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TEPLATOR: Residual Heat Dissipation By Energy Storage

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ABSTRACT

TEPLATOR stands for an innovative concept for district and process heating using already irradiated nuclear fuel from commercial nuclear powerplants (NPPs). There are several variants for TEPLATOR, one of which being TEPLATOR DEMO. TEPLATOR DEMO is operating at atmospheric pressure, is a three-loop design with three primary heat exchangers, three circulation pumps and has 55 fuel elements in the core. The primary coolant after leaving the fuel part enters the primary heat exchanger (HE I), where the heat is transferred to the intermediary (secondary) circuit heat transfer fluid (HTF). This secondary HTF transfers heat from HE I via secondary circuit into the secondary heat exchanger (HE II), where heat enters the actual heating (tertiary) circuit (i.e., supplying heat to end consumers).

The HE I (i.e., the one between the primary and the secondary circuit) has two roles. During heat production, heat from primary circuit is transferred via HE I into the secondary circuit. From here it goes into the heating (tertiary) circuit and to the end consumer. During other operating conditions, when either the heating circuit is not in operation or the TEPLATOR is shut down, the HE I is used for removing the residual heat from the primary circuit. For this purpose, there is an energy storage circuit interconnected to the secondary circuit with two storage tanks, ‘hot’ one and ‘cold’ one. These two tanks are connected to each other via secondary side of the HE I and primary side of HE II. In need of residual heat removal, heat from primary circuit is transferred via HE I into the HTF flowing from the ‘cold’ to the ‘hot’ storage tank. Thus, no heat/energy is wasted.

KEYWORDS: TEPLATOR, TEPLATOR DEMO, heat, energy storage, residual heat

1 INTRODUCTION

TEPLATOR is an innovative concept and as such it is trying to provide an innovative solution for all parts of heat production process. One of the parts of heat production process is a heat removal and in our concept it is closely related to energy storage or thermal storage specifically. Energy storage has been among most discussed topics for past several years. When using a term thermal energy storage (TES) (in a larger scale), mostly concentrated solar plant (CSP) and its technology is the first thing to be pictured these days. However TES can be implemented in other technologies as well. Nuclear industry has started to investigate options for coupling energy storage with nuclear power plants [1] in terms of operation, heat and electricity production [2] optimization and grid operation optimization [3].

Our concept is also coupling nuclear technology with energy storage technology and the basic idea behind is to prevent energy wasting. We are aware this is a very challenging and ambitious task and we are working on implementing the system in order to meet the highest and best safety, reliability, economy and ecology standards.

2 BASIC WORKING PRINCIPLE OF TEPLATOR

The whole system with all three circuits, primary being TEPLATOR, secondary with energy storage and tertiary being actual heating circuit is schematically shown in FIG. 1.

