jntes
1
2021

Alina V. KONYK
Volodymyr V. DEMCHENKO
Institute of Technical Thermophysics of the NAS of Ukraine
Corresponding author: vladimirdemcenko71@gmail.com

DOI: 10.53412/jntes-2021-1.1

INTEGRATION OF HEAT STORAGE TECHNOLOGIES IN CENTRAL HEATING SYSTEMS

Abstract: *The global energy sector is undergoing a major transformation, from increasingly greater electrification to increased use of renewable energy sources. Along with this, the areas of relevance are considered to be the directions of creating a system of district heating and cooling system of the 4th generation.*

Keywords: *district heating systems heat supply systems, heat accumulator.*

Introduction

Total saving of energy contributes to increase of efficiency of heat supply, it is realized mainly by means of network of pipelines. District heating (DHS) and cooling networks are branched pipeline transport infrastructure, used for transportation of heat energy from energy source (e.g. boilers) to numerous users. The main consumers remain apartment buildings, the private sector and industrial enterprises. In the European Union, the residential sector uses about 26.1% of final energy consumption [1]. In Ukraine, 1.6 times more initial energy is used for heat production than for electricity production. Electricity production accounts for 39%, while high-potential (T > 100°C) heat production consumes 21% and low-potential (T < 100°C) 40%, respectively. Therefore, improving the efficiency of the DH system can contribute to overall energy savings.

The main advantages of the DHS system include:

- the ability to provide heat to a significant number of customers at the same time, located over large areas;
- use of different local fuels and energy sources which makes it possible to reduce the cost of heat;
- possibility of centralized regulation of heat carrier temperature, allows to minimize heat loss;
- the system is controlled remotely by specialized organizations, provides high reliability, environmental friendliness and ease of use.

However, such a system has a number of disadvantages:

- large losses during transportation and distribution of heat;
- lack of quantitative regulation capability;
- violation of the temperature regime at peak loads.

The current state of heating networks does not meet the technical requirements. In the EU about 11% of heating systems are inefficient [2]. In Ukraine this figure reaches 17%. Thus, the ageing and breakdown of heat networks is growing and in some regions Ukraine it is to 22.3%.

Systems of accumulation and storage of thermal energy (TES) can solve the problems of unstable DHS system operation in the peak period of heat consumption, provide stable operation of boiler equipment with the highest possible efficiency, reduce the consumption of electricity and fossil fuels, as well as significantly reduce harmful emissions into the environment. In addition, the use of TES allows to attract to the multifuel balance of renewable energy systems and secondary energy resources.

These tasks are especially relevant in the current socio-economic conditions to ensure energy security and flexibility of DHS systems, decarbonization of generation, reducing the cost of transportation and distribution of thermal energy and the prospects for transition to new advanced technologies of the fourth generation. DHS systems of the fourth generation is a modern trend of heat supply, is 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 greenhouse gas emissions by 50% by 2030 compared to 1990 [3].

Purpose and objectives of the work

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

Research objectives:

- to determine the main directions of development of central heating;
- to present modern classification of heat storage technologies;
- to define perspective variants of application of technologies of heat storage in central heating systems.

Directions for development of district heating

Directions of modernization of central heating system are conditioned by mismatch of priorities of district heating enterprises and consumers. Our analysis shows that they coincide only at the level of installation of heat regulation systems and reduction of heat losses for technological needs. Consumers are interested in reducing payments for heat consumption, with maximum comfort in the premises, while suppliers of thermal energy are interested only in the transition to the multi-purpose balance and reducing the cost of heat production.

In order to increase the efficiency of using district heating, there is a tendency to lower operating temperatures in heating networks. Lower network temperatures reduce heat losses and allow the integration of low-grade waste heat and renewable energy sources.

In the future the need for heating is expected to decrease, the need for cooling in buildings will increase significantly in the coming decades. The task of an emission-free supply of heating and cooling energy is a challenge, especially in urban areas. Thus, the supply of energy by decentralized sources of supply is not acceptable. On the other hand, district heating and cooling DHS is becoming increasingly important. The development of district heating and energy storage systems are shown in Figure 1.

