ANNALS OF FACULTY ENGINEERING HUNEDOARA
– INTERNATIONAL JOURNAL OF ENGINEERING
Tome X (Year 2012) – FASCICULE 2 (ISSN 1584 – 2665)

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PERFORMANCE CHARACTERISTICS OF VAPOR-COMPRESSION REFRIGERATION SYSTEMS

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ABSTRACT: *In nature, the heat-transfer process occurs in the direction of decreasing temperature, that is, from high-temperature regions to low-temperature ones without requiring any devices. Refrigerators are cyclic devices that work with fluid refrigerants, having the objective to maintain the refrigerated space at a low temperature by removing heat from it. The reversed Carnot cycle can serve as a standard against which actual refrigeration cycles are compared. In the article is analyzed a vapor-compression refrigeration system using R12 refrigerant. With experimental values of the evaporating and condensing temperatures and using the CoolPack program, the system performance may be evaluated.*
KEYWORDS: *Vapor-compression refrigeration cycle, Thermocouple, Temperature measurements, R12 refrigerator*

INTRODUCTION

In nature, the heat-transfer process occurs in the direction of decreasing temperature, that is, from high-temperature regions to low-temperature ones without requiring any devices. The reverse process, however, cannot occur by itself. The transfer of heat from a low-temperature region to a high-temperature one requires special devices called refrigerators [1-4]. Refrigerators are cyclic devices that work with fluid refrigerants, having the objective to maintain the refrigerated space at a low temperature by removing heat from it. The reversed Carnot cycle can serve as a standard against which actual refrigeration cycles are compared.

Alternatives of refrigeration cycles [2,3]:

- *Vapor-compression refrigeration cycle in which the refrigerant is vaporized and condensed alternately;*
- *Gas refrigeration cycle in which the refrigerant remains in the gaseous phase throughout;*
- *Cascade refrigeration, where more than one refrigeration cycle is used;*
- *Absorption refrigeration, where the refrigerant is dissolved in a liquid before it is compressed;*
- *Thermoelectric refrigeration, where refrigeration is produced by the passage of electric current through two dissimilar materials.*

The most commonly used system for industrial and commercial refrigeration is the vapour-compression refrigeration system. In this type of system, the refrigerant flows through a closed cycle in the following four states: compression, condensation, expansion and evaporation (Figure 1).

The evaporation process takes place at low pressure and temperature in the evaporator. Here the refrigerant absorbs heat from the warm environment and thus cools it (q_0). The still cold refrigerant steam is aspirated by a compressor and subjected to higher pressure by using mechanical energy. The refrigerant steam heats up due to the compression.

The hot refrigerant steam is cooled down in a condenser where it condenses while discharging heat to the environment (q_1). The liquid pressurized refrigerant is then expanded to the low evaporation pressure in an expansion element (capillary tube) and returned to the evaporator.

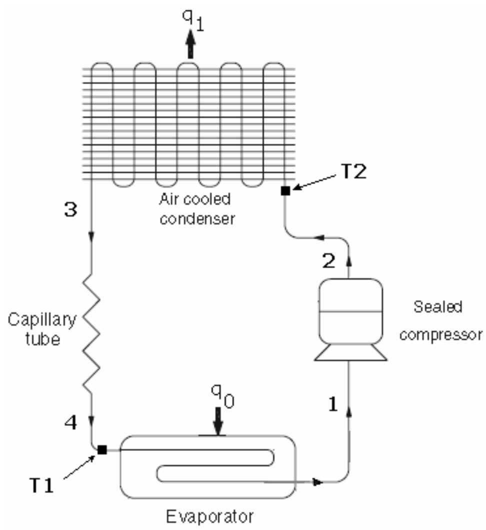

Figure 1. Vapor compression system used in domestic refrigerators

The refrigerant evaporates again and thus completes the circuit [5]. Moreover, these cycles are well described by the pressure–enthalpy diagram [log(p)- h] which shows the liquid and vapour states *of the fluid during the cycle (lines 1-5, Figure 2 [5]) and give a direct measure of the energy transferred in the process.*

In a working circuit, the vapour leaving the evaporator will probably be slightly superheated and the liquid leaving the condenser subcooled. The gas leaving the evaporator is superheated to point 1 and the liquid subcooled to 4'. Also, pressure losses will occur across the gas inlet and outlet, and there will be pressure drops through the heat exchangers and piping. The final temperature at the end of compression will depend on the working limits and the refrigerant.

Taking these many factors into account, the refrigerating effect and the compressor energy may be read off directly in terms of enthalpy of the fluid. The condenser receives the high-pressure superheated gas, cools it down to saturation temperature, condenses it to liquid, and finally subcools it slightly. The energy removed in the condenser is seen to be the refrigerating effect plus the heat of compression.

