Current Status on Development of Integrated Sodium Purification System

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1. Introduction

In order to operate in reliable and safe conditions sodium Fast Reactor, it is necessary to maintain the quality of the coolant. Maintaining the sodium coolant circulating in high temperature in pure state is one of the most important conditions required for securing efficient and safe operation of these installations. The required quality of the coolant circulating in sodium cooled loops is maintained by means of special purification devices, which use different physical principles for binding the impurities that have to be removed from sodium [1]. Cold trapping based on the crystallization of Na_2O and NaH, by lowering the sodium temperature below the saturation temperature and thus creating the optimal conditions for Na_2O and/or NaH nucleation and growth on a steel packing distributed in an auxiliary cooled vessel.

Primary sodium purification with cold trap located in the reactor vessel has two disadvantages, transfer of a radioactive fluid outside the vessel and risk of partial draining of primary sodium.

So new concept, the integrated purification system was developed for Superphenix, FBR-1&2, and BN-1200 in order to provide high efficiency, safety, and reliability in operation.

This paper deals with the developments of the integrated purification systems for the primary circuits of a SFR.

2. Control of sodium quality

The monitoring of sodium quality can be performed by numerous on-line such as plugging-meters, hydrogen meter, oxygen meter, carbon meter and more recently LIBS technology is investigated. Off-line (sampling by dip sampler then analysis in laboratory: atomic absorption, distillation is also possible, particularly to investigate abnormal situations, following incidental pollutions, or to characterize radioactive species.

In a cold trap (Fig.1), the sodium is first cooled in a heat-exchanger-economizer down to a temperature close to the saturation temperature of oxygen and/or hydrogen [2]. It then flows through a cooler where it reaches a temperature below the saturation temperature. Sodium oxide or hydride crystals form and are retained on a packing which can be a stainless steel knit packing. The retention area may correspond to the cooling area. This process allows obtaining a large trapping capacity and efficiency if the design takes into account some specific rules based on the basic studies related to the mechanisms and kinetics of crystallization and also on some operational feedback from reactors.

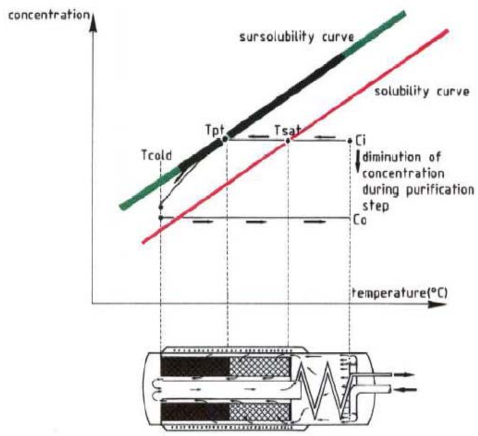


Fig. 1. Cold trapping operation.

3. Current status on development of integrated sodium purification system

3.1 Necessity of integrated sodium purification system

There are two primary sodium purification systems which are different in principle. They are a ex-vessel purification system and a in-vessel purification system. The primary sodium purification system beyond the reactor vessel has the following advantages:

- Quite simple design of cold traps
- Simple maintenance of the system
- Wide range for selection of cooling agent to cool cold traps
- Quite simple repair operations

Disadvantages of the external location of the purification system are the following:

- Specially equipped rooms are required for system arrangement
- Presence of sodium circuit beyond the boundaries of the reactor decreases reactor plant safety
- Large surfaces of equipment and primary sodium communications also decreases safety

Purification system arrangement with primary cold trap location in the reactor vessel is associated with advantages of the integral reactor layout, which are the following:

- Plant construction cost reduces because there are no rooms occupied by the external system
- Increase of reactor plant safety
- Probability of radioactive sodium leakages into the process rooms

Disadvantages of the built-up purification system are the following:

- Complex design of the cold trap
- Difficult maintenance
- Possible direct effect of failures of purification system elements
- Necessary large scope of research activities caused by cold trap design

Because of high-level requirements for the safety of a SFR, a SFR plants apply the purification system with cold traps located in the reactor vessel [3].

3.2 Development of integrated sodium purification system

3.2.1 Superphenix

The primary purification system is integrated (Fig.2): the full application of pool concept for SFRs induced the necessity to foresee an integrated concept, allowing avoiding any pipes with active sodium out of the main reactor vessel [3]. Moreover, it avoids the occurrence of an active sodium fire, and also the release of the inventory of radionuclides accumulated in the cold trap during its service life. Each unit consists of a main structure entering the vessel sodium header and an interchangeable structure, comprising a plug (biological shielding) and filter cartridge: when a spent cartridge is replaced, special equipment (handling flask) is required to ensure containment of the reactor cover gas and radiological protection of the personnel. The main parts of the integrated trap are: the Electromagnetic pump, the exchanger-economizer, the cooler, the cartridge with the packing. Even if this concept can be considered very complex, the operational feedback was excellent, particularly for the purification campaign following the large pollution induced by an air ingress. Moreover, easy was the dismantling of the cartridges, less contaminated than large external cold traps, designed to be operated for the whole life duration of the plant.

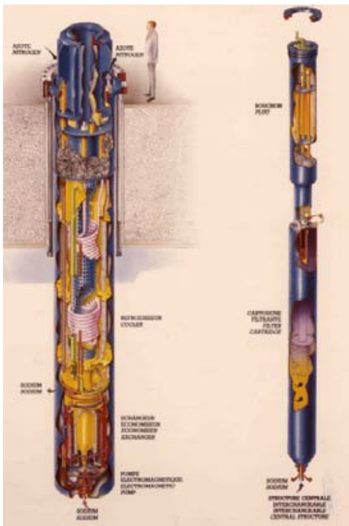


Fig. 2. Superphenix integrated purification system.

