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Flashing Flow in Submerged Orifice

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ABSTRACT

The aim of the present work is to measure the discharge coefficient of submerged orifices of three different geometries for a flow of flashing water. The discharge coefficients were measured at different operating parameters. These parameters are: The water saturation temperature (40-95 °C), total pressure difference (100-800 mm H_2O), the water flow rate(60 -160 m^3/hr.m), and the water level in the flashing chamber(90-250 mm).

It is found that the discharge coefficient of the three orifices increases with the saturated water flow rate and the water level in the flashing chamber and the decrease of flashing temperature and the total pressure difference. The discharge coefficient of the weir-type orifice is higher than that of the variable area orfice, which in turn is higher than that of the two step flashing box orfice. In addition the discharge coefficient of the developed variable area is found to be constant at different water flow rate.

INTRODUCTION

The flow of saturated liquids through orifices, nozzles, short pipes and equilibrium chambers has many engineering applications. This includes steam power plants, evaporating equipment, distillation columns, refrigeration and cryogenic units and water desalination plants. Flashing flow occurs when a saturated liquid flows through any conduit. In the flashing phenomenon several processes take place: (1) the liquid pressure decreases due to of friction and acceleration, (2) the liquid saturation temperature decreases due to the pressure drop, and (3) a portion of the liquid is vaporized throughout the liquid phase. Hence, two phases exist with continuous change of the two phase quality.

The flashing flow is characterized by the significant deviations from thermal and mechanical equilibrium between the two phases. This means that the temperatures of the formed vapor and the liquid phase differ from the saturation temperature and that the phases flow with different local velocities.

A large of effort has been directed toward the investigation of the flashing flow in different geometry of orifices. One of the articles, often cited in the literature, and reported by Benjamin and Miller [1] explains the flow of saturated water through sharp edged orfice. These investigators did not find any differences in throughput of the orifice whether the water was saturated or subcooled. Silver et.al. [2] proposed a model describing the flow of saturated water through a sharp edged orfice. They postulated that the evaporation takes place at the fluid surface and that heat is transferred by conduction from the fluid at the core to the surface, which is in thermal equilibrium with the formed vapor. Their experimental results showed that the measured flow rate of saturated water through the sharp edged orfice is less than that calculated theoretically. Simpson and Silver [3] presented another model in which they assumed that, the bubble nucleation takes place within the liquid bulk and the bubble growth is due to the formation of the vapor on its surface. The flow is assumed to be homogeneous and unidirectional. They found that the calculated flow rate according to their model is lower than that measured experimentally.

Hideo Uchido and Hideki Nariai [4] observed experimentally that the flow rates are the same for both cold and saturated water, when discharged through sharp edged orifices and short pipes. This is due to the existence of a metastable state. In contrast, for pipes longer than 100 mm, the flow rate of cold water is higher than that of saturated water. Furthermore, Isbin [5] reported the same results where he experimentally found the flow rate of cold, hot, and saturated water in sharp edged orifice and short tubes to be the same.

The weir-type orifice consisting of a submerged sluice gate and a weir, is one of the widely used orifices in the Multi Stage Flash (MSF) desalination plants. This is mainly used in stages of relatively low temperature or small interstage pressure difference, and for the purpose of interstage sealing, flow regulation, and flash efficiency improvement.

Williamson and Gilbert [6] measured the discharge coefficient Cd for submerged orifice (Fig.1.A) when saturated water at different saturation temperature flow through the orifice. They found that Cd varies over a wide range between 0.2 to 0.8 but it follows, approximately, a normal distribution over the range of 0.4 to 0.474. Fujii et.al. [7] found that the Cd of the submerged orifice was 0.59, but it was 0.52 when a baffle of 0.2 m height installed at 50 mm downstream the gate (Fig.1.B). Yokoyoma [8] reported that the mean value of Cd for the orifice configuration shown in (Fig.1.C) was about 0.42. When the splash plate was removed, the Cd was 0.5, while when both the splash plate and the baffle were removed, Cd was 0.63. Fernondez [9] measured the Cd for the three different configurations of submerged orifice. The first one was a simple sluice gate (Fig.1.A), the second was a weir-type orifice (Fig.1.B), and the third is shown in (Fig.1.D). He observed that the Cd for the three orifices was the same with a mean value of 0.63.

