Researching of the possibility of using absorption heat exchangers for creating the low return temperature heat supply systems based on CHP generation

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Abstract. This paper deals with the variant of modernization of the heat point within urban heat supply network in order to create the system of heat and cold supply on its basis, providing the suppliers with heat in cold months and with heat and cold in warm months. However, in cold months in the course of heating system operation, the reverse delivery water temperature is maintained below 40 °C. The analysis of heat and power indicators of the heat and cold supply system under different operating conditions throughout the year was conducted. The possibility to use the existing heat networks for the cold supply needs was estimated. The advantages of the system over the traditional heat supply systems that use Combined Heat and Power (CHP) plant as a heat source as exemplified by heat supply system from CHP with ST-80 turbine were demonstrated.

1. Introduction
While addressing the energy saving issues, a special attention should be paid to the complex use of fuel and energy resources based on energy-saving cogeneration and especially on trigeneration power supply systems. The climatic conditions of the Russian Federation are characterized as follows: long-term heating season with a high design heating load on heat supply because of sufficiently low design temperature of the outside air during the heating season (-25 °C for Moscow city), which results in the necessity to use a great number of heat-radiating equipment and lay a significant amount of high-level and distributing heat supply networks (using the centralized heat supply model). At the same time, the atmospheric temperature may exceed +30 °C in warm months, which results in significant cooling load on the air conditioning system. It is well known that a combined generation of heating and electric energy at CHP is one of the most energy-efficient ways of centralized energy supply to the consumers [1]. That is why the paper deals with CHP as a generating source. Two problems are considered.

On the one hand, a significant reduction of the heating load occurs in warm months because of termination of the heating period. It leads to the significant unloading of the heat extraction of the turbines, and even to their transfer to condensing mode of operation, so in this case, CHP as a source will begin to concede condensation power plant (CPP) in terms of effectiveness. At the same time in warm months, there appears a significant cooling load in air conditioning systems in public and administrative buildings. At present, vapor compression refrigerating machines are most often used for cold production, consuming a significant quantity of electric energy on compressor drive. The use of
absorption refrigerating machines is an alternative choice [2, 3]. The production of cold by means of the excess amount of heat in warm months can significantly reduce the electrical energy consumption for such purposes, besides there will appear a possibility to load the heating extraction of CHP.

On the other hand, an important problem is the limited transfer capacity of the existing heating networks in cold months, caused by the impossibility of further temperature increase of heating water and a heating medium movement rate [4]. It leads either to the necessity to lay the bigger diameter transmission lines or install the local heat supply sources, which in its turn means the abandonment of the combined generation.

From the economic and technological viewpoint, the distribution of the trigeneration system is considered to be promising [5]. The following model of the consumers’ provision will be regarded as the trigeneration systems using the absorbing heat-exchange apparatuses. Heating energy and electric energy are produced on a relatively big source in the combined cycle. In cold months the consumers’ heat supply for the needs of heating and hot water supply (HWS) is carried out through the system of high-level and distributing networks, the increased transmission capacity of the heating system is provided by means of operation of the absorbing heat transformer, functioning on the cycle of absorbing heat-exchange unit, installed on central heat distribution station (CHDS). However, in warm months, cold is generated on the same CHDS with the use of delivery of heat energy of networks water heat by means of the same absorbing heat transformer, which now works according to the cycle of absorption refrigerating machine. In such a way the offered decision to increase the energetic efficiency of the existing heat supply cogeneration system allows transferring the cogeneration system into the trigeneration one in warm months.

2. Distributing trigeneration system operating principle
The basic block diagram is shown in figure 1. It is important to note, that the greatest power-producing effect during the heating season will be received in the case of organization of a multi-level source heating of the delivery water. This owes to the fact that during the reduction of temperature of the reverse delivery water only in case of multi-level heating the weighted average pressure value in heating extractions of CHP may be reduced, which in turn will lead to additional electric energy generation by the extraction steam, and consequently, to the increase of the source cycle efficiency factor. Currently, two-level delivery water heating is the most common method.

