APROS Thermal Hydraulics

COMPARISON OF DIFFERENT THERMAL HYDRAULIC MODELLING APPROACHES: BASIC CONSERVATION EQUATIONS

The calculation of thermal hydraulics is based on the conservative equations of mass, momentum and energy for both phases. The equations are written in an Eulerian form by neglecting the diffusion term.

The equations in the following table are solved for different approaches. The most relevant approaches for the thermal hydraulic simulation are the homogeneous model (3 conservation equations), drift flux model (5 conservation equations) and two-fluid model (6 conservation equations).

Conservation equations	*Homogeneous model*	*Drift-flux model*	*Two-fluid model*
1: Vapour mass		*X*	*X*
2: Liquid mass		*X*	*X*
1&2: Mixture mass	*X*		
3: Vapour momentum			*X*
4: Liquid momentum			*X*
3&4: Mixture momentum	*X*	*X*	
5: Liquid energy		*X*	*X*
6: Vapour energy		*X*	*X*
5&6: Mixture energy	*X*		

Additional equations are needed if the noncondensable gas components in vapour (nitrogen, hydrogen, radioactivity) and dissolved substances in liquid (boric acid, impurities) are included in the models.

Two-fluid model

The discretized conservation equations are solved in an iterative solver. The physical content in 6-equation model is described as closure relationships for:

- wall heat transfer in all heat transfer modes
- interfacial heat transfer between liquid and vapour
- wall friction for vapour and liquid separately
- interfacial friction between liquid and vapour.

The formulation of physics is built in a mechanistic way by considering each phenomenon through the elementary relationships.

Drift flux model

In the 5-equation model the liquid and vapour momentum equations (3 and 4) are replaced by the mixture momentum equation. In drift-flux model the momentum equation is solved only for the mixture and the phase separation is solved by a diffusion equation of void fraction. The physical content in 5-equation model is described as closure relationships for:

- wall heat transfer in all heat transfer modes
- interfacial heat transfer between liquid and vapour
- wall friction for vapour and liquid mixture
- drift flux model parameters.

Homogeneous model

Simplified equations are achieved by assuming same velocities for both phases (= mixture momentum equation) and one energy equation for the mixture. This homogeneous model is practical for small diameter pipeline networks. Due to the simplicity the calculation is faster than that of the 5- and 6-equation models. The physical content in 3-equation (homogeneous) model is described as closure relationships for:

- wall heat transfer in all heat transfer modes (if structures are described)
- wall friction for vapour and liquid mixture.

The 3-equation model can be improved by assuming a complete phase separation in large volumes like tanks and pipes with a large flow area.

Applicability of different models

In general the homogeneous model (3-equation model) is a practical solution for auxiliary systems, feedwater systems, main steam system after the turbine control valve etc. The model can also describe the phase change due to flashing or condensation, but does not take into account different phase velocities. On the other hand the phase separation in small diameter piping is negligible. And in large diameter tanks also these features can be described. Like other models, the 3-equation model can be expanded for noncondensable gas and soluble components in the liquid.

5-equation or 6-equation models are suitable to describe the primary circuit of the nuclear power plant, water circulation in the boiler plant etc… It is not easy to give any direct recommendation whether to use 5- or 6-equation model. The arguments regarding different approaches can be described as follows.

Drift-flux model features

- The solution of the phase separation for mixture makes the solution more stable and allows more simple (clear) solution algorithms (+)
- Only few analysis codes (ATHLET) apply 5-equation solution. The comparison of phase separation models on the correlation basis is more difficult than for two-fluid models. In drift flux model typically many subphenomena are tailored in (-). A good reference for comparing the model is the full range drift flux model developed by EPRI (+).
- Due to limited instrumentation in experiments the results are typically measured for mixture, not separately for phases. Thus drift flux correlation can be easier to determine using the experimental data (+).
- Stratification in long pipes (water on the bottom, steam flows freely above the water level) cannot be described well enough with the 5-equation model (-). The modelling is not a big problem in reactor piping (+).
- The momentum added into liquid phase is not modelled properly (ECCS-injection in hot leg, entrainment of liquid droplets in core during emergency core cooling, spray injection into BWR core) (-)
- Water level void profile is sharper than with two-fluid model. The drift flux formalism works best for continuous water with rising bubbles. Thus it naturally predicts best the physics where the water level is essential (core uncovery, steam generator secondary side, pressuriser, loop seals) (+).

Two-fluid model features

- The solution of the phase separation separately for both phases is more difficult than for 5-equation model (-), but with present knowledge possible (+). Two approaches, iterative solution (longer solution time (-), clear structure (+)) and two-step SETS-method (fastest solution (+), complicated structure (-)) can be mentioned.
- The most of well-known analysis codes (TRAC, RELAP5 and CATHARE) apply 6-equation solution. Thus the physical content is easy to compare to other analysis codes. Because the physics in two-fluid models is described typically in a mechanistic way also for phase separation, the comparison of elementary pieces is easier than the comparison of complex drift flux formulations (+). The problems in numerical algorithms may cause that the physical response of a two-fluid model cannot be predicted from the correlation (-)
- Because the parameters in experiments are typically measured for mixture, not separately for phases, the interfacial friction and heat transfer relationships have to be based on additional assumptions.
- Stratification in long pipes (water on the bottom, steam flows freely above the water level) can be described also in long pipes with the 6-equation model (+).
- The momentum added into a single phase is modelled properly. If ECCS water in hot leg is injected towards pressure vessel, the flow water can reach upper plenum in spite of large steam velocity. In BWR the spray injection into the core can be described more physically with two-fluid model. In PWR the water entrainment during reflooding is described more physically (+)
- Water level void profile needs more nodes than the drift-flux model (-).