The ORNL [10] reported that, the mean value of Cd for the sluice gate was 0.74, while it ranges from 0.45 to 0.603 when weir was installed of a 0.127 m height and inclined at 60 degree from the horizontal with its top edge at 30 m from the sluice gate. It was also

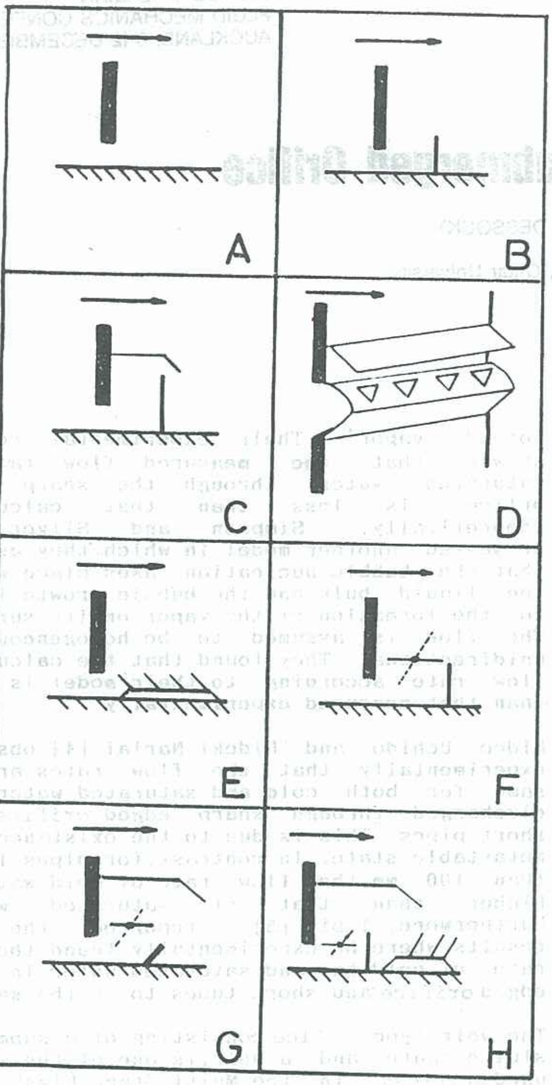


Figure 1: Different Submerged Orifices

reported that the Cd for the orifice shown in (Fig.1.E) was 0.43. In Clair Engle MSF desalination plant [11], the reported values of Cd for the three configurations shown in (Fig.1.F,G&H) were as follows: For orifice 1.F. Cd=0.44 to 0.59, for orifice 1.G. Cd=0.4 to 61 and for orifice 1.H.Cd=0.29 to 63. Kishi et.al.[12] developed a mathematical model relating the flow rate for a weir type orifice to the different operating parameters. They found experimentally that, a wide range of operation can be performed by changing the weir height instead of the sluice gate opening. Also, they found that the round edged gate has a higher value of Cd compared to that of the sharp edged orifice.

This survey shows that, there is disagreement among the experimental results reported by different investigators. In addition, there is no correlation based on the experimental data relating the discharge coefficient of variable area submerged orifice to the various operating variables.

In the present work, the Cd of three different configurations of submerged orifice were measured. The obtained results for the variable area one were used to develop a correlation relating the orifice discharge coefficient to the different operating parameters.

EXPERIMENTAL WORK

The aim of the present work is to measure the discharge coefficient Cd of three different geometries of submerged orifice at a flow of flashing water. Figure 2 shows the configuration of the three different submerged orifices. Figure 2-A displays the developed submerged orifice with variable cross sectional area. In this orifice, the cross sectional area A_3 can adjust itself according to the water flow rate. This allows the variation of the flow rate of flashing water through the sluice gate without changing the sluice gate opening. This developed submerged orifice is vital for the Multi Stage Flash desalination plant where is a large number of flashing chambers are arranged in series and the water flow changes often. The change in water flow rate is due to either the change in demand or to the variation of the flashing range, which is controlled by the temperature of the heating steam and/or the ambient air. In addition, the presence of the splash plate Y reduces the water entrainment with the formed vapor, thus reducing the load on the mist eliminator.

The second configuration, shown in Figure 2-B, is called two step flashing box. This type of orifice is used in some MSF desalination plants, mainly to improve the flashing process efficiency. The third type, shown in Figure 2-C, is the submerged sluice gate with a weir and is the most widely used orifice in the Multi Stage Flash desalination plants.

The discharge coefficient of the three orifices configurations is measured experimentally at different operating parameters. These parameters are: flashing temperature T_f (40-95°C), the total pressure difference ΔP_t (100-800 mm H_2O), the saturation water flow rate V(60-160 $m^3/hr.m$), and the water level in the flashing chamber H_2(90-250 mm).

