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ECONOMIC EFFICIENCY OF HEAT PUMP STATIONS FOR HEAT SUPPLY SYSTEMS

Economic efficiency of heat pump stations (HPS) with different sources of low-temperature heat for heat supply systems is analyzed taking into account the increased prices for energy carriers. The proposed recommendations can be used for predicting the conditions of efficient HPS integration into heat supply systems.

Key words: *economic efficiency, heat pump station, heat ump unit, prices of energy carriers.*

Introduction

The shortage of heat power resources in Ukraine and ecological advantages of heat pumps stimulate introduction of heat pump stations (HPS) into the industry and municipal power engineering. For HPS economical operation favorable ratio between the prices for heat and electricity is required, which is valid only for heat pumps with electric drives. Economic efficiency of HPS driven by internal combustion engines or by a gas-turbine plant does not depend on the electricity cost but only on the cost of fuel. However, such plants require great capital investments. At the power market of Ukraine the ratio between electric energy and fuel prices is favorable for the implementation of heat pumps. With the growth of natural gas prices above $330 – 340 per thousand cubic meters the majority of municipal steam boiler houses suffer losses, which causes the necessity to increase heat power tariffs for the consumers. The way out of this situation is implementation of modern energy-saving technologies (particularly, construction of heat power stations on the basis of steam boiler rooms), which will make it possible to reduce the natural gas consumption and heat power costs.

During recent years a number of research efforts have been directed towards studying the efficiency of heat pump units (HPU) application in heat networks of heat power supply sources. In work [1] the authors have conducted the research on increasing the energy efficiency of heat supply sources by HPU application taking into account the influence of circuit solutions and operation modes. HPU efficiency estimation was performed according to the following criteria: fuel saving as compared with the existing circuit, annual expenses for fuel and electric energy, capital investments, the heat unit cost, payback time, reduced annual expenses and profit.

In work [2] economic indicators of heat supply systems with HPU in the conditions of Russian economy were determined. Calculations were performed for different ratios between fuel (gas, coal) and electricity prices. In [2] the following criteria of economic efficiency estimation are proposed: integral effect (net profit), profitability index and capital investment payback time. In [3] the schemes of HPU application at the industrial electric stations are considered. In research [4] the efficiency of HPU with electric drive is analyzed as well as that of HPU driven by a gas-turbine plant with a waste-heat boiler.

The authors of [5] have conducted comparative study of three power supply systems as to the heat cost (on the basis of gas boiler, heat pump and co-generational unit with a heat pump) under the conditions of changing cost of electric energy and gas for different groups of consumers. The costs of gas and electricity only for social-budget as well as for housing and utility sphere were considered. The proposed results are obtained only for the existing electric energy prices and, therefore, they do not enable estimation of efficiency of HPU application in the case of changing prices for fuel-power resources.

Work [6] conducts the estimation of efficiency of four heat supply sources with the power of 3MW on the basis of an electric boiler, a fuel boiler (gas, liquid fuel) and a heat pump unit. Economic models are based on the average indicators of the cost of fuel-energy resources in

Ukraine. Work [7] performs the comparative estimation of energy efficiency of low-power heat pump unit and traditional heat supply sources on the basis of electrical and gas boilers. The changes of fuel and electricity costs are taken into account for a limited number of variants.

The authors of works [1 – 7] did not estimate economic efficiency of HPU with different types of drives for heat supply systems in a wide range of fuel and electricity cost variations for identical HPU connection schemes. The economic efficiency of HPU with different low-temperature heat sources is not analyzed.

The goal of the research is estimation of economic efficiency of a heat pump station with the power of 1MW for heat supply systems taking into account the complex influence of low-temperature heat sources, the type of HPU compressor drive and prices of energy carriers; optimization technical-economic research aimed at finding optimal economic conditions of HPU application in heat supply systems.

