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REQUIRED CONDITIONS FOR OPTIONAL OPERATION OF AN AIR-CONDITIONING SYSTEM

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Abstract: *The paper discusses two aspects of refrigeration systems based on mechanical compression used for air conditioning: first the subcooling in relation with the refrigerant charge and liquid-line temperature, and second the evaporator-leaving air temperature as a function of the fan-speed and of the entering temperatures (dry-bulb and wet-bulb). Both conditions are of importance for a proper operation of air conditioning systems and the analytical interpretation is given in a simple form of relationships.*

Key words: *refrigeration, subcooling, proper airflow.*

1. Introduction

In vapor compression refrigeration systems subcooling is used so that when the refrigerant reaches the thermostatic valve, it is totally in its liquid form, thus allowing the valve to work properly and avoiding excessive and unnecessary misuse of power, malfunction and deterioration of several components in the system.

The subcooling of a refrigeration system is important to know because it gives an indication if the amount of refrigerant flowing into the evaporator is appropriate for the load. If the subcooling is too high, then not enough refrigerant is being fed resulting in poor refrigeration and excess energy use. If the subcooling is too low, then too much refrigerant is being fed possibly resulting in liquid getting back to the compressor and causing compressor damage.

On the other hand, the air flow rate provided by the fan for the evaporator must be fitted to reach the desired temperature and humidity inside the air conditioned space. If the evaporator fan-speed is to low the temperature of the leaving air is smaller than desired temperature and if the evaporator fan speed is to high the temperature of the leaving air is higher than desired temperature, both situations causing problems for the humidity and comfort too.

2. Study Objectives

The analytical correlation of the liquid-line temperature with the liquid-pressure at service valve is the aim of this paper, having the subcooling as a parameter. Values measured in practice [4] have been used for this purpose and the resulting equation represents a useful tool for the refrigerant charging process.

The comfort to be achieved for the indoor space can be correlated with the temperatures measured in front of the evaporator coil (dry and wet), and after this

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one (dry). The comfort condition can be reached by adjusting the fan speed in relation with temperature, using the equation obtained in this paper.

Both equations resulted from practice for two refrigerants, i.e. R-410A and R-22 [5].

3. Required Liquid-Line Temperature

Figure 1 shows a schematic of a single-stage vapour-compression system with parameters measured for an optimal operation of the subcooler:

- The temperatures of the liquid:
  - leaving the condenser T_c^l;
  - leaving the subcooler T_s^l;
- The pressure of the liquid
  - leaving the subcooler p_s.

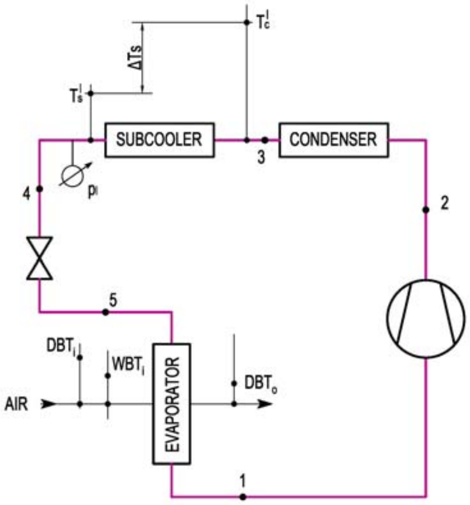

Fig. 1. *Liquid-line temperatures before/after the subcooler, and dry/wet-bulb temperatures of the air flowing over the evaporator*

3.1. Subcooling

Additional subcooling provides additional capacity while the power input to the compressor is not affected [3] as can be seen from Figure 2:

$$q_0^s = h_1 - h_5 > q_0 = h_1 - h_3 \text{ [kJ/kg].} \qquad (1)$$

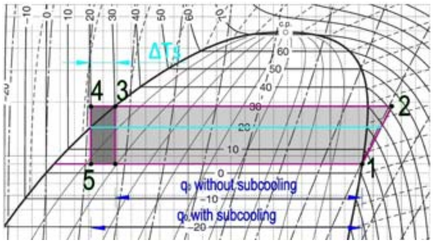

Fig. 2. *Single-stage vapour-compression cycle in p-h diagram for R- 410A refrigerant*

The subcooling expressed as a temperature differential $\Delta T_s = T_c^l - T_s^l$ can be correlated with the liquid pressure at the service valve p_l and with the liquid-line temperature T_c^l for R-410A refrigerant as shown in Table 1.

