ABSTRAKSI

Operasional pembangkit tenaga nuklir mensyaratkan sistem keselamatan yang handal. Karenanya, skenario kecelakaan seperti LOCA yang berkorespondensi terhadap fenonema *flooding* di *hot leg* dan berisiko memantik kegagalan mekanisme pendinginan inti reaktor menjadi perhatian spesifik. Penelitian ini menginvestigasi karakteristik *flooding* pada aliran berlawanan arah di geometri *hot leg* PWR dengan mempertimbangkan pengaruh sifat fisis cairan. Hasil penelitian memperkaya basis data eksperimental mengenai perilaku antarmuka, serta prediksi permulaan *flooding* untuk turut mempromosikan menejemen strategi keamanan dan keselamatan operasional pembangkit tenaga nuklir.

Dalam penelitian ini fluktuasi tekanan diakusisi menggunakan *differential pressure tranducer,* sementara fluktuasi antarmuka di bagian horizontal seksi uji diperoleh dari sensor kawat sejajar. Sementara itu, satu unit kamera berkecepatan tinggi difungsikan untuk merekam fenomena aliran. Selanjutnya, karakterisasi statistik didapatkan melalui analisis stokastik berbasis domain waktu dan/atau frekuensi, analisis multiresolusi diskrit serta analisis chaotik. Di sisi lain, suatu model empiris berbasis analisis dimensional dilakukan untuk menyelidiki faktor dominan pengaruh sifat fisis cairan terhadap permulaan *flooding*.

Visualisasi yang dikuatkan oleh sinyal menunjukkan bahwa perkembangan aliran melibatkan penebalan film cairan dikombinasikan antarmuka tidak stabil di wilayah loncatan hidrolik akibat perubahan debit gas. Hal ini menuntun pada *liquid blockage* yang menginisiasi *flooding*, diikuti rezim *partial delivery*. Karakterisasi statistik perilaku antarmuka mengungkapkan bahwa rezim pra-CCFL diindikasikan oleh kurva distribusi unimodal dengan karakter fluktuasi gelombang antarmuka landai dimana energi fluktuasi terdistribusi dari frekuensi tinggi ke frekuensi lebih rendah. Sementara itu, rezim paska-CCFL didekati dengan karakter gelombang antarmuka tinggi yang membentuk suatu kurva distribusi multimodal dimana distribusi energi fluktuasi meningkat bertahap dari band frekuensi tinggi ke rendah. Selanjutnya, analisis ketidakteraturan memperlihatkan kecenderungan penurunan entropi Kolmogorov seiring peningkatan debit udara. Permulaan *flooding* diindikasikan dengan penurunan entropi secara drastis, dimana rezim paska-CCFL bersifat lebih prediktif.

Di sisi lain, debit udara untuk menginisiasi *flooding* menurun seiring peningkatan debit cairan. Perubahan sifat fisis cairan meningkatkan sensitivitas perubahan debit fluida untuk menginisiasi *flooding*, dimana permulaan *flooding* lebih cepat dicapai untuk cairan dengan viskositas dinamik lebih tinggi. Selanjutnya, kombinasi parameter Wallis dengan koreksi parameter sifat fisis cairan yang diajukan oleh Zapke & Kröger (1996) memberikan *fit* data terbaik. Pada akhirnya, korelasi empiris berbasis analisis dimensional mengungkapkan bahwa viskositas dinamik cairan memberikan pengaruh lebih kuat daripada tegangan permukaan terhadap rasio kecepatan superfisial.

Kata kunci: Permulaan *flooding*, *hot leg*, sifat fisis cairan, karakterisasi statistik, transformasi wavelet, entropi Kolmogorov, analisis dimensional

ABSTRACT

An operation of nuclear power plants requires a reliable management of safety. Therefore, strategies to mitigate accident such as LOCA which corresponds to the flooding are of a large interest since they further relate to the failure in cooling systems. The present work investigates the effect of liquid physical properties on CCFL characteristics during gas/liquid counter-current two-phase flow in a hot leg typical geometry. The results enrich the experimental database on the interfacial behaviors and the approaches to predict the onset of flooding which can further promote the management strategy on the nuclear reactor operation.

In the present work, both the signals of pressure and interfacial fluctuations along the horizontal pipe were acquired by using differential pressure transducers and parallel wire array probes, respectively. On the other hand, a high speed video camera was particularly employed to capture the flow phenomena. Furthermore, statistical characterizations were elaborated through stochastic analysis on the basis of time and/or frequency domains, wavelet decomposition and chaotic analysis. Subsequently, an empirical model on the basis of dimensional analysis was developed to investigate the dominant parameters which affect the CCFL characteristics.

The visualizations, emphasized by the signal analyses, show that the typical flow development involves the thickening of liquid film combined by unstable interface at the hydraulic jump due to the change of air flow rate. This further leads to a liquid blockage which initiates the flooding, followed by partial delivery. The statistical characterization of the interface reveals that pre-CCFL is characterized by the unimodal distribution curve in which the smooth interfacial wave and the wavelet energy is distributed from the lower to higher frequency band. On the other hand, post-CCFL is characterized by highly fluctuated interface which exhibits multimodal distribution curve and the wavelet energy stepwise increase from the high to the lower frequency band. Next, the chaotic analysis reveals that the Kolmogorov entropy tends to decrease with the increase on the air flow rate. Here, the inception of flooding is indicated by the drastic decrease in entropy, in which post-CCFL exhibits a predictable characteristic.

Moreover, air flow rate to initiate the flooding decreases as the increase of liquid flow rate for the entire test fluids. Furthermore, the change in liquid properties also relates to the increase of sensitivity of the change of fluids' flow rate in which the inception of flooding is faster obtained for the liquid with higher viscosity. Next, the Wallis parameter combined with liquid properties number proposed by Zapke & Kroger (1996) obtains the best data fitting. In addition, the developed empirical correlation employing dimensional analysis reveals that the liquid dynamic viscosity obtains a stronger effect rather than the surface tension on the ratio of superficial velocity.

Keywords: Onset of flooding, hot leg, liquid physical properties, statistical characterization, wavelet transform, Kolmogorov entropy, dimensional analysis