The main part

Economic efficiency of HPS implementation is defined as the difference between maintenance costs of a steam boiler house and HPS that is used instead of it. The maintenance costs of a steam boiler house or HPU include: expenses for fuel, electric energy, water, equipment depreciation and current repairs, salary and others. Expenses for fuel (for boiler houses and HPS driven from a gas-piston engine) and electric energy (for HPS with electric drive) form the weightiest component in the structure of maintenance costs and heat power costs. Besides, the temperature level of the chosen low-temperature heat source makes significant influence on HPS energy efficiency: the higher the temperature of a low-temperature heat source, the lower energy consumption for HPU compressor included in HPS will be under constant-temperature conditions in the condenser. Thus, as the temperature of the low-temperature heat source increases, the expenses for electric energy or fuel for HPU compressor drive included into HPS are reduced. Hence, according to [1], economic efficiency of using HPS with a definite type of drive is, to a great extent, determined by the fuel / electricity cost ratio.

Taking into account the conclusions and recommendations from [1 – 7], we investigated the influence of the cost of fuel and energy resources on the economic efficiency of heat pump stations in heat supply systems.

Economic efficiency of HPS with the power of 1MW was estimated for heat supply systems taking into account complex influence of the low-temperature heat sources, the type of HPU compressor drive and the prices of energy carriers. Economic efficiency of HPS with the following sources of low-temperature heat and the heat of a technogenic origin was investigated: sea water, water reservoir, thermal waters, air, river and sewage, secondary energy resources (SER) of metallurgical complexes, mining waters, and ground waters. These low-temperature heat sources are common at the territory of Ukraine. Economic efficiencies of HPS with the electric drive of HPU compressor and with a gas-piston engine drive were investigated. The schemes of the above-mentioned HPS are given in [1]. For comparison, the variant of the operation of a steam boiler house with the same power was adopted.

Economic efficiency investigation was conducted using the aggregate indicators. Economic efficiency and simple payback were determined for HPS variants with different sources of low-temperature heat and types of HPU compressor drive. Simple payback of HPS variants was determined as the ratio between capital investments into HPU and HPS economic efficiency. In calculations specific investments into HPU were assumed to be 800 UAN/kW of the HPU installed capacity [9]. Expenses for the construction of the systems for heat take-off from the low-temperature source were not taken into account for different HPS heat sources. The research results can be used for pre-estimation of HPS efficiency in definite economic conditions with changing cost of energy carriers.

Taking into account the complexity of current situation in the fuel and energy sector of the country and the tendency towards the growth of prices for fuel and energy resources, investigation of HPS economic efficiency was performed for the current level of prices for energy carriers and the predicted growth of them in the nearest future. The variation range of prices for the investigated energy carriers is presented in fig. 1.

Таблица 1

Changes of cost of fuel-energy resources

Value of the cost of energy carriers (as of 01.03.11) [8]		Increase of the energy-carrier cost				
		by 10 %	by 20 %	by 30 %	by 40 %	by 50 %
The price of electric energy, \$/(MW/hour)	93,75	103,125	112,5	121,875	131,25	140,625
The price of electric energy, UAH/(kW/hour)	0,75	0,825	0,9	0,975	1,05	1,125
The price of natural gas, UAH / thousand m^3	2688	2956,8	3225,6	3494,4	3763,2	4032
The price of natural gas \$ / thousand m^3	336	369,6	403,2	436,8	470,4	504

As economic efficiency of HPS with electric drive depends, to a great extent, on the prices for gas and electric energy, we conducted research for the following cases: 1) increase of the natural gas cost; 2) increase of the electricity cost; 3) simultaneous increase of the natural gas and electricity costs.

Fig. 1, 2 present the results of the research on the economic efficiency of HPS with an electric drive in the case of growing electric energy cost for different sources of low-temperature heat. The natural gas cost was considered to be at the current level of 336 \$/thousand m^3.

