Design of the intermediate heat exchanging-depressurizing loop for low pressure operation of the SI cycle

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1. Introduction

Sulfur-Iodine (SI) has been researched for many years as a favorable candidate of thermo-chemical process for nuclear hydrogen production. However, there are obstacles to be actualized the cycle such as efficiency, material problems, economics, and etc. Reactants used in the SI cycle are extremely corrosive and harsh operating condition (e.g., over 50 bar and 700℃) accelerates the corrosion problem. Highly anti-corrosive materials should be used as structural materials and those metals necessarily lead to increase of large capital costs. Ceramics such as SiC was suggested structural material, but it is not easy to obtain processability and high quality sealing at high pressure condition [1].

The authors suggest a low pressure operation of SI cycle can reduce the corrosion problem by eliminating high pressure condition. In this case, the large pressure difference between the primary (nuclear reactor) side and the secondary (hydrogen plat) side can be a big burden to heat exchanger designers.

In this article, the authors describe the effect of low pressure operation of the SI cycle and how to solve pressure difference between primary and secondary sides by adopting an intermediate heat exchanging and depressurizing loop.

2. Intermediate heat exchanging-depressurizing loop

Based on the previous researches, the authors founded the possibility of the high-temperature and low-pressure operation of the SI cycle. By eliminating high pressure environment on hydrogen side, the conversion yield on sulfuric acid decomposition section is increased that is most energy-consuming section. The corrosion problem of the process material could be reduced. At low pressure environment, the selection of structural material is more flexible.

2.1 Loop layout

A schematic diagram of the proposed loop is shown in Figure 1. The main concept of the loop is based on the pressure balance on each side by changing the pressure of the intermediate loop. Process starts with the high-pressure heat exchanger connected to the VHTR which

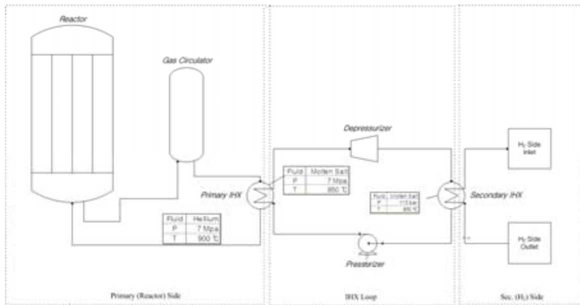

Fig 1. Schematic diagram and flow condition for intermediate heat exchanging-depressurizing loop

pressure is about 70 bar at both sides. In the next step, it goes to a de-pressurizer, which reduces the system pressure to the hydrogen plant side. Heat is transferred to the low-pressure heat exchanger connected to the SI cycle. The fluid is re-pressurized downstream the low-pressure heat exchanger up to 70 bar. By balancing the pressure at each side within the loop, the stress to the structural material can be moderated, and low pressure operation can be allowed in the hydrogen plant.

2.2 Loop operation

Pumping power could be one of the most important parameter, because the pressure variation in the intermediate heat exchanging loop is large. Gas such as helium which typically has been proposed as working fluid is not suitable. In the proposed loop, liquid phase fluid is favorable with no phase change during operation. Molten salt can be good candidates considering their physical properties such as boiling point, viscosity, thermal conductivity, toxicity, and so forth. Molten salts are chemically stable, no reaction with moisture and air, no fire hazard or explosion, non-corrosive with structural material. Neutron-free condition is another advantage using molten salt in the intermediate loop.

The properties of fluid and rough calculations are listed in the Table 1.

Assumptions used in the calculations are as follows: the heat transferred from reactor (Q) is 600 MW, temperature difference ($\triangle$T) between each side is 400℃, the heat capacity (C_p) is constant and the difference between primary side and secondary side is 100m.

