Energy efficiency of an absorption thermotransformer with two-stage absorption as part of a heat and cold supply complex based on a gas boiler house

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Abstract. The article proposes a scheme for using a lithium bromide absorption thermotransformer (LBATT) with two-stage absorption for deep utilization of the heat of combustion products (CPs) of gas boilers. At the same time, this solution allows heating the district heating systems return water in the cold season. In the warm season, LBATT is used to cool the water of the air conditioning system or process equipment cooling. In this case, heat removal from LBAHT with two-stage absorption in the warm season is carried out using a drycooler. The analysis of the effectiveness of the use of LBATT in the cold and warm seasons is carried out. The theoretical transformation coefficient of LBATT with deep utilization of flue gases reaches 1.72. The theoretical thermal coefficient of LBATT when cooling water in the warm season reaches a value of 0.7.

Introduction

The main sources of low potential waste heat are recycling water supply systems engineering and industry and combustion gases in boiler houses. Recovery of combustion gas heat (including hidden) is one of the essential types of energy saving and saving of burning fuel, which also includes environmental effects, realized by reducing the emission of nitrogen oxides and other harmful gases. For these purposes, it is advisable to use thermal transformers (TT). The main purpose of TT in relation to the generation of thermal energy: heating water for the needs of hot water supply and heating of residential, industrial and public premises with the synchronous utilization of waste low potential heat. In the heat power industry, LBATT are mainly used, since this allows to much increase the efficiency of plants when production thermal and electrical energy [1, 2]. In many industrialized countries, LBATT used as part of heat supply systems [3]. In the warm season, when there is no heating, it is advisable to use LBATT for cooling water in air conditioning systems. Thus, the complex with LBATT is used all year round. Significant opportunities for using LBATT are based on the following advantages, such as: energy efficiency, high reliability and low noise level, affordable service, a useful life of at least 25 years.

1. Use of LBATT as part of a heat and cold supply complex

The refrigerant LBATT is water, the absorbent is an aqueous solution of lithium bromide. Steam, hot water, exhaust and natural gas considered to be heat sources of LBATT. The ability of an aqueous solution of lithium bromide to absorb water vapour at a lower temperature relative to the solution is the basic operation principle of LBATT. Thus, a low-potential heat can be transferred up to a higher temperature level which is suitable either for discharge into the atmosphere
(chiller - LBAC) or can be used to heat water (heat pump - LBAHP). Thus, the LBAC is designed to cool the liquid (water mostly) in the evaporator, and the LBAHP – for sequential heating of the liquid (water mostly) in the absorber and condenser. Working processes in LBATT are proceeded at an equilibrium pressure of water vapour under conditions of significant vacuum, which excludes the ingress of LBATT working fluids both into the atmosphere and into external heat carriers (cooled liquid, heated liquid, and heat source).

The analysis for the operation of gas boiler houses shows that efficient way to reduce the fuel consumption coefficient (FCC) are deep chilling (below the dew point) of exhaust gases with the use of condensation heat-exchangers (CHex). Deep cooling the flue gases by about 2–4 °C in the CHex will reduce the FCC by about 1%. In addition to cooling the exhaust gases, the use of CHexs allows to reduce the emission of nitrogen oxides into the environment [4]. Depending on the excess air ratio, the dew point (dew point) CPs ranges from 45 to 55 °C. For deep and efficient use of heat, CPs must be cooled below the dew point temperature given above. While cooling and condensation of CPs, sensible heat (up to 40–45% of the total heat content of CPs) and latent heat of condensation of water vapor are recovered. The vapor content of CPs is approximately up to 13% by weight.

Due to the typical dew point temperatures, and taking into account the irreversible losses (temperature difference), the return water from the heating system must have a temperature at the inlet to the CHex not exceeding 40 °C, which is achievable at outdoor temperatures above 8 °C.

When the outside air temperature is below 8 °C and above "minus" 10 °C, the return water temperature of the heating system rises steadily, which, at certain values, makes it impossible to deeply utilize the heat in CHex.