As it is evident from fig. 1, 2, for the current level of prices for energy carriers and the predicted 10 – 50% growth of the electric energy cost HPS with the application of heat of mining and thermal waters, water reservoirs, sewage and SER of metallurgical complexes are economically efficient. For the above-mentioned heat sources economic efficiency of electrically-driven HPS (fig. 1) is reduced with the growth of prices for electric energy, which is caused by the increased electricity expenses for a compressor drive. Such heat sources as sea water, air, river, ground waters are not acceptable for electrically-driven HPS as operation of such stations will become loss-making (they are not shown in fig. 1 – 2). If the electric energy cost will rise above 20%, HPS variants where the heat of water reservoirs and SER of metallurgical complexes is used become not cost-effective. Simple payback of HPS variants with an electric drive (fig. 2) increases considerably with the growth of electric energy cost, which leads to the reduction of their investment attractiveness.

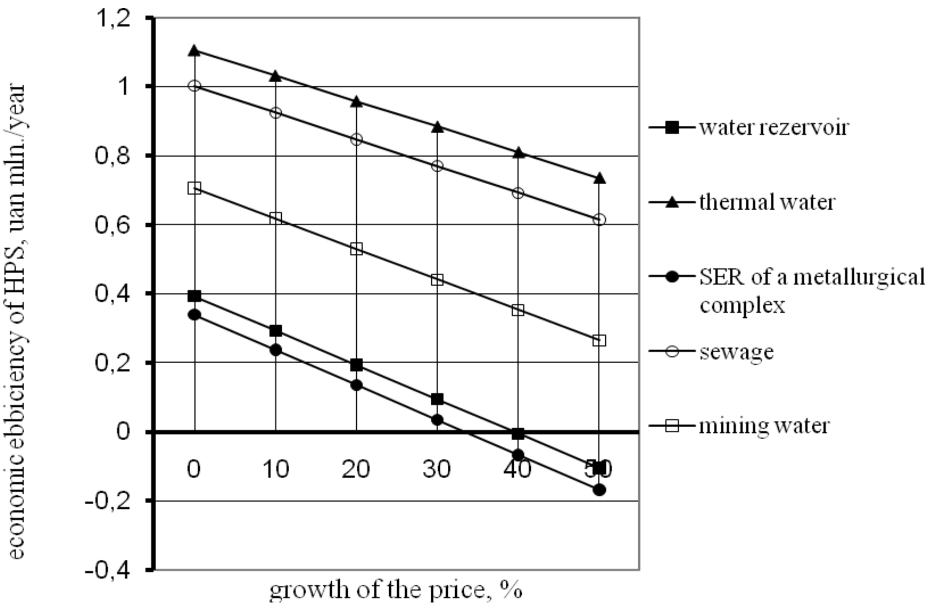

Fig. 1. Economic efficiency values for HPS with electric drive in the case of growing electric energy cost for different heat sources.

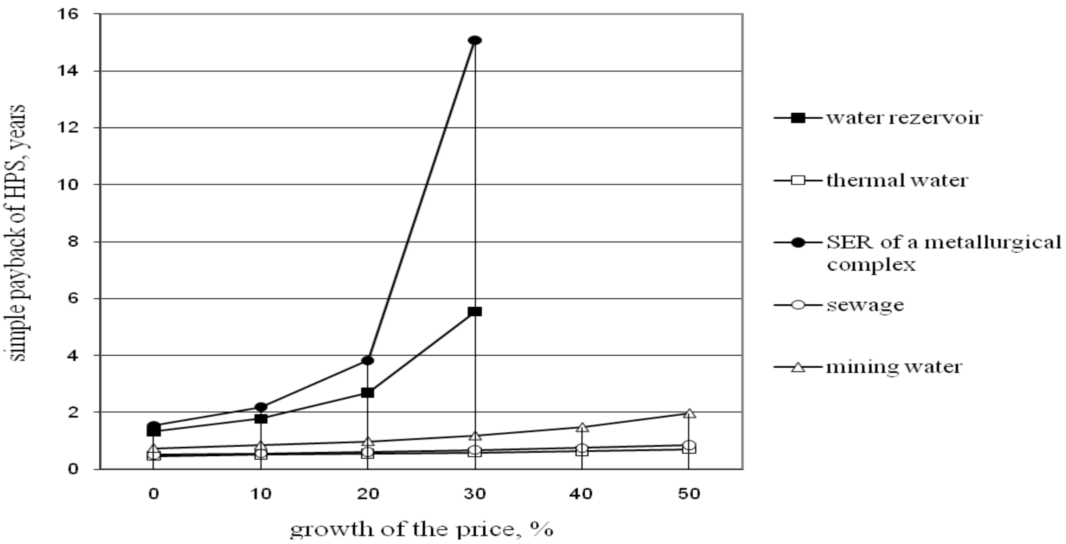

Fig. 2. The values of simple payback of HPS with electric drive in the case of growing electric energy сщіе for different heat sources