The mass flow rate is simply calculated as follows:

Table 1. Summary of the properties of working fluid and loop operating

Salt	ρ (kg/m3)	Cp (kJ/kgC)	ρCp (kJ/m3C)	$\dot{m}$ (kg/s)	W_{pump} (MW)	D (m)	# of baffles	inventory (liter)
water(300°C)	1370.00	3.04	4.16	494.23	2.49	0.28	68	12,025
Helium (1 bar)	0.07	5.19	3.74E-04	288.85	2.77E+04	29.18	1298555	133,727,026
Helium (7MPa)	3.50	5.19	1.82E-02	288.85	5.69E+02	4.18	26713	2,750,956
Pb-Bi	10059.00	0.15	1.47	10248.00	7.03	0.46	9	33,960
Tin	7310.00	0.18	1.31	8394.63	7.92	0.49	13	38,279
LiF-NaF-BeF2	2000.00	2.06	4.12	728.86	2.51	0.28	47	12,148
Li_2BeF_2	1940.00	2.34	4.54	641.03	2.28	0.26	48	11,014
LiF-BeF2(66-34)	1940.00	2.42	4.70	618.62	2.20	0.26	48	10,629
NaF-BeF2(57-43)	2010.00	2.19	4.41	683.67	2.35	0.27	47	11,338
LiF-NaF-KF(11.5-46.5-42)	2020.00	1.89	3.82	792.78	2.71	0.29	46	13,082
LiF-ZrF4	3090.00	1.22	3.78	1226.19	2.74	0.29	30	13,228
NaF-ZrF4(58-42)	3140.00	1.18	3.70	1274.35	2.80	0.29	30	13,528
KF-ZrF4	2800.00	1.05	2.94	1428.57	3.52	0.33	33	17,007
Rb-ZrF4(58-42)	3220.00	0.83	2.69	1796.88	3.85	0.34	29	18,601
LiF-NaF-ZrF4(26-37-37)	2790.00	1.26	3.53	1186.22	2.93	0.30	34	14,172
LiF-NaF-ZrF4(42-29-29)	2706.00	1.47	3.98	1020.41	2.60	0.28	35	12,570
NaF-KF-ZrF4(10-48-42)	2827.00	1.09	3.09	1373.63	3.35	0.32	33	16,197
KF-KBF4(25-75)	1696.60	1.34	2.28	1116.07	4.54	0.37	55	21,928
Na(550°C)	820.00	1.28	1.05	1171.43	9.86	0.55	114	47,619
NaF-NaBF4(8-92)	1754.30	1.51	2.65	992.06	3.90	0.35	53	18,850
LiF-NaF-RbF	2690.00	0.98	2.65	1524.94	3.91	0.35	35	18,896
LiF-RbF(43-57)	2817.00	1.19	3.36	1257.55	3.08	0.31	33	14,880
KBF4	1657.50	1.34	2.23	1116.07	4.65	0.38	56	22,445
NaBF4	1737.30	1.51	2.63	992.06	3.94	0.35	54	19,035
Lead	207210.00	0.12	24.23	12825.64	0.43	0.11	0	2,063

$$\dot{m} = \frac{Q}{C_p \Delta T} \quad (1)$$

Pumping power (W_{pump}) required to the pressurizing-depressurizing process is calculated as follows:

$$W_{pump} = \dot{m}\frac{\Delta P}{\rho} \quad (2)$$

where the pressure difference is 69 bar which is the maximum value.

In this calculation, the baffle type is considered as a good candidate of the depressurizer. We estimates the number of baffles in order to drop the high pressure to the low pressure. The pressure drop of one turn of a baffle is calculated as follows:

$$P_{drop} = k\frac{1}{2}\rho v^2 \quad (3)$$

where k is the friction coefficient which is 4.1 and v is the linear velocity under the assumption of 6 m/s[2].

The price of molten salt is comparably lower than operation cost (e.g. pumping cost), therefore pumping power is a cost-determining factor[3]. The $BeFe_2$-containg salts can be good candidates because they had less pumping power. Salts containing Lead look like good candidates, however it is excluded because of its toxicity to human.

3. Conclusions

This study proposed the intermediate heat exchanging-depressurizing loop to make it possible the low pressure operation of SI cycle with molten salt as a working fluid. The $BeFe_2$-containg salts were figured out to be good candidates considering cost-effective aspects.

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