HEATED DOWNWARD FACING STEEL PLATE IN POOL BOILING

Ryan H. Lin
McMaster University, Ontario, Canada

Abstract

Experimental study will be conducted to examine a heated downward facing plate in pool boiling environment at atmospheric pressure. Simulation with FlexPDE, a finite element software, will be used to first establish the best setup of the equipments. The goal is to create an experimental apparatus to produce results that can give insightful information for the calandria vessel under the LOCA scenario. This will be able to determine the possibility of the calandria vessel acting as a core catcher with a molten core condition.

1. Introduction

Under normal operating condition, the Canada Deuterium Uranium (CANDU) reactor core is constructed with pressure tube (PT), clandria tube (CT), clandria vessel (CV) and the shield tank (ST). There is a large volume of light water between CV and ST for shielding purpose. Under a large loss of coolant accident (LOCA), which would potentially cause the reactor core to deform into a molten core, it is critical to contain the radioactive material inside the core itself.

The purpose of this research is to construct an experimental apparatus to represent the CV in such a scenario. It is important to determine the heat transfer mechanism and the physical phenomenon under this scenario and the physical integrity of the CV itself. The experimental data and results will help in analysing the sufficiency of the CV been a core cater for the molten materials. .

2. Literature review

Transition boiling is a commonly observed heat transfer mode under high wall superheat and high heat flux system. This heat transfer mode plays a significant role to the safety analysis of nuclear reactors. Researches conducted over the years have contributed to the wide knowledge on nucleation and film boiling. With the recent theoretical and physical models, surface roughness, wettability and other thermal properties are shown to affect transition boiling. However, the physical phenomenon between the heating surface and the fluid could not be easily observed.

With the current theoretical studies on transition boiling, Haa and Nob [1] concluded that the nucleate boiling over the wetted area is the only mechanism for transition boiling. Parameters such as active site density, bubble departure diameter and etc. were used in their model development. In the study of Zhao et al. [2], they suggested a model by using the microlayer to predict the transition characteristics in saturated pool boiling environment. Based on Peng et al. [3][4], it is said that the interaction between the dry patches also plays an important role in transition boiling. Qiu and Dhir [5] examined sliding bubble dynamics, heat transfer and flow patter in pool boiling environment. Su et al. [2][7] also conducted new experiments with downward facing steel plate in pool boiling setup. The experiment is conducted under a confined space which indicated that the gap size does affect the wall superheat, Prandtl number, Nusselt number and etc.

However, with all these experiments and studies, there is still a need to build a test section that can actually represent the CV under the abnormal scenario.

3. Methodology

In the CANDU reactor, the CV is surrounded by a large volume of light water which could form a pool boiling environment under a large break LOCA situation. The CV is constructed with relatively thick steel. Due to the size of the reactor core, the CV can be safely assumed to be a flat steel plate with a slightly inclined angle. The following figure is a flow chart on how this research is going to be carried out.

