Experiment 3: Refrigeration Cycle for Air-conditioning Plant

Introduction

Vapour compression refrigeration systems are the most commonly used among all refrigeration systems and is the most widely used method for air-conditioning of buildings. In a vapour compression refrigeration system, refrigeration is obtained as the refrigerant evaporates at low temperatures. The input to the system is in the form of mechanical energy required to run the compressor. The purpose of this experiment is to practically show how to construct a complete refrigeration cycle diagram for the air-conditioning plant and analyse its performance.

Objectives

- To study an actual vapour compression refrigeration cycle for an air-conditioning unit.
- To assess the coefficient of performance and volumetric efficiency of the system.

Theory and Principles

The main components of the vapour compression refrigeration system include the compressor, the condenser, the evaporator and the expansion valve. The components are illustrated in Figure 1. In general, the vapour compression refrigeration cycle of the system can be represented on a *P-h* diagram as shown in Figure 2. The state points on the diagram are usually defined by measuring the temperature and pressure of the refrigerant along the cycle.

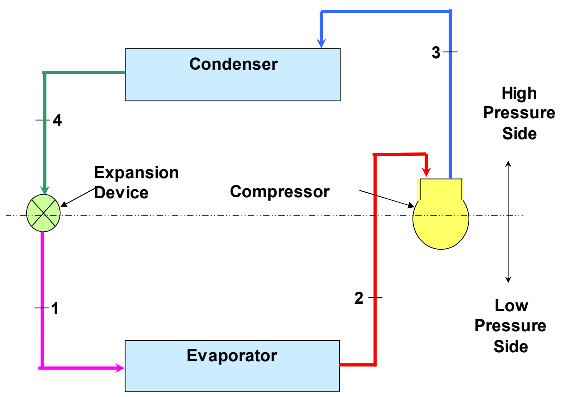


Figure 1. Components of a vapour compression refrigeration system

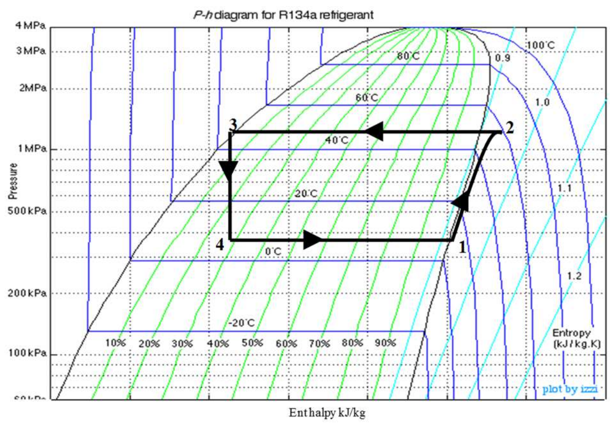


Figure 2. Vapour compression refrigeration cycle represented on a P-h diagram

(a) <u>Condenser Power Dissipation</u>

The refrigeration system condenser serves to reject heat from the system that has been extracted from the air stream, via the evaporator and the compression work input to raise the pressure from that of the evaporator to the condenser. The condenser power dissipation can be calculated as:

$$Q_{condenser} = m_{ref}(h_2 - h_3) \qquad (1)$$

where $\dot{m}_{ref}$ is the mass flow rate of the refrigerant (kg s^{-1})
h_3 , h_2 are the enthalpy of the refrigerant after and before the condenser (kJ kg^{-1})

(b) Refrigeration Capacity

The refrigerating capacity may be expressed as:

$$Q_{evaporator} = m_{ref}(h_1 - h_4) \quad (2)$$

where h_1 , h_4 are the enthalpy of the refrigerant after and before the evaporator (kJ kg^{-1})

(c) Compressor Power

The compressor power may be expressed as:

$$W_{compressor} = m_{ref}(h_2 - h_1) \quad (3)$$

where h_2 , h_1 are the enthalpy of the refrigerant after and before the compressor (kJ kg^{-1})

(d) Coefficient of Performance

The coefficient of performance (COP) is defined as the ratio of useful energy, i.e., heat transfer from low temperature source, to the costing energy, i.e., the energy consumption of the compressor.

$$COP = \frac{Q_{evaporator}}{W_{compressor}} = \frac{(h_1 - h_4)}{(h_2 - h_1)} \quad (4)$$

In real applications, energy consumption of the cycle is different from compressor power as shown above and is equal to energy consumption of the driving motor. The actual compressor power input, W_{actual}, can be measured from the electrical power input.

$$W_{actual} = V_L \text{ x } I_c \quad (5)$$

where V_L and I_c are the electrical supply voltage (Volt) and electrical current of the compressor motor (Ampere).

