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Conditioning Orifice Application for Steam Flow Measurement at Lahendong Geothermal Field

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ABSTRACT

Flow measurement is vital for both production and reservoir requirement. Orifice has extensively been used for flow measurement device, due to its cost, simplicity and the accuracy. Typical standard orifice require certain long distances between orifice and major flow disturbances, which might not come in handy in some area. A product called conditioning orifice by Rosemount offers a shorter pipe length requirement thus reducing the material cost. Both orifices were successfully applied in steam flow measurement during well testing at the Lahendong geothermal field with less than 5% deviation on conditioning orifice compare to standard orifice. This paper analyzes the application of conditioning orifice on geothermal steam flow measurements.

1. BASIC THEORY

1.1. Standard Orifice

Fluid flow rate through an orifice can be calculated by the following equation:

$$M = 0{,}03959172 \quad xcxZxexExd^{2}\sqrt{\frac{\Delta P}{\upsilon_g}} \qquad (1)$$

where :

- ✓ M = fluid mass flowrate (tonnes/hour)
- ✓ Z = 1
- ✓ c = coefficient from Fig. 1, 2 and 3 as a function of m, which m = $\left(\frac{d}{D}\right)^2$, d is orifice inner diameters (cm) and D is pipe inner diameters (cm). Both of d and D should be actual value (measurement result instead of nominal value). Just to make it simple, d and D are determined by multiplytheir nominal value with material heat factor.
- ✓ e = expansibility factor, determined from formula as follows :

$$e = 1 - (0.41 - 0.35m^{2})x\frac{1}{k}x\frac{\Delta p}{P_{upstream}} \qquad (2)$$

where k is adiabatic index (1.33 for *saturated steam* and 1.3 for *superheated steam).*

- ✓ E= velocity factor, $E = (1 - m^2)^{-0.5}$
- ✓ ΔP = differential pressure of *upstream* and *downstream*, kscg
- ✓ P_u = upstream pressure, ksc absolute
- ✓ v_g = specific volumeof steam at P_u, m^3/kg

If equation (2) is used to measure brine water flowrate, then e = 1

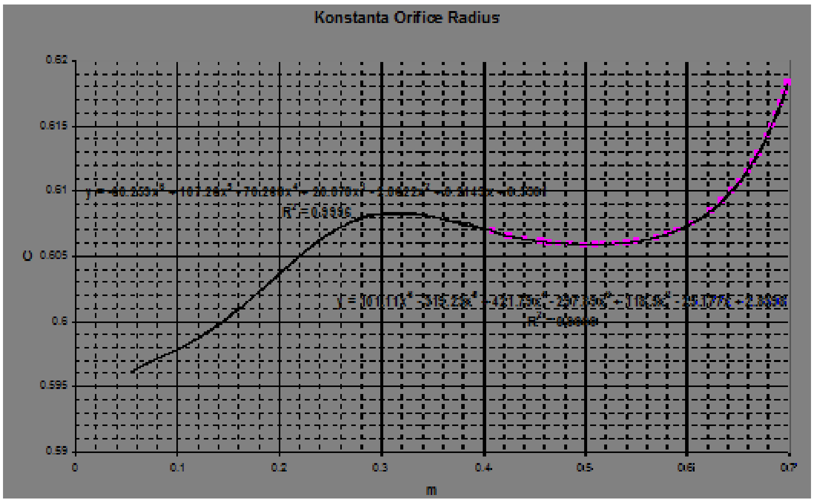

Figure 1 : Radius Tapping Orifice Coefficient (PelatihanSistemPanasBumi ITB-Amoseas)

