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Integrated Energy System Fuel Saving by Implementing Absorption Lithium Bromide Heat Pumps at Industrial Heating CHP Plant

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Abstract. This paper presents the results of a study of overall fuel consumption reduction for electricity generation in the Belarusian Integrated Energy System (IES). The solution is relevant for combined heat and power plants at industrial sites with significant non-return rates of process steam condensate, viz. Novopolotsk CHPP, Mozyr CHPP, and Grodno CHPP-2. The essence of the modernization lies in the beneficial use of heat from the steam turbine condenser circulation circuit to heat makeup water. Calculations are provided for units with PT-60 and PT-70 steam turbines which are the most common types in the Belarusian IES. Implementation of this solution at the CHP plant requires the installation of an absorption heat pump (AHP), which is driven by flue gases extracted from the steam boiler gas duct. The calculation is based on the condition that steam flow to the condenser is maintained constant before and after the modernization, which also leads to a slight reduction in the turbine unit's electrical power. As a result, for all plants increase of efficiency factors were achieved, which are energy, electrical, and exergy efficiencies. The greatest reduction in annual fuel consumption was achieved for power units with high process steam extraction flows and a significant operating hours per year. When implementing this measure on the PT-60 and PT-70 turbine units of these plants – a total of five units – the annual reduction in primary fuel consumption in the power system will reach 12.8 thousand tons of coal equivalent (tce) per year (with a specific fuel consumption of 302.8 gram tce per kWh for the reference power plant). This solution not only reduces the cost of electricity production, but also reduces greenhouse gas emissions, which is one of the goals of sustainable development.

Keywords: integrated energy system fuel saving, low-potential heat flows, absorption heat pump, CHP make-up water heating, PT-60 steam turbine

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Системная экономия топлива при внедрении абсорбционных бромисто-литиевых тепловых насосов на промышленно-отопительных ТЭЦ

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Реферат. Приводятся результаты исследования по снижению общего расхода топлива в Белорусской объединенной энергосистеме (ОЭС) при производстве электроэнергии.

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Решение актуально для теплоэлектроцентралей промузлов со значительными невозвратами конденсата пара производственного отбора – Новополоцкая ТЭЦ, Мозырская ТЭЦ и Гродненская ТЭЦ-2. Суть модернизации заключается в полезном использовании теплоты циркуляционного контура конденсатора паровой турбины для подогрева подпиточной воды. Расчеты приводятся для блоков с паровыми турбинами типа ПТ-60 и ПТ-70 как наиболее распространенных в Белорусской ОЭС. Для реализации данного решения на станции необходима установка абсорбционного бромисто-литиевого теплового насоса (АБТН), где в качестве привода используются дымовые газы, отбираемые из тракта парового котла. Расчет проводился исходя из условия сохранения пропуска пара в конденсатор до и после модернизации, что приводит также к некоторому снижению электрической мощности турбоустановки. В результате для всех станций получено увеличение показателей эффективности, а именно энергетического, электрического и эксергетического КПД. Наибольшее сокращение годовых расходов топлива получено для энергоблоков с большими нагрузками производственных отборов пара и значительным количеством числа часов работы в году. При реализации мероприятия на блоках турбин ПТ-60 и ПТ-70 перечисленных станций – суммарно пять блоков – годовое снижение расхода топлива в энергосистеме составит 12,8 тыс. т у. т./год (в качестве замыкающей станции принята КЭС с удельным расходом топлива 302,8 г у. т./(кВт·ч)). Данное решение позволяет не только снизить себестоимость производства электрической энергии, но и сократить выбросы парниковых газов в атмосферу, что является одной из целей устойчивого развития.

Ключевые слова: системная экономия топлива, низкопотенциальные тепловые потоки, абсорбционный тепловой насос, подогрев подпиточной воды ТЭЦ, паровая турбина ПТ-60

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Introduction

In recent decades, the rate of climate change on the planet has been increasing, which is associated not only with natural processes [1]. This circumstance forces humanity to take steps to reduce the anthropogenic impact on the environment [2].

In accordance with the program of socio-economic development of the Republic of Belarus for 2026–2030, by 2030 the level of greenhouse gas emissions must be reduced by 37 % of the 1990 level [3]. The main source of greenhouse gas emissions in the world, as well as in Belarus (Fig. 1), is the energy sector.

Emissions reduction in the production of heat and electricity is possible by increasing the share of renewable energy sources, as well as by improving the efficiency of primary fuel use.

In the Republic of Belarus in 2024, 62.25 % of all electricity was generated through direct combustion of natural gas [5], which shows the need to continue works of improving the organic fuels use efficiency.