The results of electrically-driven HPS investigation in the case of growing natural gas cost for different low-temperature heat sources are shown in fig. 3,4. In this case the current level of electric energy cost was considered to be 0, 75 UAH/(kWh).

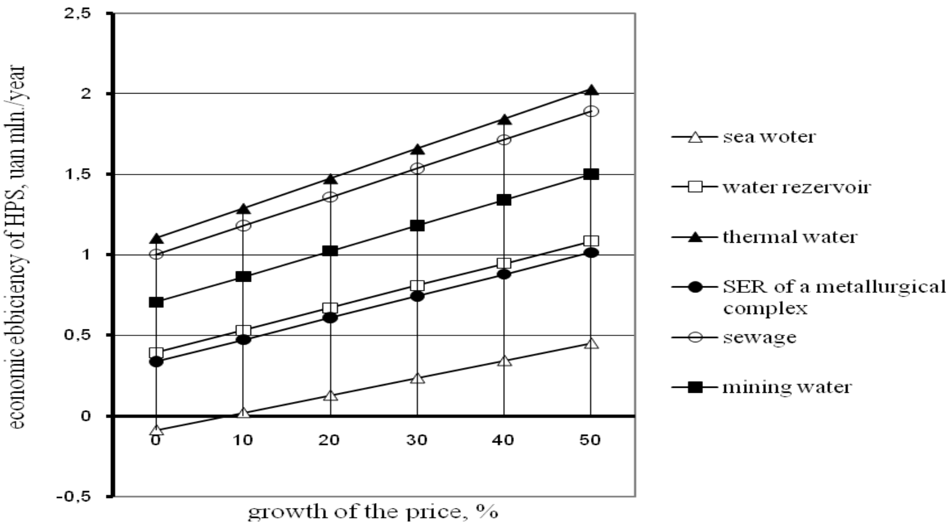

Fig. 3. Economic efficiency values for electrically-driven HPS in the case of growing natural gas cost for different heat sources.

From fig. 3 it is evident that under the current level of prices for energy carriers and the predicted 10 – 50 % increase of the natural gas cost HPS with the application of heat of mining and thermal waters, water reservoirs, sewage, SER of metallurgical complexes and sea water are cost-effective. In the case of growing natural gas price economic efficiency of HPS with electric drive increases for the above-mentioned heat sources, which is caused by the considerable reduction of expenses for fuel due to the natural gas economy. In this case HPS where the heat of air, river and ground waters is used turn to be not cost-effective.

As it is seen in fig. 4, in the conditions of more than 20% growth of the natural gas cost the variant of HPS where the heat of sea water is used becomes cost-effective. 50% fuel cost increase leads to double reduction of simple payback of HPS variants with electric drive (fig. 4), which is the reason for investment attractiveness of these variants

The results of electrically-driven HPS investigation in the case of simultaneous growth of natural gas and electric energy costs for different sources of low-temperature heat are shown in fig. 5 – 6.

