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Integration of Heat Storage Technologies in District Heating Systems

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Abstract: Global trends in the efficiency, safety of energy systems and energy conservation actualize the task of developing new technologies for energy storage and transportation. The article considers current technologies of storage and accumulation of thermal energy, which can be used in central heating systems, and draws conclusions about the feasibility of their use. Also, the classification of energy storage systems is presented. The most perspective thermal energy storage, which can be used to equalize the load on the energy source to ensure the peak demand for heat with a high coefficient of utilization of the equipment capacity, is noted.

Keywords: thermal energy storage, district heating system, mobile thermal energy storage

1. Introduction

Improving the efficiency of heat supply contributes to overall energy savings at the national level. The heat supply is carried out mainly by a branched pipeline infrastructure – a network of district heating (DH) and cooling. Consumers remain apartment buildings. Partially, the private sector and industrial enterprises. In the European Union, the residential sector uses about 26.1% of final energy consumption (European Commission 2019). In Ukraine, 1.6 times more primary energy is used for heat production than for electricity. Electricity production accounts for 39%, while high-potential (T > 100°C) heat production consumes 21% and low-potential (T < 100°C) 40%. Therefore, increasing the efficiency of the DH system can contribute to overall energy savings.

The main advantages of DH system are the possibility to provide a large number of consumers with heat at the same time, the use of various local fuels and energy sources which makes it possible to reduce the cost of heat. In DH-systems there is possibility of centralized regulation of the heat-carrier temperature, allows to minimize heat losses. There is also the possibility to control the DH work remotely, which ensures high reliability and easy use of the system.

But the significant disadvantages of the system, level out the listed advantages – there are significant losses during transportation, lack of quantitative regulation and violation of the temperature regime during peak loads. Currently, the state of heating networks does not meet the current technical requirements. For example, in the EU countries up to 11% of heating systems are inefficient (European Commission 2016), in Ukraine from 22.3% to 17%. This is due to the difficult technical condition of the pipeline, insulation, distribution systems.

The use of thermal energy storage systems (TES) allows to stabilize the DH system operation during the peak period of heat consumption, significantly reduce harmful emissions into the environment. And also, to ensure the systematic operation of boiler equipment with the highest possible high efficiency, to reduce the consumption of electricity and fossil fuels and to attract to the multi-power balance of renewable energy systems and secondary energy resources.

These tasks are especially relevant nowadays, to ensure energy security and flexibility of DH systems, decarbonization of generation, reduction of the cost of transport and distribution of thermal energy and the prospects for transition to the new advanced technologies of the fourth generation. DH systems of the fourth generation is a modern trend of heat supply, actively implemented in the EU, the U.S. and China. In particular, their introduction allows to solve ecological problems, so the European Union announced the "green agreement" aimed at reducing of greenhouse gas emissions by 50% by 2030 in comparison with 1990 (Union European 2020).

2. Purpose and objectives of the work

The purpose of this work is to investigate the integration of heat storage technologies in central heating systems.

According to the set goal, the following tasks are formulated:

- determine the promising directions of development of central heating,
- to review modern technologies of heat storage and identify promising options for their use in DH systems.

3. Directions for development of district heating

Modernization of the central heating system makes it possible to level out the divergence of priorities between district heating companies and consumers. The conducted analysis indicates convergence of priorities at the level of installation of heat regulation systems and reduction of heat losses for technological needs. Consumers are interested in reducing the cost of heat supply services, and heat suppliers are interested only in the transition to the multi-parallel balance and reducing the cost of heat production.

In order to improve the efficiency of district heating, there is a decrease in operating temperatures in heating networks. Low temperatures in the network allow to reduce heat losses and to integrate low-grade waste heat and renewable energy sources.

Due to changing climatic conditions, the demand for heating is expected to decrease, as opposed to the demand for cooling increasing significantly. The task of an emission-free supply of heating and cooling energy is a challenge, especially in urban areas. Therefore, energy supply from decentralized sources of supply is not feasible. On the other hand, district heating and cooling (DHS) is gaining in importance.

