Primary Issues of Mixed Convection Heat Transfer Phenomena

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1. Introduction

The Very High Temperature Reactor (VHTR) is one of the advanced reactor concepts within the internationally-supported Generation IV program. There is advantage that can supply not only heat but also hydrogen due to the achievement of high temperature heat source. In the development of the VHTR, the technical level of the domestic thermal hydraulics area was identified to be far behind the international level [1].

The computer code analyzing the system operating and transient behavior must distinguish flow conditions involved with convective heat transfer flow regimes. And the proper correlations must be supplied to those flow regimes. However the existing safety analysis codes are focused on the Light Water Reactor and they are skeptical to be applied to the GCRs (Gas Cooled Reactors).

One of the technical issues raise by the development of the VHTR is the mixed convection, which occur when the driving forces of both forced and natural convection are of comparable magnitudes. It can be encountered as in channel of the stacked with fuel elements and a decay heat removal system and in VHTR.

The mixed convection is not intermediate phenomena with natural convection and forced convection but independent complicated phenomena. Therefore, many researchers have been studied and some primary issues were propounded for phenomena mixed convection.

This paper is to discuss some problems identified through reviewing the papers for mixed convection phenomena. And primary issues of mixed convection heat transfer were proposed respect to thermal hydraulic problems for VHTR.

2. Literature survey

2.1 Flow Regime Map

The flow regime map by Metais and Eckert [3] is widely referenced map and it classifies the modes of convection into nine regimes: forced, mixed and natural convection and laminar, transition and turbulent regimes as shown Fig. 1. It was developed based upon several experimental and numerical studies. Once the flow regime is known then the selection of the proper *Nu* correlation can be decided.

The flow regime map used the diameter *D* as the characteristic length for both *Re* and *Gr* instead of height *H* of vertical pipe.

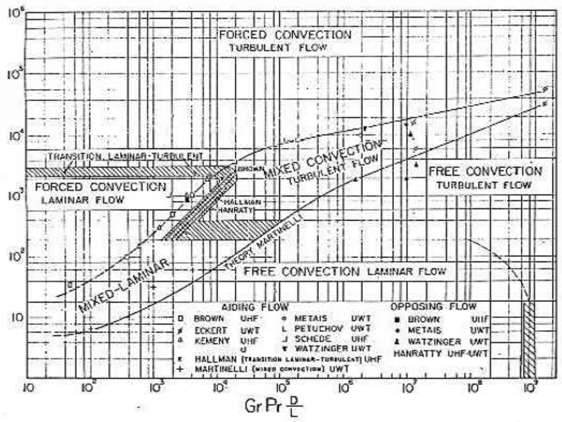

Fig. 1. Regimes of forced, mixed and natural convection insid e a vertical pipe [3].

2.2 Mixed Convection of Laminar and Turbulent Flow

In a vertical pipe, the natural convective force due to buoyancy acts upward only, but forced convective force can be either upward or downward. This determines buoyancy-aided and buoyancy-opposed flows depending on the direction of forced flow with respect to the buoyancy forces.

In laminar mixed convection, buoyancy-aided flow presents enhanced heat transfer compared to the pure forced convection and buoyancy-opposed flow shows impaired heat transfer as the flow velocity affected by the buoyancy forces. However, in turbulent mixed convection, the trend is reversed. Buoyancy-aided flow shows an impairment of the heat transfer rate for small buoyancy, and a gradational enhancement for large buoyancy. The impairment of heat transfer is due to the laminarization. While, buoyancy-opposed flow indicates enhanced heat transfer due to increased turbulence production, returbulization [4, 5].

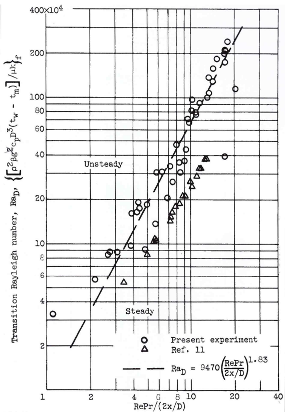

Fig. 2. Correlation of data for transition in buoyancy-aided flow with heating [6].

