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An experimental analysis of subcooled leakage flow through slits from high pressure high temperature pipelines

Sandip Ghosh [a,*], Deb Mukhopadhyay [b], Samir Kumar Saha [a]

[a] Mechanical Engineering Department, Jadavpur University, Kolkata 700032, India
[b] Reactor Safety Divison, Bhabha Atomic Research Center, Mumbai, India

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ABSTRACT

The work presented here is an experimental investigation of the critical flashing flow of initially subcooled water through circumferential slits in pipes. The study provides first hand information about the prediction of leak flow rates in piping and pressure vessels retaining high temperature and high pressure. The dedicated experimental facility loop simulates the thermal hydraulic condition of Pressurized Heavy Water Reactors (PHWR). The critical flow characteristics found for varying leakage cross sections at different stagnation pressure and different degree of subcooling has been demonstrated in this paper. A marked decrease in mass flux has been found as subcooling decreases for a fixed stagnation pressure. More observation has revealed that the tighter slits or openings with very short duct as small as 0.8 cm flow length have different flow behavior than greater opening dimensions or with longer flow channels or that for nozzles. The critical flow has been seen to occur at higher pressure differentials along the flaws and prominent changes in the flow rate is reported to occur with varying dimensional parameters of the slit or cracks.

1. Introduction

Leak Before Break analysis has been proven a mandatory safety analysis for cost-effective high pressure high temperature system design. This particular analysis looks for formation of cracks and their subsequent growth before complete disruption of the whole system. Safety is a prime concern in the nuclear reactors for their primary system pipelines carrying radioactive coolants. Therefore these pipelines are designed with high grade tough (ductile) materials which are least susceptible to instantaneous breakage. An example of that kind is a Double Ended Guillotine Break (DEGB) assumption which necessitates building costly shields against dynamic effects like potential missile, pipe whipping, blowdown jets etc. On the other hand analysis of fracture mechanism and rupture dynamics shows possibility of a stable and detectable leak flow occurring through the leakage. These cracks grow at a stable rate due to the sustaining mechanical and thermal loads. Therefore leak detection and measurements are primary requisite in LBB analysis which also provides useful information about the probable crack size and geometry. In this context works by Bertholome et al. [1] on leak detection system have demonstrated that certain pipes under specific thermal hydraulic conditions produces small through wall cracks resulting in coolant leak rates in the range of 0.05 kg/s which are easily detectable by installed leak detection system. Once the leak flow or loss of coolant (LOCA) exceeds a certain limit called reactor shutdown limit, operation is halted and corrective measures are taken for that particular section. Applying US Nuclear Regulatory Commission's factor of safety of 10, the leak detection capability or reactor shutdown limit is set to 0.5 kg/s. Thus LBB approach results in significant saving in plant layout, labor cost and radiation dosage for maintenance. Analyzing the flow pattern and upstream–downstream conditions for this kind of leakages a critical flow is suspected with instant flashing. While passing through the leakage at local acoustic velocity the flow gets choked and become independent of further change in pressure differential. Rapid transformation from subcooled single phase stagnation condition to a two phase accelerated flow into very low pressure regions, lacks thermodynamic equilibrium due to very small residence time. A flow problem of this kind in a compressible zone involves a lot of unknown parameters which makes it more unpredictable. An experimental approach in this context becomes very useful to have direct data about the condition. For larger confidence on the LBB methodology rigorous experimentation at reactor conditions and validation of critical flow models such as those developed by Henry and Fauske [2] are

* Corresponding author. Tel.: +919433871094; fax: +913324146354.
E-mail addresses: pleasant_sandy@yahoo.co.in (S. Ghosh), dmukho@barc.gov.in (D. Mukhopadhyay), sahasamir7@yahoo.com (S.K. Saha).

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