The actual COP based on the actual compressor power input is:

$$COP_{actual} = \frac{Q_{evaporator}}{W_{actual}} \quad (6)$$

A further parameter for the refrigeration system is the compressor compression ratio, Ψ. This provides an indication of the increase in pressure that takes part in the compressor. It is given by the ratio of the upper and lower isobars for the cyclic process.

$$\Psi = \frac{P_{2/3}}{P_{1/4}} \quad (7)$$

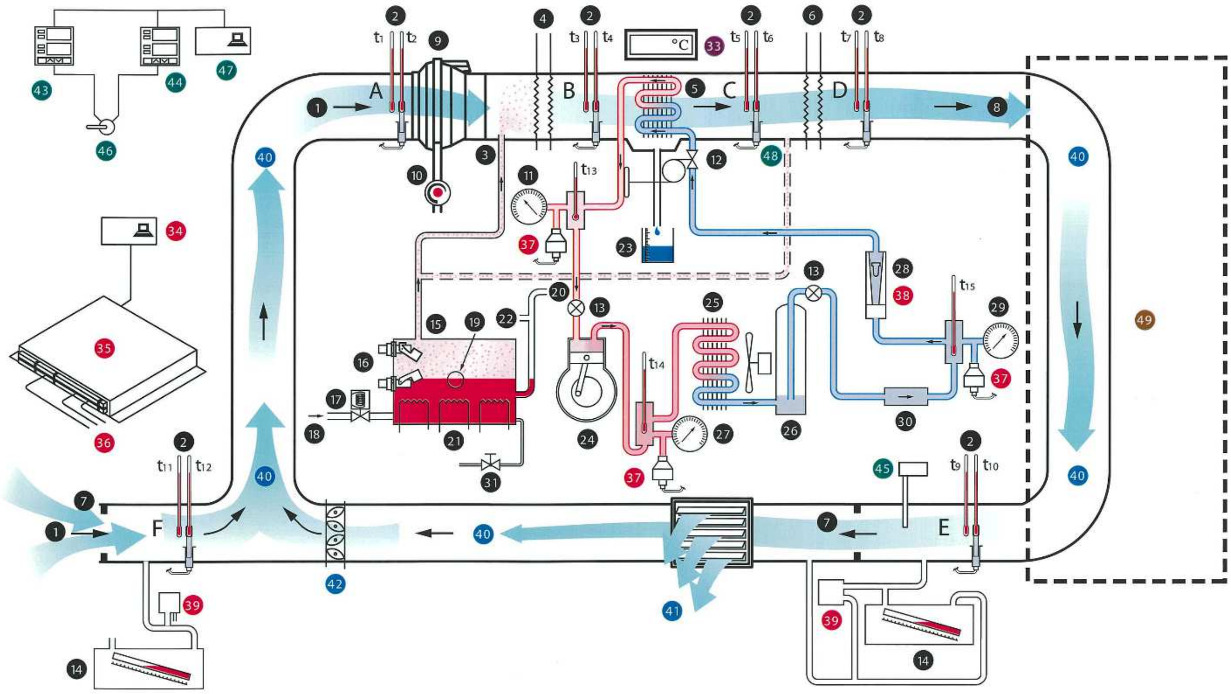
The compression ratio may affect the COP of a refrigeration cycle.

Equipment and Instruments

- A660 Air Conditioning Laboratory Unit, with a refrigeration system (hermetic unit with air cooled condenser using refrigerant R134a; compressor speed: 2700 to 3000 rev min^{-1} at 50Hz, according to load. 3300 to 3600 rev min^{-1} at 60Hz; swept volume: 25.95 cm rev^{-1})