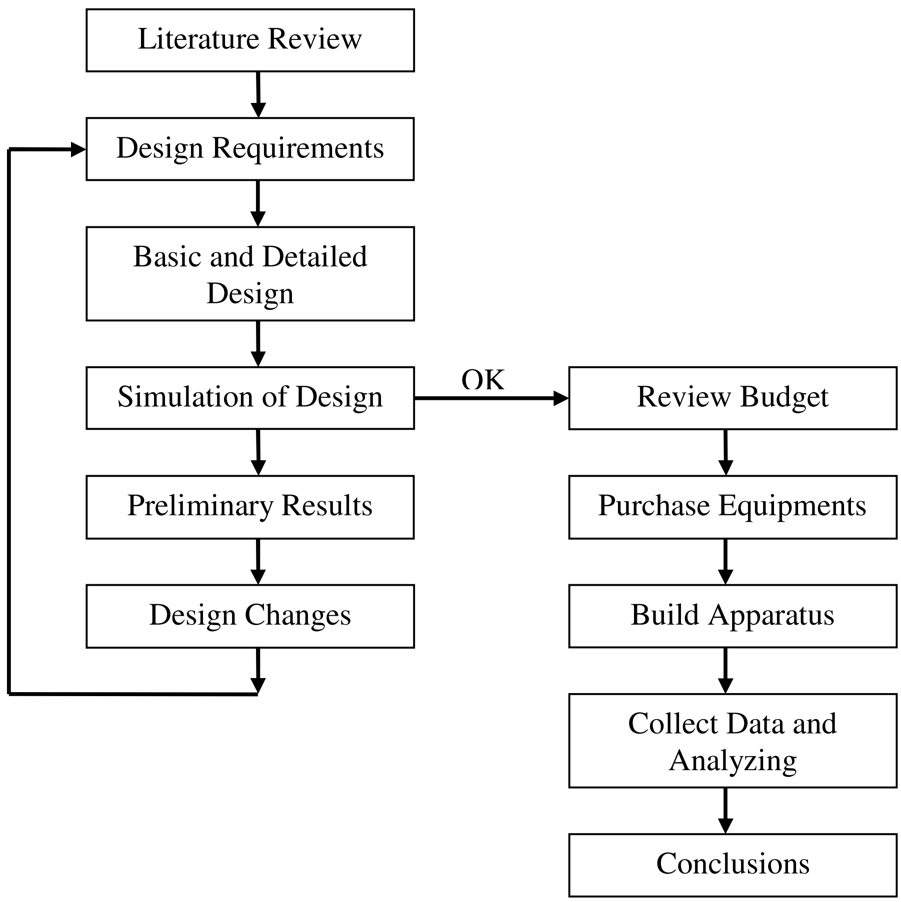

Figure 1 Flow chart of the design and research process

3.1 Current progress

3.1.1 Design requirements

The designed apparatus needs to simulate the CV with a molten core. Due to the property of the molten core, the heat flux needs to be driven downward toward the bottom surface. This is also to ensure to reach the highest possible temperature on the bottom surface. The CV is constructed with steel; therefore, the test section should be steel with a relatively thick thickness to have the closest representation of the CV surface. During normal operation of the apparatus, the physical integrity of the heater should not be damaged by means such as excessive stress and strain or out of spec. temperature. The test section should reach the critical heat flux and potentially dryout if it can be achieved.

3.1.2 Basic and detailed design

The designed apparatus is formed by three different layers of material. The bottom layer consists of a 3.5cm thick steel plate. The middle layer is made of a 1cm thick Inconel to simulate the heater material. The top layer is formed by a 2.5cm thick Zirconia Oxide to act as the thermal insulator to drive the heat flux downward. The following figure is the original design with simulation in FlexPDE.

