# +CFD Analysis of Segmental Wedge Flowmeter for Sodium Flow Measurement

Jung Yoon [a*], Eui Kwang Kim [a], Jong Man Kim [a], Chung Ho Cho [a], and Ji Young Jeong [a]
[a] *Korea Atomic Energy Research Institute, Fast Reactor Development Div., 1045 Daedeok-daero, Daejeon*
[*] *Corresponding author: jyoon@kaeri.re.kr*

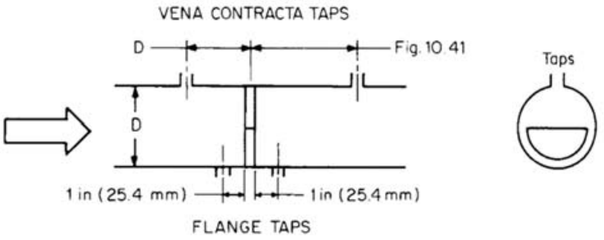
## 1. Introduction

Sodium has a higher boiling point than water, and is present in a liquid state over a wide temperature range. This avoids the risk of phase changes within the temperature range in which most power generation and heat transfer system operate. Therefore, pressurization is unnecessary during operation and high temperature operation is possible. Also, because of its excellent thermal properties, sodium is used as a coolant in many fast reactor.

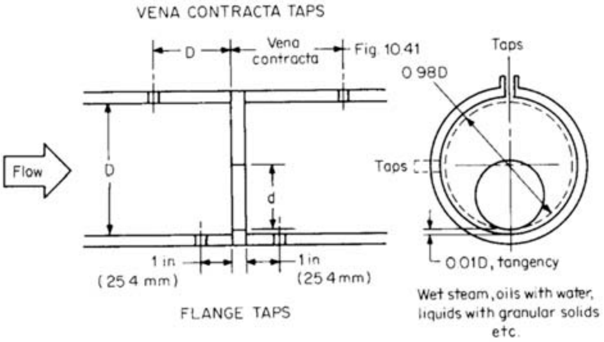
Flow measurement is one of the important factors in understanding the flow of coolant in a reactor. It is very important to measure the sodium flow at high temperature accurately and stably because the sodium coolant has different physical and chemical characteristics compared to other coolants. For this, continuous research and development of liquid sodium flowmeter is needed.

There are various measurement methods for flow according to each application. If the working fluid is sodium, there is a restriction on the use of various conventional flow measurement methods due to the opacity of sodium, and chemical reaction with air and water. Therefore, liquid sodium flow measurement should be selected considering high sensitivity, long term stability, high temperature and corrosion resistance. Typical instruments used to measure the liquid sodium flow include permanent magnet flow meters and electromagnetic flow meters. Among them, the permanent magnet flow meter measures the flow by the electric signal, so the response is very fast and the flow rate can be confirmed at a long distance, so that it can be used at the point where the flow condition of the transition state frequently occurs or the point where the human is not accessible. It eliminates the need for a complicated system due to not only no power source but also the extraordinarily linearity. However, when exposed to a high temperature environment for a long time, uncertainties may increase due to contamination near the electrodes, flow disturbance, and distortion of the magnetic field.

Flow measurement using differential pressure is one of the easiest and most economical methods, and since it has been developed for a long time and is well proven technology, a vast amount of related data is being provided[2]. Especially, representative restriction devices such as orifice, venturi, nozzle, etc. are established international standards[3][4][5][6][7]. Therefore, it is possible to guarantee the accuracy of flow measurement when manufacturing, installing, and operating in accordance with these standards. When there is suspended matter or sediment in the working fluid, or accumulation due to the solidification of the working fluid may occur, the restriction devices such as eccentric orifice, segmental orifice[8], or segmental wedge[9] which can prevent the accumulation of foreign matter can be used. However, the eccentric orifice or segmental orifice has a disadvantage in that the accumulation of foreign matter cannot be completely excluded due to a structure similar to a general orifice as shown in Fig. 1. Therefore, it can be seen that the segment wedge type restriction device is the most suitable for sodium flow measurement.