In previous studies [6, 7] it has been shown that modernization of the regenerative feedwater heating system, and in particular, the implementation of an absorption heat pump (AHP) in the thermal circuit of an industrial heating power plant with significant share of non-return of condensate, allows to increase the efficiency of electricity generation in the cogeneration cycle. Increasing electrical, energy and exergy efficiency and, accordingly, increasing the efficiency of primary fuel use at one specific station also makes it possible to increase the efficiency and sustainability of the entire energy system by reduction of fuel consumption for the same amount of energy generated.

Primary fuel saving is achieved through the regenerative use of low-grade waste heat flows, which in a conventional system is dissipated into the environment. Specifically, this paper examines the use of steam turbine condenser circulating water.

Steam from turbine extraction [6], as well as flue gases [7], taken in the required quantity from the steam boiler gas duct, were previously considered as the drive for the AHP. It was obtained that the variant with AHP driven by flue gases is more efficient. Further results are presented specifically for this option – a gas-driven AHP. Flue gases are withdrawn from the steam boiler gas duct with temperature of approximately 350–400 °C.

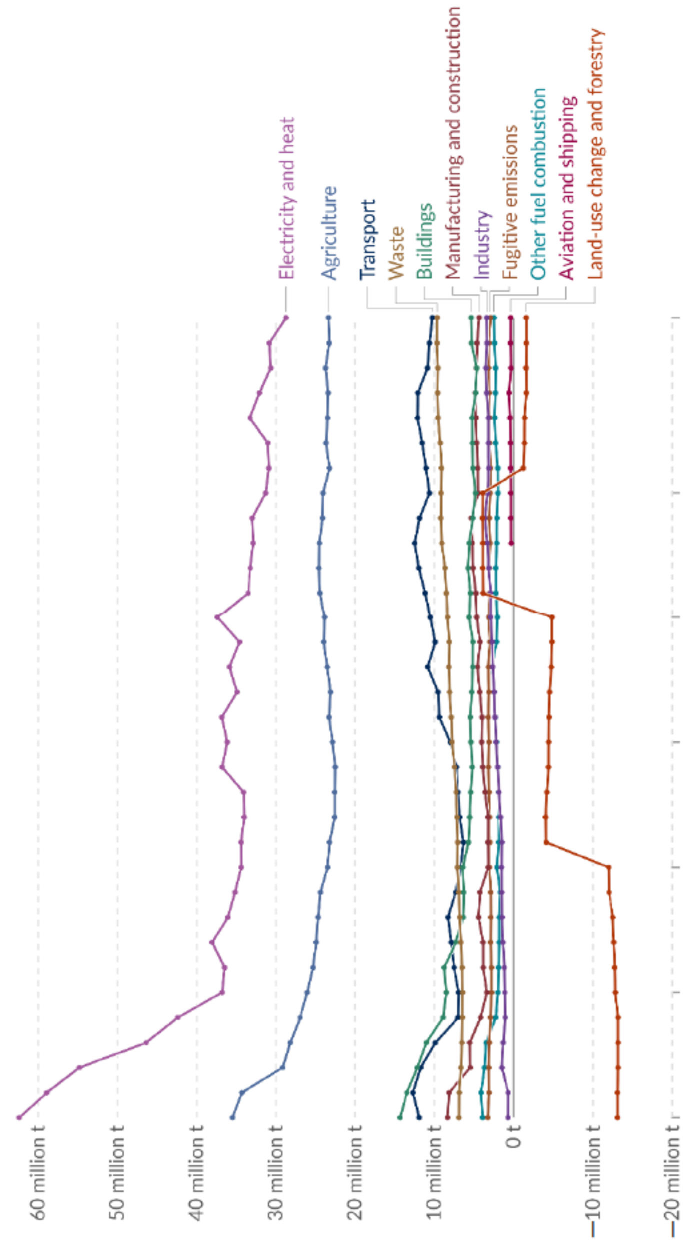

Fig. 1. Greenhouse gas emissions by sectors of economy for Belarus for the period from 1990 to 2022 [4]

Main part

The schematic diagram for integrating the AHP into the layout of a CHP equipped with a PT-60 steam turbine is shown in Fig. 2. The flue gas stream, directed from the boiler to the AHP, is discharged into the atmosphere after cooling.