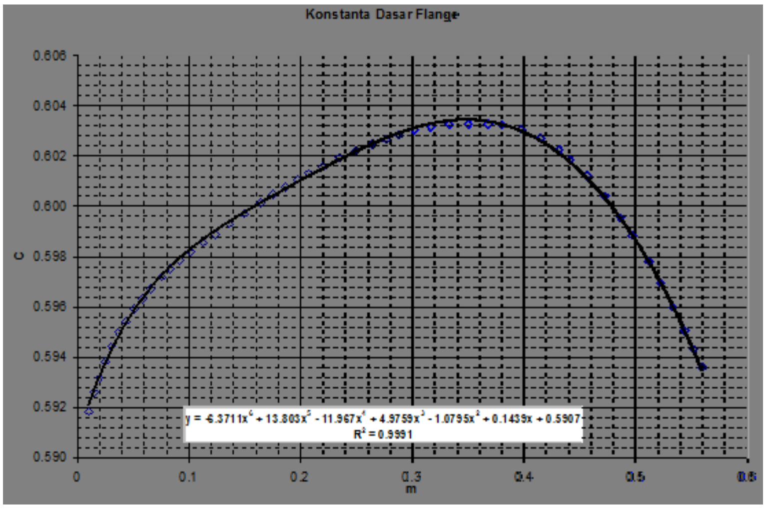

Figure 2 : Flange Tapping Orifice Coefficient (PelatihanSistemPanasBumi ITB-Amoseas)

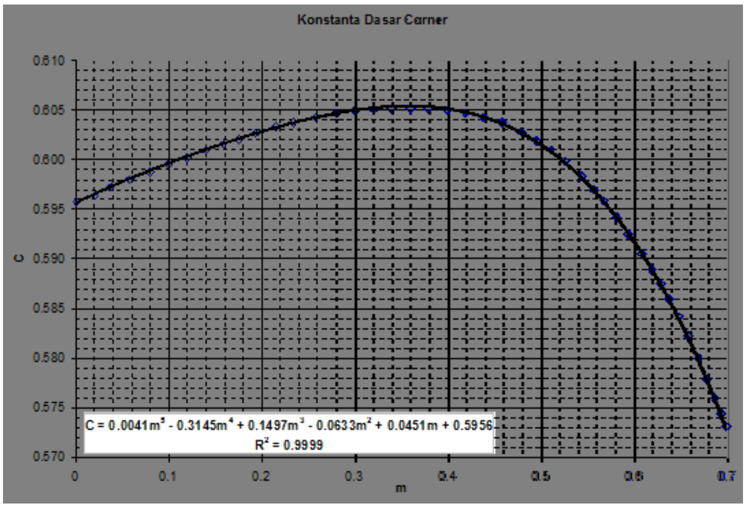

Figure 3 : Corner Tapping Orifice Coefficient (PelatihanSistemPanasBumi ITB-Amoseas)

1.2. Conditioning Orifice

The Rosemount 1595 cconditioning orifice, based on orifice plate technology, is a device used to measure the flow of a liquid, gas, or steam fluid that flows through a pipe. It enables flow measurement by applying a differential pressure (DP) that is proportional to the square of the velocity of the fluid in the pipe, in accordance with Bernoulli's theorem. This DP is measured and converted into a flow rate using a secondary device, such as a DP pressure transmitter.

The relationship of flow and DP has been determined as follows:

$$Q = K\sqrt{\frac{DP}{\rho}} \tag{3}$$

where :

- Q = flowrate
- K = units conversion factor, discharge coefficient, and other factors
- DP = Differential Pressure
- ρ = fluid density

For more complete discussion on the flow equation, refer to as below :

Flow rate Equation (ASME MFC-3M and ISO-5167), US units

$$q_m = 0.09970190 \quad C_c Y_1 d_c^2 \sqrt{\frac{h_w \rho}{1-\beta_c^4}} \tag{4}$$

Reynold Number Equation, US units

$$R_D = \frac{22737.47\, q_m}{\mu P_{ID}} \tag{5}$$

Calculated Bore Size

The calculated bore size is two times the typical hole size (size of one of the four holes)

$$d_c = 2d \tag{6}$$

Beta is calculated using the meter internal diameter and calculated bore diameter

$$\beta_c = \frac{d}{M_{ID}} \tag{7}$$

Thermal Expansion Correlations

$$d = \left[1 + \alpha_{PE}(t - t_{meas})\right] d_{meas} \tag{8}$$

$$M_{ID} = \left[1 + \alpha_{PE}(t - t_{meas})\right] M_{ID\ meas} \tag{9}$$

$$P_{ID} = \left[1 + \alpha_{PE}(t - t_{meas})\right] P_{ID\ meas} \tag{10}$$

Conditioning Orifice 1595 Plate Line Sizes 2 to 24-in. (50.8 to 610 mm)