There is a general tendency of correspondence of stages of development of heating networks to stages of development of industries. DHS 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 (coal, peat) and oil products (oil, mazut, diesel). Generation 1 DHS is characterized by high temperature of the heat carrier above 150°C and low efficiency of 50%.

Generation 2 DHS heating and hot water supply determines a mass use of natural and liquefied gas, the use of secondary energy resources (SER) in the fuel mix, compatible generation of heat and electricity, the heat carrier temperature is 115/70°C and the system efficiency is around 60%. It should be noted that thermal accumulators (TES) appear at sources of heat generation. DHS of the 2nd generation developed from the 40s to the 90s of the last century.

Generation 3 DHS unfolded in Western Europe and the U.S. from the early 2000s to 2020. They are characterized by compatible generation of heat and electricity and the use of renewable energy sources (wind, solar, geothermal heat), alternative and biological fuels and abandoning the use of fossil fossil fuels. The operating temperature of the heat carrier is 90/70°C and the efficiency of the system has increased to 70%. Widespread use of renewable sources led to the wide introduction of heat storage technologies. It should be noted that Ukraine is currently actively developing DHS 3rd generation. Now the vast majority of energy comes from non-renewable sources such as oil, coal, natural gas and uranium, causing greenhouse gas emissions, global warming and related climate change. Counteracting these adverse phenomena is a huge challenge for modern science and economy, which calls for research on the possibility of using renewable energy sources as alternatives with solar energy and methods of production, conversion and storage being the highest. High potential for the use of heat derived from solar energy, due to the high efficiency of storage and conversion of this energy. The main elements used in this area are solar collectors and heat storage systems.

