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Experiments on the Sodium-Sodium Hydroxide Reaction for a Sodium Waste Treatment

J. H. Choi, B. H. Choi, J. M. Kim and B. H. Kim
Korea Atomic Energy Research Institute

1. Introduction

The purpose of this study is to find a reactivity moderation method for the sodium-sodium hydroxide (Na-NaOH) reaction to treat the sodium waste more stably, because if there is moisture in the sodium during a sodium treatment, the process of a sodium and water interaction is a rapidly process with a release of a lot of heat even at room temperature [1].

Twelve experiments were performed based on the sodium hydroxide concentrations of 30, 40 and 50%, and temperatures of 30, 40, 50 and 60℃. The amounts of sodium and solvent (NaOH solution) used for each test are 1 and 300g, respectively.

2. Experiment

As shown in Figure 1, the test apparatus for a batch caustic process is comprised of a reaction vessel and associated components: sodium melting pot, sodium storage tank, sodium injection device, gas supply system, instrumentation and data acquisition system. Chemicals and gases used in the experiments are the sodium hydroxide solution (30, 40, 50%) as a solvent, 0.1N-HCl standard solution for the acid-base titration, mixed gas (4.05%; hydrogen, balance; nitrogen) for hydrogen analyzer calibration, and nitrogen gas (99.95%).

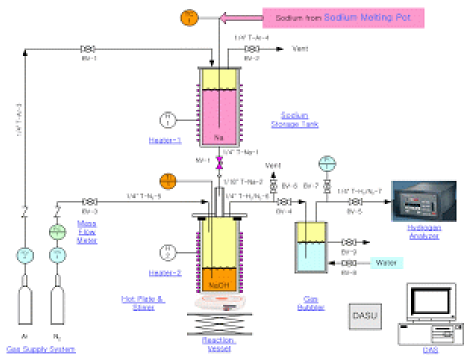

Figure 1. Flow diagram of the Na-NaOH reaction test.

In the reaction vessel, sodium is reacted exothermically with water to form a caustic (NaOH) solution and hydrogen (H2) according to the following chemical reaction [2]:

$$Na(s) + H_2O \rightarrow NaOH(s) + ½H_2(g), \quad \Delta Hr = -151 \text{ kJ/mol}$$

The quantity of sodium in reaction at these experiments is very small (1g) which makes it possible to avoid the risks of massive sodium-water reaction.

3. Result and Discussion

Figure 2 shows the rate of hydrogen concentration change with time in the sodium-sodium hydroxide (Na-NaOH) reaction for all tests. The reaction was occurred within about one minute after the sodium injection into the reaction vessel. The peak of the hydrogen concentration appeared after a few seconds after a reaction, and the maximum hydrogen concentration of 0.659x10-3 g/sec appeared in test no. 5 (40%-60℃). The Na-NaOH reaction was vigorous but not violent which is different from the $Na\text{-}H_2O$ reaction.

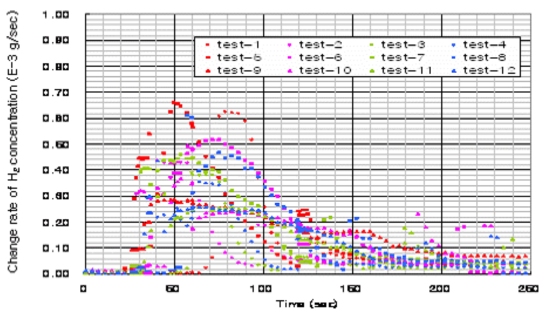

Figure 2. Rate of the hydrogen concentration change with time during a reaction (Test No. 1~12).

Figure 3 shows the results of the test no. 1 (30%-60℃) as a representation of the all test results. It contains the reaction temperature, pressure, nitrogen flow rate and hydrogen concentration to confirm the measured variables with time relatively. Similar trends of these results were obtained in other tests, also. The maximum, minimum and average value of the reaction pressure of the mixed gas (hydrogen and nitrogen) was 12.54, 11.34 and 18.00 kPa, respectively. The maximum, minimum and average value of the reaction temperature was 64.01, 61.16 and 62.62℃, respectively. Hence, the increase of the temperature by a reaction was 4.01℃ at a maximum. The hydrogen occurred after about seven seconds after a reaction, and attained a maximum rate of the hydrogen concentration change of 0.627x10-3 g/sec. The average reaction rate in this test was 0.134x10-3 g/sec.

