thermochemical study of material compatibility for sodium cooled fast breeder reactor application

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1. Introduction

In fast breeder reactors, liquid sodium is preferred as a coolant due to its high thermal conductivity, high specific heat, low viscosity, wide liquid range, remarkable thermal stability [1]. However, it must be in the pure form to be compatible with structural materials in which chemical compounds of Austenitic stainless used include carbon, chromium, nickel, molybdenum, iron, niobium, zirconium and so on [2]. Traces of impurities play an important role in corrosion, mass transport and other processes taking place in the heat transport loops of the reactor [1,3].

Corrosion of structural materials in liquid sodium is deeply affected by the oxygen concentration. Some of these corrosion products which find their way into sodium can cause risk when they deposit on parts like heat exchangers and pumps, which have to be periodically maintained [1]. Thus one must not only control and monitor the oxygen impurity level, but also understand the mechanism of the chemical reaction in the reactor. In this way, thermodynamic approach is obtained by analyzing compatibility of chemical compounds of structural materials with liquid sodium.

2. Methods and Results

2.1 Compatibility of structural materials with liquid sodium.

Austenitic stainless steels and Ferritic Martensitic steel are used to the structural materials with which liquid sodium comes into contact in a fast breeder reactor. Because the anticipated life of the reactor is over 30 years, it is important to detect even low levels of corrosion and understand the effect of oxygen and carbon in liquid sodium [1]. There are three principle interactions between the fused sodium and structural materials.

First, dissolve the components of construction material in the sodium and occur mass transfer. Second, interaction between the construction material and the impurities such as oxygen and carbon present in the sodium. Third, interaction between the sodium and metal so that formation of an intermetallic compound or solid solution [2].

2.2 Corrosion in low-oxygen sodium

The solubility in sodium of the components of construction material is not considerable. Especially, in pure sodium containing low-oxygen, the corrosion rate is lower. The mechanism of corrosion in this regime is the selective leaching of alloying elements [2]. Temperature dependent leaching of substitutionary alloying components is occurred in the hot legs [3]. This process of dissolution is dependent on the solubility of the metallic element in sodium [1]. The temperature dependent solubility of an element in liquid sodium can be made only from the experiment [4]. Some temperature dependent solubility of certain metals of austenitic stainless steel used for structural materials in the fused sodium systems are collected in figure 1.

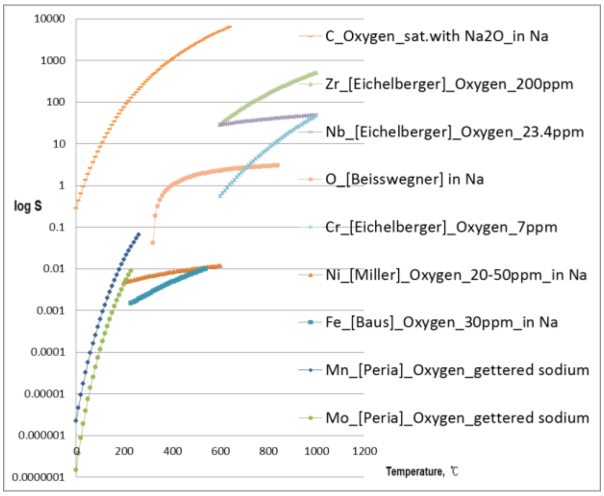

Figure. 1. Solubility of chemical compounds of structural material

The carbon in overall temperature is expected to effect on the sodium system due to its relatively higher solubility. On the other hand, molybdenum and manganese in low temperature has lower solubility compared to the other compounds. It has been observed that after long time operation for ~2000h at high temperature as 755℃ in sodium containing low oxygen the depleted zone at the austenitic steel surface becomes considerable [1]. Mass transfer and the corrosion process may occur on them. In non-isothermal systems with circulating heat-transfer and with a temperature gradient, the leached elements in the hotter zone become saturated in liquid sodium. Then in the cold zone the components are precipitated from the solution and settle on the walls of the vessels [4].

