Study on Hydrodynamic Characteristics of Two-Component Two-Phase Flow in Anti-siphon Equipment of China Experimental Fast Reactor

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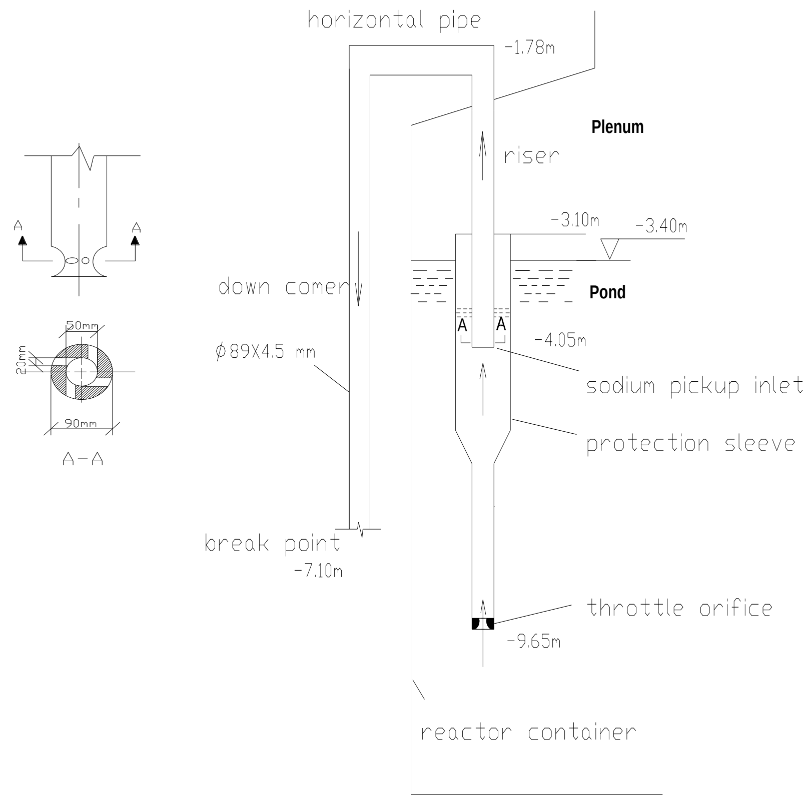
Introduction

In order to satisfy the requirement of high purity sodium in China Experimental Fast Reactor (CEFR), there sets a sodium purification system in the primary coolant circuit .



Anti-siphon structure configuration

Experiment

When the pipe in the purification system of CEFR suffers a pipe-break accident, such as the double-ended guillotine break, this anti-siphon equipment can passively reduce the leakage of sodium.

The course is as followed: *at the beginning* of the accident, the level of the annular plenum's liquid quickly decreases to the inlet of sodium pickup; *then,* the gas of the plenum and the liquid of the pond are both letting out through the inlet; *and finally*, the pressure of the plenum falls.

Hence, the driving force of the leakage is successfully changed from the difference of liquid levels, which is main driving force of the siphon phenomenon, to the difference of pressure between the inlet and the break position of the pipeline, and the anti-siphon equipment realizes passively reducing the leakage of sodium mainly by depressurization of the gas plenum.

Numerical simulation

A two-phase flow analysis and simulation code for one dimensional and unsteady two fluid flowing in a bend pipe is used to simulate the whole two-phase flow process of the anti-siphon equipment pipeline's leakage, to calculate the corresponded parameters, and to anatomize the effects with varieties of these parameters.

$$\frac{\partial \alpha}{\partial t}+\frac{\partial(\alpha u_g)}{\partial z}=0$$

$$\frac{\partial(1-\alpha)}{\partial t}+\frac{\partial[(1-\alpha)u_l]}{\partial z}=0$$

$$\frac{\partial(\alpha u_g)}{\partial t}+\frac{\partial(\alpha u_g^2)}{\partial z}=-\left(\frac{\alpha}{\rho_g}\right)\left(\frac{\partial P}{\partial z}\right)+(u_l-u_g)F_i+u_gF_g$$

$$\frac{\partial[(1-\alpha)u_l]}{\partial t}+\frac{\partial[(1-\alpha)u_l^2]}{\partial z}=-\left(\frac{1-\alpha}{\rho_l}\right)\left(\frac{\partial P}{\partial z}\right)+(u_g-u_l)F_i+u_lF_l+G_l$$

Numerical simulation

Two-phase flow

An applicable algorithm solution to incompressible fluids, the implicit finite volume method， is required to solve the two-phase flow field equations. Specially, this algorithm method is improved according to the phenomenon of the experiment and the structure of anti-siphon equipment which produces a particular two-phase flow.

