Comparison of Thermal Storage Media for Nuclear Renewable Hybrid System

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1. Introduction

With increasing interest in renewable and sustainable energy, there are many attempts to combine renewable energy with current energy grid system. Especially, technological advances in renewable energy are creating a new field of integrating nuclear power to solar energy.

Recently, a research team has been developing a nuclear renewable hybrid energy system namely Hybrid Micro Modular Reactor (H-MMR) which combines concentrated solar power (CSP), micro modular reactor (MMR) and thermal energy storage (TES) systems [1].

This system has been developed as a countermeasure to the power demand variation over time. Basic concept is that both MMR and CSP operate during the daytime while following the power demand and store any surplus energy in the TES system. Surplus energy is stored in the thermal storage media in the form of latent heat or sensible heat and the stored heat is used to generate electricity during the night time. Because of this storing mechanism in H-MMR, TES system is one of the most essential components.

The purpose of this study is comparing properties of thermal storage media in thermal energy storage system (TES) using thermal resistance network model. For more practical assessment, seven widely used materials are selected for TES design [4]. From given material properties, the required total mass and the optimized tank size are compared in normal operating condition and the expected storage costs are also estimated.

The selected materials are Hitec solar salt, VP-1(synthetic oil), Hitec XL, Solar salt, Molten Sodium, LBE (Lead-bismuth Eutectic), FLiBe (LiF-BeF2). These materials are highly anticipated as a thermal storage media of TES [4].

The research objective is comparison of Thermal storage media in the normal operating conditions of H-MMR.

2. Methodology

2.1 TES system

There are several TES models. Two tank model, Thermocline model and Phase Change Material model (PCM) are widely used in a TES system [5]. For assessing thermal storage media for given condition, two-tank model is first selected due to simplicity of its system and easy to calculate required properties. Fig.1 shows how the two tanks are connected to CSP and MMR which exchange heat and store energy with multi-channel IHX.

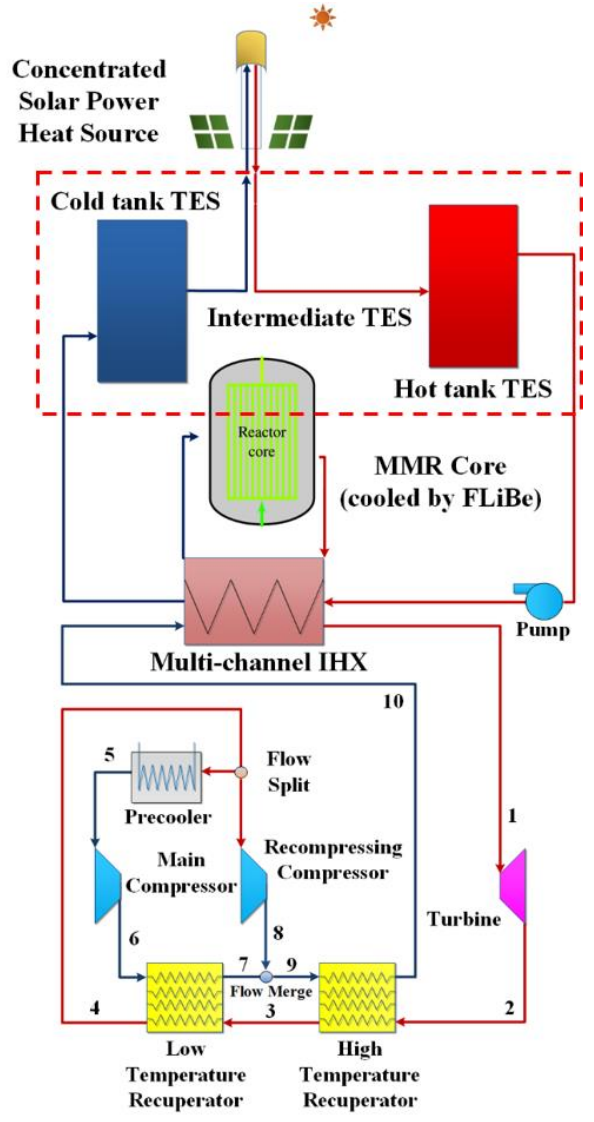

Fig. 1. Configuration of HMMR and TES system

2.2 Design requirement

There are two requirements to design TES, tanks components and the required heat capacity of TES. First, Two tanks are assumed to be cylindrical tanks containing thermal storage media. The tank is made of non-corrosive material and encapsulated in the insulation material. According to [3], 316SS and Polystyrene are widely used material for the non-corrosive thermal tank and insulating materials, respectively. For a simple calculation, thickness and thermal conductivity of tank materials are assumed as constant and listed in Table 1 [3].