Table 1

Required liquid-line temperature [^{o}C]

Pressure [MPa]	**Required subcooling [°C]**					
	0.00	**3.00**	**6.00**	**9.00**	**12.00**	**14.00**
1.52	24.72	21.72	18.72	15.71	12.71	10.70
1.60	26.29	23.28	20.28	17.27	14.27	12.27
1.68	27.83	24.82	21.82	18.81	15.81	13.81
1.76	29.48	26.47	23.47	20.46	17.46	15.46
1.84	31.10	28.09	25.09	22.09	19.08	17.08
1.92	32.69	29.69	26.68	23.68	20.67	18.67
2.01	34.25	31.25	28.24	25.24	22.24	20.23
2.10	35.91	32.91	29.90	26.90	23.89	21.89
2.19	37.66	34.65	31.65	28.65	25.64	23.64
2.29	39.37	36.36	33.36	30.35	27.35	25.35
2.39	41.03	38.03	35.03	32.02	29.02	27.02
2.48	42.66	39.66	36.65	33.65	30.65	28.64
2.59	44.47	41.47	38.46	35.46	32.46	30.45
2.70	46.12	43.12	40.11	37.11	34.11	32.10
2.81	47.83	44.83	41.82	38.82	35.82	33.81
2.92	49.59	46.59	43.58	40.58	37.57	35.57
3.04	51.29	48.28	45.28	42.28	39.27	37.27
3.16	52.93	49.92	46.92	43.92	40.91	38.91
3.28	54.60	51.60	48.59	45.59	42.58	40.58
3.41	56.29	53.29	50.28	47.28	44.28	42.27
3.54	57.91	54.91	51.90	48.90	45.90	43.89
3.67	59.46	56.45	53.45	50.44	47.44	45.44
3.81	61.00	58.00	54.99	51.99	48.99	46.98
3.96	62.54	59.53	56.53	53.53	50.52	48.52

From the table above it can be noticed that for a required subcooling (0 to 14 ^{o}C) and for a measured liquid-pressure at the service valve (1.5 to 3.9 MPa) a required liquid-line temperature will result.

These values presented in Figure 3 in a graphical form suggest a possible analytical correlation: the required liquid-line temperature T_c^l as a function of the measured liquid pressure at the service valve p_l, and having as a parameter the required subcooling ΔT_i (temperatures in ^{o}C and pressure in MPa):

$$T_c^l = -2.1557 \cdot p_l^2 + 27.353 \cdot p_l - (1.0013 \cdot \Delta T_s - 11.951)\,. \tag{2}$$

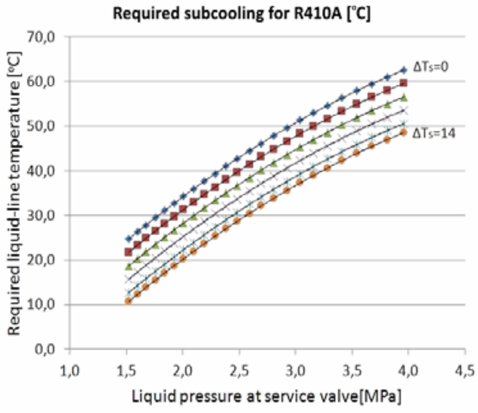

Fig. 3. *The required liquid-line temperature correlated with the liquid pressure at service valve and having the subcooling as a parameter for R-410A*

A similar correlation can be noticed for R-22 refrigerant, as shown in Figure 4.

