Improvement and Verification of
Fast Reactor Safety Analysis Techniques

Progress Report

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ABSTRACT

A calorimeter was designed and built to measure reaction power in the range where liquid is boiling. Measurements made with the new calorimeter at a concentration just lower than what would produce boiling (3m) was about 10% lower than those measured using the Precision Calorimeter. A heat loss of about 40% due to a non-adiabatic vessel was determined by comparing the reaction power in solution of the reaction vessel to that of the calorimeter.

A closed reaction vessel was designed to observe the effects of pressure (up to 3 atm) on the dispersion height.

A preliminary calculation of the theoretical critical superficial vapor velocity was 0.0412 m/sec.

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INTRODUCTION AND SCOPE

During this contract period, work proceeded in three areas. The following sections summarize the research carried out.

1. Calorimeter design and comparison.
2. Closed vessel reactor design.
3. Vapor velocity calculation.

Calorimeter Design and Comparison

A precision titration calorimeter is designed to measure reaction heating, very accurately, by carefully controlling the environment. The reaction vessel is adiabatic, so all of the heat produced in the reaction is measured as sensible heat. To assure that no boiling or large temperature gradients occur, chemicals are diluted.

All previous measurements of the DMSO-Acetyl chloride reaction were made on a precision titration calorimeter. In order to make these measurements it was necessary to dilute both chemicals. Because of the non-linearity of the reaction kinetics, it was difficult to extrapolate the power information to the concentrations of interest without a full kinetic analysis of the reaction. To solve this problem it was decided to design and build a non-precision calorimeter that can measure the reaction power in the concentration range where boiling occurs.

The basis of design for the calorimeter is to allow boiling. Several assumptions are made in the design. A precision calorimeter can measure small temperature changes, therefore small heat sources and sinks must be taken into account, e.g. stirring heat, viscous

heat from fast injection, heat flow through the flask, etc. In high power reactions the heat produced is large compared to these errors. No constant temperature bath is needed.

The calorimeter built is shown in Figure 1. The reaction takes place in a one liter dewar flask. The instrument head is supported by a steel stand. A motorized stirrer is used for even mixing. The titrant is injected by means of a syringe pump through the titrant tube. A thermister and heater feed into a control box which connects to a plotter and digital voltmeter. There is a vent at the top to allow the vapor to escape or be collected. The instrument head is seated into the flask by a rubber stopper. A plastic guide was first used to support the wires and stirrer, but later replaced with glass when the plastic melted from the heat.

The control box contains a wheat stone bridge across which the output of the thermister is read. The heater may be switched on or off and the voltage read across the bridge, standard resistor, heater, or power supply.

The reaction power is measured as the average rate of temperature increase from room temperature to boiling temperature. This will represent the initial power burst of the reaction. It is expected that this value is slightly greater than the steady state power during boiling. The collected vapor can give an idea of how much vaporization occurred.

This method cannot measure the actual heat of reaction, but it is the reaction power which is of interest. The measurements made are somewhat crude compared to precision calorimetry, but the error is much less than the power information in a LMFBR accident.

Figure 1. Calorimeter.

Measurements were made at several concentrations. The power density at a 3m concentration with the precision calorimeter was $7.97 \times w/l$. The power density measured with the boiling calorimeter was $7.13 \times w/l$. This represents a -10.5% error. A temperature difference between the acetyl chloride solution and the DMSO while injecting could account for this error.

The actual void fraction experiments are carried out in a non-adiabatic environment. Because of heat loss, the power producing vapor is less than the vapor producing power in an adiabatic container. To determine what fraction of the heat is lost, we calculated the temperature rise in the non-adiabatic reaction vessel. There was a 42% decrease in sensible heat in the non-adiabatic vessel.

Closed Vessel Reactor Design

The design of the closed reaction vessel is shown in Figure 2. The main structure is a graduated type cylinder wrapped with a coil of cooling tube. The radial heat transfer is regulated by the inlet temperature of the water in the cooling tube. The temperature difference between the inlet and outlet is measured to determine the heat loss. A stopper, inserted into the cylinder, is held in place by a stand. Axial heat transfer is measured by water flow in a cooling tube in the stopper. Temperature and pressure changes can be measured and plotted. A safety relief valve is installed on the pressure gauge.

The purpose of the closed test system is to see the effects of heat loss in the axial and radial positions on the dispersion height. Experiments will be limited to about 3 atm.

Figure 2. Closed Reaction Vessel

Vapor Velocity Calculation

The Kutateladze number K is given as the ratio of the dynamic and surface tension forces.

$$K = \frac{U_u^* \sqrt{\rho_c}}{4\sqrt{g\sigma(\rho_H - \rho_c)}}$$

The critical superficial vapor velocity, e.g. the vapor velocity at the breakdown of bubbly flow, can be calculated from

$$U_u^* = \frac{K \sqrt{4g\sigma(\rho_H - \rho_c)}}{\sqrt{\rho_c}}$$

where $K = 0.3$ and $\rho_c = \rho_H$ for breakdown of bubbly flow. For the DMSO-Acetyl chloride reaction we assume that the acetyl chloride boils to produce the vapor. Since it boils at 51-52 C compared to 129 C for DMSO. The DMSO remains as liquid droplets dispersed in the tube. This assumption simplifies the properties of the reaction so that pure component properties may be used. Future study of properties of mixtures may refine these results.

The density of the light phase ρ_c is much less than that of the heavy phase, ρ_H , so it is neglected. For breakdown of bubbly flow, the density of continuous ρ_c is the same as the heavy phase. For DMSO, $\rho_H = 1.1016 \text{ gm/cm}^3$. The surface tension for DMSO is $\sigma = 40.7 \text{ dyne/cm}$. The calculated critical superficial vapor velocity for the DMSO-Acetyl chloride system is 0.041 m/sec. This compares with 0.074 m/sec for a water system and 0.05 m/sec for a fuel.

Experimental data are now being compiled to compare the experimental vapor velocity with the calculated.