Table 1. Thermophysical properties

Thermophysical properties	value
Heat transfer coefficient, h_{air} (W/m^2 K)	5
Thermal conductivity of tank, k_{tank} (W/m K)	0.04
Thermal conductivity of insulator, k_{insul} (W/m K)	15
Thickness (m)	0.3

For calculating thermal capacity, KAIST HMD (Hybrid Micro Modular Reactor Design) code is used to verify appropriate TES installing location based on South Korea electricity data and calculated the required TES heat capacity. The selected city is Jinju which has high solar heat potential. The calculated results are listed in Table 2.

Table 2. Calculated design requirement

Design requirement	Values
TES capacity	440MWh
Charge ramp rate	61.8MW$_{th}$/h
Discharge ramp rate	-94.1MW$_{th}$/h
Response time	6h

Fig. 2 shows schematic of TES and thermal resistance model. For calculating heat loss from TES to air, thermal resistance equation at (1) is used. With increasing tank radial size, the minimum heat loss is calculated and the optimized tank size and the total mass are determined. Thermophysical properties used in a thermal network model are listed in Table 1. The properties of the selected seven materials are listed in Table 3.

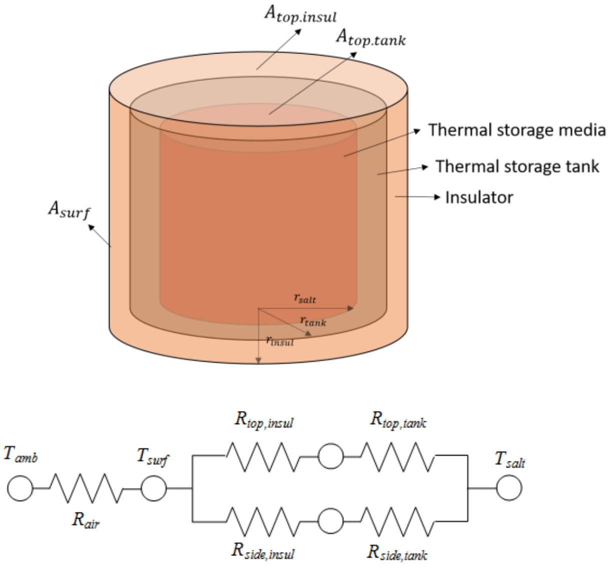

Fig. 2. Schematic of TES and Thermal resistance network

$$R_{air} = \frac{1}{h_{air}A_{surf}}$$

$$R_{top.insul} = \frac{1}{h_{air}A_{top.insul}}$$

$$R_{top.tank} = \frac{1}{k_{tank}A_{top.tank}}$$

$$R_{side.insul} = \frac{\ln(\frac{r_{insul}}{r_{tank}})}{2\pi k_{insul}L}$$

$$R_{side.tank} = \frac{\ln(\frac{r_{tank}}{r_{salt}})}{2\pi k_{tank}L}$$

$$R_{total} = R_{air} + \frac{(R_{top.insul}+R_{top.tank})(R_{side.insul}+R_{side.tank})}{R_{top.insul}+R_{top.tank}+R_{side.insul}+R_{side.tank}}$$

$$Q_{loss} = \frac{T_{salt}-T_{air}}{R_{total}} \quad (1)$$

Table 3. Material properties

	Sodium	**LBE**	**FLiBe**	**Solar salt**	**HiTec XL**	**HiTec Solar Salt**	**VP-1**
Temperature range (melting-boiling) °C	98 to 890	125 to 1533	459 to 1430	220 to 565	150 to 700	175 to 700	50 to 600
Thermal conductivity (W/m K)	119.3	13.7	0.78	0.53	0.519	0.2645	0.0756
Density (kg/m^3)	820	10139	2397	1804	1827	1714	695.1
Specific heat (kJ/kg K)	1.256	0.143	2.38	1.52	1.447	1.495	2.319
Storage cost ($/kg)	2	15	26.3	5.8	20.1	10.7	57.5

3. Results

Calculated tank size, total mass and heat loss percent are listed in Table 4. Fig. 3 shows the sensitivity of heat loss to the tank size. FLiBe shows significantly small heat loss and molten sodium shows the largest heat loss among the selected materials. Hitec Solar Salt, Hitec XL and solar salt show less difference in heat loss. LBE and VP-1 show quite higher heat loss.

