Results from testing heat-recovery accumulator

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Abstract. Many different sources are used for obtaining and supplying heat, which do not require immediately fuel combusting. However, as a rule, such sources do not allow independently controlling an amount of heat to be supplied, while heat consumption is an independent process. Matching heat production and consumption curves is usually done using heat accumulators. Heat-recovery accumulator for utilizing waste-gases heat of a small-capacity power station was developed, fabricated and tested. To exclude superheating of the accumulator working fluid, a system of “thermodynamic” self-controlling of heat utilization was applied. The tests conducted confirmed the rated characteristics of the developed heat-recovery accumulator, as well as a reliability of self-control system.

Introduction

There are many sources of heat, which do not require fuel combustion. First of all in this context, we can point out waste heat of electricity-production or industrial technological installations. In addition, presently renewable energy sources are widely used for producing heat. A specific peculiarity of producing useful heat from these sources is a need in providing heat supply rate that differs and does not depend on the current heat input to the source. For example, if we utilize waste heat of the electricity generating installation, heat supply can be realized only if there is a demand for electricity. A decrease in electricity demand leads to reducing heat supply up to fully shut-up. Heat-demand curves do not match electricity-consumption curves. Similar problems exist when using renewable energy sources. In the case of solar energy application, in day time at bright weather there is much available energy, while at bad weather there is a lack of energy, or it is absent at all. One of ways to solve this problem is using heat accumulators. When developing heat accumulators, it is very important to correctly choose a heat-accumulating substance. The substance chosen must have maximally possible specific heat capacity within a required temperature range. The best results are obtained if the chosen substance undergoes phase changes in this temperature range. For example, for the temperature range from 50 to 80°C, common paraffin is a very promising substance. Another very important problem for heat-accumulating systems is proper controlling the heat-accumulation process. Let consider the case, where the heat source supplies heat independently of the current state of the accumulation system. Then the following situation will be inevitable. With fully charged heat accumulators, the heat supply from the heat source can create an emergency regime, that is,
superheating and destruction of the device. It is evident, that a corresponding system is needed that would switch-off the energy source from the fully charged heat accumulator.

**Heat-recovery accumulator design**

AO “Scientific and Production Enterprise “LEMZ” in collaboration with the Joint Institute for High Temperatures of the Russian Academy of Sciences have developed a heat-recovery accumulator, which is designated for using at independent objects that operate at complex climatic conditions without a presence of servicing personnel [1]. Figure 1 shows heat-recovery accumulator principle layout. Heat-recovery accumulator 1 is connected to the heat source by inlet and outlet ports 2 and 3, through which heating gas is inputted and removed, respectively. In the heat exchanger a secondary coolant is evaporated. In the tests conducted, isopropyl alcohol was applied as the secondary coolant. Through pipe 4 the alcohol vapor enters into heat accumulator 5, where it condenses and the condensate is returned to the accumulator heat-exchanger through the pipe 6. The accumulator is filled by substance 7 that undergoes a phase change in the required temperature range. Paraffin was used as a substance that undergoes the phase change within a temperature range from 60 to 70°C. The heat accumulator has air channels 8, through which air is pumped and then supplied to a consumer. In the secondary-coolant circuit there is expanding tank 9. From below, by pipe 10, the expanding tank is connected to the bottom point of pipe 6 that returns condensate to the heat-exchanger.

![Figure 1. Principle layout of heat-recovery accumulator.](image)

When the secondary coolant is heated up to the boiling temperature, the vapor of the secondary-coolant starts expelling the liquid phase into the expanding tank. The expanding tank is a hermetic reservoir that is partially filled by air. The secondary-coolant liquid phase, which comes to the tank, reduces the volume occupied by air thus increasing a pressure in the secondary coolant system. An amount of the vapor phase is determined by a correlation between heat transfer rates in the evaporator and the condenser. But the governing factor is the condensation temperature, which directly depends on the heat-accumulating substance temperature. As the latter temperature increases, the condensation temperature and pressure also increase. Figure 2 shows the equilibrium dependence of the condensation pressure on the condensation temperature for isopropyl alcohol.
The higher the accumulating substance temperature, the higher the pressure in the secondary-coolant system and the more an amount of the liquid phase that is expelled into the expanding tank. At a certain temperature all the liquid is displaced into the tank. Due to the absence of the liquid phase boiling is ceased in the heat exchanger. The secondary-coolant vapor is heated practically up to the heating gas temperature, but there is no driving force that would transfer this vapor to the condenser. Therefore, the heat exchange in the heat-utilizing unit reduces down to zero. However, if the temperature in the accumulator drops a little, the pressure in the secondary-coolant system will decrease also, and the air cushion (as an air spring) will return part of the liquid phase to the evaporator. The evaporation and condensation processes will be recovered until the temperature in the condenser reaches the limited value. The temperature, at which the accumulator heating is stopped, depends on the ratio of volumes of the expanding tank and entire secondary-coolant system, as well as on an amount of the secondary coolant in the system. A temperature regime of the system self-controlling process can be adjusted by changing the amount of the coolant.

**Testing experimental accumulator model**

The experimental model of the heat-recovery accumulator was designed, fabricated, and tested. The model used the waste-gases heat of a small electricity-generating unit (working gases flowrate is 0.2 kg/s at a temperature of 600°C). The rated heat accumulator capacity is 200 MJ. During the tests, diesel power plant of 30 kW was used as a heat source. The tests were conducted at an ambient air temperature of minus 3°C. The diesel unit operated at such a power, at which the capacity of waste gases was equal to 22 kW. Heat was permanently consumed from the accumulator and it depended on accumulator temperature. The average value of the energy consumed was 6 kW. During the tests a temperature of the accumulating substance and a pressure of the secondary coolant were monitored. Figure 3 shows a change in the accumulating substance temperature in time.

