SBS5225 HVACR II

http://ibse.hk/SBS5311/

Experiment 1: Analysis of Refrigeration Circuit

Introduction

Refrigeration engineering describes the removal of heat from a space which is to be cooled. Thermal energy is transferred from the warmer to the colder medium due to a temperature difference. In a compression refrigeration system, a refrigerant flows through the refrigeration circuit and is subject to different changes of state. The ET 350 experimental unit represents a refrigeration circuit of the compression refrigeration system, consisting of a hermetic piston compressor, condenser, expansion valve and evaporator. Temperatures and pressures are captured and displayed. The key points of the cyclic process can be read and entered into a log p-h diagram. Furthermore, the output of the compressor and flow rates of the water flows and the refrigerant are also displayed.

Objectives

- To study the evaporation and condensation processes of the refrigeration circuit
- To represent the refrigeration cycle in the log *p-h* diagram
- To determine the coefficient of performance of a vapour compression refrigeration cycle

Theory and Principles

The basis of refrigeration systems is a thermodynamic cycle working between two different temperature sources. In this cycle a refrigerant (Solkane SES36) passes through various changes of state in a defined sequence and returns to its initial state. A refrigerator is a machine that removes heat from a low temperature region. Since energy cannot be destroyed, the heat taken in at a low temperature must be dissipated to the surroundings. The Second Law of Thermodynamics states that heat will not pass from a cold region to a warm one without spending energy or work. Therefore, a refrigerator requires energy input for its operation. It should be noted that heat pump and refrigeration cycles are the same, but in the case of a heat pump the heat emitted is utilized whereas in the case of a refrigeration system the amount of absorbed heat is beneficial.

One of the common refrigeration systems in use today is the Vapor Compression Cycle. Schematic of a vapour compression refrigeration cycle is shown in Figure 1. This cycle has the following component:

1. A compressor which compresses the vaporous working fluid and provides the required mechanical energy, $\dot{W}$, to the system.
2. The condenser that absorbs heat (at constant pressure) from the working medium and transfers it to the high temperature source.
3. An expansion (throttling) valve that expands the liquid working medium during a constant

enthalpy process.

4. An evaporator facilitates the evaporation of the working medium while it absorbs heat from the low temperature reservoir.

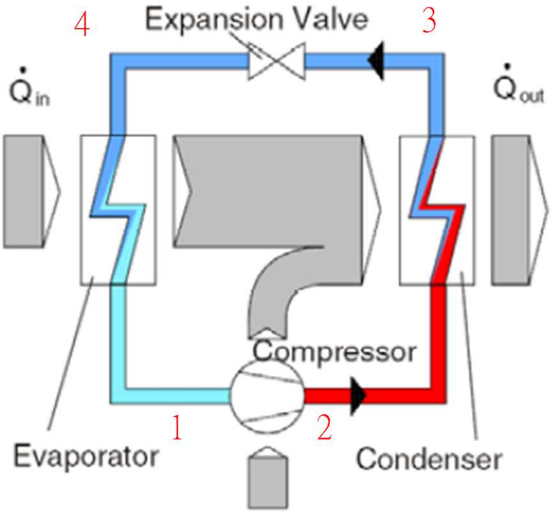


Figure 1. Schematics of a vapor compression refrigeration cycle

For thermal analysis of refrigeration cycle several diagrams such as log *p-h* diagrams can be used. The pressure-enthalpy diagram of an ideal refrigeration cycle shown in Figure 2, includes the following processes:

1) 1-2: Isentropic compression to the final compression temperature with superheating of the working medium, adiabatic
2) 2-2’: Isobaric cooling to the condensation temperature
3) 2’-3: Isobaric condensation, releasing the condensation enthalpy
4) 3-4: Expansion in the wet vapour region,
5) 4-1: Isobaric evaporation, absorption of the evaporation enthalpy