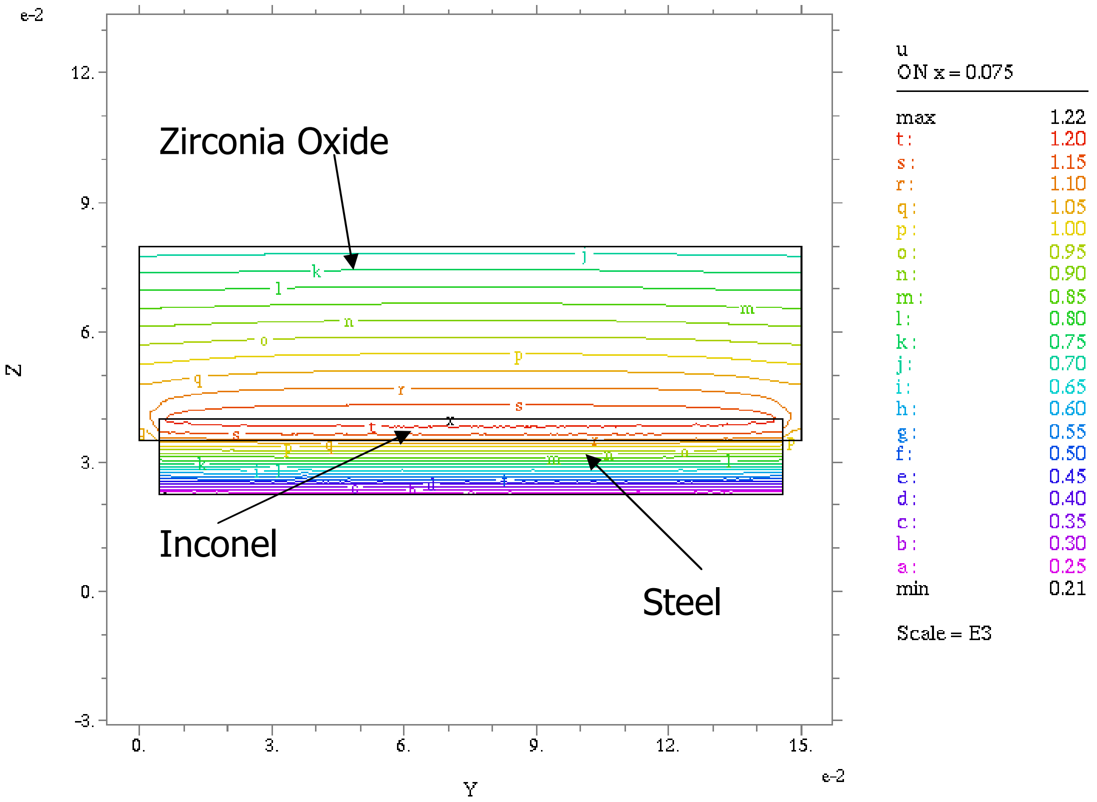

Figure 2 Original design

3.1.3 Simulation

FlexPDE is a finite element analysis software. In the simulation a three layer test section is defined in 3D space. The primary heat transfer mechanisms used are conduction (1), convection (2) and radiation (3).

$$k\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}+\frac{\partial^2 U}{\partial z^2}\right)+q_g^{'''}=0 \qquad (1)$$

$$q'' = -h\left(U - U_{fluid}\right) \tag{2}$$

$$q'' = -h\left(U - U_{fluid}\right) - e\sigma U^4 \tag{3}$$

Conduction is used for contacting surfaces between the three layers of solid. Convection is used for the fluid underneath the bottom steel surface. Convection is used again in combination with radiation for all surfaces that are surrounded by air. Contact resistance, which is assumed to be a small number, is also incorporated within the simulation. This can be justified by ensuring the contact surface between the Inconel and steel layers to be as smooth as possible. However, the contact resistance between the Inconel layer and Zirconia Oxide layer is assumed to be zero. This will ensure the real apparatus to obtain the highest temperature possible on the bottom surface. In order to guarantee the physical integrity of the heater, a 10% safety margin is used during the simulation. The Inconel layer will only reach 90% of full power.

3.1.4 Preliminary results and design change

During the incorporated simulation, it is found that the original design was not sufficient to provide a satisfactory temperature on the bottom surface. With some design changes on the layout and the thickness of each layer, the bottom temperature is capable of reaching 110 degree Celsius. The following figure is the preliminary results with the design changes. It is noticed that there is an optimum thickness for the insulating layer. By inclosing most of the steel layer with the insulation, it would also focus the heat flux more toward the centre of the steel plate hence increasing the bottom temperature.