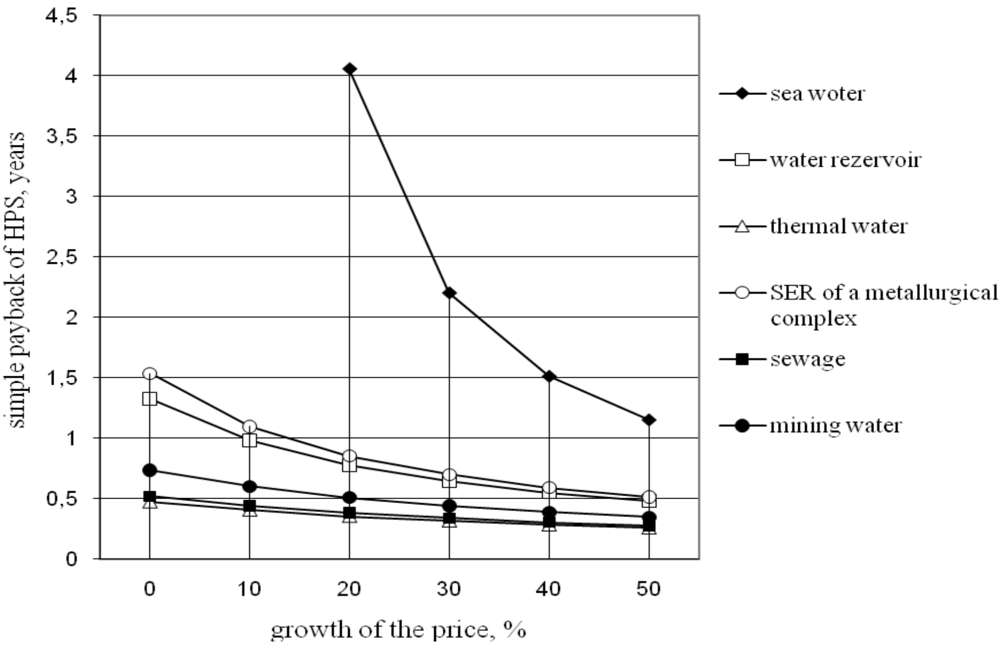

Fig. 4. Simple payback values for HPS with electric drive in the case of increasing natural gas cost for different heat sources.

