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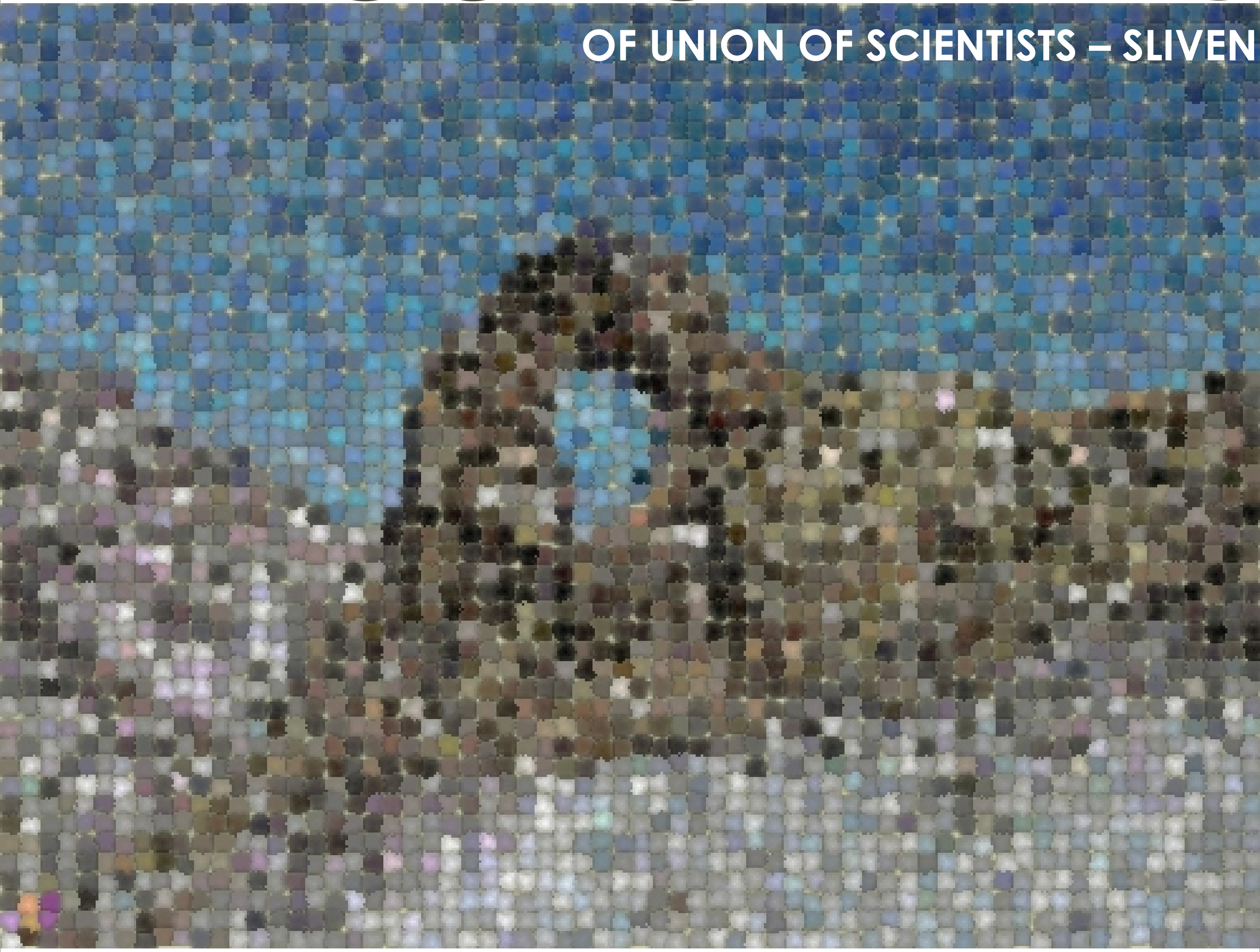

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# ANNOUNCEMENTS
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✓ Social and Healthcare sciences
Natural sciences