(a) Segmental orifice



(b) Eccentric orifice

Fig. 1. Geometry of segmental orifice and eccentric orifice

For flow measurement using a restriction device, determination of the discharge coefficient is most important. However, the segmental wedge type restriction device is relatively insufficient in the industry, and the related researches are also lacking. In previous studies, Oguri et al.[10] studied the variation of the discharge coefficient for three types of wedge ratios and two types of wedge angles. Also, Yoon et al.[11] investigated experimentally the discharge coefficient according to the variation of the wedge ratio and the location of pressure tap.

In this study, the variation of the discharge coefficient according to the variation of Reynolds number for various wedge ratio is investigated by using CFD.

## 2. Methods and Results

### *2.1 Principles of the method of measurement*

The principle of the method of measurement is based on the installation of the wedge meter into a pipeline in which a fluid is running full. Flow through a wedge meter produces a differential pressure between the upstream and downstream tapping. The mass flow rate can be determined by the following equation.

$$q_m = \frac{C}{\sqrt{1-\beta^4}}\varepsilon\frac{\pi}{4}(D\beta)^2\sqrt{2\rho_1\Delta p}$$

Where ε is the expansion factor for compressible fluids, C is the discharge coefficient, β is the ratio of the contracted area to the pipe area, D is the diameter of pipe, $\rho_1$ is the density at given temperature, and Δp is the pressure difference between upstream and downstream tapping.

$$\mathrm{C} = \frac{q_m}{q_{theoretical}}$$

And

$$\beta = \sqrt{\frac{A_t}{A}}$$

A larger β corresponds to a larger wedge gap height, h (see Fig. 2), and therefore a larger throat area $A_t$. The value of β can be calculated using the following equation.

$$\beta = \sqrt{\frac{1}{\pi}\left(arccos\left(1-\frac{2h}{D}\right)-2\left(1-\frac{2h}{D}\right)\sqrt{\frac{h}{D}-\left(\frac{h}{D}\right)^2}\right)}$$

Wedge meters can only be used in accordance with this part of ISO/DIS 5167-6 under the below conditions:

- 50mm (2”) ≤ D ≤ 600mm (24”)
- 0.377 ≤ β ≤ 0.791 (0.2 ≤ h/D ≤ 0.6)
- 1.0e4 ≤ Re ≤ 9.0e6

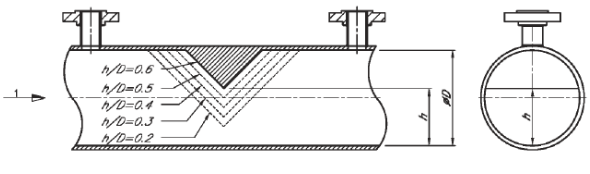


Fig. 2. Wedge meter showing different values of wedge ratio

Under these conditions the value of the discharge coefficient for an uncalibrated meter is:

$$\mathrm{C} = 0.77 - 0.09\beta$$

he pressure loss, $\Delta\bar{w}$, for the wedge meter itself is approximately related to the differential pressure, Δp, by the following equation.

$$\Delta\bar{w} = (1.09 - 0.79\beta)\Delta \mathrm{p}$$

This pressure loss is the difference in static pressure between the pressure measured at the upstream tapping and that measured on the downstream side of the wedge, where the static pressure recovery by expansion of the jet may be considered as just completed (approximately 5D downstream of the centerline of the downstream tapping).

According to Miller[2], the discharge coefficient can be also defined as the Table 1.

Table 1. Discharge coefficient according to line sizes

| Line size (“) | Discharge Coefficient |
|---|---|
| 0.5 | $\mathrm{C} = 0.7883 + 0.107(1-\beta^2)$ |
| 1~1.5 | $\mathrm{C} = 0.6143 + 0.718(1-\beta^2)$ |
| 1.5~24 | $\mathrm{C} = 0.5433 + 0.2453(1-\beta^2)$ |

### *2.2 Geometry & boundary condition for CFD analysis*

The schematic of analysis domain is shown in Fig. 3. The pipe size is 4” SCH 20, the pressure tappings are located at 1D from the end of the wedge to upstream and downstream, and upstream and downstream pipe lengths are 10D for fully developed flow, respectively.

