Analysis of the energy efficiency of the implementation power electric generated modules in the CHS

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Abstract. Application on the Central heat source (CHS) local generation of electricity is primarily aimed at solving problems of own needs of electric energy that not only guarantees the independence of the work of the CHS from external electrical networks, but will prevent the stop of heat supply of consumers and defrosting heating networks in case of accidents in electrical networks caused by natural or anthropogenic factors. Open the prospects of electric power supply stand-alone objects, such commercial or industrial objects on the territory of a particular neighborhood.

1. Introduction

One of the areas of work using low-grade heat is to develop power plants of low power (10-100 kW). Similar installations are in full compliance with the modern concept of decentralized electricity and can be used as autonomous power supply of country houses, small villages, remote from electricity grids industrial facilities, as well as auxiliary energy sources for autonomous objects. This article discusses and analyses the effectiveness of the inclusion of such installation is part of the Central Heating Station (CHS).

2. Analysis of the energy efficiency of the implementation power electric generated modules in the CHS

In Fig. 1 shows a schematic circuit of a power electric generating module (ELGM), consisting of the utilization heat exchanger, micro-turbines, regenerative heat exchanger and condenser, part of Central Heating Station (CHS).

The essence of the present technical proposal is to use the temperature potential of the direct network of water, coming to the transit center from the CHS to generate electricity and exhaust heat in the condenser to be used for heating cold water entering the heat water system.
RHE – recycling heat exchanger Freon\ Water; T - Micro turbine; G – Generator; R - Regenerator; P – pump; C– condenser.

**Figure 1 – schematic diagram of the inclusion of the power generating module to CHS**

Figure 2 shows the T,S - the coordinates of the configuration for the basic cycle ELGM on the selected substance (octafluorocyclobutane RC318 (C4F8)) according to the recommendations of works [1-3], of the following processes:

1-2d - The process of expansion of the refrigerant vapor in the micro turbine;
3-4’ - Isobaric process of cooling and condensation of freon in the turbine exhaust steam;
4’-5 - The process of compression (pump work);
6-1 - Isobaric process of heat supply in the RHE;
2d-3 - The process of cooling the heating medium by heating the liquid in a 5-6 in the regenerator.
Figure 2 – Configuration of the thermodynamic cycle on octafluorocyclobutane C4F8

For a number of pressures: 1.5...8 MPa was calculated to select the optimum pressure at which the internal cycle efficiency is maximum. The dependence of the internal efficiency of the cycle from the pressure shown in figure 3. At a pressure of 1.5 to 3 MPa, it is possible to establish regenerative heater, which significantly improves thermodynamic efficiency. The calculation showed that the maximum internal efficiency of 15.63 %, is achieved when the freon pressure before the turbine, equal to 2.4 MPa. Thus the actual work of the pump is equal to the 1.57 kJ/kg, turbine 21.42 kJ/kg, heat of regeneration 31.28 kJ/kg; the heat supplied in the heat-recovery heat exchanger 127.0 kJ/kg of heat rejection in the condenser for heating make-up water of system of hot water supply (HWS) 107.15 kJ/kg.

Initial data for calculation of the configuration of the thermodynamic cycle to RC 318: p1=2.4 MPa; t1=120°C, internal relative efficiency of the turbine: 0.92; inner relative efficiency of pump: 0.88; the condensation temperature tc=30°C.

Figure 3 – Dependence of the cycle efficiency of the pressure, MPa
For the calculation of thermal schemes were selected CHS with the structure loads, the most suitable for the implementation of the power generating module, for efficient operation which requires the HWS load, because it assumes heat of condensation to transfer heat to cold water entering the heater first stage of the HWS. The characteristics of this CHS are given in table 1.

**Table 1 - Characteristics of loads CHS selected for implementation of power generating module**

| № CHS   | Heat load, Gcal/h | Heating, Gcal/h | HWS, Gcal/h | Ventilation, Gcal/h | Consumpion of network water, t/h | The warm pressure of network (bar) min. | The scheme of connection of the consumer | Temperature chart output from CHS, °C |
|---------|-------------------|-----------------|-------------|--------------------|---------------------------------|----------------------------------------|-----------------------------------------|-------------------------------------|
| 05-02-0204/072 | 1.9441           | 1.3239         | 0.6202      | 0                  | 32.4                            | P1=8.0                                 | Independent                            | 120-70                               |

The results of calculation of the main indicators ELGM in the composition of the CHS performed using in MathCad, is given in table 2.