During the heating season, the system operates as follows. The delivery water is being heated step by step by extraction steam of the turbine. Then it is delivered to absorption heat transformer (AHT), installed on central heat distribution station, operating according to the absorption heat exchanger (AHE) cycle. Some part of delivery water heat should be used for heating cold water for HWS system. It may lead to some overheating of the reverse delivery water after AHT. However, as long as the HWS system load often does not exceed 15 – 20% of the heating system load the increase will be insignificant. Besides, it is possible to preheat cold water in absorber and condenser, which will significantly decrease the amount of delivery water required to heat HWS. The reverse delivery water after AHT returns to the source. According to the published data in AHT, operating based on AHE cycle, in case of sufficient temperature of the heating water it is possible to reduce the temperature of the reverse delivery water to 25 – 40 °C, which will lead to the possibility to transfer by 60 – 90% more heating load with the same amount of the delivery water consumed [6,7]. This will also allow increasing the amount of combined cycle electric energy.

In warm months the system operates in a different way. AHT operates according to the absorption refrigerating machine cycle, producing cold from heating water warmth, that is why one fails to achieve the low value of delivery water temperature within this period, moreover, it will have sufficiently high value, which is stipulated by the need to maintain the required generation temperature. This problem to a certain extent may be solved by means of multi-level AHT apparatuses layout scheme, in particular, some sources state that the temperature of the reverse delivery water in the scheme with a three-stage generator for the absorption refrigerating machine cycle is 55 °C, while the temperature in the supply pipeline is 95 °C (according to Lessar company data for example).
Nevertheless, the negative effect of the reverse delivery water temperature increase will be compensated by the positive effects. Firstly, the heating extractions of the turbine on the source will be loaded. Secondly, for cold production, there will be used not the electric energy but heating energy, the expenditures of the electric energy for the operation of AHT will be minimum in comparison with those of vapor-compression machines. Actually, in the electric power system, the percent of combined electric energy generation will increase and the consumption of electric energy for the needs of cold supply will decrease.

To estimate the effects of implementation of the offered system it is necessary to evaluate the consumers’ load rate. The procedure for the calculation of heat consumption rate for the heat supply system during the heating season with the help of the heating load length diagram is unknown. Another knotty issue is the estimation of the cooling requirement for air conditioning systems and, correspondingly, the required quantity of heat for its production in the system under the consideration. The Russian Federation currently has no adopted method for calculation of the cold amount required during the warm months, the similar method for calculation of the required amount of warmth during the heating season. That is why it is necessary to offer the way to estimate this amount. The relation between the current heating load on the heating system $Q_t^h$ and design load $Q_{max}^h$ is as follows:

$$Q_t^h = Q_{max}^h \frac{t_{in} - t_{out}}{t_{in} - t_{min}}$$  \hspace{1cm} (1)

It is suggested to introduce the same relation between the current cooling load on the air conditioning system and design load, however, using its enthalpies instead of outside air temperature, because in warm months in case of significant air humidity a phase transition of water vapor starts affecting significantly the amount of the transferred heat.

$$Q_t^c = Q_{max}^c \frac{h_{out}^c - h_{in}}{h_{max}^c - h_{in}}$$  \hspace{1cm} (2)

The calculation results show that it makes sense to take the value of the outside air total heat $h_{out}^{max}$ not on the basis of normalized value of the design temperature and relative humidity, but on the assumption of the average climatic data of the region under consideration. In particular, according to the rate parameters, $h_{out}^{max} = 54 \text{ kJ/kg}$ for the Moscow region. At the same time in order to provide the air conditioning system with the cooling requirement within 98% of the warm months, the target value $h_{out}^{max}$ should be taken for 59 kJ/kg. This value was received by means of averaging out the climatic...
variables of the outside air based on outside temperature within a five-year period on the basis of the archival depository of one of the meteorological observing stations in the Moscow region. The number of hours of the outside temperature standing is shown in figure 2. There have been calculated the corresponding average values of the absolute humidity, water vapors bubble point pressure and outside air total heat.