Списание

# ИЗВЕСТИЯ НА
# СЪЮЗА НА УЧЕНИТЕ –СЛИВЕН

в областта на

**Технически науки**
✓ **Социални и медицински науки**
**Естествени науки**

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Националната конференция с международно участие
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на ТУ – София, ФАКУЛТЕТ И КОЛЕЖ - Сливен*

# СЪДЪРЖАНИЕ

## Социални и медицински науки

# INVESTIGATION OF THE INFLUENCE OF SUB-COOLING THE LIQUID REFRIGERANT AGENT AT THE OPERATION OF A ONE-STAGE REFRIGERATION MACHINE

**Konstantin KOSTOV, Neven KRYSTEV**

***ABSTRACT:*** *Increasing the energy efficiency, respectively the refrigeration coefficient of a refrigerating machine can be accomplished by sub-cooling the liquid refrigerant. In practice, water cooling and regenerative principles are applied, in which the spent work remains the same as in the non-sub-cooling cycle. When cooled with water, the temperature and amount of cooling water have a significant effect on the efficiency of the refrigerator. In the presence of large quantities of cold water, the condensing temperature can be significantly lowered, thus reducing the cycle work. However, in practice, the required amounts of low temperature water are not always available. Therefore more often in practice applies sub-cooling the liquid refrigerant in regenerative principle. Therefore more often in practice applies sub-cooling the liquid refrigerant in regenerative principle. By incorporating a regenerator after the evaporator into the refrigeration system, the liquid refrigerant is cooled by the cold vapour leaving the evaporator.*

***KEYWORDS:*** *single-stage compressor refrigerating machine, sub-cooling, irreversible losses from throttling*

## INTRODUCTION

Refrigeration technology has as its main task the artificial production of cold, which is currently most widely used in the food industry, for refrigeration, storage and transportation of food products.

In the food industry, refrigeration plants are the main consumers of energy (primarily electrical), which, depending on the production technology, can reach 60-70% [1, 2]. On the other hand, the energy consumption of refrigeration installations is relatively constant, unlike technological facilities, due to the need to maintain stable temperature conditions. Therefore, the profitability of the production is to a large extent dependent on the energy efficiency of the refrigeration plants. Knowledge of the processes for obtaining artificial cold helps to reduce energy costs and modernize existing facilities.

In recent years, with a view to reducing energy consumption, much of the research has focused on improving energy efficiency by introducing innovative designs in refrigeration. Analysis for optimizing the performance of refrigeration cycles based on thermodynamic parameters have been reviewed by a number of authors [3, 4, 5, 6, 7]. Other authors introduce new criteria for evaluating the performance of refrigeration cycles [8, 9, 10], with the aim of proposing new models, seeking to optimize thermodynamic cycles, and obtaining results that are closer to the actual operation of refrigeration installations.

## ANALYSIS OF VAPOR-COMPRESSION REFRIGERATION CYCLE

According to the second law of thermodynamics, entropy of a closed system, which is not in equilibrium, increases with time, reaching its maximum value when equilibrium is reached? Therefore, the transfer of heat from a lower temperature body to a higher temperature body can only take place if some compensating positive process is introduced which will lead to an increase in the entropy of the system. For the offsetting process, such a circular process may be selected to result in the addition of a certain amount of heat to the environment.

Since in the circular process the change in internal energy is zero ($\Delta u = 0$), according to the first principle of thermodynamics it can be written:

$$\Delta q = \Delta u + l \qquad (1)$$

$$\Delta q = l = T\Delta s \qquad (2)$$

$$\Delta s = \frac{\Delta q}{T} \qquad (3)$$

It follows from equation (3) that in order to transfer a quantity of heat from a body with a lower temperature, it is necessary to consume minimal work, which is transferred to the environment in the form of heat.

Applying the second law of thermodynamics, it is possible to optimize complex thermodynamic systems [11, 12].