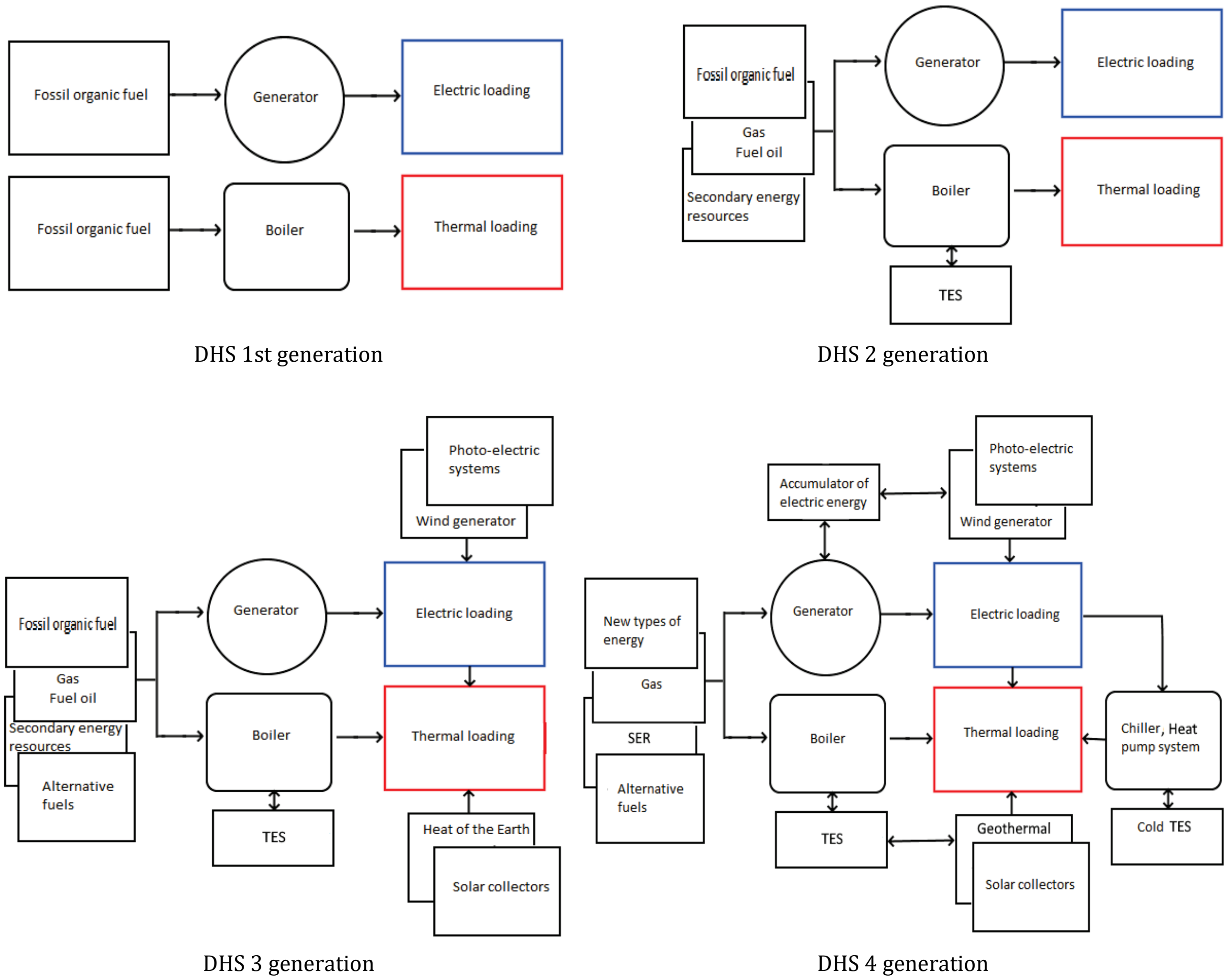

***FIGURE 1.** Development of district heating and energy storage systems*

This has led to the transition to 4th generation DHS systems. The EU is currently implementing an ambitious plan to create a new generation heating, hot water and cooling system by 2050. It covers the development and introduction of new energy sources, and almost complete abandonment of the use of fossil fuels. The temperature schedule of such a system is 70°C/50°C, and the overall efficiency is envisaged above 70%. The focus is on thermal and electrical energy storage and storage systems. Scientific research carried out over many years has been aimed at developing appropriate accumulators, which will allow energy storage and will be characterized by high efficiency.

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.

Classification of technologies of storage of heat

TES technologies provide the ability to store heat or cold and use excess thermal energy 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 the form of energy storage, general heat storage technologies fall into the following categories:

1. Technologies for transforming mechanical energy into thermal energy, such as hydroelectric power plants, steam turbines, Stirling engine, widespread, but characterized by low efficiency, about 30%. It should be remembered that there are thermodynamic limitations of power generation at temperatures below 340°C. Therefore, they are not used in DHS systems.
2. A large amount of heat is available between 40°C and 200°C, but there are inherent difficulties in its utilization and utilization that require separate and in-depth research. Because lowtemperature heat involves a smaller temperature gradient between the two fluid streams, large heat transfer surfaces are required for heat transfer. This limits the economic viability of their use as they require the use of a heat pump to increase the temperature of the heat transfer fluid. TES based on singlephase capacitive storage for seasonal or shortterm thermal energy storage allow 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 accumulators ranges from a hundred kilowatts to hundreds of megawatts. Payback period of 4 to 6 years.
3. Hidden heat including a significant part of the energy. Thermal energy storage in the so-called latent TES systems are based on the use of materials with phase transition of organic (high molecular weight paraffins, waxes and glycols) or inorganic origin (crystalline hydrates, salt hydrates and eutectic water-salt solutions), which are characterized by high latent heat capacity. The limited use of thermal storage with phase transition can be explained by the low thermal conductivity coefficient and excessive corrosiveness of inorganic materials, as well as the change in volume during melting of materials of organic origin. Payback period of about 3 years.
4. Of general interest are technologies of use of latent chemical energy, based on adsorption processes. These are equipment for heat receiving from gas for low and medium temperatures. Zeolites and silica gel are used as the working body, air is used as the coolant. Thermal energy storage can be daily, weekly, monthly or even seasonal, depending on the volume of the working body. Payback period up to 7 years.
5. Heat accumulators based on photochemical and thermochemical reactions, thermoelectric and triboelectric principles of action have not found wide application and are currently at the stage of research trials. 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.