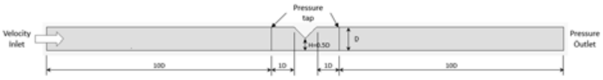


Fig. 3. The schematic of analysis domain

Assumptions for the CFD analysis are shown below. Detailed boundary conditions are also shown in Table 2.

- 3D, steady-state
- Working fluid: Liquid sodium at 250 °C
- Density: 891.97 kg/m$^3$
- Viscosity: 3.89e-4 kg/m-s
- Inlet/outlet: Velocity inlet / pressure outlet

Table 2. Boundary condition at inlet (m/s)

| Re | 2e4 | 5e4 | 1e5 | 2e5 | 3e5 | 4e5 | 5e5 |
|---|---|---|---|---|---|---|---|
| h/D=0.2 | 0.08 | 0.21 | 0.41 | 0.82 | 1.23 | 1.64 | 2.05 |
| h/D=0.3 | | | | | | | |
| h/D=0.4 | | | | | | | |
| h/D=0.5 | | | | | | | |
| h/D=0.6 | | | | | | | |

### *2.3 Selection of mesh level and turbulence model*

A numerical analysis was performed by STAR-CCM+ V11.02.009. Mesh sensitivity test and turbulence model test were performed for h/D=0.5, and Re=1.0e5 to choose the optimal mesh level and turbulence model. The first layer thickness was fixed so that Y+ was constant.

Table 3. Mesh sensitivity test results

| No. of cells | 54,184 | 83,603 | 127,512 | 194,327 | 249,219 | 288,064 | 343,525 |
|---|---|---|---|---|---|---|---|
| dP (Pa) | 434.56 | 446.5 | 448.14 | 447.16 | 448.79 | 448.61 | 449.09 |
| dP/dP_max | 96.76% | 99.42% | 99.79% | 99.57% | 99.93% | 99.89% | 100.00% |
| Y+ | 60.95 | 62.8 | 62.9 | 63.29 | 63.72 | 63.86 | 63.93 |

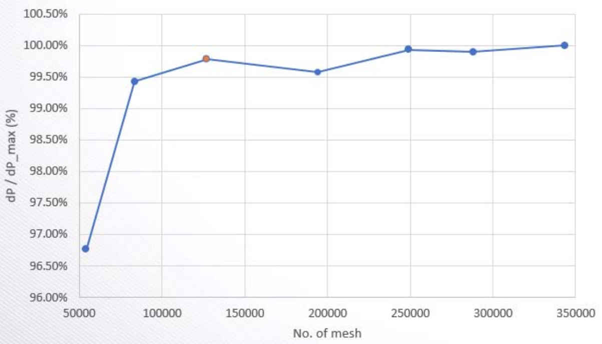


Fig. 4. Mesh sensitivity test results

Table 4. Turbulence model test results

| Turb. Model | k-e real | k-e std | k-w SST | k-w std |
|---|---|---|---|---|
| dP | 435.58 | 403.03 | 448.14 | 439.93 |
| Q_ISO | 3.190408 | 3.068887 | 3.23608 | 3.2062991 |
| Q_miller | 3.007887 | 2.893318 | 3.05095 | 3.0228689 |
| Q_real | 3.247676 | 3.247676 | 3.24768 | 3.2476764 |
| Q_ISO/Q_real | 98.24% | 94.49% | 99.64% | 98.73% |
| Q_miller/Q_real | 92.62% | 89.09% | 93.94% | 93.08% |
| Y+ | 62.45 | 62.41 | 62.9 | 63.53 |