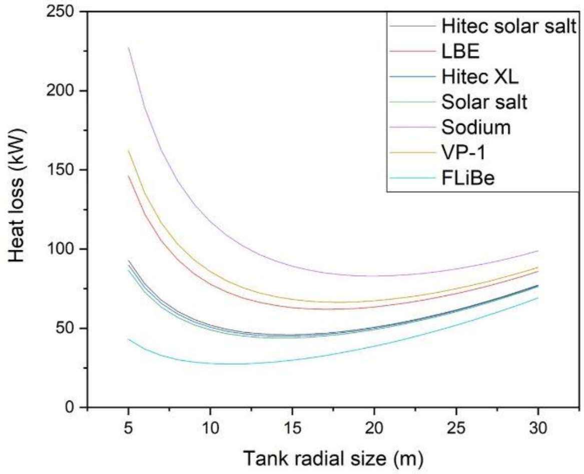

Fig. 3. Heat loss vs tank size for storage materials

Table 4. Design specification of TES

	Tank volume (m^3)	Total mass (ton)	Heat loss percent (%)
Sodium	15369	12603	0.0159
LBE	10918	110690	0.0151
FLiBe	2774.7	6650.9	0.0062
Solar salt	5749.3	10147	0.0100
Hitec solar salt	6177.4	10588	0.0104
Hitec XL	5987.6	10939	0.0102
VP-1	9820.3	6825.9	0.0141

In terms of the storage cost, sodium shows the lowest value followed by Solar salt and Hitec Solar Salt. However, FLiBe is still a good storage media when both cost and heat loss are considered.

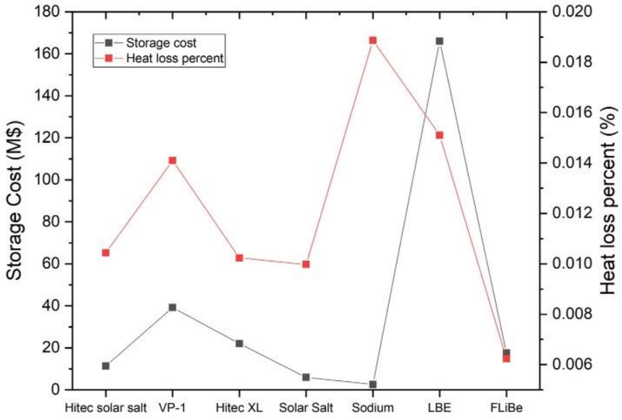

Fig. 4. Storage cost vs Heat loss percent

For the given operation temperature of each material at fig. 5, melting point of FLiBe is slightly higher than the minimum operating temperature of H-MMR, freezing and crystallization problem can be caused. Therefore, considering heat loss, storage cost and operating temperature, Hitec solar salt is the most promising storage media.

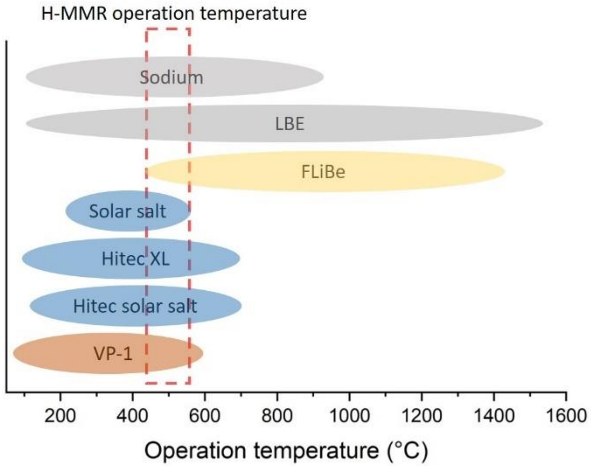

Fig. 5. Operation temperature of various materials

4. Conclusions

Seven thermal storage media, Hitec Solar Salt, VP-1, Hitec XL, Sodium, Solar salt, LBE and FLiBe are compared in three categories, heat loss, required tank size using thermal resistance network model and operation temperature. As a result, FLiBe shows good features for heat loss (~0.006%) and storage cost However, since the operation temperature of HMMR is from 450℃ to 550℃, high melting point of FLiBe may cause freezing and crystallization problem. The storage cost of Hitec XL and Solar salt are higher than Hitec solar salt, therefore Hitec solar salt is the most suitable material for the nuclear renewable hybrid system. This research is a basic analysis under normal operation conditions, and further research works are required under transition and dynamic conditions.

5. Acknowledgment

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