First of all, in this two-phase flow, the quotient of the bubbly flow is small, and most flows belong to the stratified or annular flow. So, in this two-phase flow, the *interfacial friction*, which is main factor to lead to the pressure loss, is mainly taken into account.

Secondly, when the continuity equations are separated, it is believed that the changes of void fraction *induce* the changes of phase velocities; and when the momentum conservation equations are separated, it is believed that the changes of phase velocities *induce* the changes of void fraction.

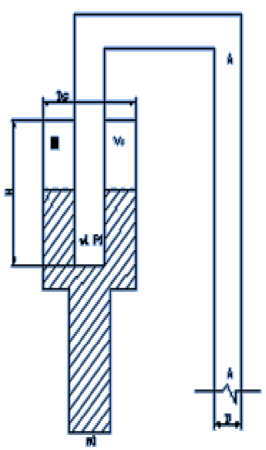
Because the number of unknown parameters is the same as the number of the independent equations, this unsteady model’s control equation group is closed, and then it could simulate the unsteady two-phase flow in the anti-siphon equipment.

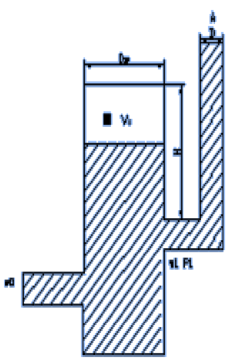
Numerical simulation

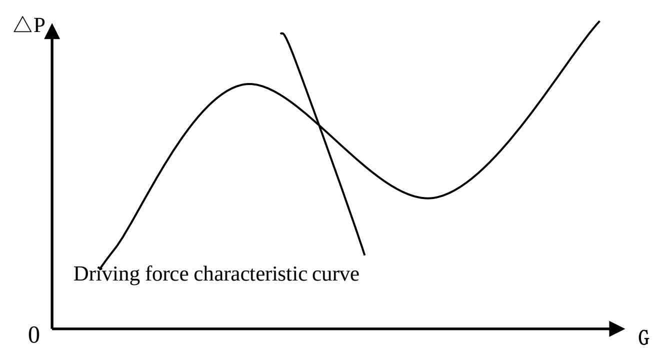
Oscillation

The structure of anti-siphon equipment, which includes the protection sleeve, the sodium pickup inlet, and the plenum, are forming two elements of the energy storage： the plenum together with the protection sleeve stores the potential energy of fluids; and the inlet stores the inertial energy.

Hence, while the pipe system of the anti-siphon equipment works in the negative slope section of the system resistance curve, the pressure-drop oscillation must occur.







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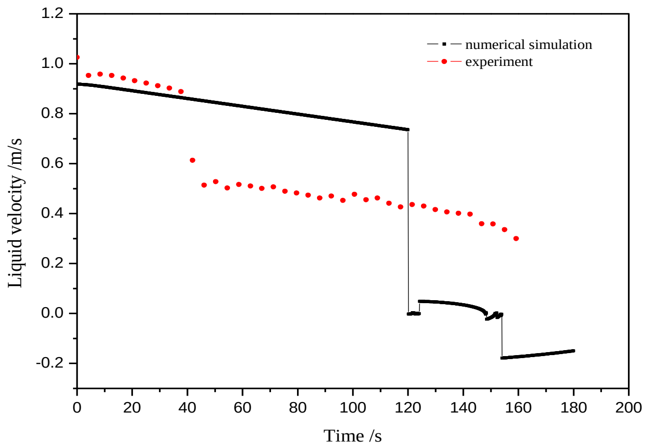
Results and Discussion