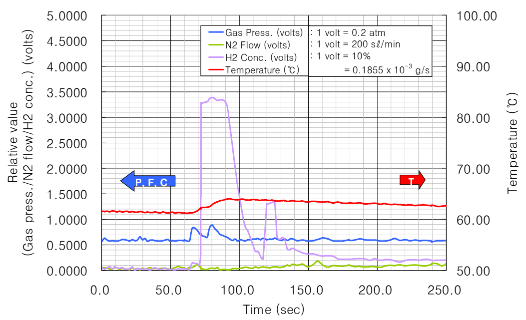

Figure 3. Data on the reaction temperature, pressure, nitrogen flow rate and hydrogen concentration in test no. 1 (30%-60°C).

Overall trends of the reaction temperature and pressure with time in other tests were similar as shown in Figure 3. The change of the average reaction temperature and pressure depending on the NaOH concentration is shown in Figure 4. The differences of those changes are small. The average reaction temperature increased the most in test no. 8 (40%-30℃), and its value was 3.14. The average reaction pressure increased the most in test no. 3 (30%-60℃) with a value of 12.16 kPa(0.124 kg/㎠).

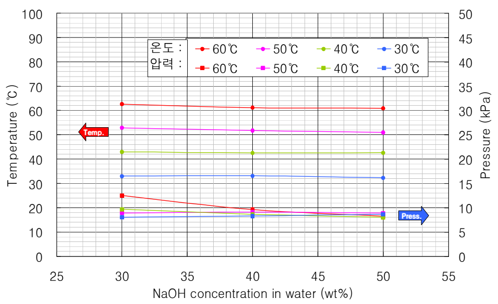

Figure 4. Change of the average reaction temperature and pressure depending on the NaOH concentration.

Figure 5 shows the reaction rate depending on the NaOH concentration and test temperature. The reaction rate was high at a 40% NaOH solution than other concentrations at the same temperature. In these tests, the higher the test temperature, the more rapid the reaction rate. The highest value of the reaction rate was 0.220x10-3 g/sec in test no. 5.

The obtained data shows that as the alkaline (NaOH) concentration in the solvent increases the allowable value of the reaction rate also increases, and as the alkaline solution concentration increases further the reaction rate decreases. In reference [1], similar phenomena was reported. It is difficult to find an explanation for this phenomena as to why the reaction rate is higher at the 40% NaOH solution than other concentrations as no discrimination was done between complex phenomena occurring.

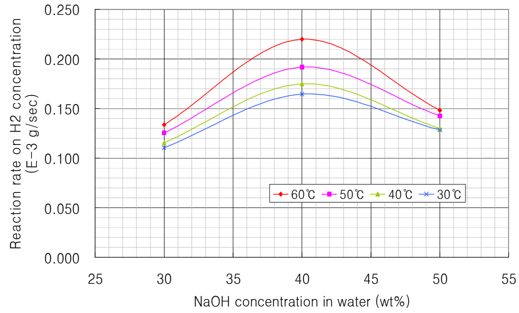

Figure 5. Change of average reaction rate on NaOH concentration.

In summary, the trend of the reaction temperature, pressure and rate of hydrogen concentration change with time was similar in these experiments. The reaction occurred rapidly within about one minute after the sodium injection into the reaction vessel, but not violently. The increasing range of the average reaction temperature from the test temperature was between 2.85 and 4.22℃. The increasing range of the average reaction pressure was between 8.05 and 12.55 kPa. The highest reaction rate was 0.220×10^{-3} g/sec in test no. 5 (40%-60℃).

4. Conclusion

In this study, we found that if an aqueous alkaline solution (NaOH) is used as a solvent instead of water, a safe mode for a sodium treatment may be realized in a wider range of temperatures and pressures. During these tests, it was shown that the NaOH concentration in a solvent and the test temperature did not have an effect on the reaction rate. The NaOH concentration in the solvent increased and the allowable value of the reaction rate also increased, and as the alkaline solution concentration is increased further the reaction rate decreased. Hence, the condition with a NaOH concentration of 40% and test temperature of 60℃ where the average reaction rate is high, will be considered as an optimum condition to treat the sodium waste.

Acknowledgement

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[2] F. Baque, French Sodium Waste Storage Rules, IAEA Technical Meeting on the Decommissioning of Fast Reactors after Sodium Draining, Sep. 2005.