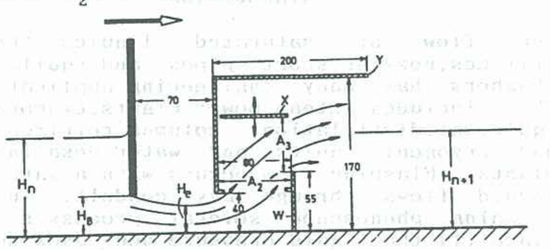


Figure 2A: Variable Area Orifice

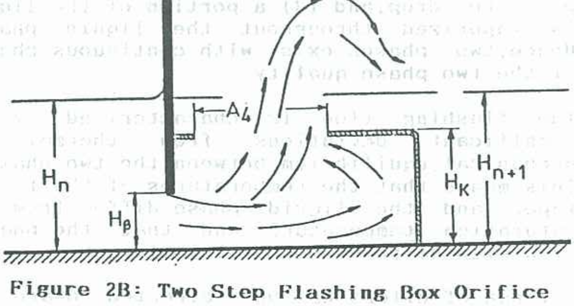


Figure 2B: Two Step Flashing Box Orifice

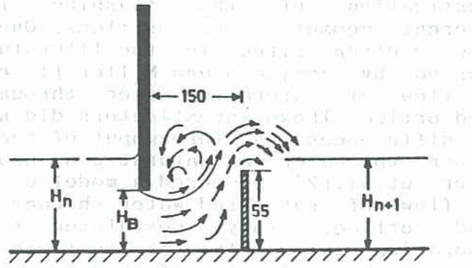
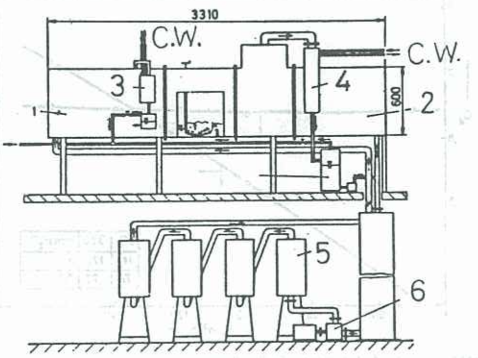


Figure 2C: Gate Weir Orifice

Experimental Set-Up

Figure 3 schematically shows the experimental set-up. The main components of the unit are: flashing chamber, main condenser, circulating pump, vacuum pump and the heating system. This unit is closed loop one. The circulating pump forces the water through the electrical heating system (48 kWatt) to the preflashing chamber (l=1000 mm, w= 100 mm, h=600 mm). The temperature of the water in the preflashing chamber is adjusted to be the same as the saturation temperature according to the pressure of the preflashing chamber. This is done by controlling the amount of power input to the electrical heaters and condensing any amount of vapor formed in the preflashing chamber.



1 Preflashing Chamber 2 Flashing chamber
3 Condenser 4 Main Condenser
5 Heating system 6 Circulating Pump

Figure 3: Experimental Loop

The main flashing chamber (l=3300 mm, w=100 mm, h=600 mm) is designed to be long enough to increase the contact time, and consequently the approach to the thermodynamic equilibrium between the water and the formed vapor. The formed vapor by the flashing process in this chamber is condensed in the main condenser. The pressure inside this chamber corresponds to the vapor condensation temperature. The condensation temperature is controlled by the amount and the temperature of the cooling water flowing through the main condenser.

The vacuum pump withdraws the noncondensable gases out of the flashing chamber. The nonevaporated water and the condensate from the two condensers flow to the circulating pump. The main flashing chamber is provided with 200x200 mm glass window allowing for observation and photographing of the flashing process in the submerged orifice. The height of the sluice gate can be controlled by special mechanism from outside.

In each experiment, the following variables were measured: the flow rate of water flowing to the flashing chambers, condensate water from the condensers, nonevaporated water, cooling water to the condensers, the liquid level in the flashing chambers, vapor pressure in each chamber, the pressure difference between the flashing chambers, and the sluice gate height. The water temperature flowing in and out of each chamber was measured. The temperature of vapor formed in the chambers and the cooling water inlet temperatures were also measured.

Figure 4 shows the locations of the different measuring instruments used in the experimental loop. The flow rate of water were measured by means of plate orifice. The U tube manometers were used to measure the absolute pressure in each chamber and the vapor pressure difference between the chambers. The water levels in the flashing chambers were measured by means of liquid level indicators.

The temperature of water outlet from the electrical heater and cooling water temperature were measured by normal glass thermometer. The temperatures inside the flashing chambers were measured by using platinum thermisters.