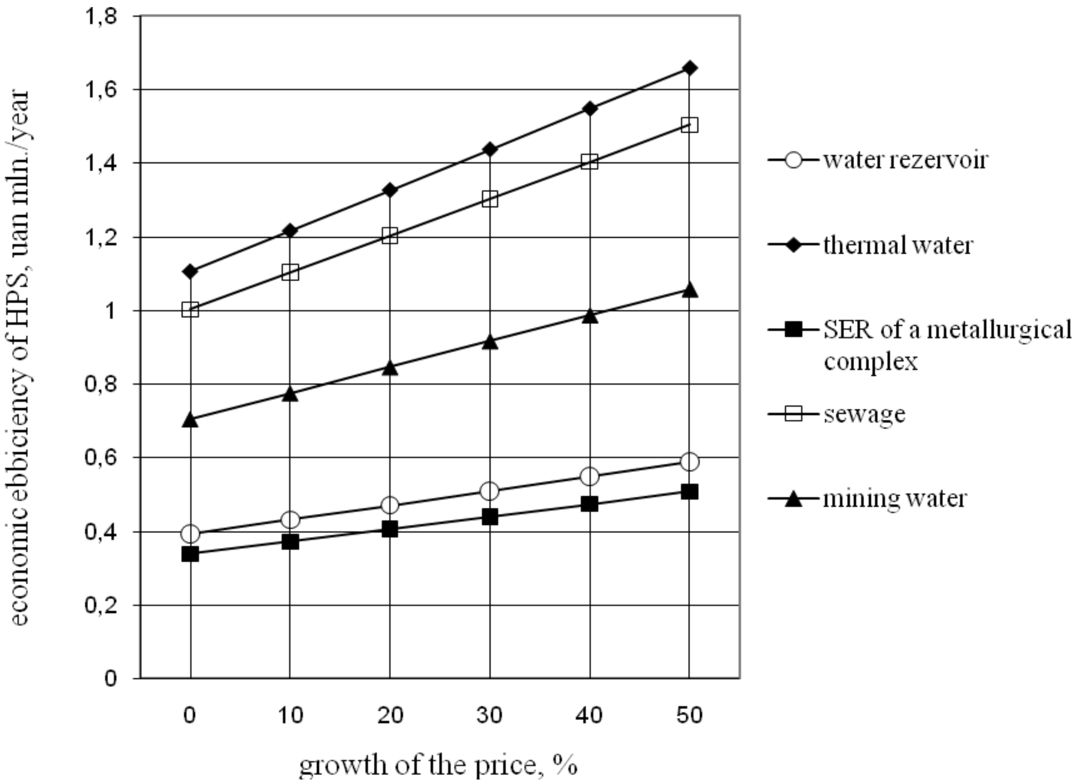

Fig. 5. Economic efficiency values for HPS with electric drive in the case of simultaneous growth of natural gas and electric energy costs for different heat sources.

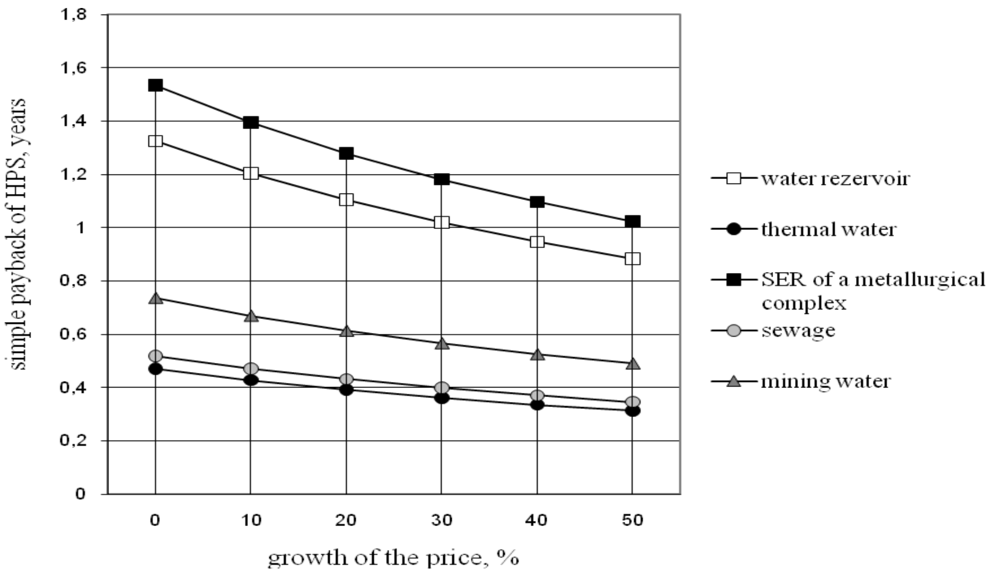

Fig. 6. Simple payback values for HPS with electric drive in the case of simultaneous growth of natural gas and electricity costs for different sources of heat

Fig. 5 shows that under current level of prices for energy carriers and the predicted 10 – 50% growth of electricity and natural gas costs HPS where the heat of mining and thermal waters, water reservoirs, sewage and SER of metallurgical complexes is used are cost-effective. In the case of growing energy costs economic efficiency of HPS with electric drive increases for the above-mentioned heat sources, which is caused by considerable fuel cost reduction due to natural gas economy. In this case expenses for electric energy are also increased but they have smaller influence on the economic efficiency of HPS. As in the previous cases, a number of HPS variants are not cost-effective: HPS where the heat of rivers, air, ground and sea waters is used.

As it is evident from fig. 6, in the case of 50% increase of the price for energy carriers, simple payback of electrically-driven HPS variants decreases by almost 1.5 times, which has positive influence on investment indicators of these HPS variants.

As it was already mentioned, economic efficiency of HPS driven by a gas-piston engine does not depend on the electric energy cost but, however, it depends considerably on the cost of gas. Therefore, the research was conducted for the cases of the predicted 10 – 50 % growth of natural gas cost.

The results of studying the efficiency of HPS driven by a gas-piston engine with different sources of low-temperature heat are shown in fig. 7 – 8. In this case the electric energy cost was assumed to be at the current level of 0,75UAH/kWh).