Discharge Coefficient Equation (ISO-5167)

$$C = 0.5961 + 0.0261\beta_c^2 - 0.216\beta_c^8 + 0.000521\left(\frac{10^6\beta_c}{R_D}\right)^{0.7} + \left(0.0188 + 0.0063\left(\frac{19000\,\beta_c}{R_D}\right)^{0.8}\right)\beta_c^{3.5}\left(\frac{10^6}{R_D}\right)^{0.3} +$$
$$\left(0.043 + 0.080\,e^{-10L_1} - 0.123\,e^{-7L_1}\right)\left(1 - 0.11\left(\frac{19000\,\beta_c}{R_D}\right)^{0.8}\right)\left(\frac{\beta_c^4}{1-\beta_c^4}\right) - 0.031\,(M_2 - 0.8M_2^{1.1})\beta_c^{1.3} \tag{11}$$

where :

$$L_1 = L_2 = \left(\frac{1}{P_{ID}}\right) \tag{12}$$

$$M_2 = \left(\frac{2L_2}{1-\beta_c} \right) \quad (13)$$

Beta is calculated using the pipe internal diameter and calculated bore diameter

$$\beta_c = \frac{d}{P_{ID}} \quad (14)$$

Discharge Coefficient Calibration Factory Adjustment

$$C_c = CF_c \quad (15)$$

Gas Expansion Factor (ISO-5167) Equation

$$Y1 = 1 - (0.351 + 0.256\,\beta_c^{\,4} + 0.93\,\beta_c^{\,8}) \left[1 - \left(1 - \frac{h_w}{27.73\,P_1} \right)^{\frac{1}{k}} \right] \quad (16)$$

where :

- C = Discharge Coefficient
- C_C = Discharge Coefficient corrected by calibration factor
- d = Bore Diameter corrected for thermal expansion (inches [US units], m [SI units])
- d_c = Calculated Bore Diameter (inches [US units], m [SI units])
- d_{meas} = Measured typical orifice bore diameter (assumed to be 68°F). See Table 1 or 2. (inches [US units], m [SI units])
- F_C = Calibration factor (0.750 < Fc < 1.250)
- F_S = Pipe schedule adjustment factor
- h_w = Differential pressure (inwc [US units], Pa[SI units])
- ΔP = Differential pressure (inwc [US units], Pa [SI units])
- M_{ID} = Meter internal diameter corrected for thermal expansion (inches [US units], m [SI units])
- M_{IDmeas} = Meter internal ID (assumed to be 68 °F) See Table 1. (inches [US units], m [SI units])
- P_{ID} = Pipe internal diameter corrected for thermal expansion (inches [US units], m [SI units])
- P_{IDmeas} = Measured ID (assumed to be 68 °F) (inches [US units], m [SI units])
- P_1 = Upstream static pressure (PSI [US units], Pa [SI units])
- P_2 = Downstream static pressure (PSI [US units], Pa [SI units])
- q_m = Mass flow rate (in lbm/s [US units] or kg/s [SI units], a conversion factor must be applied to other units)
- R_D = Pipe Reynolds number
- t = Process temperature (°F [US units], °C [SI units])
- t_{meas} = Temperature at bore / pipe ID measurement (assumed to be 68 °F) (°F [US units], °C [SI units])
- Y_1 = Gas expansion factor
- α_P = Thermal expansion factor of the pipe (in./in./°F [US units], m/m/°C [SI units])
- α_{PE} = Thermal expansion factor of the primary element (in./in./°F [US units], m/m/°C [SI units])
- β_c = Beta ratio using calculated bore diameter
- ε_1 = Gas expansion factor
- κ = Isentropic exponent
- μ = Viscosity (cP [US units], Pa-s [SI units])

- ρ = Density (lbm/ft^3 [US units])
- ρ_{F1} = Density (kg/m^3 [SI units])

1.3.Comparison conditioning and standard orifice

Table 1 describe a comparison between conditioning orifice plate technology and standard orifice plate technology, highlighting the deviations from the standards. These deviations allow for more flexible installation as straight pipe requirements are reduced in some cases by as much as 96%.