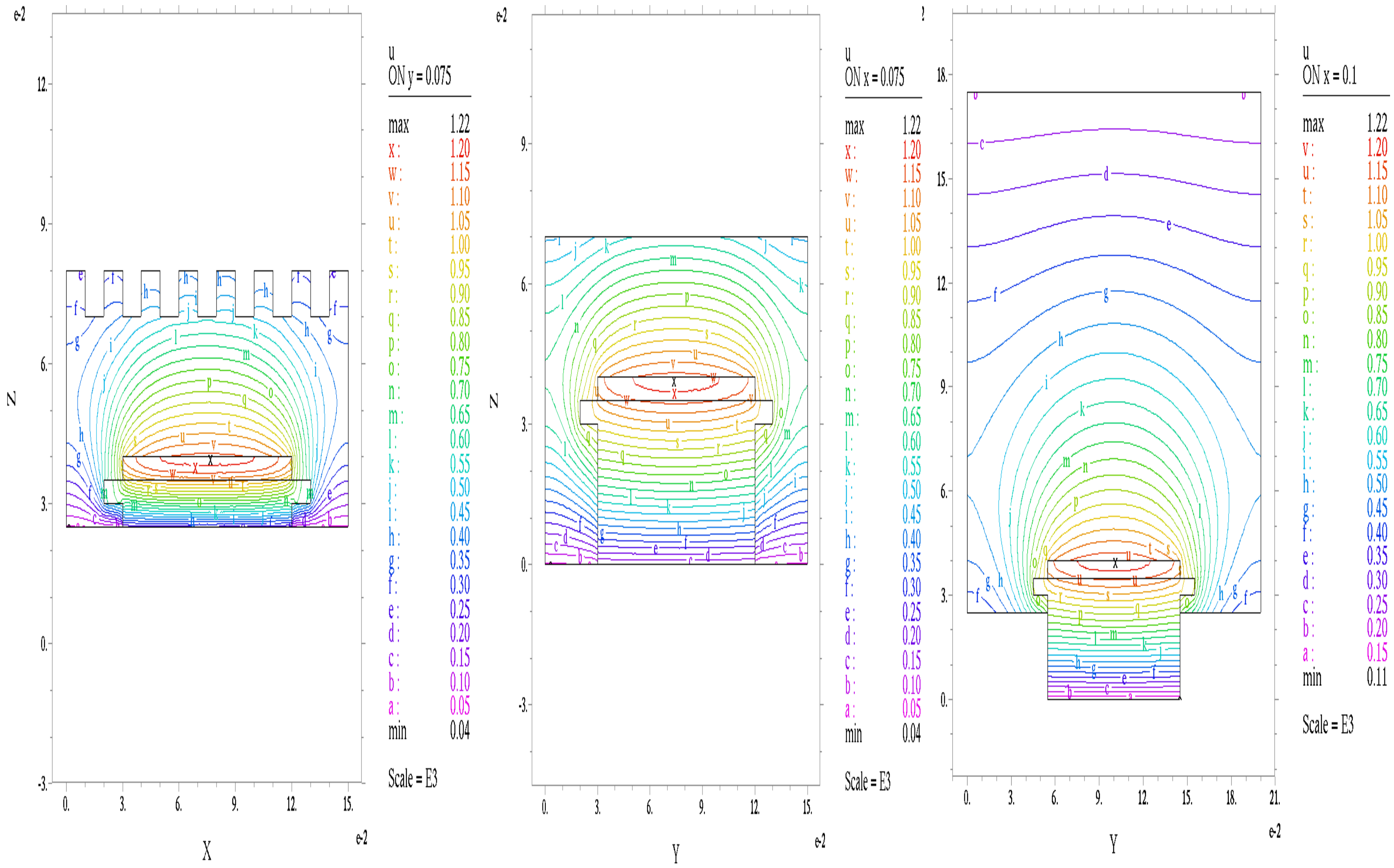

Figure 3 Various design changes

4. Future work

In order to meet the design requirements of reaching CHF and dryout scenario while keeping the physical integrity of the heater, the usage of a high performance heater will be taken into consideration. A high performance heater is capable of reaching a maximum temperature of 1900 to 2000 degree Celsius which is 800 to 900 degrees higher than the one used. Simulation with the high performance heater will need to be conducted. It is important to change the geometry of the heating layer to cylindrical shape to represent the actual heating elements. Further work on a holder to support the test section will be required. Lastly, the thermal couple will also need to be strategically placed in the test section and the tank.

5. References

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