**Figure 2.** Equilibrium dependence of the isopropyl alcohol condensation pressure on the condensation temperature.
At the first moment (the time is counted off from taking the given power by the diesel engine) a temperature of the accumulating substance was 3°C. The solid line shows the calculated temperature value at the assumption of uniform heating of the accumulating substance. The points show the experimental temperature values. The temperature gauge was removed from the condenser and located near the air channels. It is apparent that due to poor thermal conductivity of the accumulating substance in a solid state its heating proceeds rather nonuniformly. This is clearly seen while considering a significant difference between the measured and calculated temperature values at time intervals, where theoretically the solid state exists (the sections with the calculated temperature being less than 70°C). After the moment, when the accumulating substance is transformed into the liquid form, convective flows are formed in it, which efficiently mix the substance. This fact is confirmed by a good agreement of the calculated and experimental values at temperatures above 70°C.

A pressure in the secondary-coolant circuit characterizes well the processes that occur in the heat exchanger and condenser. Until the secondary coolant is not being heated to the boiling temperature (the circuit was filled at the atmospheric pressure – 100 kPa, the boiling temperature of the isopropyl alcohol at this temperature is 82.4°C), the pressure in the circuit will be equal to 100 kPa. Figure 4 shows the change in the secondary-coolant pressure in time. The curve represents equilibrium pressure that corresponds to the condensation temperature, which is equal, in turn, to the calculated temperature of the accumulating substance. The dashed line shows the equilibrium pressure less than 100 kPa (the pressure in the circuit can not be less than 100 kPa). The points correspond to experimental values. Less than 10 min were required for heating secondary coolant up to the boiling temperature (at the five hundred second the pressure reaches 150 kPa). After this, during 1.5 h the pressure evenly grew to 180 kPa. Such a pressure value corresponds to a condensation temperature of about 95°C. During the following hour the pressure dropped a little to 165 kPa and remained at that level for another hour. Then an intense increase in pressure up to more than 300 kPa was observed. After 300 kPa a rate of pressure changing dropped sharply and it stabilized at a level of 330 kPa up to the moment of the diesel-engine shut-down. After the diesel-engine was stopped, the pressure dropped

**Figure 3.** Change in time of the accumulating substance temperature.
quickly. Already after 0.5 h it decreased to 250 kPa and after another 1.5 h reached atmospheric pressure (100 kPa).

![Dependence of the secondary-coolant pressure on accumulator operation time](image)

**Figure 4.** Dependence of the secondary-coolant pressure on accumulator operation time.

Such an evolution of the secondary-coolant pressure can be explained as follows.

- Initially, when both the evaporator and the condenser of the secondary-coolant circuit are filled with liquid phase, all heat, which enters the heat-recovery unit, is used for heating the secondary coolant. The rate of secondary-coolant heating completely corresponds to the utilized power;
- When the secondary coolant is heated to the boiling temperature and starts boiling, the secondary-coolant vapor presses out the liquid phase from the condenser and intense heating of the accumulating substance starts due to condensation of the secondary-coolant vapor. Because the accumulating substance has a low conductivity, all the heat inputted is localized near the condenser heating surface and the heating surfaces themselves are heated to temperatures, which are considerably greater than the melting temperature of the accumulating substance;
- When a considerable part of the accumulating substance is transformed into the liquid phase, the heat transfer process in the condenser enhances and the condenser heat-transfer surface temperature decreases, thus approaching the melting temperature of the accumulating substance;
- When the entire accumulating substance is transformed into the liquid phase, its temperature starts growing rapidly: the condensation temperature and pressure of the secondary coolant grow, respectively;
- The pressure of 300 kPa is close to the value that takes place when the entire secondary-coolant liquid phase is pushed-off to the expanding tank and a rate of evaporation is reduced.
rapidly due to a lack of the liquid phase. The rate of heat transfer from the heating gases to the accumulating substance falls respectively and accumulating substance heating ceases;

- After the diesel is shut-down, the secondary-coolant temperature is unambiguously determined by the temperature of the accumulating substance. When the latter decreases to $82^\circ$C the entire secondary-coolant vapor phase condenses and the pressure falls to 100 kPa. When this happens, only 20% of heat stored in the accumulator is spent.

The heat balances have shown that with the heat source capacity of 22 kW and the heat consumption capacity of 6 kW the charging capacity of the completely discharged heat accumulator is 12 kW. Taking into account the fact that the heating gases cannot be cooled lower than the accumulating substance temperature, the available capacity of the heat source is 19.5 kW. Thus, the efficiency of heat utilizing at completely discharged accumulator is 92%. While reaching a definite temperature (self-control temperature), accumulator charging fully ceases, and an amount of the utilized heat fully corresponds to an amount of the consumed heat. The self-control temperature can be finely adjusted by changing the secondary-coolant mass.

**Conclusion**

The tests conducted completely confirmed the designed technical characteristics of the heat-recovery accumulator developed. The reliable operation of the self-controlling device was confirmed also and the possibility of finely adjusting the self-control temperature was demonstrated. The obtained efficiency of heat utilization at completely discharged accumulator was more than 90%. As the accumulator charge increases, the rate of heat utilization decreases and becomes equal to the heat consumption rate at completely charged accumulator.

**References**

[1] Kosoi A. S., et al. *Sistema podogreva ustanovki s teplovym dvigatelem* [Heating system of the installation with thermal engine]. Patent RF, no. 2641775, 2016