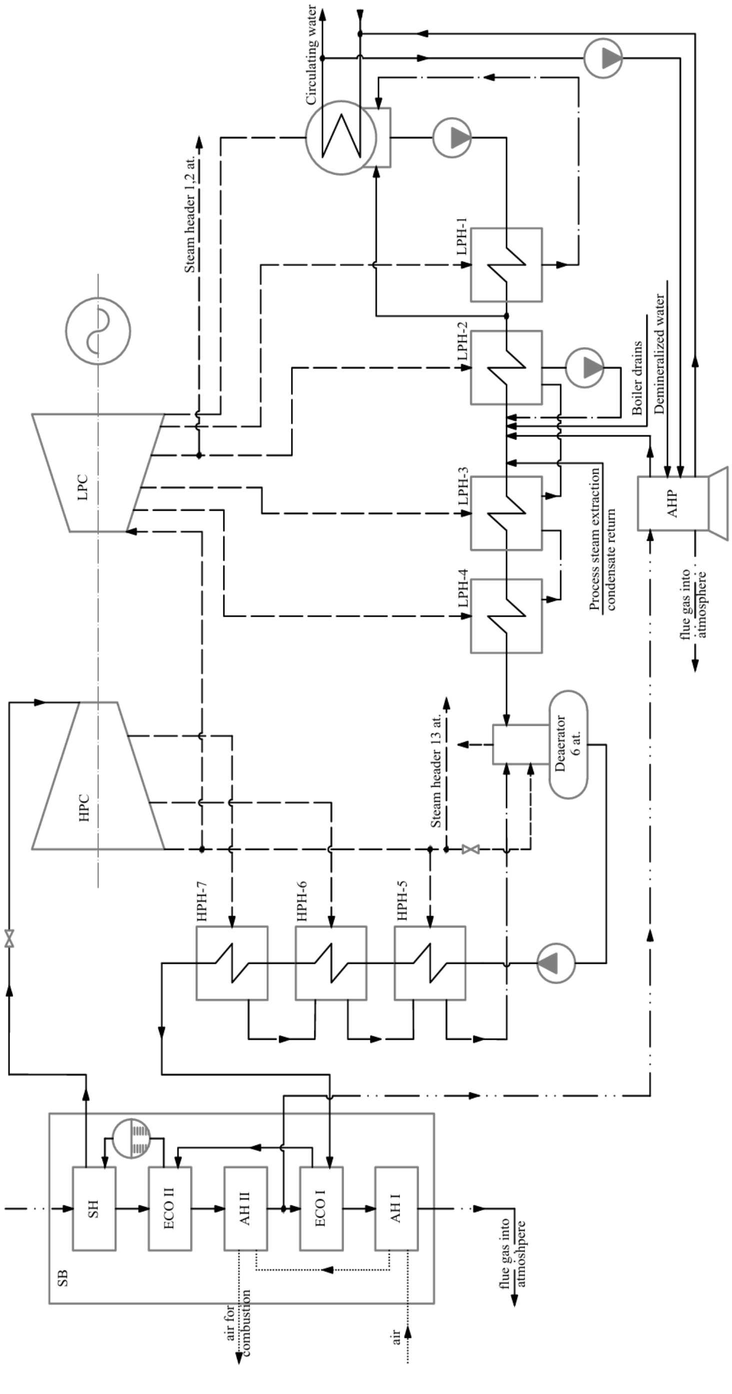

Fig. 2. Schematic diagram of AHP integration into the TPP thermal cycle (SH – superheater, ECO – economizer, AH – air heater, SB – steam boiler, HPC – high pressure cylinder, LPC – low pressure cylinder, HPH – high pressure heater, LPH – low pressure heater)

The plants selected for implementation of AHP for the feedwater heating system are those with significant condensate non-returns – plants at industrial hubs, namely Novopolotsk CHPP, Mozyr CHPP, and Grodno CHPP-2. The study is being conducted only for the PT-60 and PT-70 turbines installed at these plants.

The thermal and electrical loads of the power plants and their operating hours in this mode were determined based on 2023 statistical performance data. Table 1 presents the average calculated operating characteristics of the units.

Table 1

Power units performance characteristics

Power plant	Tirbine	Mean electrical load, MW	Heat supply from process extractions, Gcal/h	Heat supply from heating extractions, Gcal/h	Operating hours, h
Novo-polotsk CHPP	No 1 PT-60-130/13	28.8	65.9	24.0	3960
	No 2 PT-60-130/13	48.4	59.4	59.7	5103
Mozyr CHPP	No 1 PT-70-130/13	47.0	113.7	31.8	3655
Grodno CHPP-2	No 1 PT-70-12,8/1,28	46.0	39.8	50.8	4051
	No 2 PT-70-12,8/1,27	48.9	54.2	45.8	7919

There is no return of process steam extraction condensate at Novopolotsk TPP and Mozyr TPP. For Grodno TPP-2, the condensate loss is 70% during the heating season and 45 % during the non-heating season. Steam pressures in the process extractions for each plant are as follows:

– Novopolotsk CHPP: 1.6 MPa;

– Mozyr CHPP: 4.0, 1.4, 1.0 MPa;

– Grodno CHPP-2: 2.7, 1.3 MPa.

The calculation was based on the condition of maintaining a constant steam flow to the condenser before and after the modernization. Consequently, while maintaining the plant's thermal loads, the modernization of the makeup water heating system – which involves reducing steam extraction for feedwater heating – results in a decrease in electrical output. Table 2 presents the changes in efficiency indicators: electrical, energy, and exergy efficiency following the modernization.

