OBJECTIVES

The primary objective of this computer lab is to develop a simple model of the vapour compression refrigeration process in EES. The process can also be presented in an h-log p-diagram created in your code.

The second objective of this computing lab is to determine the compressor power, the condenser capacity, the coefficient of performance, and the volumetric refrigerating effect based on some given experimental data measured previously in the laboratory.

Work in groups of two persons.

PREPARATORY WORK

Read chapter 3 in Refrigerating Engineering, and solve computer lab 1.

THEORY

The main components of the vapour compression refrigeration cycle are the compressor, the condenser, the evaporator and the expansion valve. The components are illustrated in fig. 1.

![Fig 1. The vapour compression refrigeration cycle.](image-url)
The **refrigerating capacity** may be expressed as:

\[ \dot{Q}_2 = \dot{m}_r \cdot (h_{2k} - h_s) \]

where \( \dot{m}_r \) is the mass flow of the circulated refrigerant, \( h_{2k} \) is the enthalpy after the evaporator and \( h_s \) is the enthalpy before the evaporator.

![Fig 2. The vapour-compression refrigeration cycle represented in h – log P diagram.](image)

The **condenser heat capacity** can be obtained from:

\[ \dot{Q}_1 = \dot{m}_r \cdot (h_{1k} - h_s) \]

where \( h_s \) is the enthalpy after the condenser and \( h_{1k} \) is the enthalpy before the condenser.

The **compressor power** may be expressed as:

\[ \dot{E}_c = \dot{m}_r \cdot (h_{1k} - h_{2k}) \]

The **power demand for an isentropic (ideal) compressor** can be obtained from
\[ \dot{E}_{\text{is}} = \dot{m}_r \cdot (h_{1k,\text{is}} - h_{2k}) \]

where \( h_{1k,\text{is}} \) is the isentropic enthalpy after the compressor. The **isentropic compressor efficiency** can be defined as

\[ \eta_s = \frac{(h_{1k,\text{is}} - h_{2k})}{(h_{1k} - h_{2k})} \]

The **volumetric refrigerating effect**, \( q_v \), is defined as

\[ q_v = \frac{(h_{2k} - h_s)}{v_{2k}} \]

where \( v_{2k} \) is the specific volume at the compressor inlet.

In the computer lab file, lab2.ess, the real isentropic efficiency for a compressor tested in the laboratory is calculated by the built-in formula. The data have been fitted to a function of the two pressures, \( p_1 \) and \( p_2 \), according to fig 3.

![Fig 3. The isentropic efficiency for the tested compressor](image)

This curve is unique for each compressor and different compressor types have different characteristics.

The **volumetric efficiency** of the compressor can be calculated from

\[ \eta_s = \frac{\dot{V}_2}{\dot{V}_s} \]
where \( \dot{V}_2 \) is the **real volume flow at the compressor intake** that can be calculated from the following equation

\[
\dot{V}_2 = \dot{m}_r \cdot v_{2k}
\]

The **swept volume flow**, \( \dot{V}_S \), can be obtained from the compressor geometry and given characteristics as:

\[
\dot{V}_S = z \cdot \pi \cdot \left( \frac{D^2}{4} \right) \cdot S \cdot \frac{n}{60} \quad \text{(m}^3\text{/s)}
\]

where
- \( z \) : number of cylinders
- \( D \) : cylinder diameter (m)
- \( S \) : length of stroke (m)
- \( n \) : number of revolutions (rpm)

The **Pressure ratio**, \( P_{ii} \), is defined as

\[
P_{ii} = \frac{P_1}{P_2}
\]

**PROGRAM AND PRESENTATION IN DIAGRAMS**

Write a program in EES that calculates the state points before and after each component in the vapor compression refrigeration process in a h-log p-diagram for R134a (similar to figure 2), the volumetric refrigerating effect, the condenser capacity, the volumetric efficiency of the compressor and the COP\(_2\).

1. The EES program Lab2 can be downloaded from the course homepage. Save the program in your own catalogue.

2. Write the program in EES using the relevant equations from the theory and the following instructions.

3. Select the high temperature, \( T_1 \), equal to \((35^\circ\text{C} + \text{average of your birth months})\); the low temperature, \( T_2 \), equal to -10°C, and the refrigeration capacity equal to 60 kW.