**Table 2 - Thermal capacity of the basic apparatus power generating module as part of CHS**

| The name of the equipment | Characteristics, kW | The cost of the working medium, kg/s |
|--------------------------|---------------------|--------------------------------------|
| Turbine                  | \( N_T = l_m \cdot G = 63.92 \) | 2.98                                 |
| Regenerative heat exchanger | \( Q_{PT} = l_{pm} \cdot G = 93.66 \) | 2.98                                 |
| Capacitor                | \( Q_K = (h_3 - h_4) \cdot G = 319.3 \) | 2.98                                 |
| The recycling heat exchanger (RHE) | \( Q_{YTA} = q_{RHE} \cdot G_{nw} \cdot \eta_{RHE} = 379.0 \) | The flow rate of network water - 9 Freon pair of - 2.98 |
| Pump                     | \( N_p = 4.68 \)    | 2.98                                 |

Modernization of CHS by installing power generating modules will significantly reduce the cost of their operation. The modules will allow to completely refuse from buying expensive electricity needed to drive pumps, automatic operation etc. and to develop it directly on the CHS with high efficiency. In selected CHS in the consumption of network water \( G_{nw} = 9 \text{ kg/s} \) the electrical power of the module will be:

\[
N_{el} = N_T \cdot \eta_{mech} \cdot \eta_{eg} = 63.7 \cdot 0.98 \cdot 0.985 = 61.5 \text{ kW}
\]

\( \eta_{mech} = 0.98 \) - mechanical efficiency freon turbine,

\( \eta_{eg} = 0.985 \) - Efficiency electric generator

The expenses of heat for generation of electric power will be:

\[
\Delta Q = Q_{RHE} - Q_C = 379 - 319.3 = 59.7 \text{ kW}
\]

Thus, for power generation capacity of 61.5 kW must be expended to 59.7 kW of thermal energy network water. The flow rate of network water is 9 kg/s. The parameters of the cycle power generating module for all CHS remain unchanged, and therefore the electrical power depends on the
flow rate of network water. When flow rate $G_{nw} = 1 \text{ kg/s}$, the generated power will be: $N_{\text{specific}} = 61.5/9 = 6.83 \text{ kW/(kg/s)}$.

To generate electricity with a power of 1 kW it is necessary to expend thermal energy capacity:

$$q = \frac{\Delta Q}{N_{\text{eg}}} = \frac{59.7}{61.5} = 0.97$$

The total capacity of own needs of CHS, in which there is a HWS load (it is possible to install power generating module), will be

$$N_{\text{own needs}} = 40 \text{ kW.}$$

The required capacity of freon turbines to the own needs:

$$N_t = \frac{N_{\text{own needs}}}{\eta_{\text{mech}} \cdot \eta_{\text{eg}}} = \frac{40}{0.98 \cdot 0.985} = 41.4 \text{ kW}$$

Consumption of thermal energy for the full coverage of own needs of CHS:

$$Q_{\text{hs}} = N_{\text{own needs}} \cdot q = 40 \cdot 0.97 = 38.8 \text{ kW}$$

Taking into account heat losses in the network heaters to CHS:

$$Q_{\text{own needs}} = Q_{\text{hs}} / \eta_{\text{own needs}} = 38.8 / 0.98 = 39.6 \text{ kW}.$$  

3. Conclusions

The modules will allow to completely refuse from buying expensive electricity needed to drive pumps, automatic operation etc. and to produce it directly to CHS with a high degree of efficiency. Electric power of one module is equal to $N_{\text{eg}} = 61.5 \text{ kW}$, enough to cover their own needs $N_{\text{own needs}} = 40 \text{ kW}$ for HCS for the entire district and even stay over. Costs in the form of specific consumption of fuel (kWh) of electricity generated using ELGM can be equated to the specific costs of fuel for the production of the same units of heat, which for thermal power plants, calculated by the method [4], is assessed on the value of the reference fuel consumption is 3.6 times less. It is this ratio, according to the authors, between the unit cost of electricity and heat is quite scientifically based.

As a result, the work was chosen as the optimum initial parameters of the working fluid ELGM, in which achieved the highest thermodynamic efficiency $p_1=2.4 \text{ MPa}$, $t_1=120^\circ \text{C}$, $t_c=30^\circ \text{C}$.

Low pressure in the circuit ELGM allows you to apply the most effective heat and mass transfer equipment – plate heat exchangers. Plate heat exchangers have large area, low metal content and high compactness, which allows to locate the whole module ELGM at the site of the transit center.

Thus, the introduction of power generating modules to CHS is an effective thermodynamic, technological and environmentally sound solution. The presence of ELGM in the composition of CHS not only savings in primary fuels, but also prevents the consequences of emergency situations when a power outage in a peak period of heat supply in connection with sharp fall of temperature of external air possible freezing of pipes and battery systems of a heat supply of residential and administrative buildings.

References

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[4] 9.0 REFPROP: Reference Fluid Thermodynamic and Transport properties: Copyright 2007 by the U. S. Secretary of Commerce on behalf of the USA.