Air Conditioning Laboratory Unit A660

with Upgrade Kits A661A, A661B, A660C A660D and AC661A



1 Air Inlet
2 Wet and Dry Temperature Stations
3 Steam Injector
4 Pre-Heaters
5 Evaporator
6 Re-Heaters
7 Orifice
8 Treated Air
9 Fan
10 Fan Speed Control
11 Evaporator Pressure
12 Thermostatic Expansion Valve
13 Stop Valve
14 Inclined Manometer
15 Steam Generator
16 Water Level Control
17 Solenoid Valve
18 Water Inlet
19 Sight Glass
20 Vent
21 Water Heaters
22 Overflow Drain
23 Condensate Measurement
24 Compressor
25 Air Condenser
26 Liquid Receiver
27 Condenser Inlet Pressure
28 Refrigerant Flowmeter
29 Condenser Outlet Pressure
30 Filter/Drier
31 Steam Generator Tank Drain Valve

Optional Upgrades:

Temperature Upgrade A661A

32 *15 Way Selector Switch (If Fitted)*
33 *Digital Temperature Indicator*

Computer Linked Upgrade AC661A

34 *Link to PC*
35 *Datalogger*
36 *Transducer Inputs*
37 *Refrigerant Pressure Transducer*
38 *Refrigerant Flow Transducer*
39 *Differential Air Pressure Transducer*

Air Reciirculating Upgrade A661B

40 *Duct Sections*
41 *Exhaust*
42 *Volume Control*

PID Control Upgrade A660C

43 *PID Controller - Humidity %RH*
44 *PID Controller - Temperature ºC*
45 *Combined %RH/Temperature Probe*
46 *Manual/PID Control Selector Switch*
47 *Link to PC*
48 *PID Steam Injector*

Environmental Chamber A660D

49 *Environmental Chamber*

Procedure

1) Inspect the apparatus and study its main components.
2) Make sure that the air flow is set to a low rate with moderate recirculation by controlling the damper on the re-circulated duct.
3) Make sure that all heaters, the compressor are set off. Also set the system control to manual.
4) Turn the fan on, and set its speed to be intermediate position.
5) Turn the compressor on.
6) Turn on the 1 kW of the electric re-heater.
7) Wait for steady state to provide by watching the variation of temperature at location 7 (i.e. t_7). Usually 10-20 minutes are enough to achieve steady state condition.
8) Record the data on Table 1. Take 5 to 6 sets of data to examine the average conditions.
9) Identify the state points of the refrigeration cycle on a P-h diagram and construct the cycle.
10) Determine the COP and compression ratio.
11) Comment on you results.

Results

The tables provided in the Appendix are for recording the measurement data and calculated parameters. After the experiment, the following information should be established to report the findings.

- Clear presentation of the measurement data
- Determination of the state properties of refrigerant from tables or charts
- Calculations to determine the COP and compression ratio

Discussions

The following issues shall be evaluated and discussed.

- How pressure ratio variation affects the COP of refrigeration cycle?
- Understanding of vapour compression refrigeration cycle

Laboratory Report

Each student should prepare their own report based on the data and information obtained during the experiment. While the results from the observations and measurements can be shared among the members in the same student group, each student shall generate information to show his/her own understanding and ideas. Students making direct copy of the information in other’s report (plagiarism), if found, will be disqualified.

The laboratory report in PDF format shall be submitted to the Moodle before the deadline. Late submission will receive reduction in marks.

References

Wang, S. K., 2001. *Handbook of Air Conditioning and Refrigeration*, 2nd ed., Chp. 9, McGraw-Hill, New York.

Web Links

Vapour Compression Refrigeration Cycle Calculator http://engr.usask.ca/classes/ME/227/Refrigeration/js/

