NENE 2020
September 7 - 10
PORTOROŽ
SLOVENIA
29th International Conference Nuclear Energy for New Europe

Thermal Energy Storage for TEPLATOR: Technology, Utilisation And Economics

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ABSTRACT

Generally, energy storage is a very current topic nowadays as renewable sources of energy produces more cheap but unpredictable energy. Energy storages became more and more common not even for electric but also for heat. Thanks, cheap energy, stronger and smarter control systems and consumption predictions energy storage is becoming not only as needed solution but also as a wanted solution even as energy storage for district heating. TEPLATOR is a critical assembly using already irradiated nuclear fuel from commercial light water power reactors which is not burnt up to its regulatory and design limits. This innovative concept for district heating could benefit from having a decent heat energy storage for compensation of: 1) TEPLATOR power fluctuations, 2) Compensation and smoothing of the demand curve and 3) can serve as an emergency and safety heat sink. Thermal heat storage is a promising solution, which operates in a suitable temperature range, could absorb adequate amount of heat in reasonable material volume and with good operation dynamics providing quick response for charging and discharging demands. In this paper we would like to point out and discuss benefits and possibilities of Thermal energy storage operating with TEPLATOR.

1 INTRODUCTION

As electricity production in Europe is moving towards renewable sources of energy, deploying wind and solar (photovoltaic and concentration) powerplants, current district heating still consists mainly of coal, gas and oil sources with some minor addition of biomass and waste incineration plants. Increasing pollution limits and departure for coal and oil burning may lead to search for innovative technologies. TEPLATOR is an industrial concept of central supply of heat/cold using spent nuclear fuel from light water reactors. Combining this new concept of heat production for district heating with Thermal Energy Storage (TES) could bring more flexibility and more safety to TEPLATOR operation and also could have significant economic value. It has been proven that he application of TES systems in industrial and building sectors is expected to provide an annual energy saving up to 7.8% in the European Union [1]. As for the environ- mental impact, the utilization of these systems can reduce CO_2 emissions by 5.5% [1]. More in general the use of TES in Europe allows to save annually about 1.4 million GWh [2].

2 DESING

2.1 General TEPLATOR design

TEPLATOR is a pool type reactor using 55 VVER-440 spent (used) fuel assemblies, moderated and cooled by heavy water. Thermal power output is from 50 to 200 MW thermal. Coolant circulation is forced during standard operation during emergency residual heat removal to heat storage is natural circulation anticipated. Reactor operates on atmospheric pressure or slightly above. Inlet / outlet temperatures for water are 45 °C and 98 °C respectively, for Santowax temperatures will be above 100 °C. [3]

TEPLATOR (Figure 1) basic design circuit layout includes 3 circuits. The primary circuit includes a so-called calandria, a core, three heat exchangers and three pumps; it is therefore a so-called three-loop design. The core is made from graphite channels in which the fuel is based. The space between the channels is filled by the moderator, heavy water. The coolant flows in the channel around the fuel and further it flows through a system of pipes at the outlet of which there is a collector. In this collector the coolant from all channels is collected. Three pipes are led out of this collector, each of which is led into one heat exchanger. The coolant passes through the primary side of the heat exchanger and returns to the fuel channels through the pump and the lower distribution chamber [4].

Three primary heat exchangers with heat transfer surface 520 m^2 each. Each heat exchanger is able to cool 100% of the power, in case of failure of the others [4].

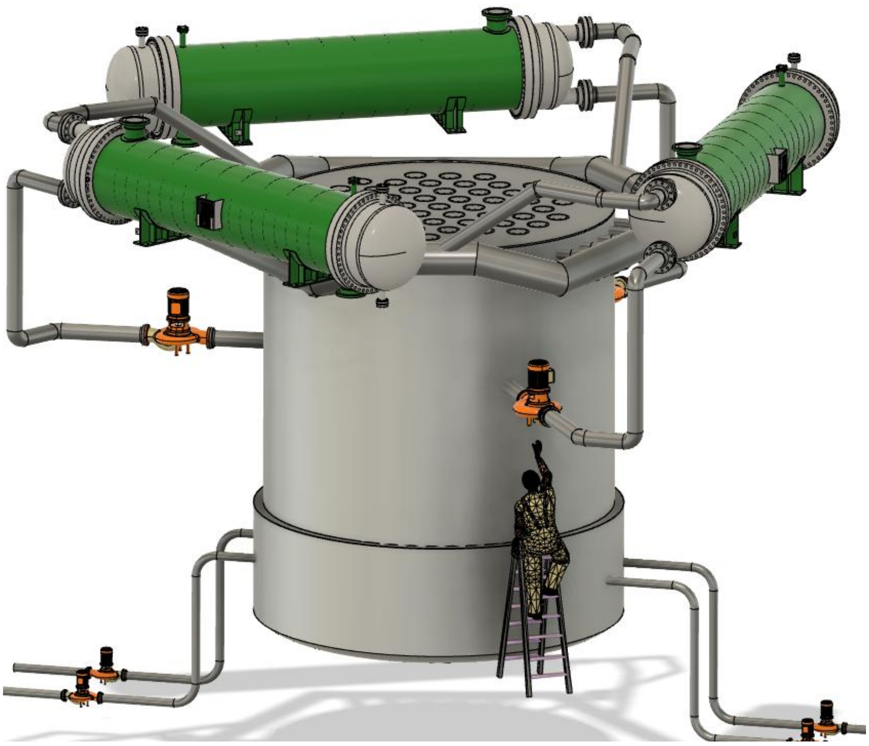

Figure 1: TEPLATOR 3D Visualization [4]

