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# CONCEPT OF AUTOMATIC CONTROL SYSTEM FOR IMPROVING THE EFFICIENCY OF THE ABSORPTION REFRIGERATING UNITS

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*Annotation:* *The general concept of the automatic control systems constructing for increasing the efficiency of the artificial cold production process in the absorption refrigerating units is substantiated. The described automatic control systems provides necessary degree of the ammonia vapor purification from the water in all absorption refrigerating units modes and minimizes heat loss from the dephlegmator surface.*

Key words: Absorption refrigerating unit, dephlegmator, energy efficiency, automatic control systems.

## 1. INTRODUCTION

Artificial cold is a priority way to long-term storage of food products. At stable temperature conditions it allows to maintain their initial properties without significant changes [1-3].

There are two main sources of the artificial cold: compression (CRU) and absorption (ARU) refrigerating units. The main advantage of the CRU, which leads to their wide dissemination, is high energy efficiency. However, ARU also has a number of advantages. But their major drawback is higher, in comparison with the CRU, energy consumption [4-6].

Existing automatic control systems (ACS) of CRU and ARU have a common drawback. They provide only stabilization of the temperature in the cooling chamber and traditionally implement the simplest positional control algorithms [4-8]. Such algorithms cause considerable amplitude of the cooling chambers temperatures oscillations (autooscillations) and, as a static, displacement of the average value of these oscillations from their set values. All of this eventually leads to a reduction in the quality of products stored therein.

It is important that the implementation of such ACS in ARU requires a significant limitation of generating unit heater’s power. Otherwise it will be impossible to provide the necessary degree of the ammonia vapor purification from the water in the dephlegmator at its inclusions. But even such a targeted reduction in the power of the heater does not guarantee the complete cleaning of ammonia in all possible modes of ARU, first of all – in transient, and especially – during start. It leads to a significant increase in the time of transients instead, which is another factor aggravating the conditions of products storage.

Analysis of the main directions of solving the problem of improving the energy efficiency of ARU has shown that the proposed options associated with changes in the ARU design, in particular related to the improvement of thermal insulation, have almost been depleted [9-11]. At the same time, to the direction associated with the improvement of ACS of artificial cold production process in the ARU has not been given a proper attention [12-14]. However, this direction has important advantages: the solutions obtained in the framework of this direction are generic for all types of ARU and can be implemented not only at the design stage of new models but also during the modernization of already issued since they do not modify the ARU construction.

Thus, improvement of the energy efficiency of the artificial cold production process and improvement of the conditions of food products storage in ARU by improving their ACS are actual tasks.

## 2. ANALYSIS OF THE ARTIFICIAL COLD PRODUCTION PROCESS IN THE ABSORPTION REFRIGERATING UNITS AS A CONTROL OBJECT

Development of the general concept of building the efficient ACS of artificial cold production process in ARU requires a preliminary analysis of this process as control object.

ARU consists of: electric heater, generator, liquid heat exchanger, strong and poor water-ammonia solution (WAS) conduits, rectifier, thermal insulation casing of the generator unit, descending and lifting sections of the dephlegmator, condenser, evaporator, absorber and receiver of strong WAS. The essence of its work (with an emphasis on the problem considering here) can be reflected by the following phases.

*Generation of ammonia vapor from a strong WAS.* When supplying sufficient heat to the bottom of the generator with the help of electric heater, ammonia, located in strong WAS, begins to boil. Bubbles that are produced include ammonia vapor (mostly) and water vapor. Bubbles, having lift force, rise to the top of the generator, separating the ammonia from WAS and dragging along its liquid phase particles. Over time, the entire height of the generator to the level $h_2$ is being filled with the vapor-liquid pillar, consisting of vapor bubbles and liquid particles. In the upper part of the generator, above the level $h_2$, the liquid is separated from the vapor, its surplus is merged into the upper part of the absorber and the vapor goes to the descending section of the dephlegmator.