Application of technologies storage heat is in the systems of the central heating

Centralized heating and hot water supply has a great potential for the use of main pipelines as heat accumulators, allowed by the current regulatory documents [4]. If in Western Europe DHS occupies about 10% of the total heating market, in Ukraine it reaches 70% [5]. 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 addition, promising technologies of heat storage in central heating systems include heat pumps – a cost-effective technology that uses electricity to obtain heat from the ground or air for heating systems of industrial, commercial and residential buildings. However, investing in electric heat pumps is not attractive due to a lack of legislative subsidies. Large capacity heat pumps for DHS are seen as an economic and energy efficient solution [6].

Widespread stationary heat storage have been used in DHS since the first generations of heating systems. Stationary TES are used both in homes and in combination with thermal power plants, boilers and heat pumps in DHS. Moreover, TES gives the possibility to optimally control the load of boilers, reducing the consumption of fuel and energy resources and harmful emissions into the environment. Mobile thermal accumulators (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 [7].

Principal technological scheme of integration of heat storage into heat supply system is shown in Figure 2 covers – direct TES on the energy source, TES on the heat network, TES of distribution heating system and M-TES on a truck.

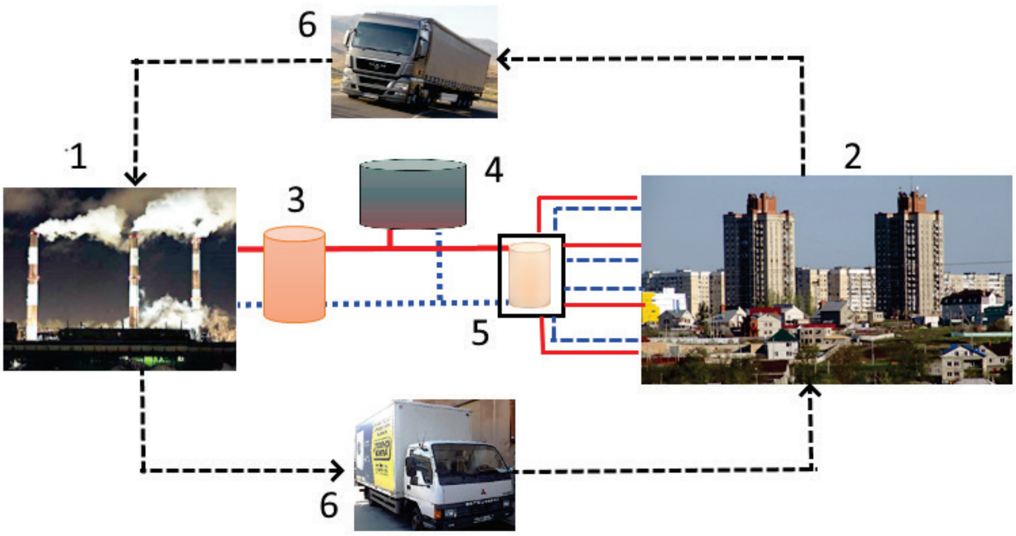

***FIGURE 2.** Of principle flowsheet of integration of thermal storage in the DHS system, where: 1 – TES an energy source, 2 – TES is an user, 3 – TES of direct action, 4 – TES a transport network, 5 – TES of the indirect operating on distributive a network, 6 – M-TES*

The issues of improving the efficiency of district heating have a number of controversies. The first is the type of heating system of the consumer or with direct connection to the pipeline, or through a heat exchanger. The second is heat losses associated with the connection points of customers and their distance from the boiler house. The third is in the heat extraction of different customers, which may have different energy efficiency characteristics and level of heat consumption. Others include the length and diameter of pipelines, environmental conditions, the number of loops and their characteristics.

It has been established that demand management using heat accumulators is a good method of managing district heating. It clearly has investment attractiveness and contributes to the decarbonization of urban areas.

Various works show that such benefits can be achieved:

- reduce peak load by up to 30%,
- significantly reduce harmful emissions and fuel consumption by up to 10%.