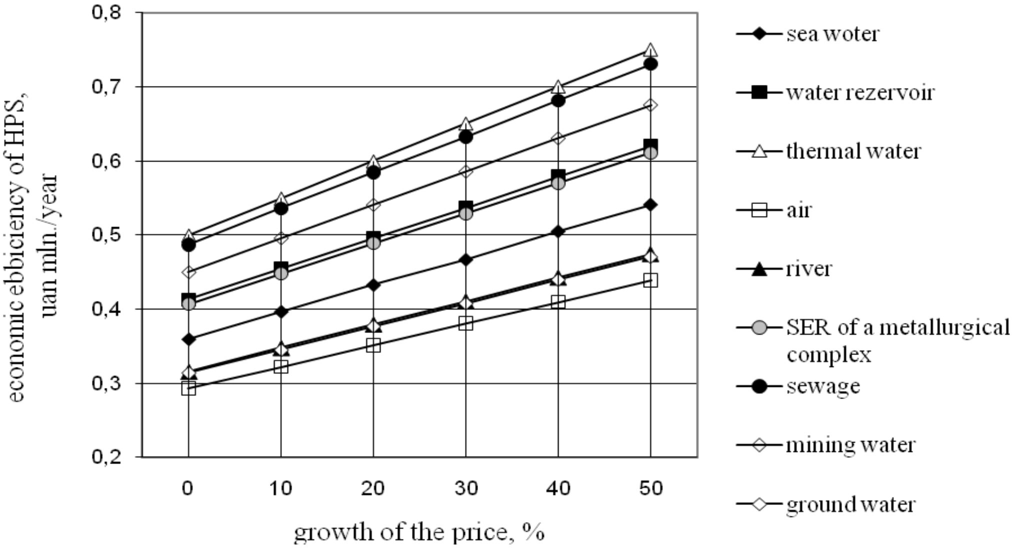

Fig. 7. Economic efficiency values of HPS driven by a gas-piston engine in the case of growing natural gas cost for different sources of heat

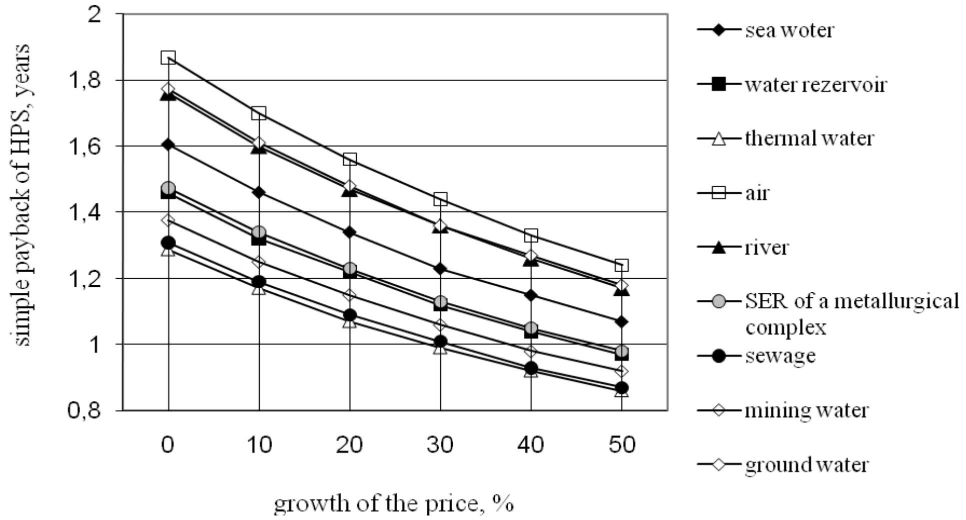

Fig. 8. Values of simple payback of HPS driven by a gas-piston engine in the case of growing natural gas costs for different sources of low-temperature heat

As fig. 7 shows, with the current level of prices for energy carriers and the predicted 10 – 50% growth of prices for natural gas all the investigated variants of HPS driven by gas-piston engines are economically efficient. Economic efficiency of HPS driven by gas-piston engines increases by almost 1,5 times for all heat sources with the growth of natural gas prices, which is explained by the considerable reduction of fuel expenses due to the natural gas economy.