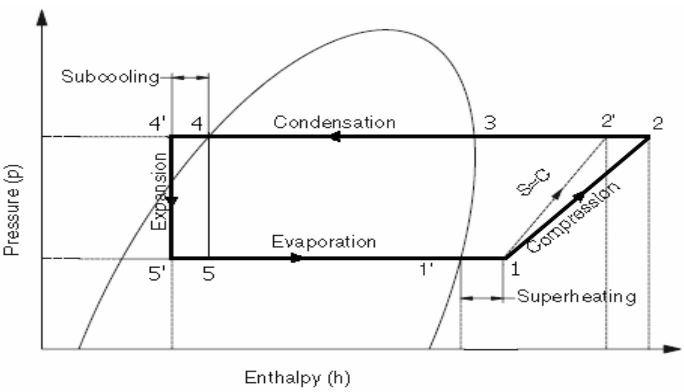

Figure 2. Pressure-enthalpy diagram (b) [5]

The real refrigeration cycle consists of the following changes of state (Figure 2) [5]:

1 – 2 polytropic compression to the condensation pressure (for comparison
1 – 2' isentropic compression)
2 – 3 isobaric cooling, deheating of the superheated steam
3 – 4 isobaric condensation
4 – 4' isobaric cooling, supercooling of the liquid
4' – 5' isenthalpic expansion to the evaporation pressure
5' – 1' isobaric evaporation
1' – 1 isobaric heating, superheating of the steam

The main parameters of refrigeration systems are:

- *The cooling capacity (heat absorbed in the evaporator):*

$$q_o = h_1 - h_5 \ [\ kJ/kg\ ] \quad (1)$$

- *The amount of heat rejected in the condenser (absolute value):*

$$|q_1| = h_2 - h_4 \ [\ kJ/kg\ ] \quad (2)$$

- *The work consumed by the system in absolute value:*

$$|l_r| = h_2 - h_1 \ [\ kJ/kg\ ] \quad (3)$$

- *The refrigeration efficiency (COP - coefficient of performance):*

$$\varepsilon_f = \frac{q_o}{|l_r|} = \frac{h_1 - h_5}{h_2 - h_1} \ [-] \quad (4)$$

- *The cooling capacity of the system (Q_o) which represent the heat absorbed by the refrigerant fluid in time:*

$$Q_o = \frac{D \cdot q_o}{3600} \cdot 10^3 = \frac{D(h_1 - h_5)}{3,6} \ [W] \quad (5)$$

where: D is the flow of refrigerant agent, in [kg / h].

If is required from a refrigerator to achieve a specific cooling capacity Qo, the relation (5) is used to determine the flow of refrigerant needed.

- *Power required to run the compressor:*

$$P = \frac{D \cdot |l_r|}{3600 \cdot \eta_c \cdot \eta_m} = \frac{D \cdot (h_2 - h_1)}{3600 \cdot \eta_c \cdot \eta_m} \ [kW] \quad (6)$$

where: η_m is the mechanical productivity of transmission;
η_c is the productivity of compressor.

The properties of three refrigerants commonly used in household applications, are given in Table 1.

Table 1. Refrigerants data comparison

Refrigerant	R600a	R134a	R 12
Name	Isobutane	Tetraflouro-ethane	Dichloro-difluoro-methane
Formula	$(CH_3)_3CH$	CF_3-CH_2F	CF_2Cl_2
Critical temperature, in [°C]	135	101	112
Molecular weight, in [kg/kmol]	58.1	102	120.9
Normal boiling point, in [°C]	-11.6	-26.5	-29.8
Pressure at -25 °C (absolute), in [bar]	0.58	1.07	1.24
Liquid density at -25 °C, in [kg/l]	0.60	1.37	1.47
Vapour density at to -25/+32 °C, in [kg/m³]	1.3	4.4	6.0
Volumetric capacity at -25/55/32 °C, in [kJ/m³]	373	658	727
Enthalpy of vaporization at -25 °C, in [kJ/kg]	376	216	163
Pressure at +20 °C (absolute), in [bar]	3.0	5.7	5.7

EXPERIMENTAL AND ANALYSIS DETAILS

As a refrigerator system is used an ARCTIC domestic refrigerator operated with a mechanical compressor and that uses R12 refrigerant. The main components of the system are given schematically in Figure 1. Also, two thermocouples are used for the evaporating (T1) and condensing (T2) temperatures measurements. In Figure 1, by the arrows are indicated the locations of temperature sensors. It should be noted that to obtain accurate data, the temperature sensor is bonded with a thermal substance.

Temperature values are measured in a 30 minutes interval, at each 5 minutes and then a mean value is calculated. Next the CoolPack program is used for refrigeration system parameters determination.

This program is separated into six categories, each can be opened by clicking the window title bar (see Figure 3): Refrigeration utility; Cycle analysis; Design; Evaluation; Auxiliary; Dynamic.

