Flow Regime Map Models for the Horizontal and Vertical Pipes for the SPACE code

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1. Introduction

A safety analysis code, named as SPACE, for a pressurized water reactor is under development to obtain a licensing to be used for the PWR design and to hold entire proprietary rights. The task of KAERI is to develop the physical models and correlations which are required to solve the field equations. It can be divided into four parts; i) flow regime determination, ii) wall heat transfer, iii) wall and interfacial friction, iv) interfacial heat and mass transfer. This paper will describe the process to develop the models for the two-phase flow regime maps in the horizontal and vertical pipes.

2. Flow Map for Horizontal and Vertical Pipes

2.1 Review of the existing models

To select the flow regime map model for the SPACE code, different flow regime models currently used in major best-estimate nuclear reactor system analysis codes, which are RELAP5, TRAC-M, COBRA-TF and CATHARE, have been reviewed. The recent suggestions have also reviewed [1]. Table 1 shows the flow regime transition criteria of various codes.

Table 1: Flow regime transition criteria used in various codes

Horizontal pipe	RELAP5	TRAC-M	CATHARE	COBRA
Stratified	Taitel(1987)	Mishima & Ishii (1980)	Stratification Ratio $R = R_1 \times R_2 = 1$	N/A
Bubbly-to-Slug	Taitel(1980) Choe(1978)	Choe(1978)	Map=Stratification Ratio(R) * Rate of Entrainment(E)	N/A
Slug-to-Churn	$\alpha = 0.75$	$\alpha = 0.5$	"	N/A
Churn-to-Annular-mist	$\alpha = 0.8$	$\alpha = 0.75$	"	N/A
Vertical pipe	**RELAP5**	**TRAC-M**	**CATHARE**	**COBRA**
Stratified	Taylor bubble rise velocity	Terminal bubble rise velocity	$R = R_1 \times R_2 = 1$	N/A
Bubbly-to-Slug	Taitel(1980) Choe(1978)	Choe(1978)	Map = R * E	$\alpha = 0.2$
Cap-slug-to-Churn	Taitel(1980)	$\alpha = 0.5$	"	$\alpha = 0.5$
Churn-to-Annular	McQuillan & Whalley (1983, 1985)	$\alpha = 0.75$	"	α_{crit}

2.2 Flow regime map model for the SPACE code

While most flow regime maps have been established using superficial velocities, a void fraction is used for a flow regime determination according to Ishii and Mishima's recommendation [2]. We determined the criteria for the selection of flow regime map models; i) no confliction with proprietary right; ii) well verified model; iii) recent model if is has similar performance. The selected correlations for the SPACE code are shown in Table 2.

Table 2: Summary of selected correlations

Horizontal pipe	Criteria	
stratified	$\lvert v_g - v_f \rvert < 0.5 \times v_{crit}$ $v_{crit} = 0.487\sqrt{(\rho_L - \rho_G) g h_g / \rho_G}$	
bubbly-slug	$\alpha_{BS} = 0.3$ for $G_m \le 2000 kg/m^2 s$ $\alpha_{BS} = 0.3 + 0.003(G_m - 2000)$ for $2000 < G_m < 2700$ $\alpha_{BS} = 0.51$ for $G_m \ge 2700$	
slug-churn	$\alpha_{SI} = 0.75$	
churn-annular	$\alpha_{IA} = 0.8$	
Vertical pipe	**Criteria**	
stratified	(1) $v_m < 0.5 \times v_{TB}$ (2) $\alpha_{g,L} > 0.7$, $\alpha_{g,L} - \alpha_{g,K} > 0.2$ *or* $\alpha_{g,K} - \alpha_{g,I} > 0.2$ (3) $\alpha_{g,L} - \alpha_{g,I} > 0.2$, $\alpha_{g,I} \le \alpha_{g,K} \le \alpha_{g,L}$, $10^{-5} < \alpha_{g,K} < 0.99999$	
bubbly-slug	$G_m < 2000$	$G_m \ge 2700$
	$\alpha_{BS} = 0.3$ for $2000 \le G_m$ $\alpha_{BS} = 0.3 + 0.003(G_m - 2000)$ for $2000 < G_m$	$\alpha_{BC} = \alpha_{CC} = 0.51$
slug-churn	$\alpha^*_{CC} = 1 - 0.813\left\{\frac{(C_o - 1)\lvert j \rvert + 0.35\sqrt{\Delta\rho g D/\rho_f}}{\lvert j \rvert + 2.25\sqrt{\Delta\rho g D/\rho_f}}\right\}^{0.75}$ $\alpha^{max}_{CC} = 0.65$ $\alpha_{CC} = \min\left[\alpha^{max}_{CC}, \max\left(\alpha_{BS}, \alpha_{CC}{}^*\right)\right]$	
churn-annular	$\alpha_{CA} = \max\left[\alpha^*_{CA}, \min\left(\alpha^f_{crit}, \alpha^e_{crit}, 0.9\right)\right]$ $\alpha^*_{CA} = \begin{cases} \alpha_{CC} + 0.05 & if\ G_m \le 2700 \\ 0.56 & if\ G_m > 2700 \end{cases}$ $\alpha^f_{crit} = \min\left\{\frac{1}{v_g}\left[gD(\rho_f - \rho_g)/\rho_g\right]^{0.5}, 1.0\right\}$ up flow $\alpha^f_{crit} = 0.75$ down and countercurrent flow $\alpha^e_{crit} = \min\left\{\frac{3.2}{v_g}\left[\frac{g\sigma(\rho_f - \rho_g)}{\rho_g^2}\right]^{0.25}, 1.0\right\}$	

