VACUUM - EVAPORATIVE REFRIGERATION AND ICE GENERATION INSTALLATIONS

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ABSTRACT

Last years a lot of attention is being paid in refrigeration engineering to the problem of alternative refrigerants as substitutes of refrigerants that destroy the ozone layer and provoke an environment warming up. Some refrigerants suggested for this purpose namely R134a, R125 are badly compatible with existing refrigerating machines and oil lubricants used now; they are expensive and have a Global warming potential. As a result the role of natural substances as water, water solution rises steeply [1]. All such substances are low pressure ones and have a great volume of vapour under pressure of 1-25 mm Hg, so they can't operate with usual refrigeration compressors. A vacuum-evaporative refrigeration installation was developed at the department of refrigeration of Moscow State University of Engineering Ecology. It may cool down liquids such as water, water-containing liquids from warm state down to 0°C. Also it is possible to freeze water to the ice state and turn it into slurry. This installation consists of the main vacuum pump with at high speed pumping, the auxiliary vacuum pump of oil type, the shell and the tube condenser and the evaporator. The manner of operation of the installation is given, as well as some results of test and theoretical analysis of the process are discussed.

1. INTRODUCTION

In modern refrigeration engineering much attention is paid to the problem of alternative refrigerants as substitutes for a long row of refrigerants deteriorating ozone layer of atmosphere or causing warming effect in environment. Some refrigerants suggested for this purpose for example R134a, R125 and others are badly compatible with existing refrigeration systems as well as with oil lubricants used now. Most of these substances are expensive and have a global warming potential. A lot of retrofits prepared as mixtures are advertised now in literature, but they are also expensive and may be affected even by a small leakage changing their composition. Besides, charging procedure of these mixtures is quite complicated. As a result, the role of natural substances as water, water - alcohol solutions is raised. All of them are low pressure substances and, having a great volume of vapour under low pressure, they can't be operated with usual refrigerating compressors because of their small volumetric speed and inability to create pressure of 1 - 25 mm Hg. At the department of Refrigeration of Moscow State University of Engineering Ecology a special vacuum - evaporative refrigeration installation had been developed. It can be used for cooling liquids such as water, milk from warm state down to 0°C. It is possible also to freeze water into ice and turn it into slurry.

2. THE PRINCIPLE OF OPERATION

The installation consists of the main vacuum pump, the shell and the tube condenser and the evaporator. It operates in the following manner (Figure 1). At the start air is pumped out of the system into atmosphere with the help of an auxiliary vacuum pump “d”, after this the main vacuum pump “b” is getting into action. It produces the bulk of work forcing H_2O vapour into the condenser, where vapour is turned into liquid being cooled by external water. While pumping vapour moisture out of the evaporator vessel the process of water boiling is going on and the temperature of water is reduced.

Greater is volumetric speed of pumping of the main vacuum pump, more is cooling effect of the water. There are several types of vacuum pumps which can be used as the main machine: Roots vacuum pumps, oil sealed rotary piston vacuum pumps, oil sealed rotary vane pumps, multi blades rotary pumps. Roots type vacuum pumps, which have no lubrication of rotors, and the lowest energy consumption per unit of out pumped gas load, are preferable. They are commonly used in industry and are easy in servicing. Mostly the speed of rotation is 3000 rev/min, and it provides a wholly satisfactory cooling capacity per unit. As the auxiliary vacuum pump we usually use a rotary oil sealed machine, its volumetric speed is much less than that of the main machine one. Our investigations have shown that the Roots rotary vacuum pump is a quite effective oil trap, which protects the evaporator from oil pollution. The vacuum refrigerating installation was equipped with a vertical cylindrical vessel having a removable cover sealed with rubber ring. The volume of the vessel is 300 1. Water vapour after the main vacuum pump is introduced to the shell and the tube condenser being cooled by water.