Long-term transformation of energy should be aimed at the development of existing and creation of new functional properties of energy system and its elements, which to the greatest extent ensure the achievement of these key values; heating network (all its elements) is considered as the main object of formation of new technological basis, which provides an opportunity to significantly improve the achieved and create new functional properties of energy system.

Comparative characteristic of functional properties of modern energy system and system based on Smart Grid concept demonstrates that Smart Grid implementation means creation of smart distribution network [8]. This allows against the background of aging of fixed assets and increase in consumption volumes, to achieve an increase in profitability, reliability and failure-free operation while reducing losses of heat and coolant in the networks. In addition, these systems are aimed at improving operational efficiency, optimization and distribution of load on the heating network. Implementation of the Smart Grid concept is innovative and reflects the transition to a new technological paradigm in the energy sector and economy in general, and strengthens energy independence.

Figure 3 summarizes the proposals of energy-saving innovations for district heating companies. At the level of use of fuel and energy resources it is a transition to the multifuel balance. At the level of generation of heat, cold and electricity it is a wide use of alternative and renewable sources. In the transportation of coolant the use of storage of heat and cold, targeted dosed supply of heat or cold to the consumer through mobile heat accumulators and maximum reduction of heat losses.

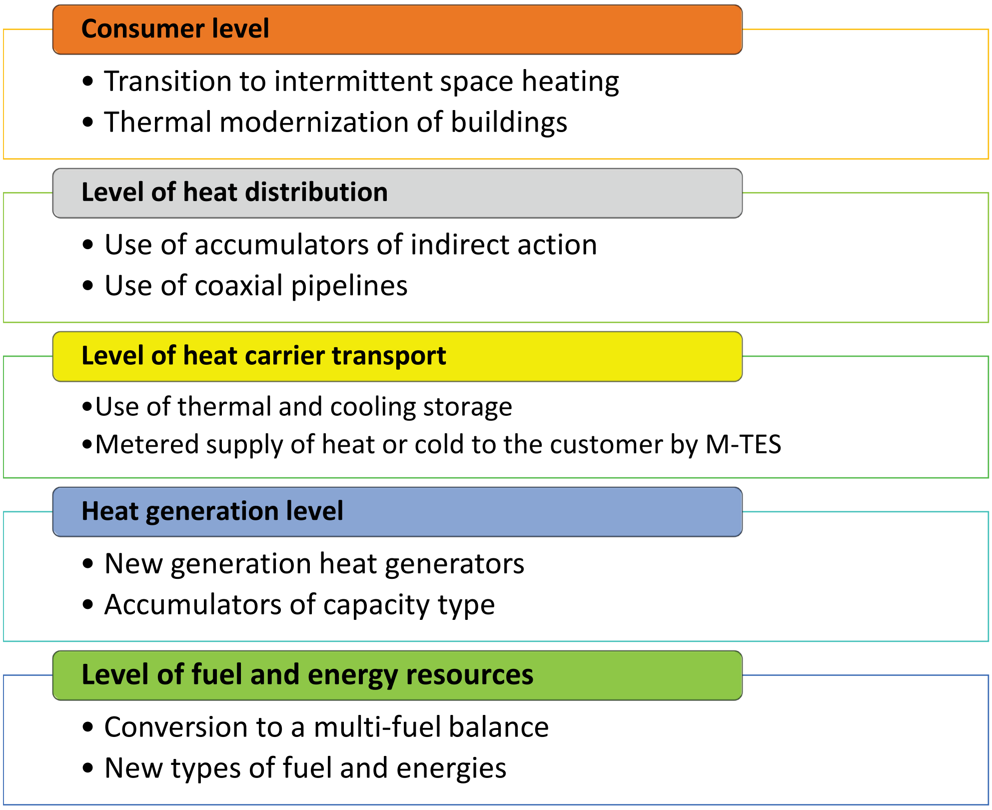

FIGURE 3. *Suggestions for energy saving innovations for district heating companies*

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

It is assumed that the consumer coolant supply pipeline is located inside another pipeline. The return coolant returns to the heat source through the intertube space [9].