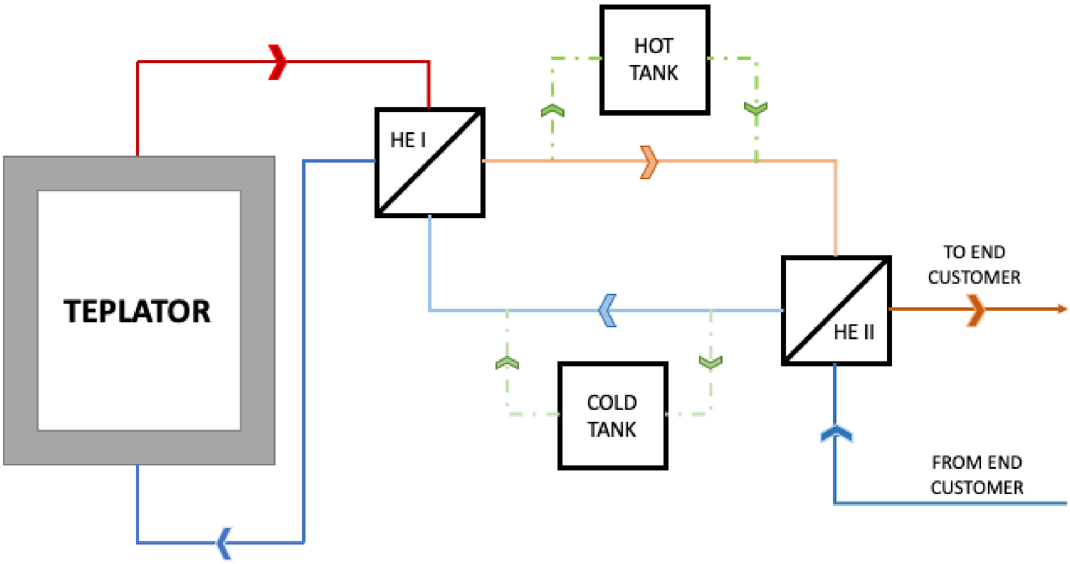

FIG. 1 TEPLATOR system with three circuits

2.1 Primary circuit

Primary circuit (FIG. 2) is a three-loop design (3 primary heat exchangers, 3 main circulation pumps, 3 loops cooling loops) operating at atmospheric pressure. The core is composed of 55 fuel channels with standard hexagonal nuclear fuel VVER-440 (already irradiated in conventional NPP) [4]. The space between these channels is filled with moderator being heavy water. This as a whole is surrounded by the reflector being graphite. Primary coolant, also heavy water, is forced thought fuel channels. This primary coolant flows through fuel channels and through piping system that is lead into the primary collector. From the collector the coolant enters primary heat exchangers (HE I) where the heat is transferred to the secondary coolant. The primary coolant then flows through main circulation pumps to the pressure vessel and back to the fuel channels. [5]

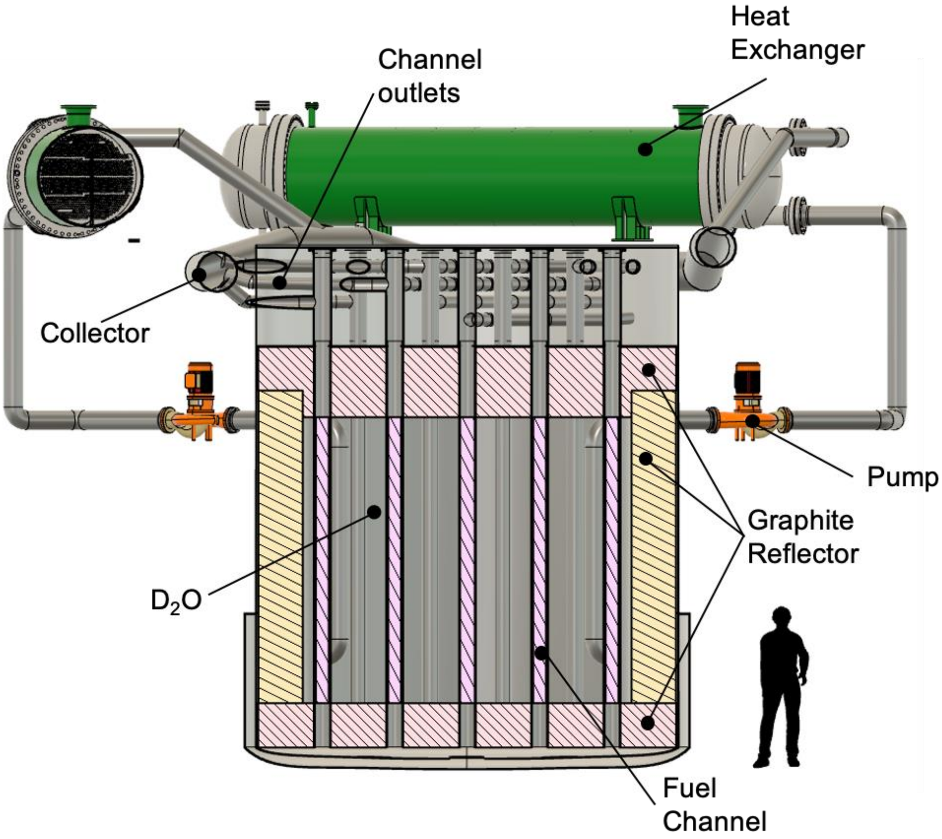

FIG. 2 TEPLATOR DEMO design

2.2 Secondary circuit

Secondary or intermediary circuit consists of primary (HE I) and secondary (HE II) heat exchangers. On the piping connecting these HEs there is a possibility of interconnecting TES. This secondary circuit is included for several reasons. One being safety reason, in case of leakage on the primary side of HE I the contaminated primary coolant would not affect the heat transfer fluid (HTF) supplying heat to the end customer. The other reason being optimization of TEPLATOR operation since interconnected TES would serve as a buffer for heating demand peaks. And the last reason being safety again. The TES can not only store heat deliberately produced for heating industry, they can also store residual heat from generated in the TEPLATOR during shut down. In this operation condition they would serve as an emergency and safety heat sink.