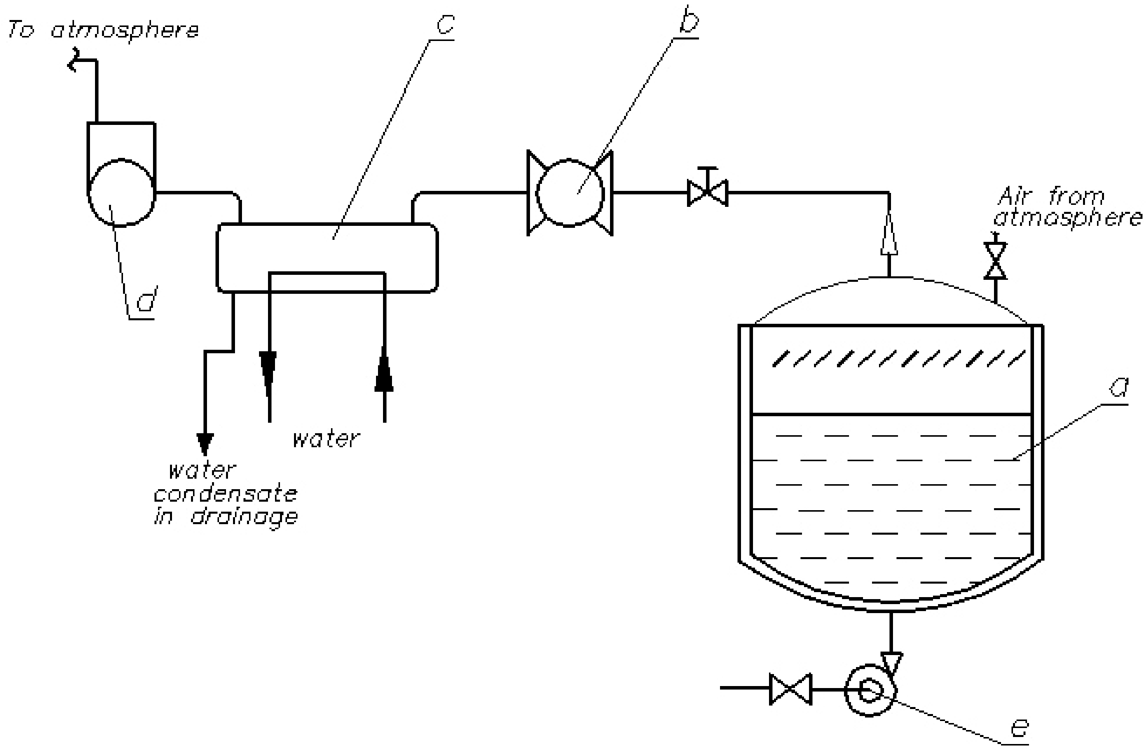

Figure l: The flowsheet of the vacuum-evaporative installation. a. Evaporator vessel. b. The main vacuum pump. c. Shell and tube water condenser. d. Auxilliary vacuum pump. e. Water or milk pump.

3. THEORETICAL ANALYSIS

Any liquid is cooled within hermetically sealed cylinder. The vapour volume of this system is pumped out at effective speed S m^3/s. The amount of liquid m_0 and its initial temperature t_S are known. The kind of liquid is defined by a molecular mass μ and a specific heat coefficient C_{Ps}.

The properties of the vessel wall, its specific heat coefficient C_P and material density are also known.

Our previous knowledge about process based on laboratory experiments proved the validity of some assumptions which are as follows:

- the temperature of the vessel wall and of the liquid in it is the same as the process is going on;
- the ambient heat flux transferred to the liquid through the wall is negligible (the vessel has a heat insulation layer);
- mass of the liquid is not changing as the process is going on;

- the latent heat of evaporation is constant, r_S=const;

The amount of heat dQ extracted from the mass of the liquid m_0 and the material mass of the vessel wall m when their temperatures are reduced by an elementary step dT can be expressed by the formula

$$dQ = (C_{Ps} \cdot m_0 + C_P \cdot m)dT \quad (1)$$

This heat flux is created by the effect of vacuum water evaporation. The cooling capacity of it dQ_0 is

$$dQ = r_s \cdot dm \quad (2)$$

Where dm – is an elementary mass of the liquid vapour pumped out of the hermetically sealed vessel in a short period of time $d\tau$

The latter depends on the vacuum pump speed S and the density of the vapour being pumped ρ''_S. In view of it the heat balance equation in the differential form is formulated as

$$(C_{Ps} \cdot m_0 + C_P \cdot m)dT = S \cdot r_S \cdot \rho''_S \cdot d\tau \quad (3)$$

The parameters ρ_S" can be expressed by a well known Mendeleev–Klaperon correlation

$$\rho_s" = \frac{P \cdot \mu}{R \cdot T} \quad (4)$$

For water, as the most wide spread substance, vapour pressure P is approximately expressed vs temperature as follows

$$P = 609e^{0,07(T-273)} \quad (5)$$

It is valid for the range of temperature from 40 down to +3ºC.