Coaxial pipelines proposed for implementation can reduce heat losses almost 2 times and 2 times cheaper than traditional two-pipe heat networks for new construction and modernization of heating networks.

The advantages of the new method of heat carrier transportation are:

- considerable reduction of costs for heat network construction;
- possibility to use existing pipelines in the modernization of the networks;
- decrease of insulation layer thickness and heat losses reduction;

- a smaller length due to a reduction in the number (or even absence) of U-shaped compensators;
- hydraulic stability during operation;
- reduced temperature and pressure drop on network structures;
- a long operational life.

At consumer level, it is proposed, apart from the thermo-modernization of buildings, a transition to intermittent heating of rooms, i.e. heating only when people are permanently inside and a reduction of the temperature at other times.

Application of mobile thermal storage M-TES

One promising direction is the use of the system of storage and mobile transport of thermal energy [10]. Since 2014, research work devoted to mobile thermal energy storage for the disposal and use of industrial waste and excess heat for distributed users has been carried out abroad, and the first commercial projects have been implemented.

Selected examples of such solutions are listed below.

Marco Deckert et al. (Germany), tested a system of two 20-foot tanks filled with sodium acetate trihydrate. The tested M-TES stores up to 2.0 MW/h of heat.

Weilong Wang (Taiwan) investigated direct and indirect heating water storage tanks filled with erythritol – a sugar alcohol characterized by a melting point of 118°C.

Andreas Krönauer et al. (Germany) presented the results of annual tests in which M-TES in the form of a tank filled with 14.0 tons of zeolite and has a heat storage capacity of 2.3 MW/h. The tank uses air as the heating/cooling medium.

In 2020 the authors' group of the laboratory "Processes and Technologies of Heat Supply" of the ITTF of the National Academy of Science of Ukraine created, tested and studied the prototype of mobile heat accumulator with heat capacity 1.2 MW/h (Fig. 4).