2.3 Tertiary circuit

Tertiary circuit is the last circuit that serves the purpose of supplying the heat to end customer. It consists of HE II and the piping system to and from the customer. As it was mentioned earlier in section 2.2., in case of leakage on the primary side, the HTF reaching the end customer would not be affected.

3 ENERGY STORAGE SYSTEMS (FOR HEAT DISSIPATION)

As it was mentioned in section 2.2. secondary (intermediary) circuit consists of primary (HE I) and secondary (HE II) heat exchangers. On the piping connecting these HEs there is a possibility of connecting TES. Thermal energy storage consisting of two tanks are connected to each other via secondary side of the HE I and primary side of HE II.

3.1 Energy storage and its interconnection with TEPLATOR

Energy storage in general is designed to accumulate energy when production exceeds demands or to operate the system where its connected optimally. Thermal energy storage accumulates energy by heating or cooling a storage medium. This energy can be used later when needed.

The mechanism for storing the heat can be divided into sensible or latent heat storage principle. For every application different storage medium and mechanism needs to be considered carefully. In fact the storage medium strongly depends on the storing mechanism. In FIG. 3 the mechanism of TES are shown. Different solid rsp. liquid materials can be used for sensible heat storage such as rocks, concrete rsp. molten salt or thermal oils. For latent heat storage phase change materials (PCM) are used.

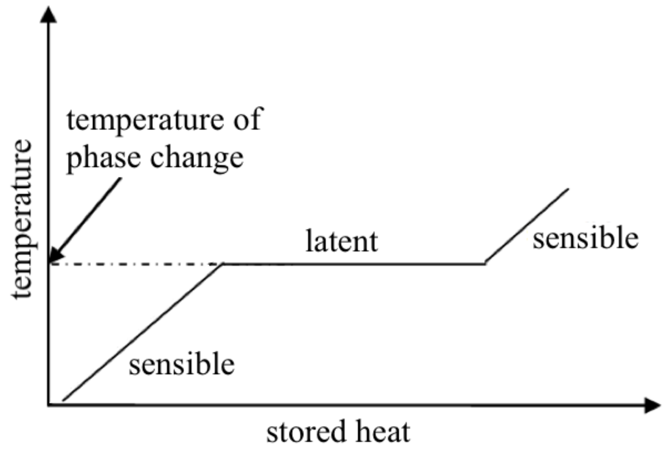

FIG. 3 Sensible and latent heat mechanism [2]

Energy stored in a sensible heat can be described in Eq. (1):

$$Q = m\, C_p\, \Delta T \qquad (1)$$

In our design we are considering TES with sensible heat storage mechanism. The TES system can generally consist of two or one tank. Each of these designs has its pros and cons, however for our purposes we are considering two tank design. One tank is so called ‘cold’ tank and the other is so called ‘hot’ tank. If energy storage system needs to be activated, heat from primary circuit is transferred via HE I into the HTF flowing from the ‘cold’ to the ‘hot’ storage tank. The HTF used in the energy storage strongly depends on operating conditions. However there is a wide range of HTF that can be suitable for such application.

The promising HTF for TEPLATOR would be molten salt mixture. The reasons for choosing this HTF and ideas behind and described in [6].

3.2 Application of energy storage for heat dissipation

During TEPLATOR shut down or during abnormal operation condition when the heat needs to be dissipated, this TES system would serve as an emergency or safety heat sink. During this operation condition the tertiary circuit would not be in operation so the heat produced in the TEPLATOR needs to be dissipated in a different way. After TEPLATOR shut down, generated decay heat (for TEPLATOR DEMO parameters see FIG. 4) is transported via primary coolant through the loops to the HE I and back to the core.