The greatest fuel saving effect was achieved for power units with a high number of annual operating hours, as well as for plants with high steam supply rates to industrial consumers, namely Novopolotsk TPP and Mozyr TPP.

According to Chinese AHP manufacturers, the unit cost of such equipment depends on its thermal capacity. This dependence for flue gas driven AHPs is shown in Fig. 3.

Table 2

Changes in plant performance indicators following modernization

Power plant	Turbine	Increase in electrical efficiency, %	Increase in energy efficiency, %	Increase in exergy efficiency, %	AHP capacity, MW	Annual fuel savings at the plant, tce
Novo-polotsk CHPP	No 1 PT-60-130/13	5.3	3.4	1.2	5.6	4034
	No 2 PT-60-130/13	3.1	2.1	0.8	5.0	4340
Mozyr CHPP	No 1 PT-70-130/13	5.3	4.0	1.7	9.6	4955
Grodno CHPP-2	No 1 PT-70-12,8/1,28	1.9	1.3	0.5	2.4	1008
	No 2 PT-70-12,8/1,27	1.8	1.3	0.5	2.7	2096

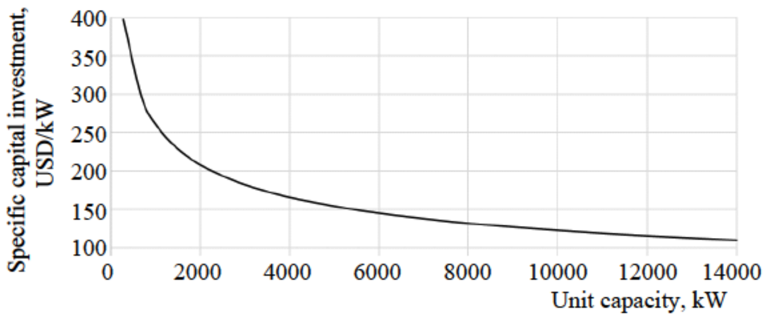

Fig. 3. Specific capital investment in AHP as a function of capacity

According to the guidelines for determining the effectiveness of funds allocated for energy-saving measures [8], the simple payback period of the implementation must not exceed 10 years. Taking into account the Energy Efficiency Department's recommendations on the estimated cost of 1 ton of coal equivalent (tce), projected at 195 USD for 2026 [9] it was found that these measures are economically viable for all the power units listed. The simple payback periods for the measures, including costs for engineering, construction, installation, and commissioning, do not exceed 2 years for all plants.

Table 3 presents data on changes in annual electricity generation at the specified plants (considering only units based on PT-60 and PT-70 steam turbines). It is assumed that all other power-generating equipment operation mode doesn't change. A condensing power plant (CPP) with a specific fuel consumption of 302.8 gce/kWh is taken as the reference power plant in the energy system [10].

By implementing this measure across all the described plants, fuel savings in the energy system will amount to 12.8 thousand tce per year.

Table 3

Energy system fuel savings

Parameter	Novopolotsk CHPP	Mozyr CHPP	Grodno CHPP-2
Annual electricity generation, GWh			
CHP before modernization	361.0	171.8	573.6
CHP after modernization	349.0	164.0	565.7
Reference power plant	12.0	7.8	7.9
Annual fuel consumption, thousand tce			
CHP before modernization	222.4	125.0	288.8
CHP after modernization	214	117.7	283.3
Reference power plant	3.6	2.4	2.4
Reduction of fuel consumption in the energy system	4.8	4.9	3.1

CONCLUSIONS

1. The implementation of absorption heat pumps (AHPs) for heating makeup water at CHPs, utilizing flue gas streams extracted from the boiler gas duct as the driving energy source, enables to reduce annual primary fuel consumption within the power system while maintaining the same total output of thermal and electrical energy.

2. Integrating AHPs for makeup water heating into the thermal cycles of PT-60 and PT-70 steam turbine units at Novopolotsk TPP, Mozyr TPP, and Grodno TPP-2 will result in annual primary fuel savings of 12.8 thousand tce for the Belarusian power system.

3. Modernization of makeup water heating systems at CHPs by integrating AHPs into the thermal cycle enhances the performance indicators of power units. The electrical efficiency increase for PT-60 turbine units at Novopolotsk TPP is 5.3 % and 3.1 %; for PT-70 units, it is 5.3 % at Mozyr TPP, and 1.9 % and 1.8 % at Grodno TPP-2.

4. The simple payback periods for the AHP-based makeup water heating implementation on the listed power units comply with the cost-effectiveness indicators for energy-saving measures, and do not exceed 2 years for all plants at current equipment prices.

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