*Purification of ammonia vapor from the water vapor.* Its essence is contained in the cooling of the ammonia and water vapor that are moving along the dephlegmator in order to condense water vapor due to the lower temperature of ammonia condensation. Cooling goes sequentially starting from the descending section of the dephlegmator – by heat dissipation through its side, in rectifier – by heat removal to a strong WAS, in the lifting section of the dephlegmator – by heat dissipation through its side (with varying intensity, depending on the presence and the efficiency of the insulation).

Condensate of water flows into the rectifier. Vapor-liquid front (VLF) defines the boundary between vapor mixtures and the pure ammonia vapor. The height of VLF lift is proportional to the energy consumption supplied to the generator.

*Cold production.* In the condenser, due to heat loss through its ribbed wall, the temperature of the ammonia vapor is further decreased, and it goes over into a liquid state. The liquid ammonia drains into the evaporator where there is the ammonia steam-gas-hydrogen mixture containing mainly hydrogen. When contacting the intense evaporation of the liquid ammonia into the gas-vapor mixture at low partial pressure and accordingly at a low temperature (–35 °C to –15 °C) takes place. This results in the cooling of the evaporator surface and associated with it cooling chambers.

Certainly, as in the existing ACS, the main controlled variable here is the temperature in the cooling chamber $\theta_{CC}$. Additionally, the prospects for using in ACS the information about the surface temperature of the heating element $\theta_H$ and the position of VLF level that defines the boundary between the pure ammonia vapor and water vapor in the dephlegmator $h_f$ are considered. The main control variable is maintained the value of the thermal power supplied to the generator P ($u_1$) and also it is offered to use the intensity of heat removal from the surface of dephlegmator ($u_2$). As controlled perturbations the ambient air temperature $\theta_{AT}$ and line voltage $u_{line}$ potentially could be considered, as uncontrollable perturbations – product characteristics and a degree of cooling chambers loading W, constructional $\psi_C$ and operational $\psi_{OP}$ features.

Features of ARU properties known a priori are the follows:

1) ARU are static objects with a high thermal inertance and a delay in the main control channel;

2) properties of control channel "thermal power supplied to the generator – temperature in the cooling chamber " are significantly non-linear;

3) maximum energy efficiency of ARU is achieved when the VLF level reaches the limit height of dephlegmator. In this case, complete clearance of ammonia vapor from the water is achieved and heat loss from the surface of dephlegmator is minimized.

It is important to note that in existing ACS the level VLF is not controlled and there are following situations that could reduce the energy efficiency of ARU:

1. In the conditions of intensive thermal power supply to the generator, in the modes of ARU withdrawal from idle state to the workload and /or high ambient temperature, the VLF level could exceed $h_f^{max}$. Herewith, water or water vapor will enter the condenser and, further, to the evaporator. The heat which is brought there with water vapors and, most importantly, which are produced during their condensation significantly reduce the energy efficiency of ARU.

2. In the conditions of a weak thermal power supply to the generator, in the modes of long term storage of products and /or low ambient temperature, the VLF level will be significantly less than $h_f^{max}$. In this case, ammonia vapor will be supercooled which leads to their partial condensation in the dephlegmator and to the reduction of supply to the condenser and evaporator. This also reduces the energy efficiency of ARU.

Thus it is clear that minimizing of ARU energy consumption requires maintaining the VLF level in the maximum proximity to the maximum permissible level $h_f^{max}$. Herewith, the value of this "maximum proximity" is defined as the limit setpoint ($h_f^{LS}$) of VLF level with a guaranteed probability of its non-infringement on the time interval $T^h$ – $P_{\bar{s}}^{g}(h_f^{max}, T^h)$ and current probability characteristics of changes of the variable $h_f(t)$:

$$h_f^{LS}(t) = h_f^{max} \mp \hat{\sigma}_{h_f}(t)\left|\sqrt{2\ln\left|\frac{T^h \hat{\sigma}_{\dot{h}_f}(t)}{2\pi\hat{\sigma}_{h_f}(t)\ln P_{\bar{s}}^{g}(h_f^{max}, T_{qs}^{h})}\left\{\exp\left(-\frac{\hat{m}_{\dot{h}_f}^{2}(t)}{2\hat{\sigma}_{\dot{h}_f}^{2}(t)}\right) \mp \frac{\sqrt{2\pi}\hat{m}_{\dot{h}_f}(t)}{\hat{\sigma}_{\dot{h}_f}(t)}\Phi\left(\frac{\hat{m}_{\dot{h}_f}(t)}{\hat{\sigma}_{\dot{h}_f}(t)}\right)\right\}\right|}\right|, \qquad (1)$$