It should be noted, the general trend according to the stages of development of heating networks of industrial development. DHS systems of the 1st generation emerged in the first half of the last century. This system is characterized by separate production of heat and electric energy and use of fossil fuels and oil products. DHS of the 1st generation is characterized by high temperature of the heat carrier >150°C and low efficiency of ≈ 50%.

DHS heating and hot water generation 2 developed from the 1940s to the 1990s. This period is marked by the active use of natural and liquefied gas, secondary energy resources in the fuel mix. Generation of heat and electric energy is compatible. The temperature of the heat carrier is reduced to 115-70°C, while the efficiency of the system is increased up to 60%. TES start to be used on heat generation sources.

Generation 3 DHS unfolded in Western Europe and the U.S. from the early 2000s to 2020, and is characterized by the cogeneration of heat and electricity and the use of renewable energy sources (RES), alternative and biological fuels. There is a gradual abandonment of the use of fossil fossil fuels. Heat-carrier temperature is reduced to 90-70°C, and the efficiency of the system increases up to 70%. Widespread use of RES leads to the spread of heat storage technologies. Today, most energy comes from such sources as oil, coal, natural gas and uranium, causes emissions into the environment, global warming and associated climate change. Countering these phenomena is one of the main challenges for modern science and economy. Therefore, it is necessary to conduct research on the widespread use of available renewable energy sources. It should be noted that the high potential for the use of heat from solar energy, due to the high efficiency of the accumulation and conversion of this energy. The main elements used in this area are solar collectors and heat storage systems.

Intensive use of RES and TES systems has led to a transition to DHS 4th generation systems. Now the EU is implementing a project for a new generation of heating, hot water and cooling systems by 2050. It covers the development and use of new energy sources and the rejection of fossil fuels. The coolant temperature of such a system is in the range of 70 to 50°C. And the overall efficiency of the system is higher than 70%. The focus is on energy accumulation and storage systems. Scientific research carried out in recent years is aimed at developing new storage technologies and battery designs that will allow for efficient and safe energy storage.

Among the various methods of heat storage are direct heat storage, latent heat storage and thermochemical energy storage. The efficiency of TES depends on the properties of the selected heat storage materials, on the conditions in which these devices are used, and on the purpose for which they are used.

4. Classification of heat storage technologies

Modern TES technologies provide the ability to store heat or cold for hours, days, or even months. Global trends in efficiency, energy savings and security of energy systems are based on the principle of energy storage. Depending on how energy is stored, heat storage technologies are divided into:

1. Technologies for transforming mechanical energy into thermal energy, such as hydroelectric power plants, steam turbines, Stirling engine. They are widespread, but are characterized by low efficiency, about 30%. Because there are thermodynamic limitations of power generation at temperatures below 340°C, so they are not used in DHS systems.
2. Low-temperature heat technologies. A considerable amount of heat is available in the temperature range from 40 to 200°C, but there are difficulties in its use, which require a separate and in-depth study. Because low-temperature heat involves a smaller temperature gradient between two fluid streams, large heat transfer surfaces are required for heat transfer. This limits the economic feasibility of their use, since it requires the use of a heat pump to increase the temperature of the coolant. TES based on single-phase capacitive accumulation for seasonal or short-term accumulation of thermal energy allows the use of heat or cold from natural sources and secondary energy resources. Thermal accumulation is carried out by solid or liquid substances due to the heat capacity of the material. The capacity of heat storage in such accumulator's ranges from 100 kW to hundreds of MW.
3. Latent heat is the accumulation of thermal energy in the so-called latent TES systems, based on the use of materials with a phase transition. Phase-transition materials can be of organic (high molecular weight paraffins, waxes and glycols) or inorganic origin (crystalline hydrates, salt hydrates and eutectic water-salt solutions). Such materials have a high latent heat capacity. The limited use of thermal accumulators with phase transition can be explained by the low coefficient of thermal conductivity and excessive corro-

siveness of inorganic materials, as well as the change in volume during melting of materials of organic origin.