For a gas boiler plant, a serious disposal problem can be solved by using LBAHP-based heat pump units (HPUs), which are an intermediate link between the heating return water and CHex and provide the required temperature of the water entering the CHex (is about 40 ° C) while simultaneously heating the return water of the heating system.

However, it should be noted that during the heating season, when the outside air temperature is significantly lower than "minus" 10 ° C, there is practically no possibility of increasing the temperature in order to heating the return water of the heating system using LBAHP. This is mainly due to the high temperature of the return water from the heating system, which is dependent on the ambient temperature: the lower the ambient temperature, the higher the return temperature of the heating system. For LBATT standard design, there is an internal functional limitation associated with the properties of the working fluid: the absorbent solution has limited solubility and, therefore, the equilibrium water vapor pressure over the solution is of finite value. In this regard, to ensure an optimal absorption process, the temperature difference (Δtws) between the cooled and cooling (heated) liquid should not exceed Δtws = tw-ts = 25 °C. An increase in the value of Δtws leads to a decrease in the absorption intensity LBATT, which leads to a decrease in efficiency LBATT in general. At Δtws ≥ 30 ° C, the absorption process in LBATT practically stops. Thus, the use of a standard LBATT design is advisable at the beginning and at the end of the heating period, when the heating system return water temperature does not exceed 45 ÷ 50 °C, and the ambient temperature is not lower than minus 10 °C.

The using of double-stage absorption scheme of LBATT solves this problem. Two-stage absorption scheme shown on Figure 1.

The scheme allows heating the return water of the heating system to temperatures of approximately 65–70 °C. At the same time, the temperature of the low-grade heat carrier (circulating water for CHex) is 25–30 °C.

In the warm season, the scheme allows you to use LBATT in refrigeration mode and cool non-freezing liquids down to temperatures "minus" 7 °C at standard temperatures (25–32 °C) of an evaporative water-cooling systems - cooling towers.

The use of refrigeration air conditioning systems operating in the range of positive cooling temperatures (5-7 °C), based on the use of LBATT with two-stage absorption, eliminates the use of evaporative cooling towers and uses a closed water circulation system based on dry coolers. Such a
system does not require replenishing and softening the circulating cooling water for the LBAC with reagents, which is a great operational advantage. LBATT with two-stage absorption as part of a heat and cold supply complex can be operated in the following modes:

1. Using a heat pump with two-stage absorption, which is optimal for use in the main heating season at ambient air temperatures below –8°C at a temperature of return supply water over 50°C at the inlet.

2. Using a heat pump with a single-stage absorption (no absorber-evaporator block of the first circuit is used); this mode is used at the beginning and at the end of the heating period with ambient air temperatures above –8°C at a temperature of return supply water less than 50°C at the inlet.

3. Using a chilling machine with two-stage absorption used in the warm season to obtain industrial cold at a cooled liquid temperature down to –5°C.

4. Using a chilling machine with one-stage absorption (no absorber-evaporator block of the first circuit is used) in the warm season for air conditioning in rooms and for technological cooling of equipment at a cooled liquid temperature amounting to at least 5°C.

Figure 1. Schematic diagram of LBATT with two-stage absorption as part of a heat and cold supply complex

During the construction of individual gas boiler houses that provide heat to large projects, such as shopping centers, warehouses, residential complexes, factory workshops, etc., in the summer there is a need for air conditioning and cooling of various technological equipment. The use of the LBATT scheme with two-stage absorption at these facilities with autonomous boiler houses is expedient.

2. Determination of the energy efficiency of LBATT as part of a heat and cold supply complex
The energy efficiency of LBATT is characterized by a coefficient of performance for LBAC and by a transformation ratio for LBAHP. Coefficient of performance \( \eta \) shows how much high-grade heat is required for the utilization of a unit of low-grade heat (in other words, for obtaining cold):

\[
\eta = \frac{Q_o}{Q_{LBAC}} \tag{1}
\]

where \( Q_o \) is the cooling capacity, \( W \);
\( Q_{LBAC} \) is the power supplied to the LBAC generator, \( W \).