4. The compressor has the following dimensions:
   - \( z = 2 \)
   - \( D = 125 \text{ [mm]} \)
   - \( S = 94 \text{ [mm]} \)
   - \( n = 1450 \text{ rpm} \)
5. Calculate the high pressure, the low pressure, the enthalpies after each component, and Entropy and specific volume (Volume in EES Function Information command) before the compressor. Select the Function Information command from the Options menu and click on the Fluid properties button. The refrigerant is R134a.

**Hint:** Use the quality \( x \) in the function info to calculate some of the variables, e.g., calculate the pressures with temperature and quality, \( x \), equal to 1 or 0.

6. Draw h-log P diagram for R134a. Select Property Plot from the Plot menu. Choose R134a, P-h as plot type and OK.

7. To draw the refrigeration cycle on the P-h diagram, construct two vectors at the Equation windows. One vector is needed for the pressures and the other for the enthalpies. The vectors have indices one to five, equivalent with the five points (1,1), (2,2), (3,3), (4,4), (5,5), in fig 2. The point (1,1) equals the point (5,5). EES array variables have the array index in square brackets, e.g., \( X[5] \). In most ways, array variables are just like ordinary variables. (More information about Arrays is in the Help menu).

**Hint:** you can construct your arrays by selecting the Insert/Modify Array from the Edit menu. Enter a name for your array and then insert your variables. Rows correspond to the numbers of points on the plot and in the column you set the coordinate. You will have to construct two arrays – one for the pressure and the other for the enthalpy variables in order to give two coordinates for each point.

Solve the equation window. Select Solve from the Calculate menu.

8. Plot the vectors in the h-log p-diagram. Select Overlay plot from the Plot menu. Click automatic update and OK.

9. Construct a parametric table containing the variables, \( T_2, \dot{Q}_2, \dot{Q}_1, \dot{E}_1, q, \) the pressure ratio \( P_n, \) the isentropic efficiency \( \eta_{is}, \) the volumetric efficiency \( \eta_s \) and COP. Enter the following experimental values obtained from a compressor test rig for the low temperature, \( T_2 \) and for the refrigeration capacity, \( \dot{Q}_2, \) for which the other variables are to be determined. The other variables are to be calculated by your program.

<table>
<thead>
<tr>
<th>( T_2 ) [°C]</th>
<th>( \dot{Q}_2 ) [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>150</td>
</tr>
<tr>
<td>0</td>
<td>98</td>
</tr>
<tr>
<td>-10</td>
<td>60</td>
</tr>
<tr>
<td>-20</td>
<td>33</td>
</tr>
<tr>
<td>-30</td>
<td>15</td>
</tr>
</tbody>
</table>

10. Plot, \( \dot{Q}_1, \) as a function of the temperature, \( T_2, \) in Plot Windows 2.
11. Plot, \( \dot{E}_t \), as a function of the temperature, \( T_2 \), in Plot Windows 3.

12. Plot, COP\(_2\), as a function of the temperature, \( T_2 \), in Plot Window 4.

13. Plot, \( q_v \), as a function of the temperature, \( T_2 \), in Plot Window 5.

14. Plot the isentropic efficiency \( \eta_{is} \), as a function of the pressure ratio, \( P_{ii} \), in Plot Window 6.

15. Plot the volumetric efficiency, \( \eta_{s} \), as a function of the pressure ratio, \( P_{ii} \), in Plot Window 7.

**CONCLUSIONS**

Hint: In order to answer some of the questions it will be helpful to build another plot for \( \dot{m}_l \) and \( v_{2k} \) vs \( T_2 \).

1. Why does the compressor power, \( \dot{E}_t \), increase when the low temperature, \( T_2 \), rise? Are the results reasonable?
2. How does the low temperature, \( T_2 \), influence the condenser capacity, \( \dot{Q}_1 \), for the vapour compression system?
3. How does the low temperature, \( T_2 \), influence the coefficient of performance, COP\(_2\), for the vapour compression system?
4. Are the results of the volumetric refrigerating effect, \( q_v \), logical?
5. How does the pressure ratio, \( P_{ii} \), influence the isentropic efficiency, \( \eta_{is} \)? Why?
6. How does the pressure ratio, \( P_{ii} \), influence the volumetric efficiency, \( \eta_{s} \)? Why?

Write a short report that includes your answers to these questions and attach the corresponding plots in a word (or pdf) file. Submit the file through Bilda, the file name should be: Lab2_Surname1_given name1_Surname2_given name2.doc (or .pdf).

Surname1_given name1 is the name of the first group member, and Surname2_given name2 is the name of the second group member.

Each group member need to submit the report individually even though you work in a group!

To receive bonus for the exam, deadline for submission is November 26, 2007.