2.3 Program module description

The program language for the SPACE code has been determined as C++. To find the flow regime for every cell and face, function “modelflowmap(int i)” has been programmed as a member function of class “CellData” for each cell and class “FaceData” for each face. The “modelflowmap” function firstly computes the inclined factor and then determines both the horizontal and vertical flow regimes for each cell and face. The function in the “FaceData” class also adjusts the face void fractions to mitigate the abrupt change in a void fraction due to a flow direction, especially for a face adjacent to a stratified cell.

2.4 Verification of the flow regime map correlations

We have verified the developed flow regime map model in compliance with the test plan as stated in the report [1].

Fig. 1 shows the comparison of the calculated results from the flow regime model with the experiments for the horizontal stratified flow transition. As shown in Fig. 1, the calculation results of the selected correlation for the SPACE code agreed well with the experimental data of Wallis and Dobson [3].

Fig. 2 shows the comparisons for the transition from cap-slug to churn flow and the transition from the churn to annular flow in the vertical pipe. As can be seen, the calculation results of the correlation for cap-slug to churn transition used in the SPACE code agrees well with the flow regime map of Mishima and Ishii [2]. The prediction for churn to annular flow transition is slightly deviated with the suggested map.

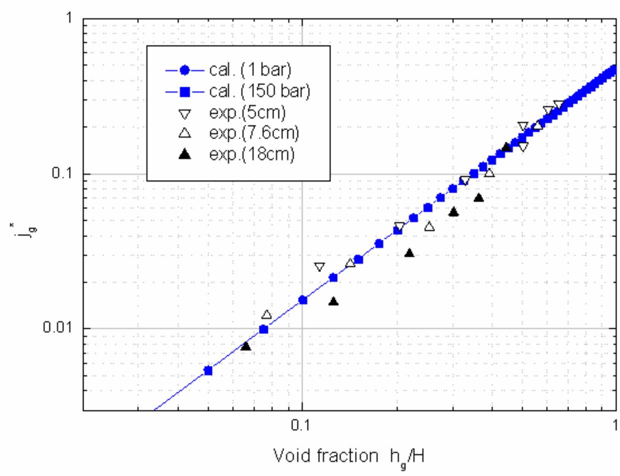

Fig. 1. Comparison of the calculated with the experiments for horizontal stratified flow transition.

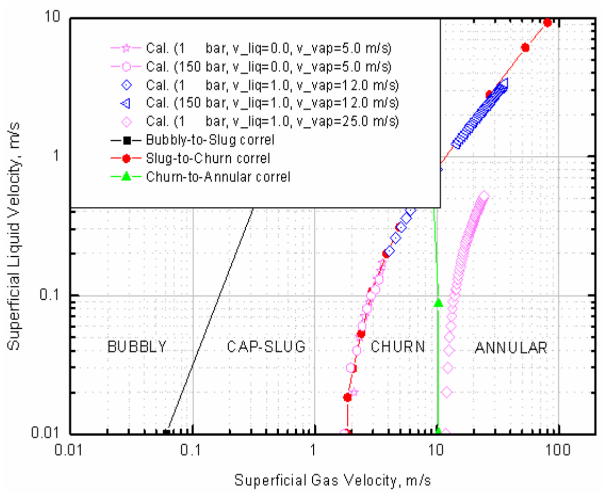

Fig. 2. Comparisons between the predictions and experiments for cap-slug to churn flow transition and churn to annular flow transition in the vertical pipe.

3. Conclusion

Flow regime map models for horizontal and vertical pipes for the SPACE code have been developed and verified with the available data in the literatures. Since the developed flow regime map model is being used in interfacial/wall friction models and interfacial heat and mass transfer models, an accurate prediction of a flow regime is essential for the fidelity of the SPACE code.

The developed flow regime model will be improved to be used in a special component such as a pump and a ECC mixing region. The model has to be extended for the prediction of reflood phenomena.

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