Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Prediction of a Drainage from an Open Water Tank

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1. Introduction

The IAEA recommended that at least one or more automatic shutdown system for a safety should be incorporated in the design of a research reactor. An independent secondary shutdown system should be considered with depending on the characteristics of a reactor[1]. The AHR(Advanced HANARO Reactor), which is under conceptual design is considered to have a SOR(Shut-Off Rod) drop as a primary shutdown system and the D_2O reflector dump system as a secondary safety system which quickly dumps the D_2O in the reflector tank into the dump tank by the activation of a secondary safety trip logic system. The reactor becomes a safe sub-critical state, when D_2O drains from the reflector tank and finally reaches a shutdown due to an excess neutron leakage. The D_2O dump system has already been adopted by OPAL and MX-10.

The D_2O should be drained to the required level from the reflector tank within a required time(for OPAL 20 second is required). For the conceptual design of the D_2O dump system we obtained two simple equations which can solve the discharge velocity and the change of a level. In this study the analytical results of the discharge velocity and the change of level for a simple geometry were compared with those by a CFD simulation.

2. Analytical Method

D_2O dump system is designed to drain D_2O by gravity force. This can be simplified as a problem of a fluid discharge from an open tank with a small hole, as shown in Fig. 1.

To obtain an equation for the discharge velocity at point ③, Bernoulli's equation is applied between ① and ③.

$$\frac{p_1 - p_3}{\rho} + \frac{1}{2}(V_1^2 - V_3^2) + g(z_1 - z_3) = 0 \quad (1)$$

Since both side ①, ③ are exposed to an atmospheric pressure (p_1 = p_3 = p_a), the first term is eliminated. Considering the mass conservations, $V_1 A_1 = V_3 A_3$ and $g(z_1 - z_3) = h + 0.1$, we can obtain an ideal relation between the discharge velocity V_3 and the open tank free surface height h. But actually we need to adjust the ideal equation by using a discharge coefficient, $C_d = \dot{m}_{actuall} / \dot{m}_{ideal}$. Discharge coefficient varies as a function of the shape. In this study we assumed C_d = 0.5 and 0.6. So we can finally obtain an equation for the discharge velocity (Eq. (2))[2].

$$V_3 = C_d \sqrt{\frac{2g(h+0.1)}{1-(r_3/r_1)^4}} \quad (2)$$

The time rate of a change of a mass contained by an open tank(m) is equal to the mass flow rate at point ③($\dot{m}_3$) as shown in Eq(3).

$$\frac{dm}{dt} = -\dot{m}_3 \quad (3)$$

Substitute $m = \rho(\pi r_1^2)h$ and $\dot{m}_3 = \rho V_3(\pi r_3^2)$, and Eq.(3) can be rewritten for the time rate of a change of an open tank free surface height, h.

$$\frac{dh}{dt} = -\left(\frac{r_3}{r_1}\right)^2 C_d \sqrt{\frac{2g(h+0.1)}{1-(r_3/r_1)^4}} \quad (4)$$

Using Eq.(4) we can explicitly calculate the variation of a tank level with time marching.

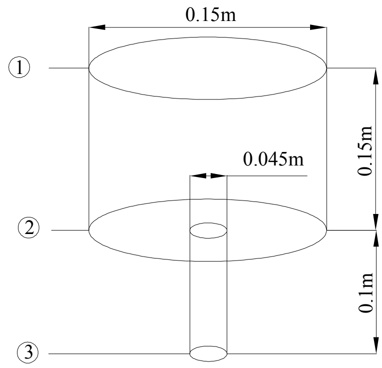


Figure 1. Schematic of simple geometry for test

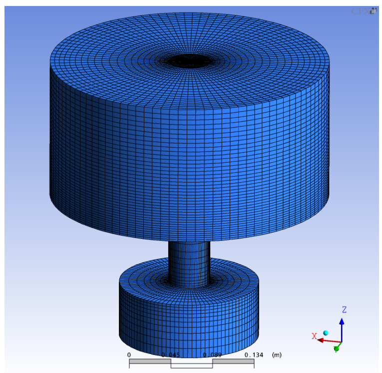
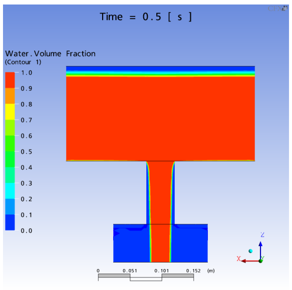