Heat Transfer Fluid (HTF) is used in the secondary circuit (intermediate circuit). Water (for lower temperature range) or molten salt (for higher temperature range and TEPLATOR design using Santowax coolant) is considered according to the operating parameters. The HTF transfers heat from the primary circuit to the heating circuit itself via the secondary exchanger. The intermediate circuit includes two storage tanks (or one in case of Thermocline design) serving as a thermal energy storage for covering demand peaks. Storage tanks are connected are able to simultaneously dissipate and store heat from the residual power of the fuel, therefore they can be used as residual heat removal system for safety purposes.

The tertiary or heating circuit is then a set of secondary exchanger and pipes, which distribute the heat to the end customer either as steam or hot water, depending on installed distribution network.

2.2 Thermal Energy Storage Design

Thermal Energy Storage (TES) connected to TEPLATOR secondary circuit is an innovative tool for compensation of TEPLATOR power fluctuations on production site and compensation and smoothing of the demand curve on consumption site in short term (minutes / hours). In longer term (hours / days) it should cover mainly disbalance between heat consumption during daytime, allowing TEPLATOR operation at full power. Seasonal heat storing is not recommendable due inapplicable TES size and significant heat loss, for this case combination with process heat or cold production or district cooling is recommended.

Optimal TES: 1/ operates in a suitable temperature range (given by required temperatures in district heating grid) 2/ could absorb adequate amount of heat in reasonable material volume, 3/ has a good operation dynamic providing quick and safe response for charging and discharging demands (operation dynamic strongly depends on length of charging / discharging periods characterized by optimized demand curve).

TES can also serve as an emergency and safety heat sink, for residual heat removal system (RHRS), after reactor shut down (scheduled e.g. for service and inspection or emergency one). TES capacity for RHRS is considered to absorb 4 % of TEPLATOR power output for 12 hours and subsequently following with 1 % TEPLATOR power output for next 60 hours. Natural convection in primary circuit and secondary circuit is anticipated. Cooling of TES is anticipated only by heat loos to environment (assuming active TES cooling and heat distribution and heat dissipation in distribution grid not operating).

Two options for TES was considered: sensible heat storage (SHTES) or latent heat storage (LHTES).

2.3 Latent heat storage

By using latent storage instead of sensible storage, the specific volume demand can be reduced of a factor 5 [2]. The main advantage of LHTES with respect of SHTES is the higher energy density, which allows storing the same amount of energy by using smaller volumes of material. Also, only one storage tank is needed, instead of two tank solution for SHTES. Lower space and material requirements, are compensated with higher heat storing material price and need for more enhanced construction of the storage tank (e.g. fins for better heat transfer). From an economic point of view, a techno-economic assessment performed in [5] shows that LHTES systems costs over 45 €/kWh, which is 4 times the cost of a water tank

TES (about 10 €/kWh) [2]. Furthermore, some experiments [6] shows that heat losses in LHTES are significantly lower in comparison to an equivalent SHTES. LHTES are generally suitable for systems with low temperature difference between outgoing and returning streams. With higher temperature gradient more phase changing materials need to be involved, this leads to more complicated construction and significant rise of construction and operation costs.

2.4 Sensible heat storage

In comparison with LHTES, SHTES are more flexible, easy to build and operate. Temperature of stored material (hot tank) could be easily changed in short or long term, without need of replacing the storage material. On the other hand, SHTES are characterized with lower heat storing density and larger storage tanks.

There are two storage tanks concepts: A/ 2-Tank storage, having hot and cold storage tank. Where hot tank is being charged by heated heat transfer fluid and cold tank, where depleted HTF is stored. And B/ one tank Thermocline system, where hot and cold HTF is separated with floating barrier or tank is filled with material restricting vertical movement of the fluid. Generally said Thermocline has lower building cost and is less space demanding then 2-Tanks, while 2-Tanks has lower operation demands and costs [7].

For sensible heat storage at temperatures above 100 °C molten salts are most suitable. Advantages of molten salts are the high thermal stability, relatively low material costs, high heat capacity, high density, non-flammability and low vapor pressure. Due to the low vapor pressure pressurized vessels are not required [7].

For temperatures below 100 °C molten salts with low melting point [8] can be used but due general due to media costs, the risk of corrosion and the difficulty in hygroscopic salt handling, water itself seems to be better solution as storage material.

3 CONCLUSIONS

To conclude: Thermal energy storage can serve for TEPLATOR's residual heat removal. Thermal energy storage could provide enough capacity to allow TEPLATOR's full power operation while covering the changes in heat consumption. Construction and Design of TES is strongly dependent on primary circuit temperatures as well as on operation temperatures at district heating grid. Sensible heat storage with molten salt as heat transfer / storing fluid is optimal for TEPLATOR operating above 100 °C (with SANTOWAX primary circuit coolant) and latent heat storage with solution of salt hydrates in water is optimal for TEPLATOR operating at temperatures below 100 °C.

ACKNOWLEDGMENTS

Authors would like to acknowledge support of Technological Agency of the Czech Republic TK02030069.

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