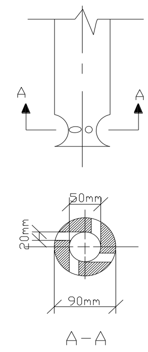


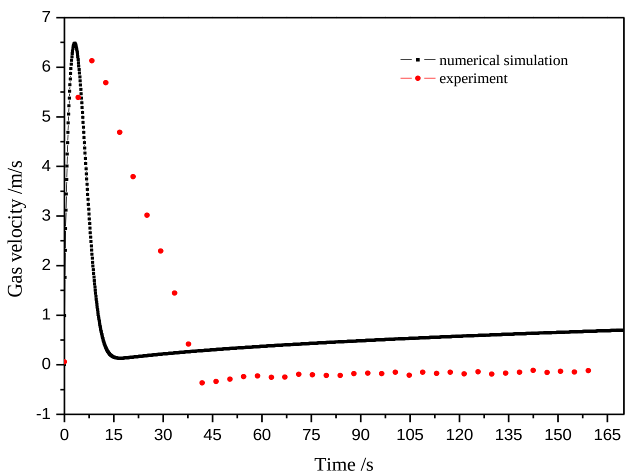
Pressure of the plenum distribution

$$F_i = \frac{2 f_{TP} \rho \left|(u_g - u_l)\right|}{D} \qquad f_{TP} = C/\mathrm{Re}^{0.25}$$

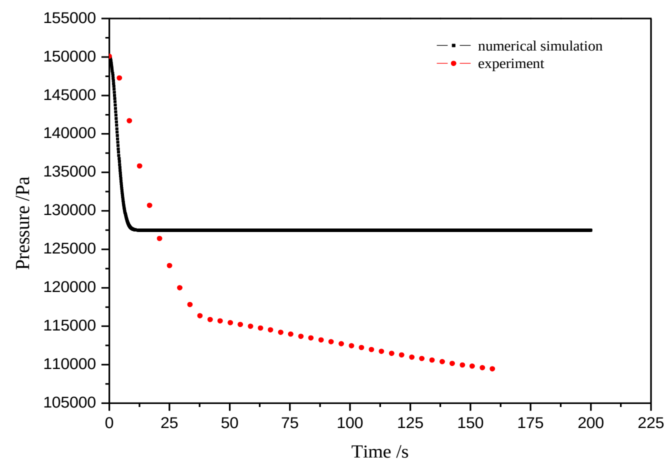
$$F_g = \frac{2 f_g \rho_g u_g}{D} \qquad f_g = C/\mathrm{Re}_g^{0.25} \qquad \mathrm{Re}_g = \rho_g u_g D/\mu_g$$

$$F_l = \frac{2 f_l \rho_l u_l}{D} \qquad f_l = C/\mathrm{Re}_l^{0.25} \qquad \mathrm{Re}_l = \rho_l u_l D/\mu_l$$





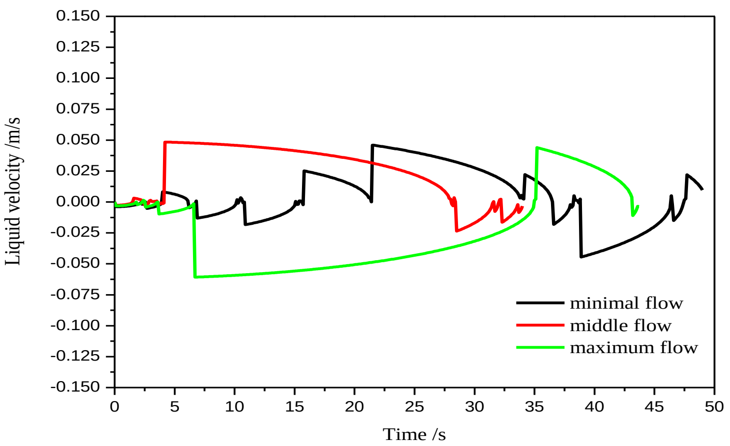
Liquid velocity of the inlet distribution