$\hat{\sigma}_{h_f}$, $\hat{\sigma}_{\dot{h}_f}$, $\hat{m}_{h_f}$, $\hat{m}_{\dot{h}_f}$ – current estimates of the RMS deviations of VLF level $h_f(t)$ and its rate of change $\dot{h}_f(t)$, its mathematical expectation which are calculated on the sliding time intervals.

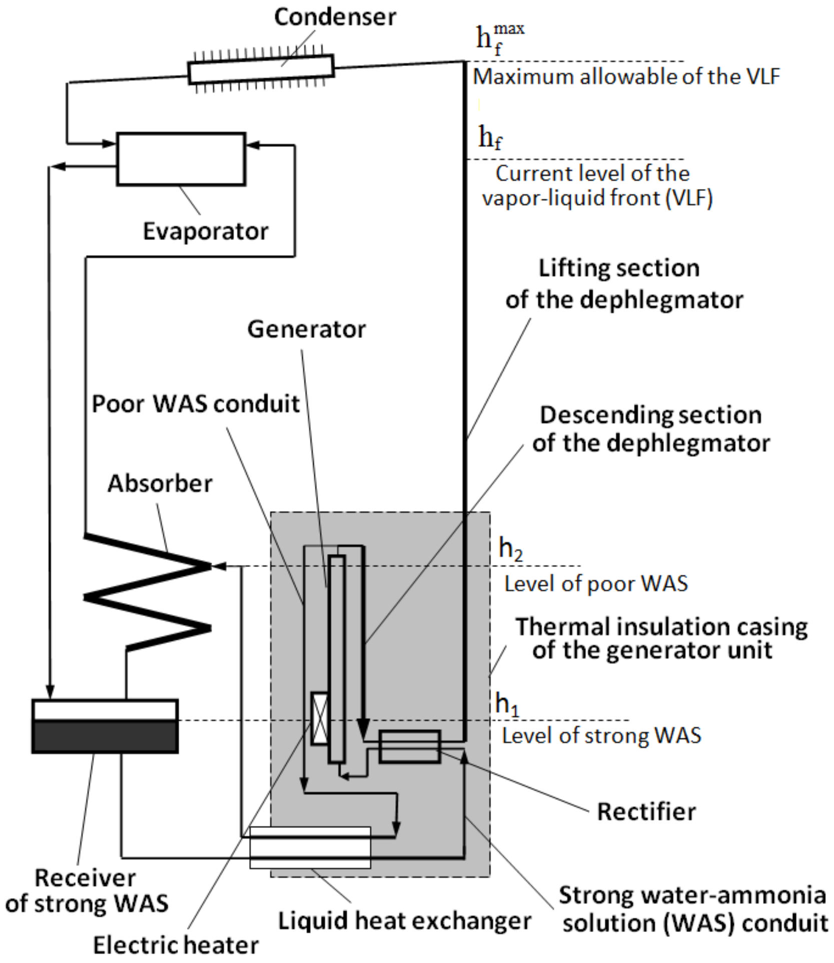


**Fig. 1 – ARU scheme**

## 3. CONCEPT OF ENERGY EFFICIENT AUTOMATIC CONTROL SYSTEMS OF THE ABSORPTION REFRIGERATING UNITS

Taking into account the discussed features of ARU as the control objects, a concept of effective ACS of ARU, which implies two tasks decision in this ACS, is suggested:

1) improving the quality of the implementation of a regulatory function (at steady and transient modes), i.e. increasing the dynamic accuracy of the cooling chambers temperatures stabilization;

2) implementation of a new function in ACS – optimization function which minimizes energy consumption of ARU in changing operating conditions.

