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Investigation of a Plugging Meter for Measuring Impurity Content in Liquid Sodium (I)

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1. Introduction

In a Sodium-cooled Fast Reactor (SFR), liquid sodium is subject to the formation of impurities by its high chemical reactivity with so many elements and common compounds used in nuclear reactor construction materials. The impurities are mainly in the form of hydrides, oxides, metallic compounds, metallic and carbon particles, which originate primarily from steam generator corrosion, moisture from system component surface, and leakage of air into the system. These are finally deposited in the form of the crystallization of sodium hydride (NaH) or sodium oxide (Na_2O) at the cold points of the circuit, which may lead to the clogging of the narrowed sections or may damage the pump. Therefore, the sodium must be purified and analyzed in order to prevent from the detrimental influence. The analysis of hydrogen and oxygen is very important. There are many chemical methods for analyzing the impurities, but these methods are time-consuming, troublesome and contamination of samples from air and containers, that is the reason why the countries develop the instruments of impurity on-line measurement. The plugging meter is one of the most important on-line measuring instruments and it is a reliable instrument which has been widely used on sodium loops [1-4].

2. Methods and Results

The plugging meter shown in Figure 1 is the on-line monitoring system designed by ourselves. The main body of the plugging meter consists of a cooler, a blower, a heating element, a plugging orifice plate, and a thermocouple. The body is 700 mm long stainless steel pipe. There are four orifices of 1.3 mm diameter around the aperture with 3 mm diameter. The orifice plate is located at the end of the annulus, near a thermocouple. In this apparatus, the sodium to be monitored flows in the outer annulus and cools the sodium flowing out the center tube. The plugging meter is cooled by blowing air and electrically heated.

A certain flow of sodium passes through a tube with an orifice, then the sodium is gradually cooled. When the sodium temperature at the orifice reaches the impurity saturation temperature, impurity begins to precipitate and deposit on the orifice surface resulting in a variation of the sodium flow rate. This temperature, measured at the moment when the flow begins to decrease, is the "plugging temperature". The impurity concentration can be determined by means of a solubility curve (refer to Figure 2) or solubility formula of impurity as a function of the temperature. The oxygen solubility data is expressed as following formula:

$$\text{Log } C_e\,[O_2,\text{ ppm}] = 6.250 - \frac{2444.5K}{T} \qquad (1)$$

After measurement of is the "plugging temperature", the cooling system of the plugging meter is switched off, the heating element is energized and the bypass valve is opened, so that the precipitated impurities can be rapidly redissolved by the sodium, it is called "unplugging".

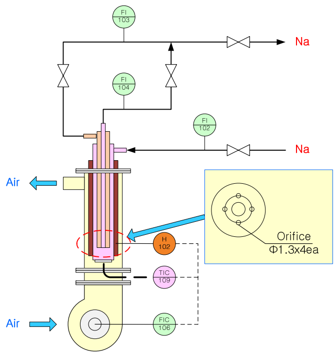

Fig. 1. Schematic diagram of the plugging meter.

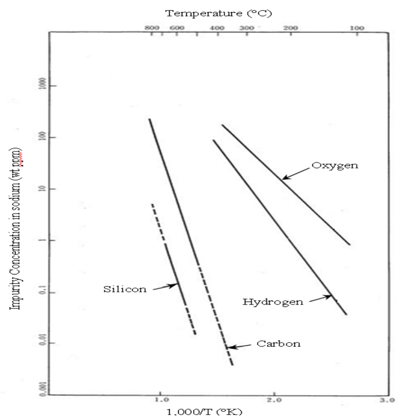

Fig. 2. Solubility of oxygen, hydrogen, carbon and silicon in sodium.

It is reported that the magnitude of the error depends on the cooling rate of the plugging orifices, sodium flow rate through the orifices and the concentration of the impurities [5]. To understand the effects of the cooling rate on the plugging temperature, changed the cooling rate in the range of 1~6°C. Figure 3 shows the variation of plugging temperature on the variation of cooling rate. A faster cooing rate caused a rapid decrease in the plugging temperature and made a bigger difference between the plugging temperature and the saturation temperature. A lower cooing rate has an advantage with a small difference between the two temperatures, but it takes longer times.

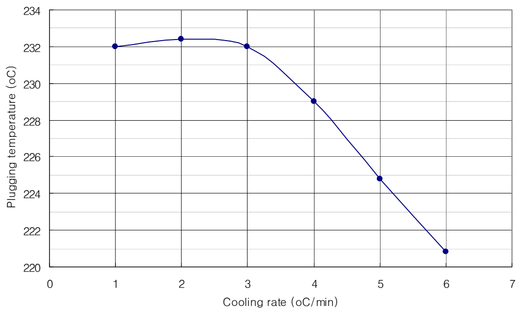

Fig. 3. Variation of plugging temperature on variation of cooling rate.

Figure 4 shows an example of recorder display, including the orifice plugging temperature and the sodium flow rate signals at the cold trap temperature of 160°C. After the orifice temperature reaches the saturation temperature, the impurity begins to precipitate out of the sodium onto the orifice surface and to attenuate the sodium flow rate at about 140°C. Since a finite time is required for precipitation of the impurity, the orifice temperature drops to a lower value than the saturation temperature, before a noticeable decrease in the sodium flow rate occurs.

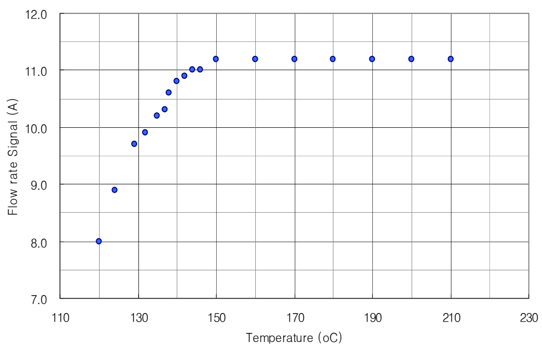

Fig. 4. Variation of sodium flow rate on variation of orifice temperature.

Figure 5 shows the correlation between the plugging temperature and the oxygen saturation temperature, and agreed well with following three polynomial equations.

$$Y=9.676E\text{-}5X^3-4.753E\text{-}2X^2+8.596X-3.744E+2 \quad (2)$$

From this figure, the oxygen concentration in the sodium will get by the plugging temperature.

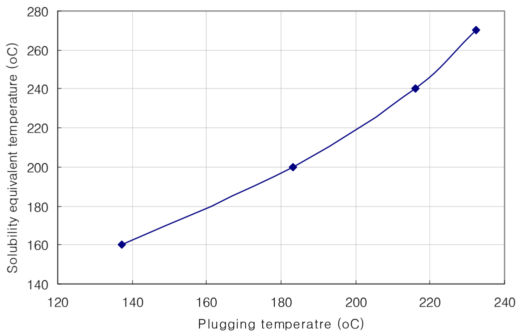

Fig. 5. Correlation between plugging temperature and oxygen saturation temperature.

3. Conclusions

Plugging meter is a simplified measuring device for impurities in the liquid sodium. The determination of the plugging temperature by the manual plugging meter is feasible in the range of 105 to 232°C. These plugging temperatures have been measured successfully. The results showed that the accurate results could be obtained by adding the difference to the saturation concentration with respect to low plugging temperature. However, the relation between the impurity saturation temperature and the measured plugging temperature is not sufficiently clear, since the plugging temperature is considerably affected by operating conditions such as the sodium flow rate and the cooling air flow rate.

This study is not enough to improve the plugging meter, so further analytical and experimental studies by an auto mode operation will be performed.

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