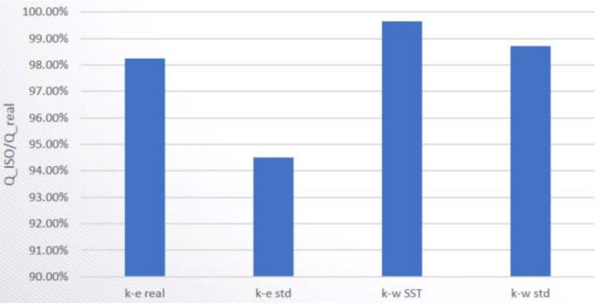


Fig. 5. Turbulence model test results

Table 3 and Fig. 4 show the mesh sensitivity test results. Pressure difference between the upstream and downstream of the wedge is less than 0.5% for most mesh level. Table 4 and Fig. 5 also show the turbulence model test results. Where, Q_ISO and Q_miller are the flow rate calculated by the correlations presented by ISO 5167-6 and Miller, and Q_real is the flow rate calculated using the velocity obtained from a given Reynolds number. Among the various turbulence model, the k-ω SST turbulence model predicts a given flow rate well. Therefore, the selected mesh number and turbulence model through tests are 127,512 and k-ω SST turbulence model.

### *2.4 Results*

A numerical analyses were performed according to the variation of wedge ratio and Reynolds number using the selected mesh number and turbulence model. Fig. 6 shows the variation of the discharge coefficient according to the variation of the Reynolds number and the wedge ratio. According to the correlation of ISO 5167-6 and Miller, the discharge coefficient only depends on the change in h/D. However, it can be seen that the discharge coefficient also changes according to the change of Reynolds number. Fig.7 shows the comparison results of the discharge coefficients between ISO 5167-6 and Miller according to the variation of the wedge ratio, h/D. The discharge coefficients obtained by the CFD results are the average of the results for all Reynolds numbers at the same wedge ratio. These results show that the results of using the correlation of ISO 5167-6 are generally better than those of Miller. However, as h/D becomes smaller, it can be seen that the results of using the correlation of Miller are more and more agreed well.

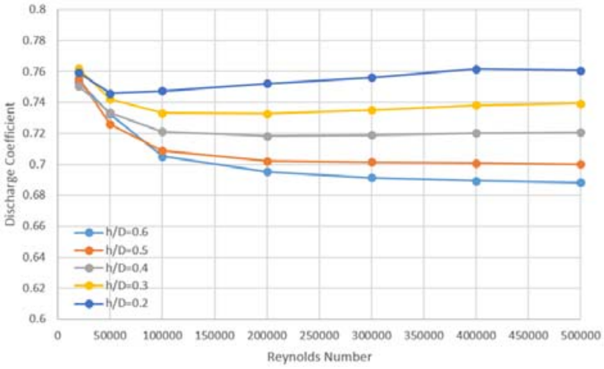


Fig. 6. Variation of the discharge coefficient

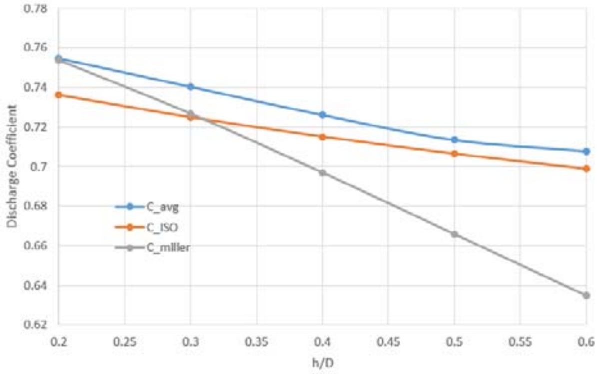


Fig. 7. Comparison of the discharge coefficient between ISO 5167-6 and Miller

## 3. Conclusions

In this paper, the methodology for the flow measurement of the segmental wedge flowmeter was investigated for sodium flow measurement. Also the preliminary CFD analyses of the correlation of the discharge coefficients were performed for various parameters such as wedge ratio and Reynolds number. As a result, it was found that the correlation of ISO 5167-6 was better than that of Miller. These results will be used as the basic data for the evaluation and application of the segmental wedge flowmeter in the future.

## ACKNOWLEGEMENT

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