4. Hidden chemical energy utilization technologies based on adsorption processes. Equipment for heat recovery from gas for low and medium temperatures, using zeolites and silica gel as the working body. The heat transfer medium is air. Thermal energy storage can be daily, weekly, monthly or even seasonal.
5. TES, the principle of operation of which is based on photochemical and thermochemical, thermoelectric reactions. Such TES have not found wide application and are currently at the stage of scientific research. However, new technologies are being developed that can produce electricity directly from heat, such as thermoelectric and piezoelectric generation with subsequent storage and application for heat carrier heating.

5. Application of heat storage technologies in central heating systems

In TES that in the future will be used in DHS systems include – main pipelines, heat pumps, stationary and mobile thermal storage.

Central heating and hot water supply has a great potential for the use of main pipelines as TES, which is allowed by the current regulatory documents (Thermal networks 2009). While in Western Europe occupies about 10% of the total heating market, in Ukraine it reaches 70% (Poredos et al. 2011). Our research shows that the use of heat supply networks as heat storage and optimization of DHS system can reduce the total cost of primary energy up to 5%.

In promising technologies of heat storage in central heating systems, also include heat pumps. However, investment in electric heat pumps is not attractive due to lack of support at the state level. Large capacity heat pumps for DHS are considered as an economic and energy efficient solution (David et al. 2017).

Widespread stationary heat accumulators are used both in homes and in combination with thermal power plants, boilers and heat pumps in DHS. TES enables optimal management of the boiler load, reducing the consumption of fuel and energy resources and harmful emissions into the environment.

Mobile thermal storage (M-TES) can be successfully used to combine several sources of thermal energy, combined into a single system. This is of particular importance, given the increasing use of renewable and secondary energy sources (Demchenko et al. 2020, Demchenko et al. 2020 september). Abroad, research work on mobile thermal energy storage for the utilization and utilization of industrial waste and excess heat for distributed users is underway, and the first commercial projects have been implemented. In Germany, for example, Marco Deckert et al., has tested a system of two 20-foot tanks filled with sodium acetate trihydrate. The tested M-TES stores up to 2.0 MWh of heat. And Andreas Krönauer et al., presented the results of a year-long test, in which M-

TES in a tank filled with 14.0 tons of zeolite, and has a heat storage capacity of 2.3 MWh.

Weilong Wang (Taiwan) investigated water storage tanks of direct and indirect heating filled with erythritol, which has a melting point of 118°C.

The author's collective of laboratory "Processes and Technologies of Heat Supply" of ISTP of NAS of Ukraine created the prototype of mobile heat storage with heat productivity 1200 kW/H, Fig. 1.

