(3) ***Constant enthalpy*** throttling from the high pressure state 3 to the low pressure state 4
(4) ***Constant pressure*** heating of the refrigerant in the evaporator, from state 4 to state 1.



Applying the steady flow energy equation (first law of Thermodynamics for open systems) to each process,

$$q - w = h_2 - h_1 + \frac{c_2^2 - c_1^2}{2} + g(z_2 - z_1) \qquad \text{J/kg or kJ/kg}$$

For all processes in the unit the changes in kinetic energy and potential energy are negligible thus: $q - w = h_2 - h_1$

- For the compressor, 1-2, q=0, $-w_{12} = h_2 - h_1$
- For the condenser, 2-3, w=0, $q_{23} = h_3 - h_2$
- For the throttle, 3-4, w=0 and q=0

$$0 = h_4 - h_3$$

For evaporator, 4-1, work is zero (w=0)

$$q_{41} = h_1 - h_4$$

Report guidance

When writing your report, the following needs to be addressed:

The report must contain the following:

1) Description of how all the pressure gauges work, plus details of any other gauges in use in industry

2) Tabulate all experimental readings.

3) Convert all experimental readings into absolute pressure in bars:

   ($P_{abs}=P_{gauge} + P_{atm}$).

4) Plot the following graphs for both (all the units must be in Bar):
   i) Bourdon gauge 1 versus DPI-603
   ii) Bourdon gauge 2 versus DPI-603
   iii) Mercury glass manometer versus DPI-603
   iv) Pressure gauge versus DPI-603

5) Comments/discussion of results including accuracy of the different gauges and for what purposes they are best suited.

6) Discuss in the context of combustion engines, measurement & control of pressure.

7) Briefly explain the principle of refrigeration, implications on efficiency, and environmental implications on the selection of refrigerants.

End of booklet

NOTE: Should you encounter any issue with this tutorial, please do contact the setter.