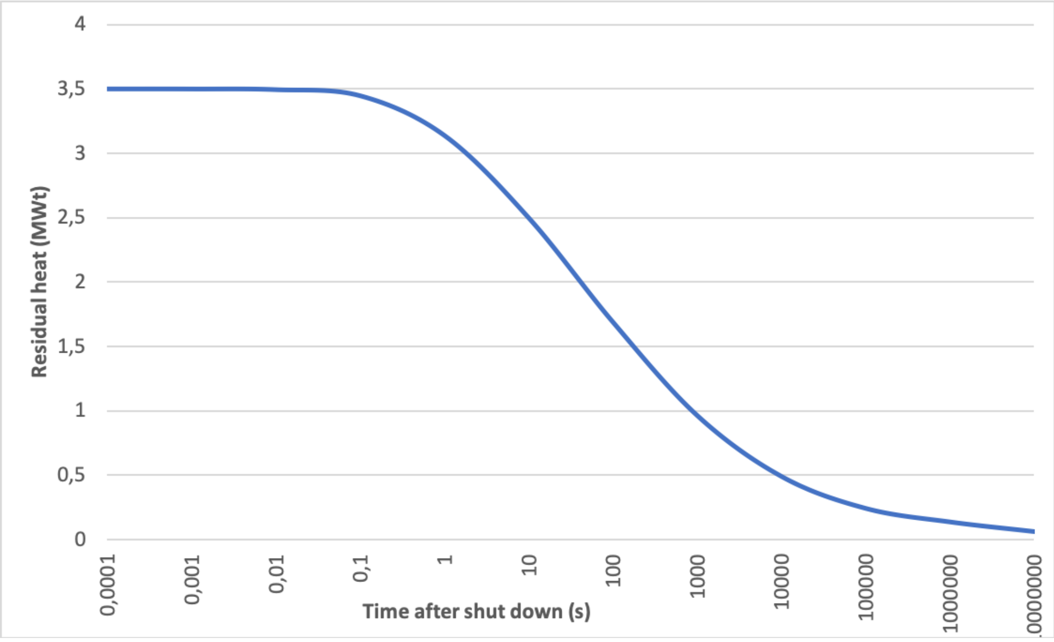

FIG. 4 Residual heat removal curve for TEPLATOR DEMO

TES system is activated and HTF from 'cold' tank flows through the HE I (light blue in FIG. 5) where the heat is transferred from the primary circuit to this TES HTF and from HE I this heated HTF is transferred to the 'hot' tank (light red in FIG. 5) as shown in FIG. 5. This process can also be referred to as charging of TES.

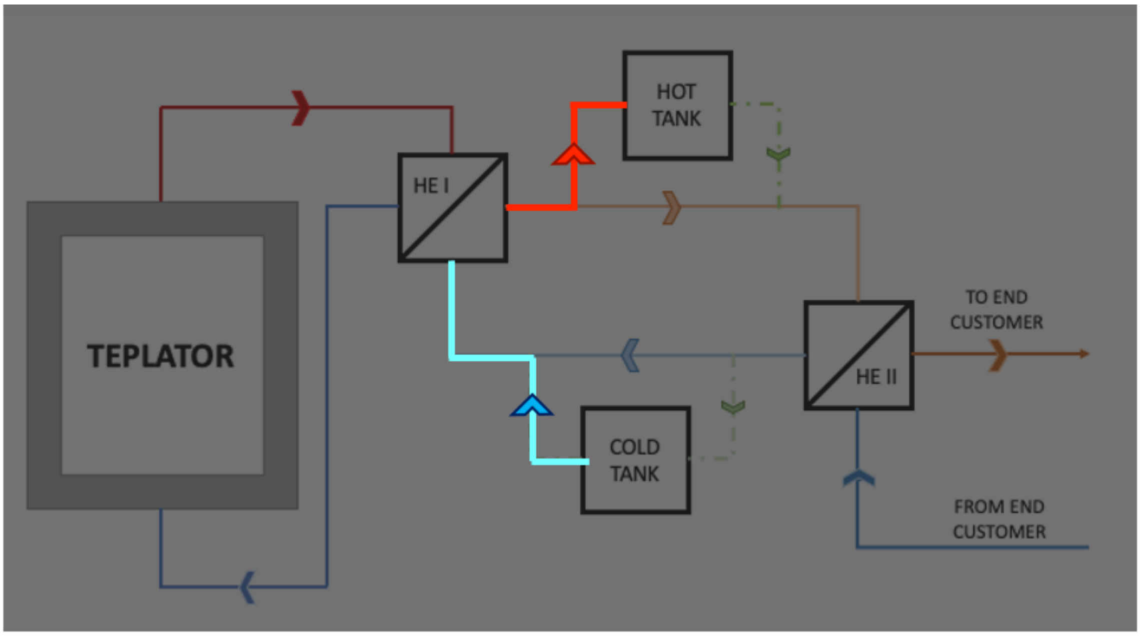

FIG. 5 Residual heat removal from TEPLATOR (charging of TES)

Heat stored in these tanks can then be used for heating the HTF in the tertiary circuit once it is put back in operation as shown in FIG. 6. This process can also be referred to as discharging of TES.