2.3 Effect of dissolved oxygen

The corrosion rate of stainless steel is proportional to the oxygen concentration in sodium [4]. There are three possible situations based on the stability of the oxide of the alloying elements. If the oxide is less stable than sodium oxide, then it is reduced to the metal by sodium. If the oxide is much stable than sodium oxide, then the metal is readily oxidized by sodium. In the intermediate case of comparable stability, ternary oxides of sodium and the alloying element are likely to be formed. The alloying elements Fe, Cr, Ni, Mn and Mo generally fall in the third category [1].

It is assumed that during the corrosion of structural materials, they primarily form simple oxides and then form complex compounds such as ternary systems [2]. After setting the Gibbs free energy diagram of certain oxidizing reactions of chemical compound of structural materials in fused sodium, find the relative ease of oxidizing and reducing a given metallic oxide with metal so that estimates the final selected form of oxidizing in the liquid sodium system. The graph of Gibbs free energy versus temperature for several oxidizing reactions is shown in figure 2. The position of the line for a given reaction on which shows the stability of the oxide as a function of temperature.

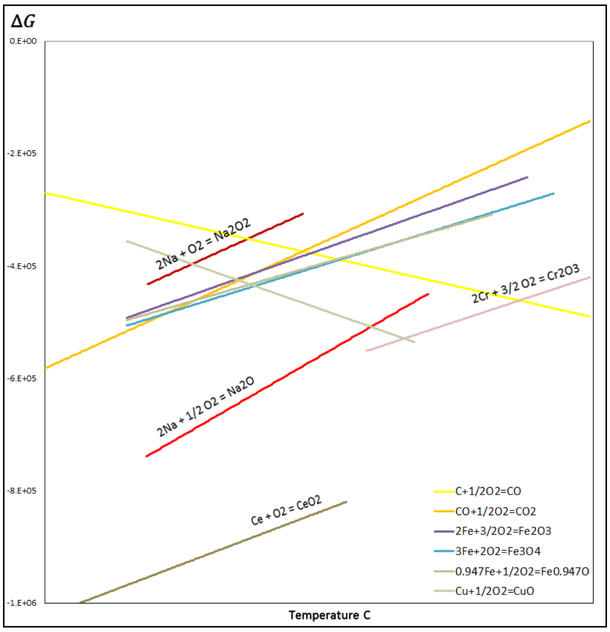

Figure. 2. Gibbs free energy diagram of chemical elements of structural materials in liquid sodium

It proves cerium oxide is the most stable to oxidizing in liquid sodium. According to Ellingham diagram, cerium oxide is prefer to form at low temperature, also oxidized chromium is seen at high temperature which are ease to form by redox reaction. Contrary to them, iron is one of passive compounds to react with liquid sodium and oxygen results to be reduced by chromium melted in liquid sodium.

The scales determine what partial pressure of oxygen will be in equilibrium with the metal and metal oxide at certain temperature which is basis of oxidizing metal and reducing metal oxide. So it is necessary to more discussion about controlling and detecting of oxygen partial pressure.

3 Summary

The solubility in sodium of the components of construction materials is not significant [1]. In a system which contains different metals at the same time in diverse temperature state, however, they competitively react with sodium and dissolved oxygen. As seen in the graph 2, oxidation of iron is unfavorable to occur due to its unstable oxide so that will be neglected. As the similar case, molybdenum shows lower solubility compared to the others in sodium system so is unfavorable with oxygen in those compounds. The study of some chemical elements such as chromium, cerium and molybdenum in structural materials is needed due to its specific behaviors in liquid sodium. Also, there are sequence process existed after simple redox reaction. This is the formation of ternary oxygen compounds, Na-M-O, where M stands for the alloying constituents of stainless steels and their participation in the rate determining steps of the corrosion reactions is depends on the oxygen concentration in liquid sodium [1]. So understand of sequence several reactions is needed.

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