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A LABORATORY EXPERIMENT DEMONSTRATING THE WAY IN WHICH
A STEAM BARRIER PREVENTS THE DISSOLUTION OF SALT BURIED
IN A FLOODED PACKED BED.

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MASTER

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A LABORATORY EXPERIMENT DEMONSTRATING THE WAY IN WHICH A STEAM
BARRIER PREVENTS THE DISSOLUTION OF SALT BURIED IN A FLOODED PACKED BED

ABSTRACT

We have conducted a laboratory experiment to demonstrate a way in which a solid material can be prevented from dissolving in water. The differential solubility of salt (NaCl) in steam vs water is exploited. As long as the temperature of the area and water surrounding the salt is maintained above the boiling point of water, the salt cannot dissolve. This phenomenon, known as the thermal barrier, has far-reaching implications for preventing the dispersal of contaminants present near groundwater sources (e.g., created by underground explosions).

INTRODUCTION

Most solid compounds are significantly more soluble in liquids than in gases. This difference in solubility persists in water even at pressures as great as 180 atm, corresponding to a hydrostatic pressure of 1800 m (6000 ft). At this pressure, the maximum solubility of sodium chloride, for example, is 0.01 wt% in steam vs 50 wt% in water¹; the maximum solubility of silica in steam only reaches 0.007 wt%, compared to approximately 0.2 wt% in water.²

Following underground nuclear explosions, compounds containing radionuclides are exposed to water, steam, and other common gases. This also would be the case if significant amounts of high-level (i.e., heat-producing) radioactive wastes were disposed by underground burial in one location.³ Obviously, contact between radionuclides and flowing underground water must be avoided to prevent the dispersion of the radionuclides.

The differential solubility of solids in water and steam plays a crucial role in these situations. In rock formations of low permeability, for example, such buried sources of heat may be able to raise and sustain the temperature of the surrounding rock above the local vaporization point of water. This should effectively prevent contact between radionuclide-bearing materials and liquid water. This phenomenon is known as the thermal barrier.

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The nuclear explosions Faultless, Shoal, Starwort, and Almendro may be examples of this phenomenon. In Almendro, it appears that six years must elapse before the temperature of the explosion site will drop below the boiling point of water and the chimney will flood. If this is the case, the adjacent ground water should show much lower concentrations of refractory fission products within the first few years after the explosion than when the liquid water contacts the radionuclide-bearing material after the sixth year. However, the necessary field measurements remain to be taken to confirm this behavior.

Modeling of material transport in flooded beds involving both heat and two-fluid flow is still in its infancy.^{4,5} If we also desire to examine the dynamics of complex natural systems (i.e., rock beds where *in situ* properties are uncertain, often heterogeneous, and affected by the process itself), the task is great indeed. To this purpose, we conducted a simple laboratory experiment with which we observed the behavior of a heat source buried in a flooded packed bed. Our goal was to demonstrate the way in which a thermal barrier can prevent a water-soluble compound from dissolving, even when it is buried below the water table.

EXPERIMENTAL PROCEDURE

The experimental apparatus (Fig. 1) employed a 1-kW electric heater (similar to that used in electric kitchen stoves) in the shape of helix. The inside diameter of the heater helix was 2.5 cm; it was buried in the center of a bed of Al_2O_3 (alumina), contained in a porous ceramic cup. The alumina had a grain size ranging from 10 to 175 μm ; the average grain size was 85 μm . The dry porosity of the alumina bed was 43% and its permeability to water at 22°C was 0.8 D. (We also tried beds with higher permeabilities but found that they admitted more water into the heater than could be boiled away, allowing liquid water to infiltrate the salt bed.)

A long tube was inserted into the helical heater before the heater was buried in the alumina. After the heater was buried, the tube extended above the bed surface and was used to position 53 g of NaCl in the center of the heater. With the salt in place, the tube was withdrawn and a small additional amount of alumina was poured on top of the salt.

Fig. 1. Experimental apparatus consisting of a packed bed of fine-grained alumina in a porous ceramic cup, suspended in a 7-litre water bath. An electrical heating element shaped like a helix was buried in the alumina bed. Granular salt (NaCl) was loaded into the center of the heater and covered with alumina. The amount of salt dissolved in the water was monitored with a conductance cell. The temperature of the system was measured at 7 locations shown by the +.

For a heated experiment, the apparatus was assembled dry. The heater was turned on to heat the bed. The temperature profile of the system when the center of the bed reached 500°C is shown by the solid curve in Fig. 2. When this temperature profile was established, the glass vessel surrounding the porous cup was filled with 7 litres of water. (Water could not be added if the temperature exceeded 500°C because the alumina bed became unstable and was subject to flash boiling.) At about one minute after the addition of the liquid water, steam began to rise from the bed outside the heater. The temperature profile changed and reached the steady state value (dashed line, Fig. 2) in about one half hour.

The temperature profile exhibits a 100°C isothermal zone extending from 2.5 to 3.5 cm from the center of the heater. This is the two-phase zone where incoming water is flashed to steam. In this zone, the out-going heat (transported by convecting dry steam and conduction through the alumina bed) was balanced by the heat necessary to boil the incoming liquid water.

The temperature of the water bath was maintained at 50°C by the flow of cold water through cooling coils (see Fig. 1). Water was added to the bath to compensate for vaporization losses; approximately one litre of water was added each hour.

To determine how much salt was dissolving, the specific conductivity of the water bath was monitored. The relation between salt content and conductance was established in a separate calibration experiment. Our calibration results essentially matched those published in Ref. 6. This method is able to measure a salt content as low as 0.0001 g per 100 g of solution. However, in our actual experiment, the alumina of the bed also dissolved into the water. This resulted in a background conductance of 0.0185 mmho/cm at 50°C. Therefore, we only were able to measure salt concentration above 0.001 g per 100 g of solution in the experiment. This limit equals 0.07 g of salt in the 7 litres of the water bath or 0.13 wt% of the total 53 g of NaCl.

As long as the system was heated, water remained essentially free of salt. In another experiment where the temperature was maintained at 50°C, almost all of the salt dissolved in 125 h (see Fig. 3). Thus, the thermal barrier effectively prevents a highly water-soluble material from dissolving in a flooded bed.

Fig. 2. Temperature profiles before and after water infiltrated the porous cup. The steady state temperature profile after water infiltration is shown by the dashed curve. The two-phase (steam-water) zone is indicated by the isothermal portion of the curve at 100°C. Inside this zone (including the salt bed), only steam is found; outside the zone, only water is present.

Fig. 3. Dissolution of salt vs time (water temperature maintained at 50°C).
When the heater is off, the salt dissolved almost completely in 125 h.
When the heater is on, the salt does not dissolve.

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