The main "mechanisms" for realization of this concept are:

- shift from positional control algorithms to continuous;
- increasing the intellectual level of control algorithms by expanding the use of the control information about the process, in particular – of the VLF level position in the lifting section of the dephlegmator;
- implementation of the new functions – optimization of energy efficiency and compliance the limitations on the process parameters;
- implementation of a new control channel – control of the intensity of heat removal from the surface of the dephlegmator lifting section into the environment.

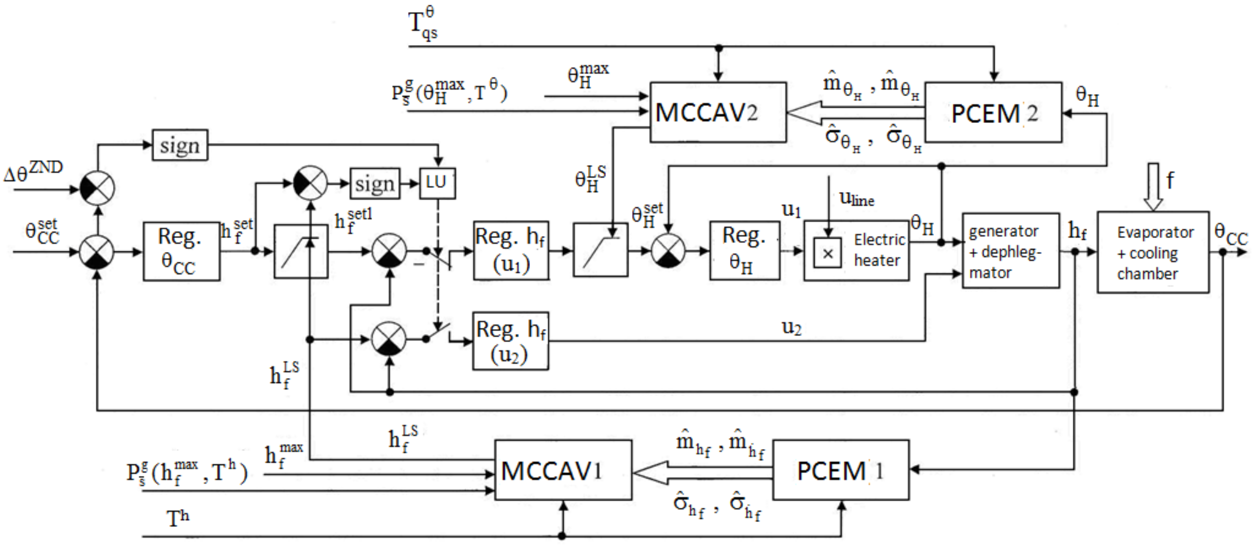
Structural diagram of the ACS implementing this concept is shown in Fig. 2. It has two switchable control channels:

1) traditional, control variable – changes in the thermal power supplied to the ARU generator;

2) new, control variable – changes in the intensity of heat removal from the surface of the dephlegmator lifting section into the environment.

## 4. CONCLUSION

The described ACS of ARU with the switched structure allows to provide optimal storage conditions of food products in the chambers and to increase energy efficiency without violation to the ARU basic elements operation. Due to the operation of two channels stabilization of the VLF level $h_f(t)$ on its set value is possible as well as limitation of the surface temperature of the heating element $\theta_H$ during start of ARU. Selection of the control channel is carried out automatically based on the current situation, in particular, the fluctuations of the thermal power intensity supplied to the generator and ambient air temperature. The control variable for the first channel is the changing the thermal power supplied to the ARU generator and for the second – the changing the intensity of heat removal from the surface of the dephlegmator lifting section into the environment. Implementing of such a system requires obtaining in real-time accurate information about the current value of the VLF level that is difficult to organize in practice. Technically, the simplest solutions are related to the  measurement of temperatures of the dephlegmator external surface.



*PCEM – Probability Characteristics Estimation Module for random processes $h_f(t)$ and $\theta_H(t)$ on a swept time interval T; MCCAV – Module for Calculating the Current Allowable Values* $h_f^{LS}(t)$ *u* $\theta_H^{LS}(t)$ *; LU – logical switch controller of ACS structure*

**Fig. 2 – Structural diagram of ARU's ACS with the switched structure**

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