The criterion for the economy of the reversible circular process is the coefficient of performance (COP), which expresses the attitude into specific cold-production to the expended specific work [13, 14, 15].

$$COP_R = \frac{Q_L}{W_{net.in}} \qquad (4)$$

In the Carnot reversible circular process, the refrigeration coefficient can also be expressed by absolute temperatures:

$$COP_{R,Carnot} = \frac{1}{\frac{T_H}{T_L} - 1} = \frac{T_L}{T_H - T_L} \qquad (5)$$

The work consumed in this case is minimal and inversely proportional to the refrigeration ratio:

$$W_{net,in} = \frac{Q_L}{COP_R};\ kJ/kg \qquad (6)$$

The COP value does not depend on the type of working body, but is a function of the absolute temperatures TH and TL only.

In Carnot's theoretical reverse process, it is assumed that the temperature differences in the processes of heat exchange between the refrigerant and the environment on the one hand and between the refrigerant and the refrigerated environment, on the other, are infinitesimal.

In real refrigerating machines, the evaporation and condensation processes take place in the presence of significant temperature differences with the respective media. This leads to the irreversibility of the circular process, i.e. to increase the cost of operating the refrigerator. Determination of temperature differences and hence the temperature regimes at which a refrigerating machine will operate should be based on a technical and economic analysis of the energy efficiency of the latter [16, 17, 18, 19].

In order to reduce to some extent irreversible losses from the throttling process, it is necessary to cool the liquid refrigerant after the condenser before entering the regulating valve, the purpose being to reduce the vapour content after the regulating valve [21, 22].

In practice, sub-cooling can be accomplished by using the refrigerant vapour leaving the evaporator via a regenerative heat exchanger before the regulating valve. The liquid refrigerant coming from the condenser passes through the inner tubes of the regenerative heat exchanger, and the vapour flowing from the evaporator flows into the interstitial space [23] and or by incorporating a water-refrigerant exchanger into the refrigerator system.

## EXPERIMENTAL SET-UP

A single-stage refrigerating machine stand was created for the experiments - figure 1. A refrigeration unit was used to make the stand AC45B3E. The machine is medium temperature with working volume 45 см3, refrigerant R134a, with three-phase power supply 380/440 V and thermostatic valve. The electric power of the compressor is 1100W. The compressor flow rate is 75 dm3/min. Realized scheme is a direct evaporation air condenser.

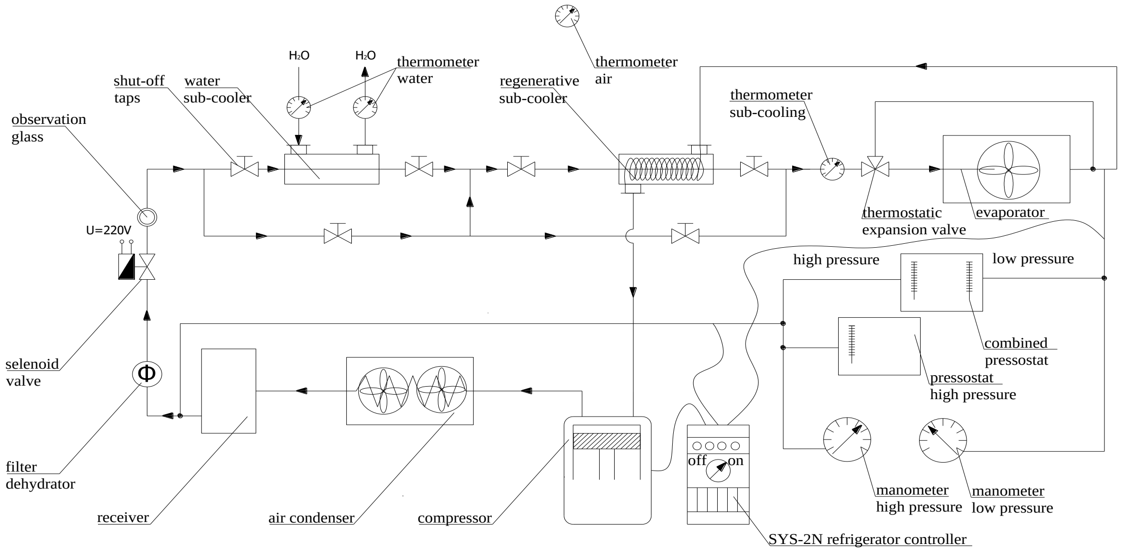

**Figure 1.** Laboratory stand of single-stage refrigerating machine

The stand is designed with two sub-coolers – water and regenerative, which allow for four different modes of operation:

- Without sub-cooling the liquid refrigerant;
- By sub-cooling the liquid refrigerant in the water sub-cooler;
- By sub-cooling the liquid refrigerant in the regenerative sub-cooler;
- By sub-cooling the liquid refrigerant in the water and regenerative sub-cooler.

## EXPERIMENTAL PROCEDURE

In order to determine the effect of the different refrigerant sub-cooling methods, tests were carried out on the operation of the refrigerating machine at constant condensation temperature TH and constant condensation pressure PH, maintained through SYS-2N refrigerator controller.

The mode is established and controlled by the readings of thermometers measuring the respective temperatures.

After entering the laboratory stand in a stationary mode (constancy of measured temperatures and pressures, or deviations of not more than 2% during measurements), 5 consecutive simultaneous measurements of the values are made at intervals of 3 minutes. The results of the measurements are given in a table.

The following values are measured to determine the effect of sub-cooling on the operation of a single-stage refrigerating machine:

☐ Using pressure gauges:
- evaporation pressure PL, bar;
- condensation pressure PH, bar.
- evaporation temperature, TL, ºC;
- condensation temperature, TH, ºC;

☐ Using temperature gauges:
- ambient temperature Tair.ºC;
- water temperature from the water network Twater ºC;
- temperature of the sub-cooled liquid in front of the thermostatic expansion valve T sub-cooling, ºC;

During the experiments, pressure and temperature readings are monitored through a data collection system. In the laboratory, by an air conditioning system to maintain the temperature of the environment Tair = 28°C ±0,5°C.

The measured values of the magnitudes necessary for analysing the operation of the refrigerator are presented in tabular form. The experiments were performed with repeated repetition, the averaged values of the measured values from all the experiments performed are presented in Table 1

**Table 1.** The measured values of the magnitudes necessary

| magnitude | $P_L$ | $P_H$ | $T_L$ | $T_H$ | $T_{air}$ | $T_{water}$ | $T_{sub-cooling}$ |
|---|---|---|---|---|---|---|---|
| dimension | bar | bar | $^0C$ | $^0C$ | $^0C$ | $^0C$ | $^0C$ |
| without sub-cooling | | | | | | | |
| | 3,2 | 13 | 2 | 50 | 28 | | 50 |
| sub-cooling the liquid refrigerant in the regenerative heat exchanger | | | | | | | |
| | 3,2 | 13 | 2 | 50 | 28 | | 41 |
| sub-cooling the liquid refrigerant with water | | | | | | | |
| | 3,2 | 13 | 2 | 50 | 28 | 21 | 35 |
| sub-cooling the liquid refrigerant with water and regeneration | | | | | | | |
| | 3,2 | 13 | 2 | 50 | 28 | 21 | 30 |

## UNCERTAINTY ANALYSIS

Physical measurements are characterized by statistical uncertainties. In physics, the measured value is assumed to have some well-defined value, but the imperfection of the measuring instruments and the presence of small differences in the conditions of the measurement itself cause random deviations. In the absence of information on the true value of a quantity, its estimation in the measurement process can only be made to the nearest magnitude of the interval at which a certain value can be expected to emerge - the uncertainty interval of the result [24]. Table 2 shows the measuring instruments used with their accuracy class.