**Figure 2.** Number of hours of the outside temperature duration in the summer season.

Such a value $h_{\text{out}}^{\text{max}}$ was selected, which would ensure the required cooling load within the specified percent of time in relation to the whole heating period. Based on the chosen $h_{\text{out}}^{\text{max}}$ and relation 2 for the building with a rated cooling load that is 1,000 kW, the required cooling loads within warm months as well as their duration were calculated. The results of calculations are shown in figure 3. Reasoning from this fact, it makes no difficulties to get the value of the required quantity of heat brought to AHT generator. In such a way, taking into consideration the amount of heat supplied in cold months calculated based on generally accepted methods and having in mind the increased transfer capacity of the heat network based on AHT operation according to the AHE cycle, the annual supply of heat from CHP extractions and, consequently, the annual electric energy generation based on heat consumption are calculated.

**Figure 3.** Required cooling loads (Qc) and their durations (n) within summer season.
3. **Maximum transfer capacity of the heat networks for cold production in warm months**

One of the problems is the limiting of the cold consumers’ circle, which can be connected to any of the heating units, in other words, one should have an idea of what AHT cold capacity may be provided when connecting it to the high-level heat supply networks.

The following estimation technique of the maximum possible cooling load in warm months with the use of the existing heating networks for the transportation of the warming heating medium to the ATT generator on the basis of the calculated heating load on heat supply system in cold period is suggested. Since the temperature difference in the existing heating network is a known value, then for the comparison, the temperature difference of the warming medium in AHT generator should be estimated. Usually, in the applied single-level AHT diagrams, it cannot be high because of the necessity to maintain the generation temperature on the required temperature level and is set to about 10 °C. On the other hand, in case of realization of the multi-level processes of heat-mass exchange it is possible to reach significant temperature differences [8], however, the temperature of warming heating medium on the outlet of the last generation level cannot be arbitrarily low, that is why it is desirable to limit it to a specified level. As a manner of AHT application experience, this temperature may be taken as such that is 75 °C. In such a way the theoretical temperature difference in the multi-level AHT generator is \( \Delta T_g = (\tau_t - 75) \) °C. The relation between the calculated heating and cooling loads is as follows:

\[
\frac{Q_1}{Q_2} = \frac{w_1 \rho_1 F_1 C_p_1 (\tau_1 - 70)}{w_2 \rho_2 F_2 C_p_2 (\tau_1 - 75) \varepsilon}
\]

where the parameters with index 1 are the parameters of the delivery water, which correspond to the calculated heating condition, the parameters with index 2 are the delivery water parameters, corresponding to the operating heating network condition in warm months for the provision of the cooling loading, \( \varepsilon \) – AHT transformation ratio. Since using one and the same mainland pipelines, it is impossible to reach a significant increase in speed of the heating medium in warm months, therefore \( w_1 \) is taken equal to \( w_2 \). Temperature conditions at the selected temperatures in the warm and cold period are close to each other, that is why the relationships of physical characteristics of the heating medium are virtually equal to 1, then:

\[
\frac{Q_1}{Q_2} = \frac{\tau_1 - 70}{(\tau_1 - 75) \varepsilon}
\]

Taking into consideration the fact that in heat extractions of the turbine the delivery water usually is not heated to more than 110 °C, and the value \( \varepsilon \) may be preliminary pre-assigned as such that is 0.7 for the considered conditions the theoretical value of \( Q_1/Q_2 \) ratio makes 1.63. The obtained relationship shows that the potential cooling load, which can be generated when using the existing heating network, is 1.63 times less than the heating load, generated by the same network. It should also be kept in mind that the calculated load on refrigeration supply for the particular object does not coincide with the calculated load on its heating and in some cases may significantly increase it. The calculation results of ratio \( Q_1/Q_2 \) for different \( \varepsilon \) and \( \Delta T_g \) are shown in figure 4.

![Figure 4. \( Q_1/Q_2 \) ratio value for different conditions.](image-url)
Based on the above-mentioned information it is possible to estimate the cooling load the heat network pipeline of a specified diameter may provide. The calculations show that, for example, the pipeline with the internal diameter that is 400 mm is able to provide the cooling load that is 37.7 MW at the temperature difference in the generator of 25 °C. Figure 5 shows the calculation results of a possible cooling load.