The transformation ratio \( M \) represents the ratio between the amount of the produced intermediate-potential heat and the amount of high-potential heat supplied to the LBAHP generator:

\[
M = \frac{Q_{a,c}}{Q_{LBAHP}} \tag{2}
\]

where \( Q_{a,c} \) is the intermediate potential heat abstracted from the absorber and condenser of LBAHP, \( W \); \( Q_{LBAHP} \) is the power supplied to the LBAHP generator, \( W \).

The values of the energy efficiency indicators of LBATT fluctuate within wide limits depending on the rate of desorption of the solution (the number of generator stages), the quality of operation of the LBATT heat exchange equipment and the ratio of the parameters of external heat carriers. Estimation of the thermal coefficient \( \eta \) and transformation ratio \( M \) for LBATT with two-stage absorption is required to determine the feasibility of using such technical solutions in certain energy applications.

The authors in [4, 5] derived the basic relations for calculating the LBATT cycle with two-stage absorption and two-stage desorption of a lithium bromide solution when operating in the mode of obtaining heat and cold. Based on the obtained ratios, theoretical calculations were made of the attainable values of LBATT with two-stage absorption coefficients \( \eta \) and \( M \) depending on the temperatures of the cooled and heated (cooling) liquid. Figure 2 shows the dependences for operation in the heat pump mode, figure 3 shows the dependences in the refrigerating machine mode, provided heat is removed using a dry cooler.

![Figure 2](image-url)

**Figure 2.** Thermal coefficient and heat transformation ratio for LBAHP with two-stage absorption and two-stage desorption depending on cooled liquid temperature \( ts2 \) in the first-stage evaporator at changing an inlet temperature of heated water \( tw1 \)
Figure 3. Thermal coefficient and heat transformation ratio for LBAC with two-stage absorption and two-stage desorption depending on cooled liquid temperature (ts2) in the first-stage evaporator at changing an inlet temperature of cooling water (tw1)

As shown in figure 2, the transformation ratio M for the heat pump ranges from 1.6 to 1.72. The lowest values of the coefficient are typical for high temperatures of the heating return water, reaching values of 65-70 °C. However, the values of the theoretical coefficients of heat transformation in LBAHP are comparable with the coefficients of the most common in the world heat power engineering LBAHP with one-stage absorption and desorption of the solution. This result shows the prospect of using LBAHP with two-stage absorption in heat supply systems typical for countries with a cold climate.

As shown in Figure 3, the thermal coefficient for the absorption chiller ranges from 0.58 to 0.7. The highest values of the coefficient are achieved at low coolant temperatures. Considering that in a dry cooler, during the hottest period, it is possible to obtain a coolant temperature of at least 40 °C, in technical and economic calculations, it is necessary to take coefficient values of no more than 0.65.

3. Conclusion

Calculated have shown the possibility of using LBATT with two-stage absorption and two-stage desorption as part of a heat and cold supply complex based on a gas boiler house in countries with a cold winter climate. Energy efficiency indicators - thermal coefficient and transformation ratio are comparable to the coefficients of LBATT of standard design with one-stage absorption and desorption of the solution. The main advantage of LBATT with two-stage absorption is the ability to generate cold for air conditioning systems with heat removal by means of a dry cooler. For LBATT standard design with one-stage absorption and desorption of the solution, heat removal is carried out using irrigation cooling towers, which require make-up water and a system to prevent the formation of deposits for their operation.

A further continuation of these studies will be conducting experimental studies to determine the attainable values of thermal coefficients and heat transformation coefficients of a prototype LBATT with two-stage absorption.

The research was carried out within the framework of the state assignment of the IT SB RAS (AAAA-A17-117030910025-7)

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