From fig. 8 it is evident that in the conditions of natural gas cost growing from 10 to 50% all the investigated variants of HPS driven from gas-piston engine are cost-effective. With 50% growth of the fuel cost simple payback of HPS variants driven by a gas-piston engine (fig. 8) reduces by almost 1,5 times, which improves economic indices of these HPS variants.

Conclusions

Economic efficiency of HPS with the power of 1 MW for heat supply systems was estimated taking into account complex influence of low-temperature heat sources, the type of HPU compressor drive and prices for energy carriers.

With the current level of prices for energy carriers and the predicted 10 – 50 growth of prices for natural gas, all the investigated variants of HPS driven by a gas-piston engine are economically efficient. In this case simple payback of the HPS variants reduces by almost 1,5 times.

For electrically-driven HPS:

– with the current level of prices for energy carriers and the predicted 10 – 50% growth of the natural gas cost all the investigated variants of HPS driven from a gas-piston engine are economically efficient. In this case simple payback of the HPS variants reduces by almost 1,5 times;

– with the current level of prices for energy carriers and the predicted 10 – 50% growth of the natural gas cost the variants with the application of heat of thermal and mining waters, water storage, sewage, SER of metallurgical complexes and sea water will be economically efficient. In this case almost double reduction of the simple payback of the HPS variants is observed;

– with the current level of prices for energy carriers and in the case of simultaneous 10 – 50% growth of electric energy and natural gas costs the variants where the heat of mining and thermal waters, water storage, sewage and SER of metallurgical complexes are used will be economically efficient. In this case almost 1,5 reduction of simple payback is observed.

The proposed recommendations could be used to predict the conditions of effective HPS integration into the heat supply systems.

REFERENCES

1. Ткаченко С. Й. Парокомпресійні теплонасосні установки в системах теплопостачання / С. Й. Ткаченко, О. П. Остапенко. – Вінниця: УНІВЕРСУМ-Вінниця. – 2009. – 176 с.

2. Новиков Д. В. Выбор рациональных схем и параметров систем теплоснабжения с теплонасосными установками: дис. … канд. техн. наук : 05.14.01 / Новиков Дмитрий Викторович. – Саратов, 2007. – 128 с.

3. Осипов А. Л. Исследование и разработка схем теплоснабжения для использования низкопотенциального тепла на основе применения теплонасосных установок: дис. ... канд. техн. наук : 05.14.01 / Осипов Айрат Линарович. – Казань. 2005. – 117 с.

4. Мариченко А. Ю. Оптимизация исследований комбинированных теплопроизводящих установок с тепловыми насосами: дис. … канд. техн. наук : 05.14.01 / Мариченко Андрей Юрьевич. – Иркутск, 2004. – 120 с.

5. Беляева Т. Г. Оценка экономической целесообразности использования тепловых насосов в коммунальной теплоэнергетике Украины / Т. Г. Беляева, А. А. Рутенко, М. В. Ткаченко, О. Б. Басок // Промышленная теплотехника. – 2009. – Т.31, – № 5. – С. 81 – 87.

6. Долинский А. А. Тепловые насосы в системе теплоснабжения зданий / А. А. Долинский, Б. Х. Драганов // Промышленная теплотехника. – 2008. – Т.30, – № 6. – С. 71 – 83.

7. Басок Б. И. Анализ экономической эффективности при реализации теплонасосных систем для теплоснабжения / Б. И. Басок, Т. Г. Беляева, А. А. Рутенко, А. А. Лунина // Промышленная теплотехника. – 2008. – Т.30, – № 4. – С. 56 – 63.

8. Національна комісія регулювання електроенергетики України [Електронний ресурс] // Режим доступу: www.nerc.gov.ua.

9. Долинский А. А. Тепловые насосы в теплоснабжении / А. А. Долинский, Е. Т. Базеев, А. И. Чайка // Промышленная теплотехника. – 2006. – Т.28, – № 2. – С. 99 – 105.

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