**Table 2.** Instrument specifications

| Measured parameter | Measuring device | Make | Range | Accuracy | Relative Uncertainty, % |
|---|---|---|---|---|---|
| Temperature | sensor NTC | Testo | -50 to+150 °C | ±0,2 °C | 0,74 |
| Evaporator Pressure | Pressure Gauge with Glycerine | Refco<br>M1-250-R134A | -1 to 10 bar | 1,5% | 1,23 |
| Condenser Pressure | Pressure Gauge with Glycerine | Refco<br>M2-250-R134A | 0 to 30 bar | 1,5% | 1,17 |

## RESULTS AND DISCUSSION

Using the values of Table 1 are graphically build processes in lgP–h diagram, from which the enthalpy values at the characteristic points of the process for each mode of operation of the single-stage refrigerating machine are taken into account.

After plotting the processes in lgP–h diagram according to [13] the values of COP, are presented in Table 3.

For specific cold production qL by the equation:

$$q_L = h_{1'} - h_4;\ kJ/kg \qquad (7)$$

For specific energy consumption (work) for compressing 1kg of steam into the compressor by equation:

$$w_{net,in} = h_2 - h_{1'};\ kJ/kg \qquad (8)$$

For COP by the equation:

$$COP = \frac{q_L}{w_{net.in}} \qquad (9)$$

**Table 3.** Calculated values for COP

| magnitude | $h_1$ | $h_{1'}$ | $h_2$ | $h_3$ | $h_{3'}$ | $h_4$ | $h_{4'}$ | $q_L$ | $w_{net,in}$ | COP |
|---|---|---|---|---|---|---|---|---|---|---|
| dimension | kJ/kg | kJ/kg | kJ/kg | kJ/kg | kJ/kg | kJ/kg | kJ/kg | kJ/kg | kJ/kg | |
| without sub-cooling | | | | | | | | | | |
| | 398,36 | | 427,91 | 271,42 | | 271,42 | | 126,94 | 29,56 | 4,29 |
| sub-cooling the liquid refrigerant in the regenerative heat exchanger | | | | | | | | | | |
| | | 402,99 | 433,22 | | 257,66 | | 257,66 | 145,36 | 30,43 | 4,78 |
| sub-cooling the liquid refrigerant with water | | | | | | | | | | |
| | | 402,99 | 433,42 | | 248,75 | | 248,75 | 154,25 | 30,43 | 5,07 |
| sub-cooling the liquid refrigerant with water and regeneration | | | | | | | | | | |
| | | 402,99 | 433,42 | | 241,46 | | 241,46 | 161,53 | 30,43 | 5,31 |

Based on the experimental data obtained for the COP value, depending on the applied sub-cooling mode, an increase of the system efficiency by 11% to 23% is observed. This is due to the greater amount of heat released through the condenser per kilogram of circulating refrigerant through the system. The low vapour content after the regulating valve due to sub-cooling causes the pumping of less refrigerant, which in turn will reduce the amount of time, the compressor has to operate to maintain the desired temperature. This, in turn, will reduce compressor wear and energy consumption.

## CONCLUSION

From a thermodynamic point of view, the COP depends only on the temperatures of the heat sources, therefore, as the temperature difference between them increases, the value of the COP will decrease:

$$COP = \frac{T_L}{T_H - T_L} \qquad (10)$$

When maintaining a constant temperature of evaporation and condensation, increasing the COP and reducing irreversible losses from throttling, in real refrigerators it can be achieved by sub-cooling.

The two considered sub-cooling modes show the impact of each one individually and their combined effect, such as a regenerative heat exchanger cycle, it has the following advantages:

- guarantees dry running of the compressor;
- there is no need to install an additional heat exchanger and the need for water;
- the heat exchanger surface of the evaporator works more efficiently since it is almost completely filled with liquid refrigerant - the percentage of money after throttling is lower;
- external losses of cold in the suction pipeline are reduced as the vapours exiting the regenerative heat exchanger are at a relatively higher temperature.

The combination the two for sub-cooling methods is most appropriate, but the need for water must be emphasized and whether it is economically feasible to use water sub-cooling.

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