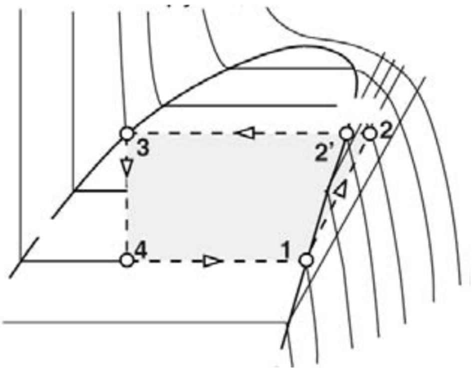


Figure 2. Pressure-enthalpy diagram of an ideal refrigeration cycle

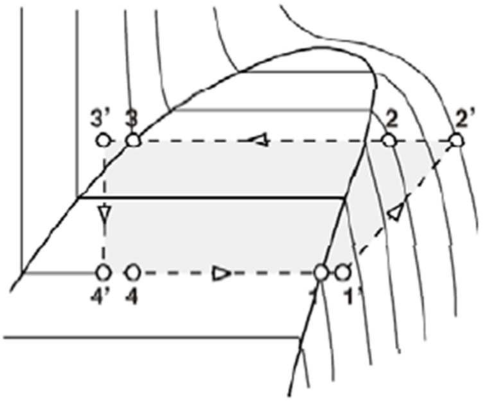


Figure 3. Pressure-enthalpy diagram of a real refrigeration cycle

Figure 3 shows the pressure-enthalpy diagram of a real refrigeration cycle. The key difference between the real cyclic process and the ideal cyclic process is that compression is not isentropic. Thus more work must be expended at the compressor to achieve the same final pressure. In addition, superheating of the refrigerant is necessary prior to compression to exclude, with certainty, the possibility of the entry of liquid droplets into the compressor. Otherwise the compressor would be damaged by the impact of liquid droplets. By means of liquid sub-cooling the vapour portion is reduced at the inlet to the evaporator. Hence, more evaporation heat can be absorbed.

To calculate the refrigerating capacity, i.e., heat transfer from low temperature source, $\dot{Q}_L$, the refrigerant mass flow rate $\dot{m}_r$ should be known beforehand. The specific volume v for the refrigerant is read from the log *p-h* diagram. Using the volumetric flow rate read on the volumetric flow meter, $\dot{V}_r$, the mass flow rate is calculated:

$$\dot{m}_r = \frac{\dot{V}_r}{v} \tag{1}$$

Consequently, the refrigeration capacity, $\dot{Q}_L$, is calculated as:

$$\dot{Q}_L = \dot{m}_r(h_1 - h_4) \tag{2}$$

This value is identical to the heat which is transferred to the water cooled in the evaporator:

$$\dot{Q}_L = \dot{m}_w\, C(T_{in} - T_{out}) \tag{3}$$

where $\dot{m}_w$ is the water mass flow rate in the evaporator, C is the specific heat capacity of water, T_{in} and T_{out} are inlet and outlet temperatures of water in the evaporator, respectively.

The compressor work $\dot{W}$ can be taken from the cyclic process plotted in the log p-h diagram. It is given by the enthalpy difference between the working fluid states before and after the compressor (points 1 and 2 in Figure 2):

$$\dot{W} = \dot{m}_r(h_2 - h_1) \tag{4}$$

Another important parameter in analysis of refrigerators is the coefficient of performance (COP). COP is the ratio of useful energy, i.e., heat transfer from low temperature source, $\dot{Q}_L$, to the costing energy, i.e., the energy consumption of the compressor, $\dot{W}$,