/SH/1710/

Appendix

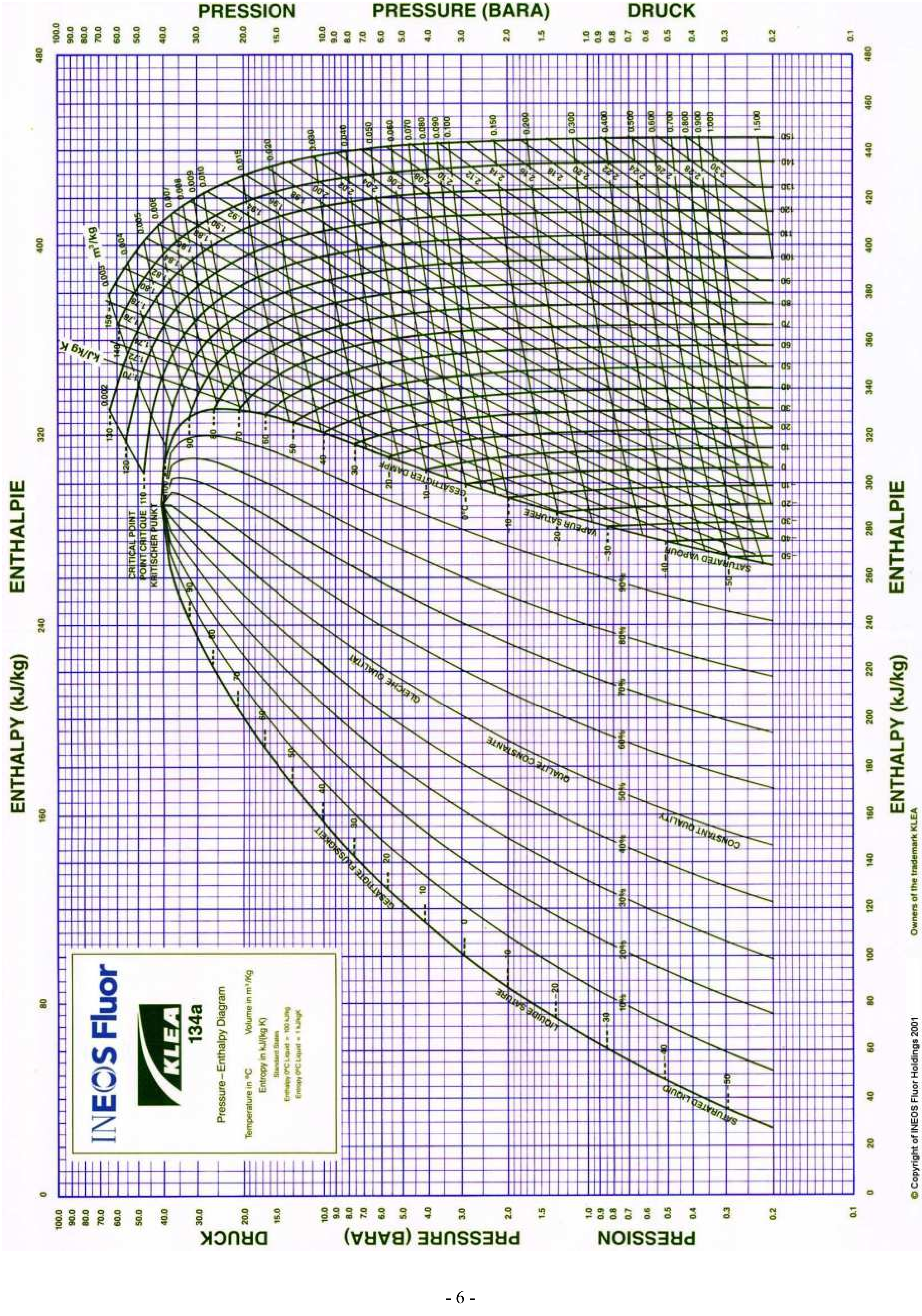
Table 1. Observed data

Atmospheric pressure: ______________________ mm Hg

Heater input power: __________________ kW

Test Reference			Units	1	2	3	4	5	6
Evaporator Outlet		t_{13}	° C						
Condenser Inlet		t_{14}	° C	`					
Condenser Outlet		t_{15}	° C						
Evaporator Outlet Pressure		P_1	kPa (gauge)						
Condenser Inlet Pressure		P_2	kPa (gauge)						
Condenser Outlet Pressure		P_3	kPa (gauge)						
R-134a mass flow rate*		m_{ref}	g/s						
Supply Voltage		V_L	Volts AC						
Electrical Current of the Compressor Motor		I_c	Ampere						

*** Divided by 1000 to get the mass flow rate in kg/s**


PRESSION
PRESSURE (BARA)
DRUCK
ENTHALPY (kJ/kg)
ENTHALPIE
INEOS Fluor
KLEA
134a
Pressure–Enthalpy Diagram
Temperature in °C
Volume in m³/Kg
Entropy in kJ/(kg K)
CRITICAL POINT
POINT CRITIQUE
KRITISCHER PUNKT
SATURATED LIQUID
LIQUIDE SATURE
GESÄTTIGTE FLÜSSIGKEIT
SATURATED VAPOUR
VAPEUR SATUREE
GESÄTTIGTER DAMPF
CONSTANT QUALITY
QUALITE CONSTANTE
GLEICHE QUALITÄT
kJ/kg K
m³/kg
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