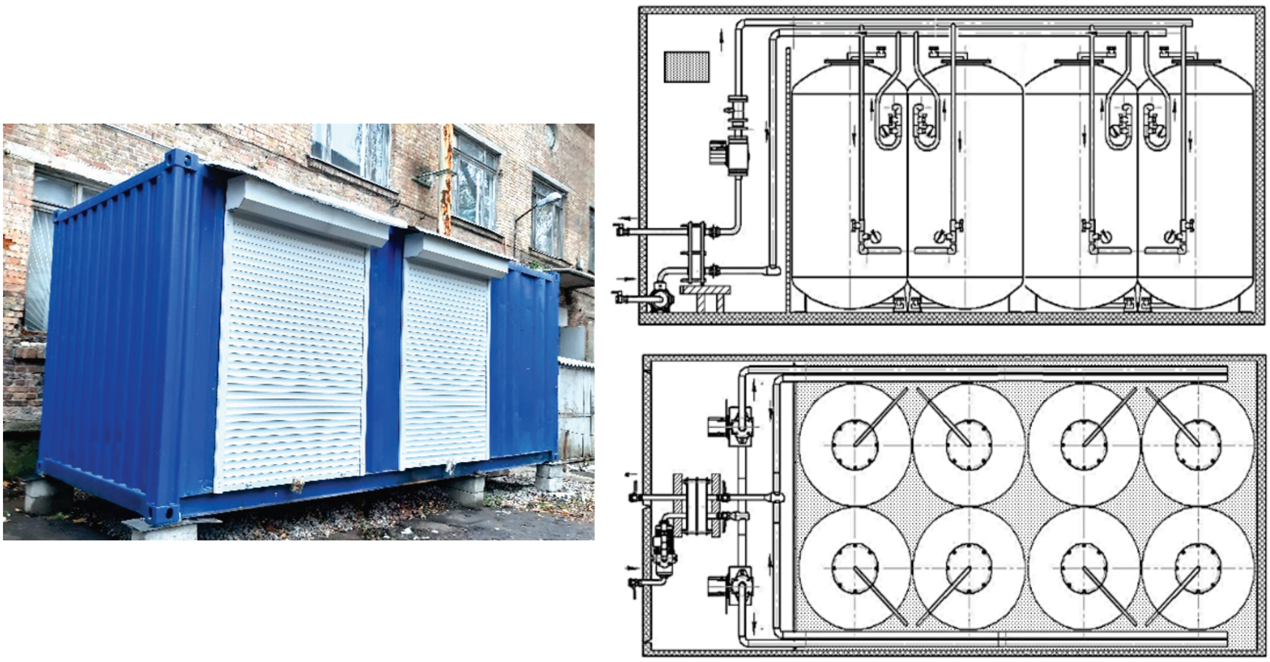

FIGURE 4. *Mobile heat storage MTA-0.5 MW*

Charging time is 4-6 hours, discharging time 10-12 hours, heat storage capacity 200 kW/h, average load power 120 kW, average discharge power 90 kW. The mobile container-type M-TES is equipped with a block heating opinion and heat storage tanks.

For the first time to solve this problem, a design of mobile thermal accumulator is proposed, which is a dry cargo container with an individual heat opinion and mounted tanks-storage of a special design. Feature of such a tank- storage is that its design can solve the problem of stratification, by using a thermal core and substances with a phase transition. As a result of the work for the first time justified and laboratory researched a mixture of functional hydrogels to create an original formula accumulating pseudo-plasticity.

The proposed abandonment of the traditional pipeline transport of heatcarrier and the creation of a fundamentally new discrete heating system. The use of M-TES makes it possible to build a flexible heat scheme for modernization and construction of new heat supply sources. And also to attract local fuels, secondary resources and renewable energy sources to the energy sector.

Conclusions

Global trends in efficiency, energy savings and security of energy systems actualize the task of developing energy storage technologies.

Thermal energy storage can be used to control the heating system load, i.e. to equalize the load on the energy generation source to provide peak heat demand with a high coefficient of equipment capacity utilization. The paper considers the actual 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.

Conflicts of Interest: The author declares no conflict of interest.

References

[1] European Commission. The European green deal: communication from the commission to the European Parliament the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, 2019, URL: https://eur-lex.europa.eu/legal-content/EN/TXT/uri¼CELEX:52019DC0640.

[2] European Commission “An EU Strategy on Heating and Cooling,” Brussels 2016, available: https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-51-EN-F1-1.PDF.

[3] Union European. EU Energy in figures: Statistical pocketbook 2020, URL: https://op.europa.eu/s/oIDP.

[4] Thermal networks, DBN B.2.5-39: 2008, Valid from 2009-01-07.

[5] Poredos A., Kitanovski A., *District heating and cooling for efficient energy supply*, International Conference on Electrical and Control Engineering, 2011, http://dx.doi.org/10.1109/ICECENG.2011.6058201.

[6] Mathiesen D.A., Averfalk B.V., Werner H., Lund S., Lund H., *Heat Roadmap Europe: Largescale electric heat pumps in district heating systems*, Energies, Review 10(4), https://doi.org/10.3390/en10040578.

[7] Demchenko V., Konyk A., *Main aspects of heat storage processes*, Scientific Works, 84(1), 2020, pp. 48-53, https://doi.org/10.15673/swonaft.v84i1.1868.

[8] Vakulenko I.A., Kolosok S.I., *Connections SMART GRIDS concept with updates of Ukrainian heat power*, Visnyk of Sumy State University Economy, 1, 2019, pp. 14-18, https://doi.org/10.21272/1817-9215.2019.1-2.

[9] Demchenko V.G., Dunyak O.V., Yevtushenko O.V., *Comparative evaluation of the effectiveness of the system of transport of heating carrier based on coaxial tubes*, Thermophysics and Thermal Power Engineering, 38(5), 2016, pp. 39-47, https://doi.org/10.31472/ihe.5.2016.07.

[10] Demchenko V.H., Konyk A.V., *Application of special multifunctional transportable capacitive type terhmo energy storage*, Collection of Abstracts of the XX Scientific and Technical Conference, Chernihiv “Creation and modernization of armaments and military equipment in modern conditions”, 2020, pp. 74-75.