$$COP = \frac{\dot{Q}_L}{\dot{W}} \tag{5}$$

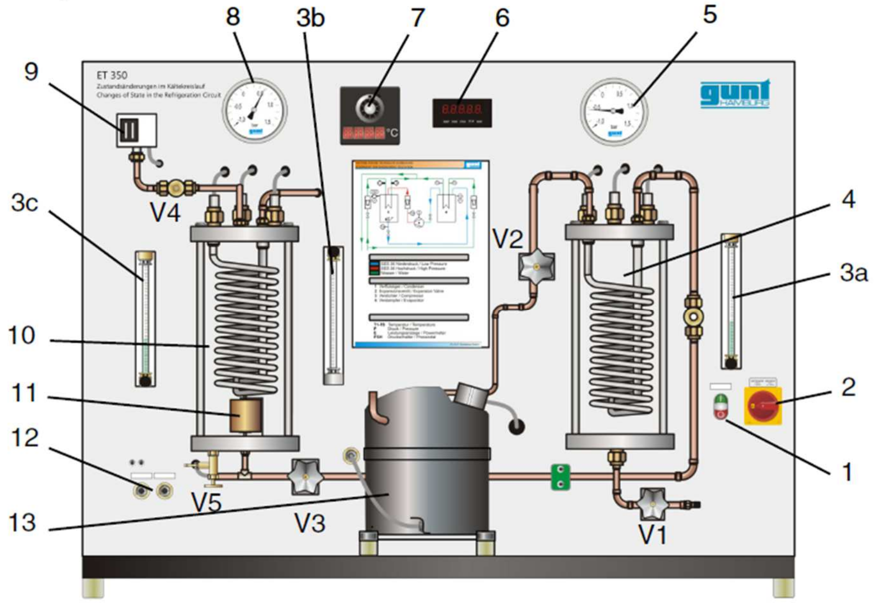
A further parameter for a refrigeration system is the compressor compression ratio, φ. This provides an indication of the increase in pressure that takes part in the compressor. It is given by the ratio of the upper and lower isobars for the cyclic process:

$$\varphi = \frac{P_{2/3}}{P_{1/4}} \tag{6}$$

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

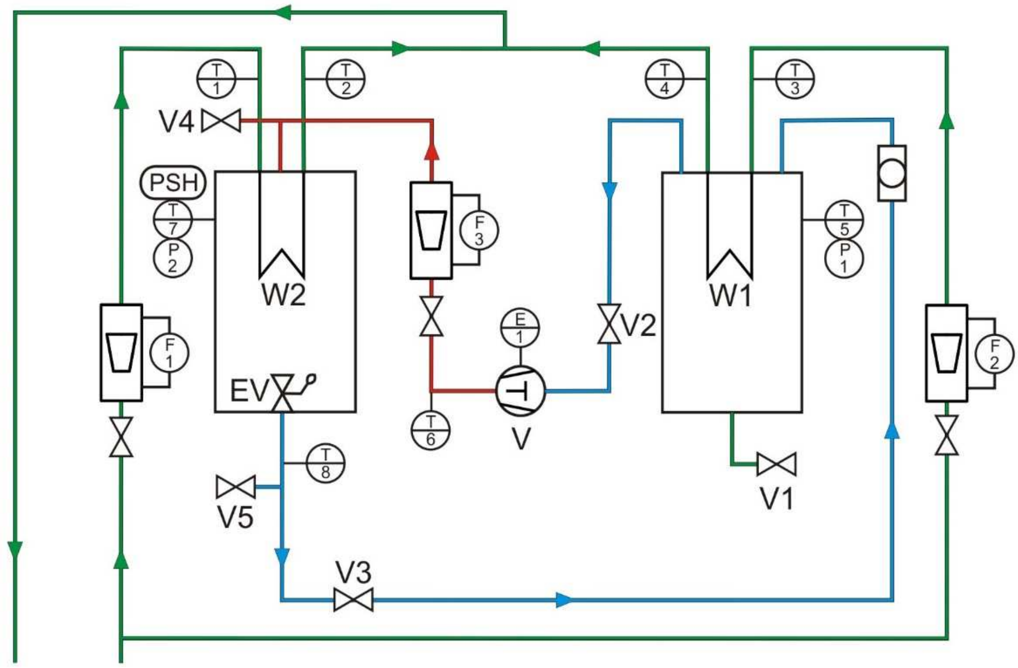
Equipment and Instruments

- ET350 Refrigeration Circuit Unit



1	Compressor on/off	9	Pressure switch
2	Main switch	10	Condenser
3a	Heating water flow meter	11	Expansion valve
3b	Refrigerant flow meter	12	Water inlet/outlet
3c	Cooling water flow meter	13	Hermetic piston compressor
4	Evaporator	V1	Evaporator fill/drain valve
5	Evaporator readout, pressure	V2	Evaporator outlet valve
6	Compressor electrical output, display	V3	Condenser outlet valve
7	Temperature display	V4	Bleed valve
8	Condenser pressure, display	V5	Condenser drain valve

Figure 4. ET350 refrigeration circuit experimental unit



Components and measurement points:

W1	Evaporator	P1	Evaporator pressure
EV	Expansion valve	P2	Condenser pressure
V	Compressor	F1	Cooling water flow
W2	Condenser	F2	Heating water flow
T1	Cooling water inlet temperature	F3	Refrigerant flow
T2	Cooling water outlet temperature	V1	Evaporator fill/drain valve
T3	Heating water temperature	V2	Evaporator outlet valve
T4	Heating water outlet temperature	V3	Condenser outlet valve
T5	Evaporator temperature	V4	Bleed valve
T6	Compressor outlet temperature	V5	Condenser drain valve
T7	Condenser temperature	E1	Compressor electrical power
T8	Temperature after expansion valve	PSH	Pressure switch

Piping

🟦	Refrigerant suction line
🟥	Refrigerant pressure line
🟩	Water, cooling and heating water

Figure 5. ET 350 process schematic

Procedure

1) Start water flow through the system.
2) Switch on compressor.
3) Set the volumetric flow rate of the refrigerant, cooling and heating waters. Leave compressor to run for a while so that a steady state condition is reached in the system. A steady state is evident from the fact that the temperature at the outlet of the compressor T_6 stops rising.
4) Measure the temperatures T_1-T_8 and also read the pressure in the condenser and the evaporator, fill out Table 1. On reading the manometer 1 bar must be added to the value read to obtain the actual pressure.

5) Change the flow rate of the refrigerant, wait until the cycle reaches its steady-state condition, and repeat step number 4.
6) Turn the compressor off.
7) Turn the experimental unit off at the main switch.
8) Turn off the water supply.

Results

The table provided in the Appendix is for recording the measurement data. After the experiment, the following information should be established to report the findings.

- Clear presentation of the measurement data
- Calculate the pressure ratio, the refrigeration capacity, heat rejection and the COP of the cycle for each pressure ratio. Also, plot the COP and the refrigeration capacity versus the pressure ratio
- Draw the refrigeration cycle in the log *p-h* diagram. With the diagram, obtain the respective specific enthalpies h_1 to h_4

Discussions

The following issues shall be evaluated and discussed.

- Comment on the important characteristics of a refrigerant.
- How pressure ratio variation affects the COP of refrigeration cycle?
- Comment on the ratio of the refrigeration effect to the electricity power consumption of the compressor.

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

ASHRAE, 2017. *ASHRAE Handbook Fundamentals 2017*, SI edition, Chp. 2: Thermodynamics and Refrigeration Cycles, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

