Thermodynamic cycle of lithium bromide absorption chillers with two-level absorption and generation processes and with associated mass flow

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Abstract. The paper presents the assessment of the energy efficiency of the thermodynamic cycle of the absorption lithium bromide refrigeration unit with two-level absorption and generation processes with the associated mass flow. The analysis of temperature effect of heating and cooling sources on thermal coefficient is carried out. The parameters of external sources when it is possible to determine the energy efficiency of the thermodynamic cycle are defined.

1. Introduction
In recent decades, there has been a growing interest to lithium bromide absorption chillers (LBAC) [1, 2, 3, 4, 5, 6, 7]. Their performance can be based on renewable energy sources (RES) and secondary energy resources (SER), which corresponds well to the world energy development tendencies aimed at increasing the share of these resources in the energy balance in order to increase energy efficiency and reduce carbon intensity of the global economy [8]. LBAC has been widely applied in cooling systems of basic technologies, comfortable and technological conditioning in chemical, oil refining, electronic, food industry, housing and communal sector and social sphere. The studies of cooling and air conditioning systems using solar-powered absorption lithium bromide refrigeration units and RES are presented in [1, 3, 7, 9, 10, 12, 13, 14, 15].

The analysis of LBAC thermodynamic cycles is considered in a number of works [11, 12, 13, 16, 17, 18, 19, 20, 21]. The authors of [17] give the classification of cycles of absorption refrigeration units thus identifying a one-level cycle, cycles with external and inner closures of devices for circulation of a solution, a coolant, heat and mass exchange. The latter two categories may include a series of simple or complex interconnected cycles. This paper briefly describes thirty-seven different absorption cycles. The one-level cycle is the most widely spread and is therefore considered the base cycle. It is most convenient to study the possibilities of other cycles and determine their advantages in comparison with a one-level base cycle. Multi-stage cycles, including cycles with multi-stage solution generation and multi-stage absorption, expand the capabilities of the base cycle. They allow using both high- and low-temperature heating sources for operation of the machine.

LBAC thermodynamic cycles involving multi-stage absorption, as well as single multi-stage absorption and generation of a solution can be carried out by externally coupled heat or mass transfer processes. These cycles are performed in a region of lower solution concentrations compared to a cycle with the two-level generation. This reduces the risk of solution crystallization during LBAC operation. All other things being equal, these cycles require a lower heating source temperature than
the base cycle. Therefore, in such cycles it is possible to effectively use low temperature RES and solar energy as a heating medium. The positive qualities of these cycles indicate the relevance of their study.

The work [22] carried out the analysis of LBAC cycles with two-level absorption and two-level generation of a solution with externally connected mass flow with air cooling of absorbers and a capacitor at a coolant boiling point of 5°C and the use of low-temperature solar heat for generation of a solution in generators. The research was primarily aimed at studying cycle parameters that exclude crystallization of the solution in the machine. It was found that this cycle can be realized at a condensation temperature of not more than 53°C. Thus, the temperature of the heating source was about 80°C. The theoretical thermal coefficient made about 0.38.

2. Research methods

The authors of this paper performed the study of the thermodynamic cycle with two-level absorption and two-level generation of a solution with externally connected mass flow. In the cycle there are two circulation loops of the solution, high-temperature G₁ – A₁ and low-temperature G₂ – A₂. The externally connected mass transfer process is G₂ – A₁. The coolant steam evaporated in the low-pressure generator G₂ is absorbed into the high-pressure absorber A₁. The actual cycle is shown in Figure 1.

The main processes of the thermodynamic cycle are as follows: 1 – 1’ – boiling of a working substance in an evaporator; 22 – 72 – heating of weak solution in a heat exchanger of the second stage solutions; 72 – 52 – adiabatic-isobaric desorption of working substance steam; 52 – 42 – solution boiling in the second stage generator; 42 – 82 – cooling of the rich solution in the heat exchanger of the second stage solutions; 82 – 22 – adiabatic-isobaric absorption of working substance steam in the second stage absorber; 21 – 71 – heating of a weak solution in a heat exchanger of the first stage solutions; 71 – 51 – adiabatic-isobaric desorption of working substance steam; 51 – 41 – solution boiling in the first stage generator; 41 – 81 – cooling of rich solution in a heat exchanger of the first stage solutions; 81 – 21 – adiabatic-isobaric absorption of working substance steam in the first stage absorber; 3’ – 3 – removal of the heat of superheat and vapor condensation of a working substance in the capacitor.