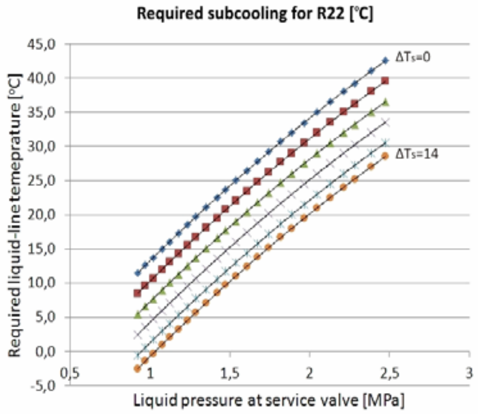

Fig. 4. *The required liquid-line temperature correlated with the liquid pressure at service valve and having the subcooling as a parameter for R-22*

The same equation (2) applies for R-22 refrigerant but the pressure range is lower for R-22 compared with R-410A refrigerant.

Considering a zero-value for the subcooling parameter the required liquid-line temperature as a function of the liquid pressure at service valve is presented in Figure 5 for both refrigerants R-22 and R-410A.

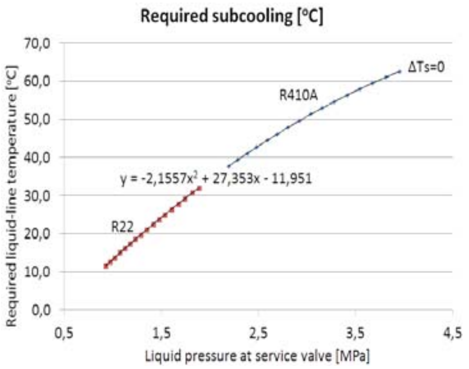

Fig. 5. *The same correlation exists for both refrigerants R-410A and R-22, except the liquid pressure range (having for R-410A)*

As a general rule the required subcooling for R-410A refrigerant is 5±1.5 ^{o}C.

3.2. Adding or removing refrigerant

The low-side float, automatic expansion valve, and thermostatic expansion valve system are not sensitive to the amount of refrigerant in the system but the high-side float systems and capillary tube systems are very sensitive to the amount of refrigerant charge. For the last ones a correct refrigerant charge is very important [1].

When the right amount of refrigerant is not indicated by the manufacturer recommendation several practical methods may be used to determine whether the refrigeration system has enough refrigerant.

A sure way to determine if the system has sufficient refrigerant is to put a sight glass in the liquid line. The appearance of vapor bubbles in the glass is a sign that the system is short of refrigerant. It should be charged until the vapor bubbles disappear.

A proper charge is best indicated by the frost on the evaporator. When frost starts to come down the suction line, a little of the refrigerant has to be purged out for a correct charge of the system.

Besides these empirical methods a more precise method to determine the correct charge of the refrigerant results from the correlation ahead presented.

Adding or removing refrigerant in/from the system result when comparing the existing temperature on the liquid-line with the calculated value by means of the equation (2):

- If the measured liquid-line temperature $T^l_{c,m}$ is 1.5 $^{\circ}$C higher than its calculated value $T^l_{c,c}$ (resulted from the equation (2) for the measured liquid-pressure at service valve p_l, and for the required subcooling ΔT_s) than refrigerant must be **added** to the refrigeration system in order to lower this temperature.

- On the contrary, if the measured liquid-line temperature $T^l_{c,m}$ is 1.5 $^{\circ}$C lower than its calculated value $T^l_{c,c}$ (resulted from the equation (2) for the measured liquid-pressure at service valve p_l, and for the required subcooling ΔT_s) than refrigerant must be **removed** from the refrigeration system in order to raise this temperature.

The required subcooling ΔT_s as the difference between the liquid-line temperature after the condenser $T^l_{c,}$ and before the service valve $T^l_{s,}$ is determined by the liquid pressure p_l and by the refrigerant charge.

4. Proper Evaporator-Coil Leaving Air Dry-Bulb Temperature

In evaporator air-cooled refrigeration systems heat from the conditioned spaces or from products is carried to the evaporator by air circulation. When air circulation is inadequate, heat is not carried from the products or conditioned spaces to the evaporator at a sufficient rate to allow the evaporator to perform at peak efficiency or capacity. It is important also that the circulation of air is evenly distributed in all parts of the cooled space and over the coil. Poor distribution of the air circulating can result in uneven temperatures and dead spots in the air conditioned space. Uneven distribution of air over the coil surface causes some parts of the surface to function less efficiently than other and lowers evaporator capacity and efficiency.