Putting this in eq. (4) and the latter into differential heat balance eq.(3) we have

$$(C_{Ps} \cdot m_0 + C_{Pw} \cdot m)dT = \frac{S \cdot r_S}{RT} \cdot \mu \cdot 609e^{0,07(T-273)} \cdot d\tau \quad (6)$$

This equation can be solved by separation of variables. Integrating each term, we secure[2]

$$\tau = -\frac{(C_{Ps} \cdot m_0 + C_{Pw} \cdot m)R \cdot e^{273b}}{r_{ё}\mu SAb}\left[-e^{-bT_{释}}\left(T_{释}+14,28\right) + e^{-bT}\left(T \;\; +14,28\right)\right] \quad (7)$$

Where T_K, T_H – are the temperatures at the end of the process (the desirable temperature) and the temperature of water at the start of the process respectively; A=606.5 ;b=0.07 - they are constants for water.

Eq. (7) can be used for an engineering calculations when designing vacuum evaporation installations.

4. THE RESULTS OF TESTS

The installation was tested on water and milk as working fluids. The results of tests were presented in

Figure 2.

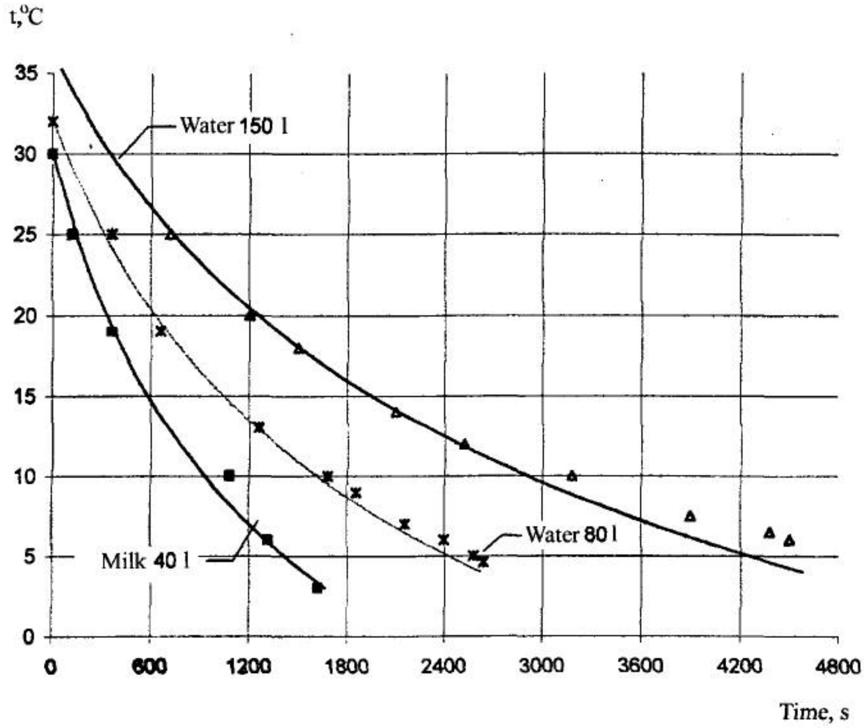

Figure 2. The results of the tests.
Solid line - theoretical data. Points – tests data.
Volumetric speed of the main vacuum pump - 150 l/s

As can be seen from Figure 2 the experimental points and theory lines are in a good compliance.

5. VACUUM ICE GENERATORS

Vacuum methods of liquid cooling and freezing open the way to create new more effective types of ice generators. The feature of existed ice generators operating on refrigerating compressors is that heat transfer between a boiling agent and water is going on through an ice layer which increases with time. A heat transfer resistance of the ice layer is raised with time and usually is the main reason of heat transfer losses in system. This drawback may be overcome if the cooling surface is moved from the inside of the ice layer to the outside of it. Then the cooling surface will be going on with the ice layer as the process is developing. Such a method permits to exclude the negative influence of an ice layer heat transfer resistance and to increase heat effectiveness of the installation. Actually the manner of operation of the vacuum ice generator is close to that of the vacuum-evaporative refrigerating machine. The difference is that in the ice generator water is supplied to the evaporator in a batch process through the nozzles and is freezing up there layer after layer.

6. CONCLUSIONS

- A special vacuum-evaporative refrigerating installation using water as a refrigerant was set up at the laboratory of Moscow State University for Engineering Ecology.
- Roots type rotary pumps are quite suitable for such installations.
- The theory of the process proposed in this paper can be considered as a basic procedure for designing vacuum-evaporative refrigerating installations.

REFERENCES

1. Paul, J. 1994, Water as Alternative Refrigerant, *Proc. Hanover Conference,* IIF/IIR: 97-108.
2. Marinuk B., Krysanov K., 2005, , Vacuum-evaporative water cooling installations. *Kholodilnaya Tekhnika* (10)*:* 30-31.