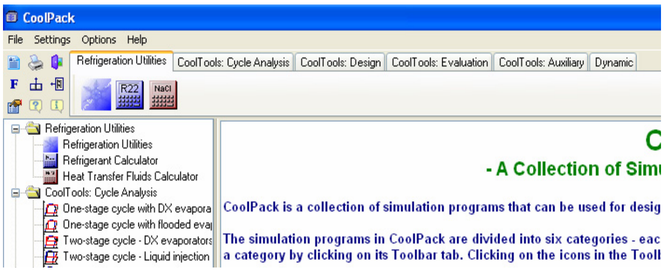

Figure 3. The window title bar of CoolPack program

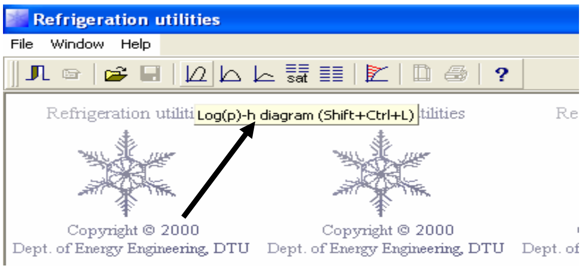

Figure 4. The "Refrigeration utility" window

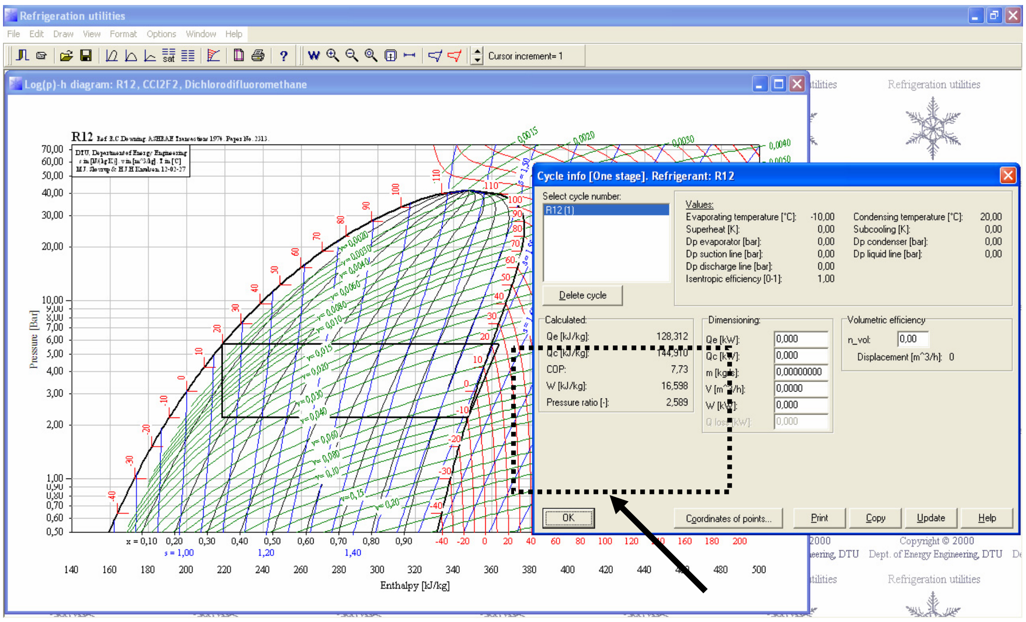

Figure 5. The "Log(p)-h" and "Show info" windows

For calculation of standard refrigeration cycle performance the "Refrigeration utility" section is used. After selecting the "log(p)-h Diagram" button (see Figure 4) and after choosing the refrigerant *type, the evaporating and condensing temperatures, the program draws the refrigeration cycle (see Figure 5). Moreover, some parameters of the refrigeration cycle are calculated (described by the relations 1-4) and the enthalpies in the critical points of the cycle are given (see Figure 5).*

So, the cooling capacity of the system Q_o (relation 5) and the power required to run the compressor (relation 6) may be calculated.

CONCLUSIONS

Thermodynamic performance of a refrigeration system is defined by evaluating the cooling efficiency, which permit the quantitative assessment of heat losses, qualitatively described by the second principle of thermodynamics.

If the evaporating and condensing temperatures are measured at selected locations on the refrigeration system, the refrigeration cycle may be drown in log(p)-h diagram using CoolPack program. This program permits the design, sizing, analysis and optimization of refrigeration cycles.

Also, a real appreciation of the quality of thermodynamic refrigeration cycle can be properly assessed only by comparison of system efficiency with an ideal machine that works after reversed Carnot cycle. The differences may arise from:

- *pressure loss in system elements with the exception of mechanical compression;*
- *heat loss between the system and the environment;*
- *losses due to vapors which deviate from perfect gas behavior.*

All these real irreversible effects influence the system performance involving a quantity of additional energy used by the compressor.

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