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

Web Links

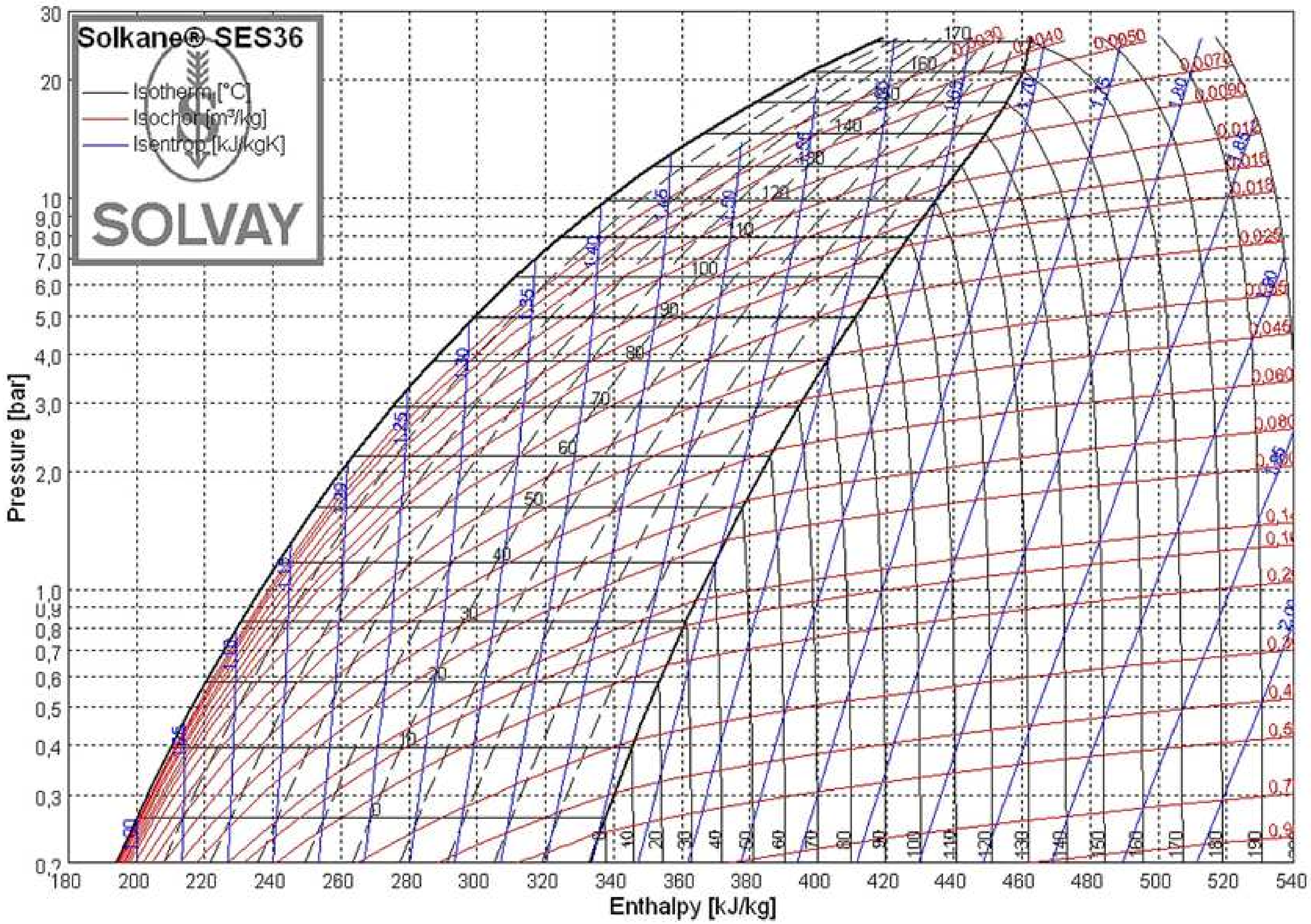
Vapour Compression Refrigeration Cycle Calculator http://engr.usask.ca/classes/ME/227/Refrigeration/js/

Appendix

Table 1: Operating parameters vapor compression refrigeration cycle

Test #	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
1								
2								
3								
4								
5								
6								
7								
8								

Test#	Cooling Water Flow Rate	Heating Water Flow Rate	Refrigerant Flow Rate	Condenser Pressure	Evaporator Pressure	Compressor Power
1						
2						
3						
4						
5						
6						
7						
8						


Solkane® SES36
Isotherm [°C]
Isochor [m³/kg]
Isentrop [kJ/kgK]
SOLVAY
Pressure [bar]
30
20
10
9,0
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
Enthalpy [kJ/kg]
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
0
10
20
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