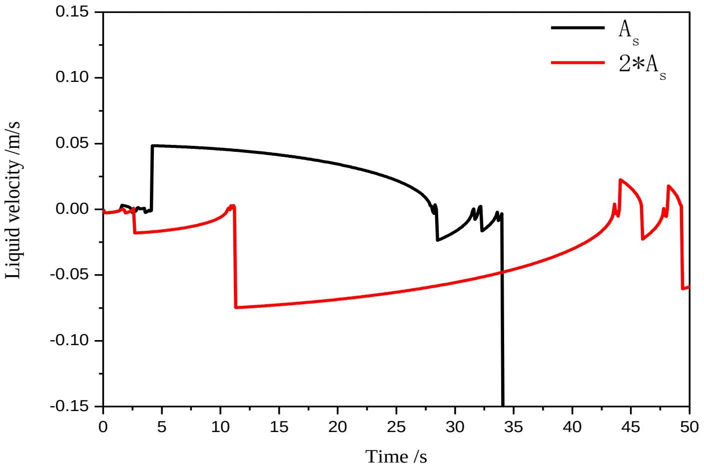
Gas velocity of the inlet distribution

Results and Discussion

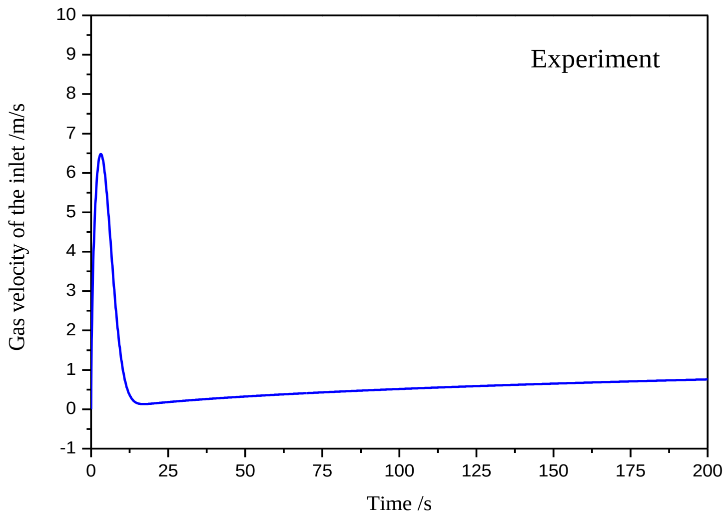
The more the inlet flow,
the longer the oscillation period.

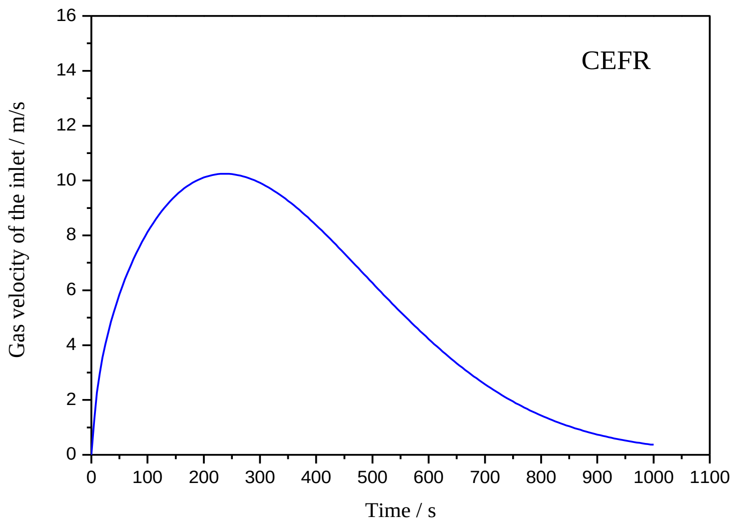


The bigger the annular plenum volume,
the longer the period of oscillation.



Results and Discussion





Gas velocity of the inlet in different regimes

Conclusion

With the results of the experiment and the numerical simulation, the function of the anti-siphon equipment, which is passively reducing the accident leakage of sodium, is obtained good quantitative and qualitative validations.

Therefore, CEFR anti-siphon equipment is certificated to be an efficiently and reliably passive facility, as an engineered safety feature, used in CEFR.

Acknowledgement

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Thank you!