3.2.2 FBR

In the ex-vessel concept as provided in PFBR, design features are provided to take care of radioactive sodium leaks and siphoning of radioactive sodium from the reactor pool (in case of leak in purification system which goes undetected). In the in-vessel concept no radioactive primary sodium is transported out of the reactor pool, therefore the possibility of radioactive sodium leak in reactor containment building is precluded and the siphoning of sodium from reactor vessel is eliminated. Hence, for FBR-1&2, the in-vessel concept is selected for primary sodium permanent purification circuit in order to enhance the safety and bring down the total cost [4].

The in-vessel concept (Fig.3) uses an integrated cold trap (ICT) with economizer, electromagnetic pump and flow meter, housed inside a single vessel. This assembly is located in the reactor pool and supported from the roof slab of the reactor. The electromagnetic pump takes sodium from the reactor pool and passes through the economizer and cold trap wire mesh. After purification the sodium returns to the pool through the economizer.

In the in-vessel concept, the external piping and associated cells are eliminated, which also offers reduction in RCB size. Operation of similar in-vessel concept is already proven in French fast reactor, Superphenix.

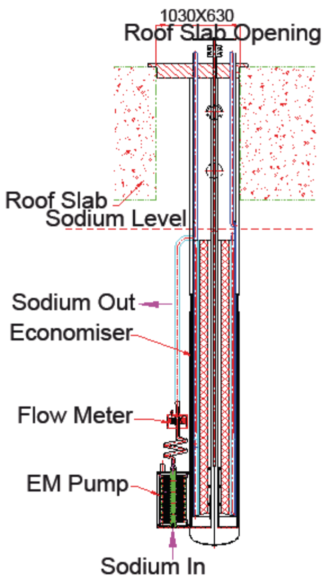
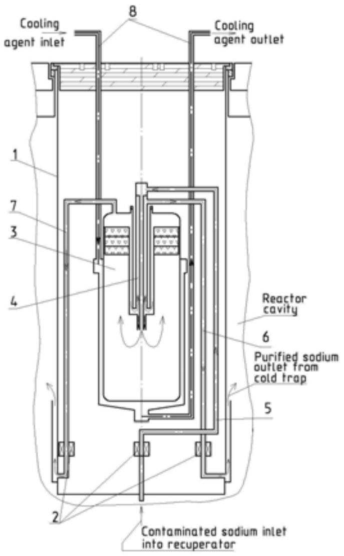


Fig. 3. Assembly of integrated cold trap.

3.2.3 BN-1200

The built-up purification system of BN-1200 primary sodium consists of three cold traps, which schematic diagram is given in Fig.4 [5]. To purify primary sodium in the advanced BN-1200 reactor plant, a purification system with cold traps has been used that are located in the reactor vessel (in-built purification system). Such decision has excluded external communications of the auxiliary system with radioactive sodium and respectively a possibility that sodium will outflow to compartments outside the reactor.



1 - casing of built-up cold trap; 2 – electromagnetic devices;
3 - working cavity of cold trap; 4 – recuperator;
5 - pipeline of contaminated sodium supply to recuperator;
6 - pipeline of purified sodium discharge from recuperator;
7 - pipeline of purified sodium bypass from working cavity;
8 - pipelines of cooling agent supply and discharge

Fig. 4. The cold trap schematic diagram

The sizes of cold traps located in the reactor are small that has limited the sodium flowrate through them, impurity storage capacity, and has made it necessary to replace traps in the course of reactor plant operation.
Cold traps include such main components of the conventional external purification system as sodium communications, a portion of the cooling circuit, flow meter devices, and electromagnetic devices (a pump and throttle pump) to ensure sodium circulation and to control the sodium flow rate. In the course of development, options have been considered to cool traps with argon, liquid sodium, and gallium.

A cooling agent type for the cold trap is selected considering the following main factors: reactor plant safety, satisfactory physical and chemical properties of the cooling agent, cost of cooling system implementation. Three types of cooling agent were chosen: pressurized argon, sodium and gallium.

To compare a coolant types a R&D complex was developed, and taking into account advantages and disadvantages of the cooling options, the option of argon cooling of the cold trap was selected.

4. Discussion

The following was considered under development of the integrated sodium purification system:

- Built-up cold trap, considering its location in the reactor, should include all basic elements of traditional external purification system: pipelines, devices providing circulation and control of sodium flow rate, flow metering devices, etc.
- Considering high-density configuration of the reactor, the overall dimensions of the cold trap were highly restricted and, consequently, capacity with respect to impurities was restricted
- Optimum sodium velocity through the cold trap should be provided
- Cold trap arrangement in the reactor made it necessary to determine a cooling agent type, as air is impossible to use because of active interaction between sodium and air in case of depressurization of cooling elements within cold trap boundaries.

4. Conclusions

The objective of the report is to provide researchers with technical information necessary for the design and construction of technological facilities for the integrated sodium purification system by reviewing the current state of technical developments for advantages, disadvantages, limitations, and safety of a integrated sodium purification system. Based on these results, a future plan for development of the integrated sodium purification system can be established.

ACNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP). (No. 2012M2A8A2025635)

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