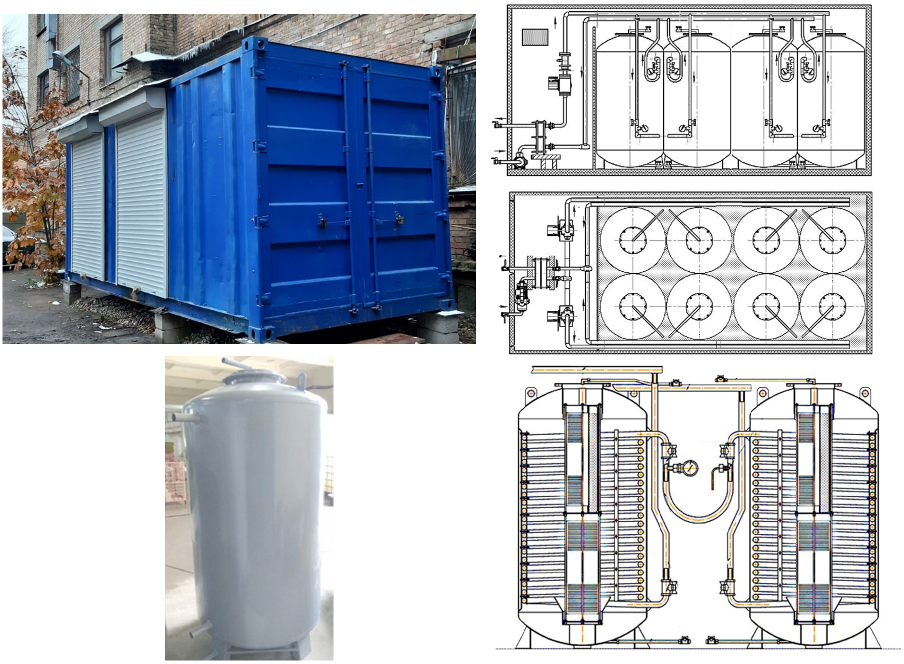

Fig. 1. Mobile thermal storage M-TES-0,5 MW

Charging time is 4 – 6:00, discharging time is 10 – 12:00, the heat storage capacity is 200 kWh, the average load power is 120 kW, the average discharge power is 90 kW. Mobile container-type M-TES is equipped with a block heat point and heat storage tanks.

For the first time in order to solve this problem a design of a mobile heat accumulator is proposed which consists of a dry cargo container in which an individual heat point is mounted and the accumulators are filled with a combination of a material with a phase transition and hydrogels.

The basic technological scheme of integration of heat accumulators into the heat supply system is shown in Fig. 2.

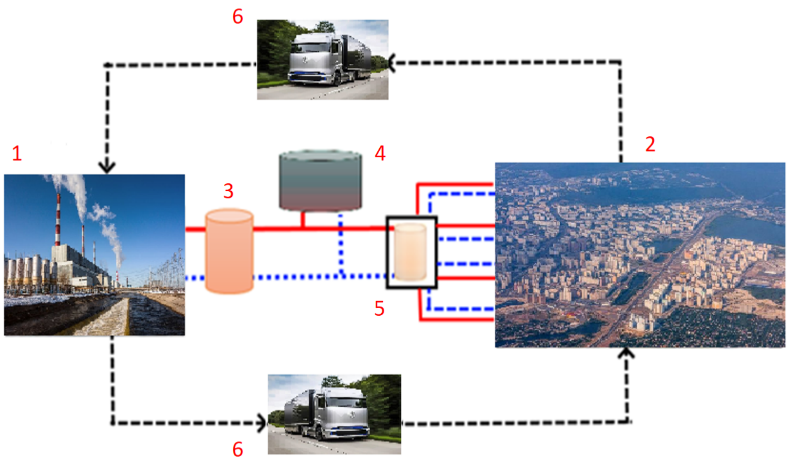

Fig. 2. Schematic flowchart of the integration of thermal accumulators in the heat supply system, where: 1 – TES an energy source, 2 – TES is a user 3 – TES of direct action, 4 – TES of transport network, 5 – TES of indirect influence on the distribution network, 6 – M-TES

Demand-side management using heat accumulators is an effective method of managing district heating, which has investment attractiveness and contributes to decarbonization. Using TES, it is possible to reduce peak loads by up to 30% and reduce emissions and fuel consumption by up to 10%.

Comparative characteristics of functional properties of modern energy system and the system based on the concept of Smart Grid demonstrates that the introduction of Smart Grid means the creation of intelligent distribution network (Demchenko et al. 2019). This allows to achieve an increase in profitability, reliability and failure-free operation with reduction of heat and coolant losses in networks. These systems are aimed at improving operational efficiency, optimizing the distribution of load on the heating network. Implementation of the concept of Smart Grid is innovative in nature and reflects the transition to a new technological paradigm in the energy sector and the economy, will have a positive impact on energy independence.