2.3 Transition of Mixed Convection

Hallman [6] reported that a transition from steady laminar flow to a slow, eddy flow was observed on experiments. This was evidenced by wall temperature fluctuations appearing on the upper portions of the heated pipe. Fig. 2 presents the transition points measured by a photoelectric recorder.

Hanratty et al. [7] explained that the transition is related to the distortions of the velocity profile caused by natural convection. When natural convection is in the direction of forced flow the transition appears to occur through the growth of small disturbances. Transition occurs when natural convection is opposite the direction of forced flow and it appears to be associated with a separation of the flow at the wall.

Brown [8] found that the location of the point of transition is not well established and is thus extremely difficult to evaluate due to the magnitude of the initial disturbances and wall roughness in the apparatus. Thus the transition distance of their study did not agree with those of Brown and Hallman, and Scheele and Hanratty's results.

2.4 Existing Correlations

The various empirical correlations developed by different authors. They defined specific buoyancy coefficients for their own test rigs.

Direct comparison of the data is not generally possible, because various investigators use different bases for calculating their correlating parameters. Thus, the correlations were used without differentiation due to the lack of literatures [9].

3. Discussions

The classical flow regime map has following problems. The results of buoyancy-aided flow and buoyancy-opposed flow were plotted in single flow regime map. It means that the influence with heat transfer by buoyancy effect in mixed convection did not reflect. Experimental results for UWT and UHF condition were also plotted in the same map without differentiation. In spite of the fact that the buoyancy forces are proportional to the third power of the height of the heated wall, most of the investigators used the diameter of the pipe *D* as the characteristic length scale for both *Re* and *Gr* [10].

In turbulent mixed flows, buoyancy-opposed flows shows enhanced heat transfer due to increased turbulence production and buoyancy-aided flow shows impaired heat transfer at low buoyancy forces due to laminarization and then, further increases of the buoyancy forces, the heat transfer is enhanced due to returbulization. It was explained the interaction between thermal layer development and buoyancy influence. The buoyancy coefficient was not generalized for correlating with effect of *Gr* and *Re*.

The defined transition regime was different with authors in mixed convection regime. Because it was difficult to evaluate due to the magnitude of the initial disturbances and wall roughness in the apparatus.

The various empirical correlations presented by different authors. They defined buoyancy coefficient as their test rig or uses one by Jackson [4]. Thus correlations are not generalized and scattered as shown Fig. 3.

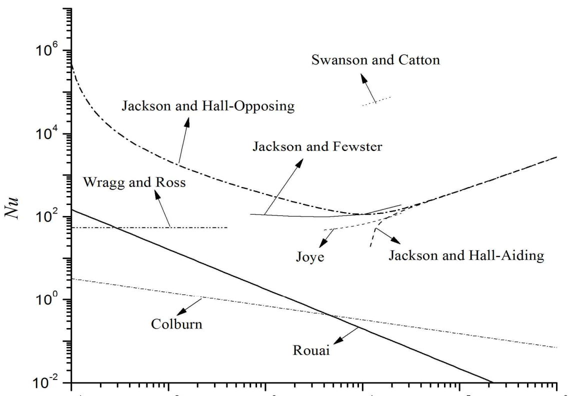

Fig. 3. Correlations for mixed convection by authors.

4. Conclusions

The VHTR thermal hydraulic study requires an in-depth study of the mixed convection phenomena. In this study we reviewed the classical flow regime map of Metais and Eckert [3] and derived further issues to be considered. The following issues were raised:

(1) Buoyancy aided an opposed flows were not differentiated and plotted in a map.
(2) Experimental results for UWT and UHF condition were also plotted in the same map without differentiation.
(3) The diameter of the pipe *D* was used as the characteristic length scale for *Gr,* which contradict on the knowledge of buoyance force.
(4) The buoyancy coefficient was not generalized for correlating with buoyancy coefficient.
(5) The phenomenon analysis for laminarization and returbulization as buoyancy effects in turbulent mixed convection was not established.
(6) The defining to transition in mixed convection regime was difficult.
(7) The various correlations developed by different authors do not reconcile with other, thus, the correlations are not well generalized.

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