When air velocity is low, the air passing over the coil stays longer in contact with the coil surface. More heat is removed and is cooled with a greater range. Thus, the temperature differential increases, the refrigerant temperature decreases, resulting in a loss of capacity and efficiency because the rate of heat transfer is lowered. As air velocity increases, a greater quantity of air is brought into contact with the evaporator coil. Consequently, the temperature differential decreases, the refrigerant temperature increases, resulting in a gain of capacity and efficiency because the rate of heat transfer is increased. Therefore air volume change across the coil will increase or decrease the refrigerant temperature [2].

4.1. Indoor entering air temperature

If a proper evaporator-coil leaving air dry-bulb temperature is desired then the fan speed must be adjusted in accordance with the indoor entering air dry-bulb temperature and its relative humidity (or indoor entering wet-bulb temperature). Resulted from practice the values presented in Figure 6 can be correlated in an analytical form.

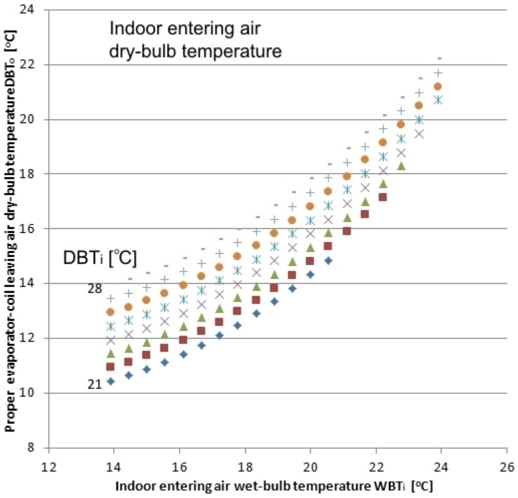

Fig. 6. *The proper evaporator-coil leaving air dry-bulb temperature* DBT_o *as a function of the indoor entering air wet-bulb temperature* WBT_i (*indoor entering air dry-bulb temperature* DBT_i *as a parameter*)

Referring to the evaporator in Figure 1 the dry-bulb temperature of the indoor air entering the evaporator (indoor entering air dry-bulb temperature) DBT_i, and its corresponding wet bulb-temperature (indoor entering air wet-bulb temperature) WBT_i will result in the evaporator-coil leaving air dry-bulb temperature DBT_o for a given fan-speed. The proper evaporator-coil leaving air dry-bulb temperature DBT_o can be calculated as a function of the dry-bulb, and wet bulb temperatures of air entering the evaporator DBT_i and WBT_i (in degrees Celsius):

$$DBT_{o,c} = 0.5 \cdot DBT_i \ + (0.049 \cdot DBT_i^2 - 1.02647 \cdot WBT_i + 4.7508)\,. \qquad (3)$$

The proper airflow can be evaluated for both refrigerants using Equation (3).

4.2. Adjusting the fan-speed

If the measured leaving air dry-bulb temperature $DBT_{o,m}$ is 1.5 °C (or more) lower than the above calculated temperature $DBT_{o,c}$, the fan-speed of the evaporator should be increased. If the measured leaving air dry-bulb temperature $DBT_{o,m}$ is 1.5 °C (or more) higher than the proper leaving temperature $DBT_{o,c}$, it is an indication of low capacity and the evaporator fan-speed should be decreased.

In practice this evaluation is called Target Evaporator Exit Temperature or shortly TEET.

To have a desired dry-bulb temperature of the air leaving the evaporator coil the fan-speed must be adjusted in correlation with the temperature of the air (dry-bulb and wet-bulb) flowing over the evaporator.

4. Conclusions

The appropriate charge of refrigerant in a vapour compression system used for air conditioning is one of the conditions for its correct operation. The amount of refrigerant to be added or removed in/from the system is indicated by the measured temperature at the exit of the condenser and by the required subcooling. The analytical correlation worked out in this paper and resulted from the practice is a tool for this purpose.

Adjusting the speed of the fan flowing the air over the evaporator with more accuracy resulted from the equation deducted in this paper based on values from practice is the second condition for an improved operation of the air conditioning system.

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