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Assessment of Wall Condensation Models Using CUPID Code

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1. Introduction

The condensation heat transfer is a relevant phenomenon in many industrial applications, including nuclear power plants. In most cases, condensation occurs in the presence of noncondensable gases. To estimate the wall condensation using CFD code, there are two types of single phase wall condensation model; resolved boundary layer approach (RBLA) and heat and mass transfer analogy (HMTA).

RBLA is based on the Fick's law approach. In order to simulate local gradient of steam mass fraction and thermal properties adjacent to the wall, this model needs mesh refinement. HMTA is based on the similarity of the equations of energy and species conservation in their boundary layer. This model allows to use coarse mesh because does not require to describe detailed gradient near the wall.

In the present study, the two models introduced above are implemented in CUPID as a source term of mass and energy equations. For the assessment of the models, the data from COPAIN experiment are considered in order to compare with calculated results.

2. Wall condensation models

In this section, RBLA and HMTA models are described. In order to implement the two models, the following assumptions are needed. First, the latent heat transfer due to the condensation is reflected only for the heat transfer. Second, liquid film modeling does not considered, because the noncondensable gas fraction is large enough (0.1 or more) that the thermal resistance of the liquid film can be neglected [1]. Third, the steam mass fraction on the condensation wall is defined by saturated pressure at the condensation wall temperature.

2.1 Resolved Boundary Layer Approach

To estimate condensation rate as volumetric form, RBLA model applies Eq. (1).

$$\Gamma_{wall} = m''\frac{A_{cell}}{V_{cell}} = -\frac{1}{\left(W_s - 1\right)}\rho D \frac{\partial W_s}{\partial n}\frac{A_{cell}}{V_{cell}} \tag{1}$$

Where W_s denotes the steam mass fraction, ρ the gas mixture density, D the binary diffusivity, n the normal direction to the condensation wall, V_{cell} the volume of cell, A_{cell} the area of the cell on the wall.

2.2 Heat and Mass Transfer Analogy

For the calculation of the condensation rate as volumetric form, HMTA model follows a mass fraction based approach described as Eq. (2).

$$\Gamma_{wall} = m''\frac{A_{cell}}{V_{cell}} = -K\ln\left(\frac{1-W_{s,w}}{1-W_{s,\infty}}\right)\frac{A_{cell}}{V_{cell}} \tag{2}$$

Where K denotes mass transfer coefficient, which is derived from correlation of local Nusselt number and local Sherwood number, is obtained as Eq. (3).

$$K = h\left(\frac{\rho D}{k}\right)\left(\frac{Sc}{\Pr}\right)^{\frac{1}{3}} \tag{3}$$

Where Sc denotes the Schmidt number, $\Pr$ the Prandtl number, k the thermal conductivity. The heat transfer coefficient, h , can be obtained from wall function for heat transfer.

3. Assessment of wall condensation models

The COPAIN test data are considered in order to assess the wall condensation models. COPAIN is a separate effect facility operated by CEA. Most tests concern condensation of superheated steam mixed with air [2]. The COPAIN test section consists of a vertical rectangular channel whose flow area is 0.6 m by 0.5 m and height is 2.5 m. The condensation plate is 0.6 m wide and 2 m long. Other walls without condensation plate are insulated. The test conditions are described in Table 1.

Table I: Parameters of the COPAIN tests

Test No.	P0441	P0443	P0444	P0344
Convective Heat Transfer	Forced	Free	Natural	Natural
Velocity (m/s)	3	1	0.5	0.3
Pressure (bar)	1.02	1.02	1.02	1.21
Gas Temp. (K)	353.23	352.33	351.53	344.03
Wall Temp. (K)	307.4	300.06	299.7	322
Quality (-)	0.767	0.772	0.773	0.864