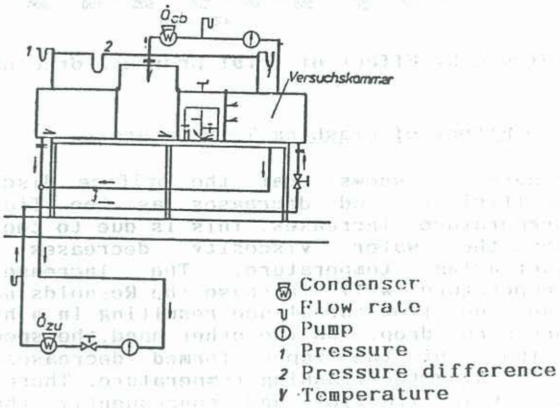


Figure 4: Location of different measuring units.

EXPERIMENTAL RESULTS AND DISCUSSION

The discharge coefficient Cd of the orifice is calculated from the following relationship:

$$Cd= \{M/A_B(2\rho \Delta P_t)^{1/2}\}$$

where

M=Mass of water flowing in the gate
ρ=water density
A_B=gate cross sectional area
$= b.H_B$
b=flashing chamber width
H_B=sluice gate height
ΔP_t=total pressure difference
$= P_v+(H_2-H_1)\rho g$
P_v=vapor pressure difference
H_1, H_2=the liquid level in the two flashing chambers.

The Effect of Total Pressure Difference

Figure 5 clearly shows that with increasing the total pressure difference the discharge coefficient of the three orifices decreases. The total pressure difference between the two flashing chambers increases with decreasing the sluice gate height, when the other variables remains constant. This leads to the increase of the velocity of the fluid as it flows through the sluice gate resulting in a drop in the fluid pressure. Consequently the flashing rate is improved. In addition, the difference in temperature between the two phases will rise as the total pressure difference goes up. This will increase the rate of vapor formation. Both the friction pressure drop between the two phases and the acceleration pressure drop increase with the increase of the two phase quality. This amounts to a drop in the Cd value.

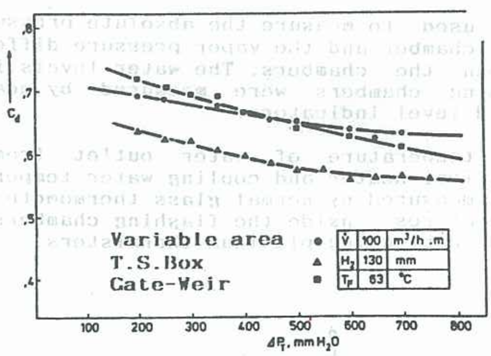


Figure 5: Effect of total pressure drop on Cd

The Effect of Flashing Temperature

Figure 6 shows that the orifice discharge coefficient Cd decreases as the flashing temperature increases. This is due to the fact that, the water viscosity decreases with increasing temperature. The increase in temperature will increase the Reynolds number and the flow turbulence resulting in a higher pressure drop. On the other hand, the specific volume of the vapor formed decreases with increasing the flashing temperature. Therefore, the void fraction and consequently the two phase friction and acceleration pressure drop will decrease, keeping all other variable fixed. The two opposite effects of the temperature may explain the constant value of Cd at high flashing temperatures.

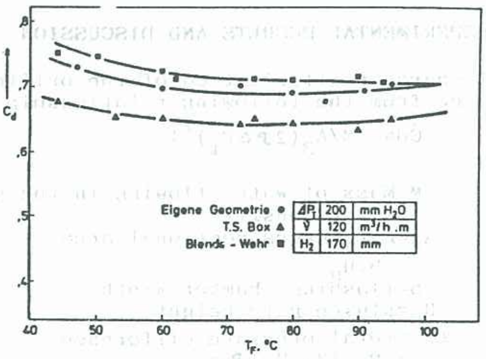


Figure 6: Effect of flashing temperature on Cd

The Effect of Water Flow Rate

The orifice discharge coefficient is found to increase with the water flow rate, Figure 7. This behavior may be explained as follows: In order to keep the total pressure difference constant while increasing the water flow rate, the sluice gate height must be increased, with the other flow areas being constant, the pressure drop in these areas will increase. This requires either an increase in the sluice gate height or a reduction in the pressure drop of the flow through the sluice gate. The further opening of the sluice gate will decrease the velocity of the fluid and increase its pressure as it flows through the gate. The result of this is a general decrease in the fluid turbulence, the rate of flashing and consequently the pressure drop.