Fig. 3 shows the proposal of energy-saving innovations for district heating companies. So, at the level of use of fuel and energy resources is the transition to a multifuel balance. At the level of generation of heat, cold and electricity – it is proposed to widely use alternative and renewable sources. When transporting coolant – it is proposed to use accumulators for targeted dosed supply of heat or cold to the consumer with the help of mobile heat accumulators.

When distributing heat – it is a quantitative-qualitative regulation, the use of a new method of transporting coolant by coaxial pipelines, developed in the laboratory of heat processes and technologies of the ITTF of the NASU.

It is supposed that the pipeline of the consumer coolant supply is located inside another pipeline (Demchenko et al. 2016)

Coaxial pipelines proposed for implementation can reduce heat losses almost 2 times.

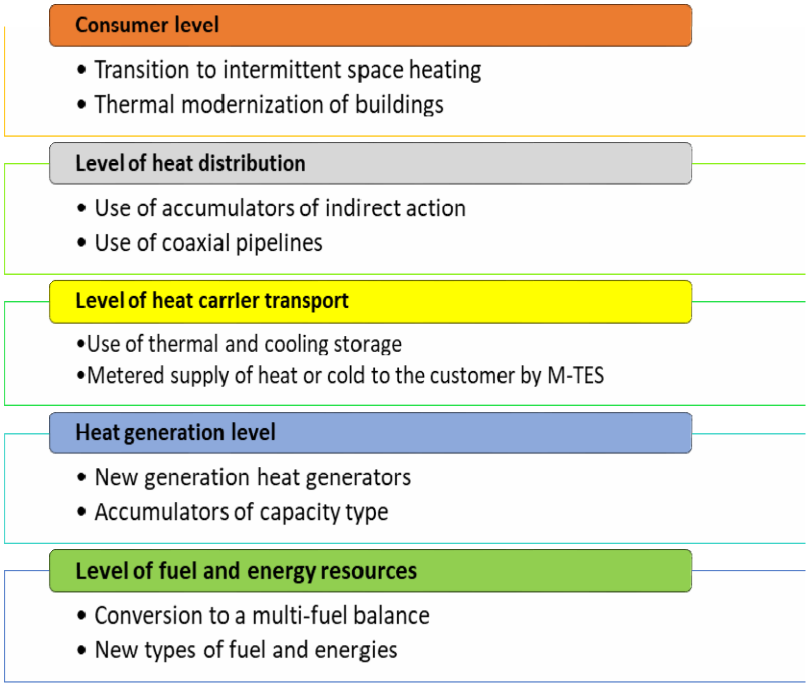

Fig. 3. Suggestions for energysaving innovations for district heating companies

Advantages of a new way of a heatcarrier transportation consist in essential reduction of means for construction of a heating network, possibility of use of existing pipelines at modernization of networks, reduction of a thickness of a layer of isolation. The length is less due to the reduction of the number or lack of expansion joints, the hydraulic stability of the operation, reducing the temperature drop and pressure in the network.

At the consumer level, in addition to the thermomodernization of buildings, the transition to intermittent space heating, that is, heating only during the permanent stay of people in them and reducing the temperature during absence.

6. Conculusions and further reserche

As a result of the analysis of existing district heating systems and the literature regarding new research on TES, the most promising proposals for energysaving innovations for district heating companies, according to the authors, are:

- The search for new energy sources and the transition to a multifuel balance,
- wide use of alternative and renewable sources and combination of TES,
- use of accumulators for heat transportation, for targeted dosage delivery of heat or cold to the consumers by M-TES – quantitative and qualitative regulation during heat distribution, use of new method of heat carrier transportation by coaxial pipelines,
- in addition to the thermal modernization of buildings, a transition to the intermittent heating of rooms, that is, heating only during the continuous stay of people in them at a comfortable temperature, followed by its reduction in their absence, is proposed.

Prospective is the search for new discrete ways of heating with the help of mobile heat storages, allow to build a flexible heating system and minimize heat losses during transportation. Creation of new materials and application of natural materials with phase transition deserve special attention.

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