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Phenomenological study of the ablation by melting of a solid impinged on by a liquid jet applications to ASTRID's core-catcher

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Abstract:

In the design of every new nuclear reactor, the possibility of a core meltdown is studied. In the case of ASTRID fast breeder a core-catcher will be placed beneath the core. To ensure that it performs as planned its ablation by a liquid jet of corium is investigated. To do so, an experimental set up was designed where the ablation of a solid by a liquid jet is studied using transparent ice as solid and water as liquid. The aim is to visualize the evolution of the cavity shape, and the ablation rate, during the ablation process. We observed that the cavity first assumes a conical shape, and the ablation rate stays constant. Then the cavity shape changes, and the ablation rate decreases with time. The aims to clarify the influence of the temperature, diameter and speed of the jet are studied as well as the inclination of the solid block on the ablation rate and mechanisms. A correlation giving the Nusselt number as a function of the Reynolds and the Prandtl number was obtained for our system. This will be used as a base to identify and model the mechanisms at stake.

Introduction:

In the past some severe nuclear accidents led to core meltdown. Therefore, now, the possibility of corium formation is taken into account in the design phase for every new nuclear reactor, and ways to mitigate it are studied. For the new fourth generation, sodium cooled, fast breeder industrial demonstrator ASTRID, the strategy adopted is to introduce discharge tubes within the core with the purpose to relocate the corium toward a core-catcher placed beneath as fast as possible. The core-catcher is designed to spread the corium as much as possible to make it easier to cool and manage. However, for it be of any use, it needs to withstand the impact of the corium flowing out of the discharge tubes. The way the corium will interact with its surroundings when it escapes the discharge tubes or the core-catcher as well as its composition all depends on the accident path. Therefore, a wide variety of interactions are possible. Among those, one of the worst happens when the corium reaches the core-catcher as a coherent jet of mostly metallic composition. In which case, the temperature of the jet ($> 2500^{\circ}C$), will lead to localized ablation of the core-catcher, and potentially the formation of a hole.

Some studies have been conducted in the past to tackle this issue (Powers (1984); Saito (1990); Sato (1991)). Experiments were designed in which the drillthrough time was measured. The ablation rate was therefore assumed constant. From these some empirical models were developed. How-

ever, in all the systems studied the jet diameter was of the same order of magnitude as the thickness of the plate. In some cases ablation rates significantly lower than the one expected were witnessed (Saito (1990)). The explanation given was that as the cavity dug deeper it reaches a point where the liquid could not flow as a film and escape the cavity, but instead falls back in the cavity and filled it thus changing what happens at impacts. This effect was called pool-effect. It has been mentioned but no exact criterion for its apparition was given. Some more general work was done to study the ablation of materials not as closely related to nuclear safety (Furutani (1991)) and try to put the system into equation (Swedish (1979)) but they still worked with the assumption that the ablation rate remains constant throughout the drilling process. Most of those studies were designed to answer the question: what would happen if a jet of corium reaches some structural elements of the core? Now the question is how to design the core-catcher to withstand such a jet? So, it has been decided to study the ablation of solid thicker structures due to the impact of a liquid jet.

Work presented:

Based on previous observations, we can state that as the jet ablates more and more a solid block, the ablation mechanism may evolve. These mechanisms as well as their onsets are difficult to study without direct measurements or observations. That is why a new experiment was design and will be presented here. It uses transparent ice as solid and liquid

water. The goal is to record the evolution of the cavity shape with time by ombroscopy. This allows us to determine the evolution of the ablation speed with time and depth, as well as times when it changes. Fig. 1 shows some example of shadowgraphs obtained at different times. We observed that first the cavity assumes a conical shape (Fig. 1 top right and bottom left). The ablation rate is constant. A coherent sheet of liquid escaping the cavity forms and disappears (Fig. 1 top right). Then, after a short transition (<1s) the cavity is filled with liquid and assumes a more cylindrical shape, rounded at the impact zone (Fig. 1 bottom right). When the cavity is filled the ablation rate decreases with time.

The preliminary work done gave a first correlation (Eq. 1) which is similar to the one obtained by Sato (Sato (1991)) (Eq. 2).

$$Nu = 0,1211Re^{0,6}Pr^{0,8} \quad (1)$$

$$Nu = 0,152Re^{0,92}Pr^{0,8} \quad (2)$$

The recordings obtained lead us to think that the apparition of the pool-effect is dictated by hydrodynamics and the formation of a hydraulic jump at the edge of the cavity.

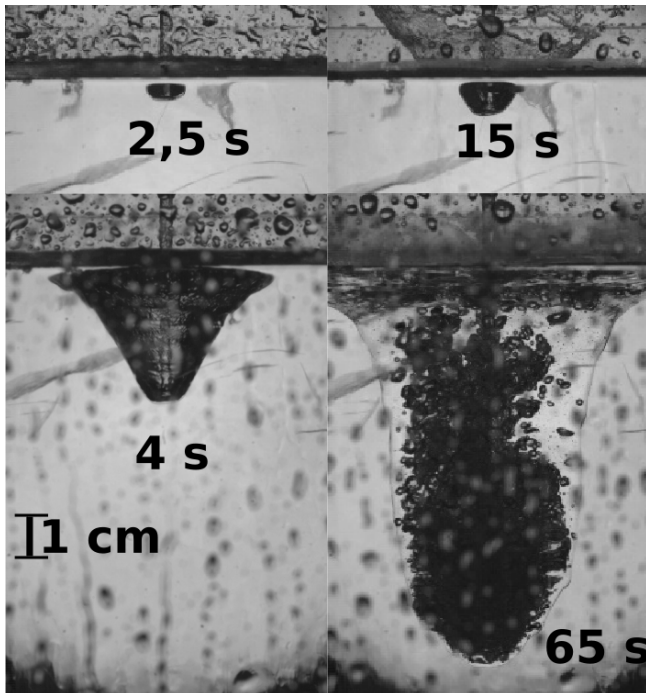


Figure 1: Pictures of the ablation front recorded by ombroscopy at different time, with a jet temperature of 23°C, a jet diameter of 3,21 mm, a jet speed of 5,7 m/s, a Reynolds number of 19000, and a Prandtl number of 6.49.

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