It is interesting to notice that the rate of decrease of Cd with the flow rate for the variable area orifice is less than that of the other two orifices. The reason for this is that the change in variable area is compensated by the increase in the water flow rate. This is also indicated by the linear relationship

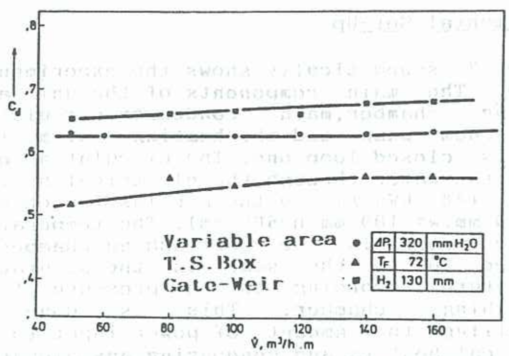


Figure 7: Effect of water flow rate on Cd

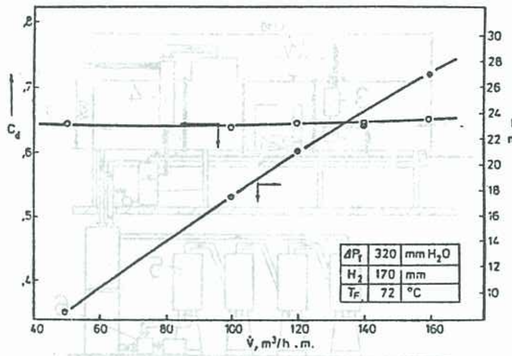


Figure 8: Effect of flow rate on gate height

between the sluice gate height and the water flow rate as shown in Figure 8. This result is very important in controlling the Multi Stage Flash desalination plants where there is a large number (about 30 -40) of submerged orifices in series.

The Effect of the Liquid Level in Flashing Chamber.

Figure 9 shows that the discharge coefficient increases as the liquid level in the flashing chamber increases. This behavior is mainly controlled by two factors: the two phase velocity and the flashing rate. Increasing the liquid level in the flashing chamber will decrease the both two phase velocity and the flashing rate. The decrease in the flashing rate results from the increase in the vapor saturation temperature caused by the increase in the static pressure on the formed bubbles in the sluice gate.

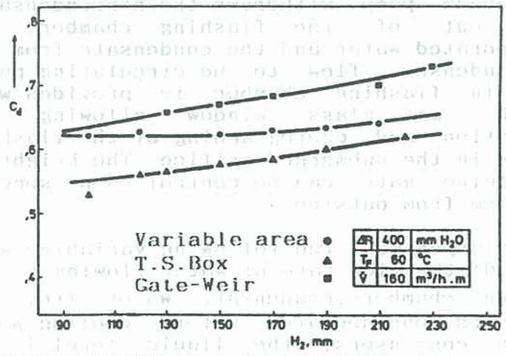


Figure 9: Effect of liquid level on Cd

All Figures show that the Cd of the sluice gate weir type orifice is higher than that of the variable area orifice which is turn is higher than that of the two step flashing box orifice. This can be attributed to the pressure drop in constant areas in the orifices and the change in the flow directions.

The experimental data obtained for the variable area orifice were used to get the following correlation. This correlation relate the orifice discharge coefficient Cd with the different operating parameters.

$$Cd=1.08\{H_2^{0.073}/V^{0.01}\,T_f^{0.03}\,\Delta P_t^{0.11}\}$$

CONCLUSIONS

The following conclusions could be derived from the present investigation, within the experimental range used:

- The discharge coefficient of the three orifices decreases with the total pressure difference between the flashing chambers.
- The discharge coefficient of the three orifices decreases with the increase of the flashing temperature.
- The discharge coefficient of the three orifices increases with the increase of liquid level in the flashing chamber.
- The discharge coefficient of the variable area orifice is nearly constant at different water flow rate. On the other hand, the discharge coefficient for the other two orifices increases with the increase of flow rate.
- The sluice gate height increases linearly with the water flow rate for developed variable area orifice.
- The discharge coefficent of the gate weir orifice is higher than that of the variable area one, which in turn is higher than that of the two step flashing box orifice.

Nomenclature

A	Area	m^2
A_B	Sluice gate area	m^2
b	Flashing chamber width	m
Cd	Orifice discharge coefficient	--
g	Acceleration of gravity	m/s^2
H	Liquid level in the flashing chamber	m
h	flashing chamber height	m
H_B	Sluice gate height	m
l	flashing chamber length	m
M	Mass flow rate	kg/s
P_v	Vapor pressure	mm H_2O
ΔP_t	Total pressure difference	mm H_2O
T_f	Flashing temperature	°C
V	Volumetric flow rate	m^3/s
ρ	Water density	kg/m^3

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