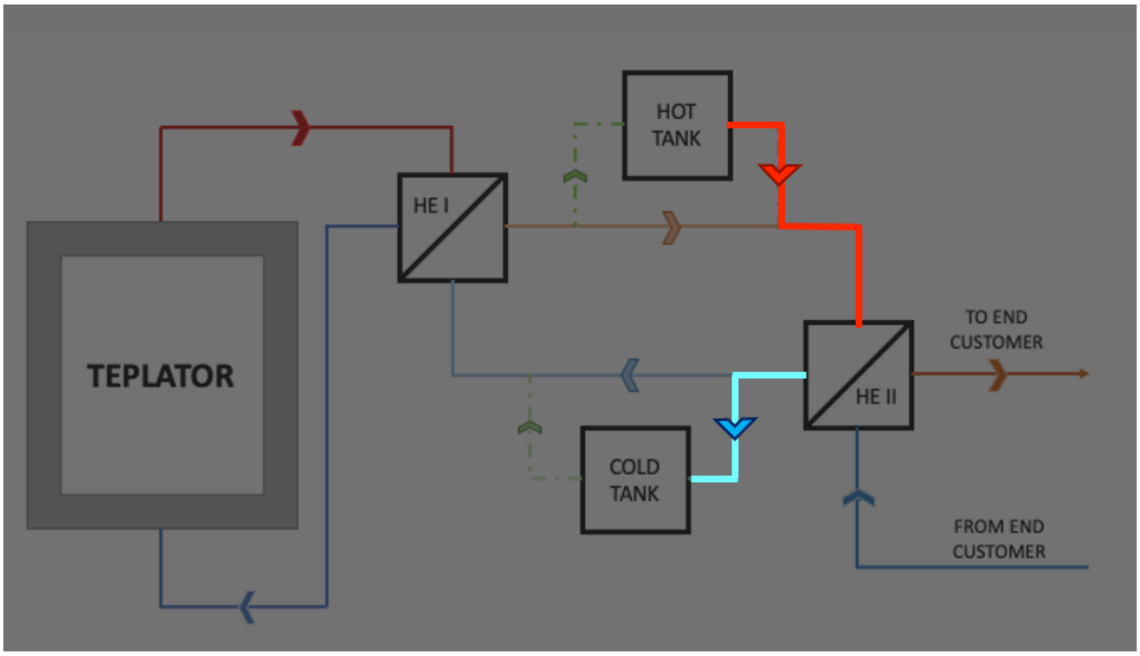

FIG. 6 Supplying heat to tertiary circuit from TES (discharging TES)

3.3 Challenges for the energy storage interconnection

In order to successfully use TES for such purposes and for regular heat storage in general, HTF in secondary circuit and in TES needs to be identical. The parameters of the HTF are carefully chosen with respect to the operating conditions of the whole system. The volume of both tanks is designed sufficient enough to remove decay heat for several hours in case of emergency. The HTF fluid will also affect used materials for piping and constructions of TES tanks.

Auxiliary systems for TES system may be introduced in case of using molten salt or other HTF such as heating of piping and tanks to prevent freezing of the HTF. In case of using molten salts, great attention will be paid to all mechanical components such as heat exchangers, pumps, valves etc.

4 CONCLUSION

This article described principles of integrating energy storage to the secondary circuit of TEPLATOR. Having energy storage integrated in the system has several economical, ecological and safety benefits. The energy storage is planned to be TES mechanism with molten salt as HTF or water strongly depending on operating conditions of the whole circuit.

We are still in a designing and developing stage of the process and so several modifications may be introduced in the later design. Our main focus when designing TEPLATOR is to meet highest safety, reliability, economy and ecology standards.

Further R&D in terms of energy storage will be focusing on optimal operating conditions for all three circuits. So the final application will also depend on the desired parameters of the tertiary circuit.

ACKNOWLEDGMENTS

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