![Possible cooling load depending on the supplying pipeline diameter.](image)

**Figure 5.** Possible cooling load depending on the supplying pipeline diameter.

We may conclude that the use of the existing heating networks for the transportation of the warming heating medium to AHT is promising and may provide some part of potential consumers with cold. Cold consumers (administrative and public buildings) most interesting for the distributed trigeneration system are those located in residential areas, which is typical for the building system of the city of Moscow. On the assumption of the well-known loading on the heat supply, using the received $Q_1/Q_2$ ratio it is possible to quickly estimate the possibility of cold supply system creation based on AHT in case of connection to the existing heat supply unit.

4. **Distributed trigeneration system performance evaluation in case of use of CHP with two-stage delivery water heating as a source**

Different types of CHP or boiler houses are usually used as the heating sources for the heat delivery systems. As it was mentioned before, the greatest system effect can be reached while using CHP with two-stage water heating as a source, as long as in such case there will take place the increase in electric energy generation based on thermal input with the decrease of the reverse delivery water temperature. Let us consider CHP with ST-80 in more detail. It has one industrial and two heat extractions. There is an analytical dependence, which connects the generator output of a turbine and heating load in extractions. For the first approximation, the crucial role with an allowance for heating load effect has the pressure value in the upper heat extraction. The pressure in the high-stage bleed point of the ST-80 turbine is 0.08 – 0.12 MPa. The analytical dependence is as follows [9]:

$$N_t = 0.542 \frac{Q_t}{(0.12p_t)^{0.14}} + 0.301Q_t \left(\frac{1.3}{p_t}\right)^{0.34} - (11.6 - 0.217Q_t) \quad (5)$$

Therefore, having determined the increase in heating load by reducing the reverse delivery water temperature there may be estimated the augmentation of the electric energy generation based on heat consumption for different pressure values in the upper heat extraction.
Figure 6. Taken under heat consumptions, electric power values \(N_t\) depending on the reverse delivery water temperature \(T_2\).

The calculations show that in case of increasing heat release from heat extractions of the ST-80 turbine by 10 MW the increase in electric energy generation will be 7.5 – 7.8 MW depending on the pressure in the high-stage bleed point. The effect from such changes in the system will be as follows: the average value of the thermal power plants efficiency factor in Russia makes about 38%, which corresponds to the heat rate of 0.3237 kg of c.f./kW∙h. According to the data published within the period from 2013 to 2015 specific reference fuel consumer for electric energy generation at CHP of Moscow made 0.2326 - 0.2409 kg of c.f./kW∙h. In such a way during the heating season in case of substitution of every kW∙h of electric energy, omitting for the present the condensing power station, on additionally generated kW∙h of electric energy on CHP there is saved at least 0.0911 kg of c.f./kW∙h. During the summer season, fuel consumption for the production of the equivalent amount of fuel, cold and electric energy will decrease due to increased generation of combined electric energy and heat consumption, rather than the electric energy for the cold generation. The savings value may reach up to 318.7 MW∙h of electrical energy per year based on the materials given in [10] in case of providing the consumer with 1,000 kW of the cooling load with the help of the above-considered system.

5. Conclusions

Thus, the distributed trigeneration system based on AHT, operating in two modes was considered. During the heating season, AHT operates in AHE mode in order to ensure the highest temperature gradient of the delivery water in heating networks. During summer season, AHT operates in the absorption refrigerating machine mode for provision of consumers with cold by means of the heat energy of networks water. Each operation mode of AHT ensures a significant increase of electric energy combined generation on CHP, which results in fuel saving in the system for the generation of the equivalent quantity of heat, cold and electric energy. Besides, during the heating season, the transfer capacity of the heating networks increases, which allows to serve more consumers. Similarly, in the summer period, a decrease in the electric energy consumption for cold supply needs to provide providing more consumers with cold.

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