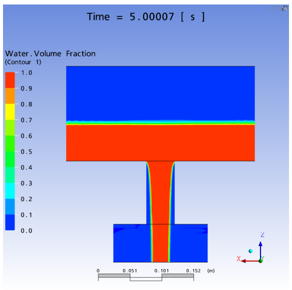
Figure 2. Computational mesh

3. CFD Method

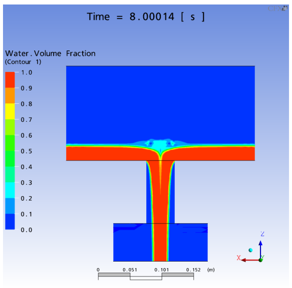
Water discharge from an open tank with a small hole was also simulated by a commercial CFD code, CFX. CFD model uses a homogeneous free surface model for



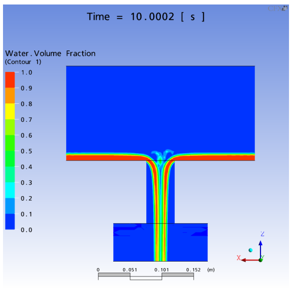
(a) t = 0.5 sec



(b) t = 5.0 sec



(c) t = 8.0 sec



(d) t = 10.0 sec

Figure 3. Variation of open tank level

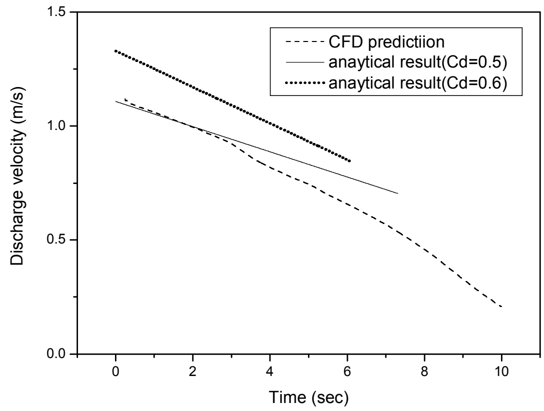
a multi-phase flow and a full buoyancy model using a density difference. Opening pressure for an entrainment as a boundary condition is applied to the top of the open tank and the end of the exit pipe. The standard k-ε turbulence model is used to simulate the turbulence effect. The fluid in the tank is 25°C water.

The variation of the tank level with time is shown in Fig. 3. It can be seen that the exit pipe is not fully filled with water by discharging it through the bottom hole due to the vena contracta, which causes a reduced flow rate. As the open tank level goes down, the water column diameter becomes smaller. When the time reaches 8 second, an air hole through water column begin to generate. After the air hole builds up as shown in Fig. 3(d), the flow rate reduces steeply. These results are physically plausible and give us help in understanding the process of a drain.

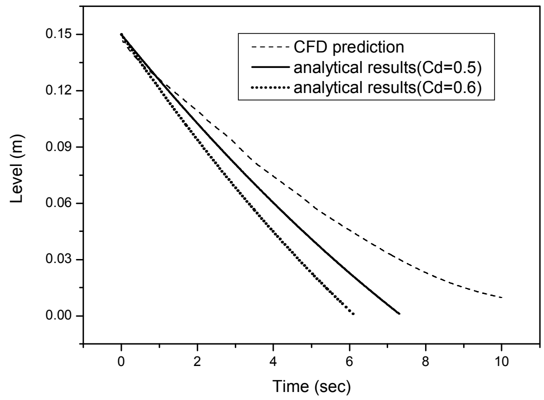
4. Comparison of Results

Two results by analytical method and CFD simulation are compared for their discharge velocity and fluid level in an open tank. Analytical method predicts that the time rate of a discharge velocity is constant depending on the discharge coefficient. But CFD shows that the time rate of a discharge velocity reduces faster as the level of the tank goes down. The experiment in a D_2O dump system for OPAL shows a similar trend[3]. The variation of the discharge velocity for C_d=0.5 by an analytical method is similar to the CFD results at an early time, but they have more differences as time marches on (actually related to tank level).

The analytical method forecasts the duration of a discharging time of water from the tank about 7.5 second, which is about 25% shorter than CFD prediction of 10 second.



(a) variation of discharge velocity



(b) open tank level

Figure 4. Comparison of results from two methods

predicts. Considering these results, if we could obtain, even roughly, the relation of a discharge coefficient change, the variation of a tank level would be predicted more actually. This analytical method may be used to design roughly the D_2O dump system. But CFD calculation would be required to design the D_2O dump system more specifically.

5. Conclusions

Water discharge from an open tank with a small hole was calculated by the CFD and analytical method. The duration for a discharging of water from the tank that the analytical method forecasts is shorter than the CFD predicts, because the analytical method does not consider a change of the discharge coefficient. If we could obtain, even roughly, the relation of a discharge coefficient change, the analytical prediction would be more accurate. Although the analytical method may be used to design roughly the D_2O dump system, the CFD calculation would be required for more specified design.

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[2] F. M. White, Fluid Mechanics, 4th Ed.
[3] C. Park et al, “Design of a New Research Reactor : Preliminary Conceptual Design”, KAERI/TR-2635/2005.