The calculations were performed with the following initial data: cooled source temperature \( t_{c1} = 12°C \), cooling source temperature made \( t_{wcl} = t_{wcl1} = t_{wcl2} = (20; 25; 30; 35; 40)°C \), temperature of the heating source varied within \( t_{h11} = t_{h12} = (50 \div 80)°C \), irreversible losses of the actual cycle were accepted according to the recommendations stated in the known literature. To calculate
thermodynamic cycles depending on different parameters of external sources, a software complex was created with the help of the gfortran compiler. The program package consists of the main program and a number of subprograms. The input of initial data and the output of results are performed in separate files. The developed complex mathematical model includes the following subprograms: calculation of thermodynamic cycle point parameters; calculation of heat loads on units; determination of thermal coefficient. A comparative analysis of one-level LBAC and LBAC with two-level absorption and generation processes was conducted.

3. Results and discussion
Table 1 shows the calculation results of a one-level LBAC.

| Parameter | \( t_{ret} = t_{out}, ^\circ C \) | \( t_{h1}, ^\circ C \) | 80 | 85 | 90 | 95 | 100 | 105 |
|-----------|---------------------------------|-----------------|-----|-----|-----|-----|-----|-----|
| \( t_{st}, ^\circ C \) | 20 | 12 | 12 | * | * | * | * | * |
| 25 | – | – | – | 12 | * | * | * | * |
| 30 | – | – | – | – | 12 | * | * | * |
| \( \xi, \% \) | 20 | 61.1 | 63.4 | * | * | * | * | * |
| 25 | – | 60.5 | 62.7 | 65.1 | * | * | * | * |
| 30 | – | – | – | – | 64.6 | * | * | * |
| \( \Delta \xi, \% \) | 20 | 5.61 | 7.94 | * | * | * | * | * |
| 25 | – | 2.1 | 4.27 | 6.69 | * | * | * | * |
| 30 | – | – | – | – | 3.61 | * | * | * |
| \( \zeta \) | 20 | 0.773 | 0.786 | * | * | * | * | * |
| 25 | – | 0.652 | 0.728 | 0.753 | * | * | * | * |
| 30 | – | – | – | – | 0.694 | * | * | * |

* Crystallization of the solution is possible.

b Cycle cannot be performed.

Figure 2 shows a diagram of thermal coefficient (\( \zeta \)) dependence on heating and cooling source temperature for the LBAC cycle (Figure 1).

![Figure 2. Diagram of thermal coefficient dependence on heating and cooling source temperature](image-url)
Table 2 shows the calculation results of LBAC with two-level absorption and generation processes with associated mass flow.

**Table 2. Calculation results of LBAC with two-level absorption and generation processes with associated mass flow**

| Parameter |  | 55 | 60 | 65 | 70 | 75 | 80 |
|-----------|---|----|----|----|----|----|----|
| \( t_{w1} = t_{w11} = t_{w12}, ^\circ C \) | 20 | – | 12 | 12 | 12 | * | * |
| 25 | – | – | 12 | 12 | 12 | * | * |
| 30 | – | – | – | – | 12 | * | * |
| 35 | – | – | – | – | – | – | – |
| \( \xi_{r2}, \% \) | 20 | – | 58.3 | 61.1 | 63.4 | * | – |
| 25 | – | – | 59.6 | 62.1 | 64.7 | – | – |
| 30 | – | – | – | – | 63.3 | – | – |
| 35 | – | – | – | – | – | – | – |
| \( \xi_{r1}, \% \) | 20 | – | 51.0 | 53.5 | 56.0 | * | – |
| 25 | – | – | 50.6 | 53.1 | 55.6 | * | – |
| 30 | – | – | – | – | 52.6 | * | – |
| 35 | – | – | – | – | – | – | – |
| \( \Delta \xi_{r2}, \% \) | 20 | – | 2.86 | 5.61 | 7.91 | * | – |
| 25 | – | – | 1.21 | 3.70 | 6.30 | * | – |
| 30 | – | – | – | – | 2.40 | * | – |
| 35 | – | – | – | – | – | – | – |
| \( \Delta \xi_{r1}, \% \) | 20 | – | 5.24 | 7.77 | 10.31 | * | – |
| 25 | – | – | 2.51 | 5.04 | 7.49 | * | – |
| 30 | – | – | – | – | 2.72 | * | – |
| 35 | – | – | – | – | – | – | – |
| \( \xi \) | 20 | – | 0.387 | 0.408 | 0.414 | * | – |
| 25 | – | – | 0.321 | 0.383 | 0.397 | * | – |
| 30 | – | – | – | – | 0.347 | * | – |
| 35 | – | – | – | – | – | – | – |

\( a \) Crystallization of the solution is possible.
\( b \) Cycle cannot be performed.

4. Conclusion

The calculations made it possible to establish that in case it is possible to avoid crystallization of a solution the studied cycle can be performed at a heating source temperature of 60°C ÷ 75°C, the cooling water temperature shall be no more than 30°C. The actual thermal coefficient of the cycle is within the range of 0.35 ÷ 0.41. At the same temperatures of the cooled and cooling media, the one-level cycle makes 0.69 ÷ 0.79, but requires a heating source with a temperature of 20°C ÷ 25°C higher than that of the studied cycle.

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