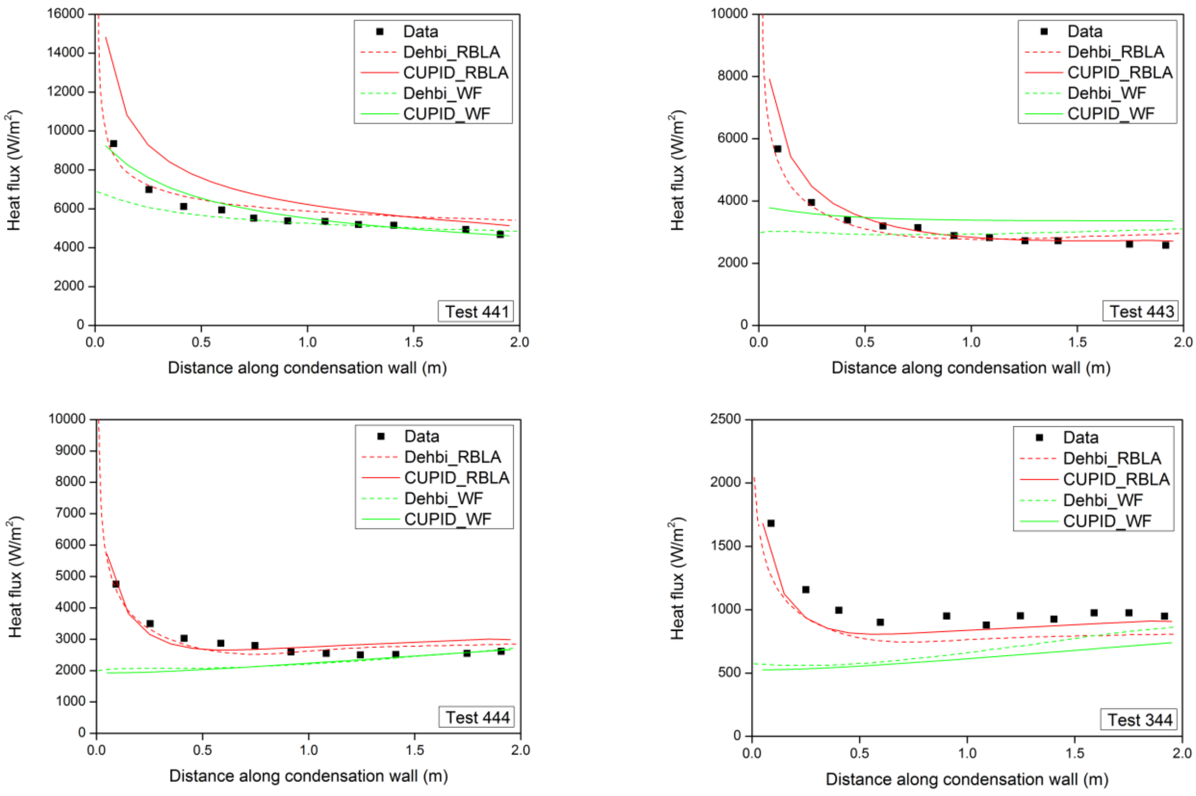

Fig. 1. Comparison CUPID simulation results with reference data [3]

For the simulation, coarse meshes whose mean wall adjacent cell y+ is about 40 are used for HMTA model, and fine meshes whose y+ is the order of 1 are used for RBLA model. Figure 1 shows the comparison of the heat flux along the distance from top of condensation wall. In the developing region of the boundary layer, which means the top of the condensation wall, HMTA model has deviation from resolved approach and experimental data in particular low velocity conditions. Because correlations in order to obtain coefficients implemented in this model are based on fully developed flow conditions. For RBLA model, reasonable calculated results are obtained. In this simulation, standard k-epsilon turbulence model is applied only, however it is need to implement other turbulence models, which are more proper to refined mesh particularly for forced convective heat transfer condition.

3. Conclusions

In the present study, single phase wall condensation models, RBLA and HMTA model, for CFD code are implemented in CUPID code. And assessment for the two models are conducted using COPAIN test data. For RBLA model, the calculated results show reasonable agreement with reference data. HMTA model, however has deviation from reference data at the developing region of the boundary layer.

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