Table 1 :ConditioningOrificePlate as Compared to OrificePlate Standards (Conditioning OrificeTechnicalNote – Rosemount 2004)

Category	1595 and 405C Conditioning Orifice Plate Technology			
Total Straight Pipe Run Requirements	**1595 and 405C**	**ASME MFC 3M**	**AGA Report Number 3**	**ISO 5167**
Upstream (In Pipe Diameters)	2	Up to 54	Up to 95	Up to 60
Downstream (In Pipe Diameters)	2	5	4.2	7
Flow Conditioners	Not Required. All three standards sometimes require flow conditioners to shorten required straight pipe run.			
Pressure Taps				
Flange Taps	Complies with all three standards.			
Corner Taps	Complies with ASME and ISO. Corner taps not included in AGA Report Number 3.			
D and D/2	In development.			
O-Plate Thickness				
2" to 4"	Complies with all three Standards.			
6"	Compliant to ASME MFC 3M and ISO 5167. Thicker than AGA Report Number 3.			
8" to 24"	Complies with all three Standards.			
Beta	Area of 4 holes = Area of same ß for standard orifice of all three standards. (1)			
All other plate dimensions (Including angle of bevel, bore thickness (e), etc.)	Complies with all three Standards.			
Surface Finish	Complies with all three Standards.			
Discharge Coefficient Uncertainty	Follows ISO 5167. (2)			
Expansion Factor	Follows ISO 5167.			

(1) At Schedule Standard
(2) Follows ISO 5167 with a bias shift – The bias is determined in a calibration flow lab and factored into the DP bore calculation.

Figure 4 : Comparison of Standard and Conditioning Orifice (Conditioning OrificeTechnicalNote – Rosemount 2004)

1.4.The advantages of conditioning orifice

The conditioning orifice plate is a revolutionary innovative technology based on the most common differential primary element in the industry. While not complying with the standards of AGA Report Number 3, ASME MFC 3M or ISO 5167, it is designed based on those standards and provides superior performance in short straight pipe run, tight fit applications with upstream flow disturbances.

- ✓ Requires 2 diameters upstream of a flow disturbance and 2 diameters downstream.
  - Shorter pipe length requirement resulting in lower material cost.
  - Provides flexibility of flowmeter placement and design
- ✓ Compact design reduces installation costs as compared to standard orifice plates.
- ✓ Highly accurate and repeatable primary elements
- ✓ With only two betas to choose, one for high flows, one for low flows, simplify when ordering and storing
- ✓ Suitable for most gas, liquid and steam applications

Table 2 :Straight Pipe Requirement in PipeDiameters (Conditioning OrificeTechnicalNote – Rosemount 2004)

	Beta = 0.4	Conditioning Orifice Plate	ASME MFC 3M	AGA Report Number 3	ISO 5167
Upstream	Single 90 Degree Bend	2	14 *86%*	16 *88%*	16 *88%*
	Single Tee	2	14 *86%*	9 *78%*	9 *78%*
	Two or more Bends in the same plane	2	18 **(17)** *89%* ***(88%)***	10 *80%*	10 *80%*
	Two or more Bends in a different plane	2	36 **(19)** *94%* ***(89%)***	50 **(29)** *96%* ***(93%)***	50 **(30)** *96%* ***(93%)***
	Reducer	2	10 *80%*	6 *67%*	5 *60%*
	Valve	2	12 *83%*	21 *90%*	12 *83%*
Downstream		2	5 *60%*	3.2 *38%*	6 *67%*

	Beta = 0.65	Conditioning Orifice Plate	ASME MFC 3M	AGA Report Number 3 [(1)]	ISO 5167 [(1)]
Upstream	Single 90 Degree Bend	2	22 *91%*	44 **(29)** *95%* ***(93%)***	44 **(30)** *95%* ***(93%)***
	Single Tee	2	22 *91%*	44 **(29)** *95%* ***(93%)***	36 **(30)** *94%* ***(93%)***
	Two or more Bends in the same plane	2	32 **(22)** *94%* ***(91%)***	44 **(29)** *95%* ***(93%)***	44 **(30)** *95%* ***(93%)***
	Two or more Bends in a different plane	2	54 **(25)** *96%* ***(92%)***	95 **(29)** *98%* ***(93%)***	60 **(30)** *97%* ***(93%)***
	Reducer	2	12 *83%*	11 *82%*	12 *83%*
	Valve	2	16 *88%*	35 **(29)** *94%* ***(93%)***	18 *89%*
Downstream		2	5 *60%*	4.2 *48%*	7 *71%*

[(1)]The piping requirements specified are for Beta = 0.67.

Note :

- The values in *Italics* reflect the reduction in straight pipe requirements.
- The values in **(Bold)** reflect the piping requirements if a 19-tube bundle flow straightener is used.

The above statement can be illustrated by the Figure below :

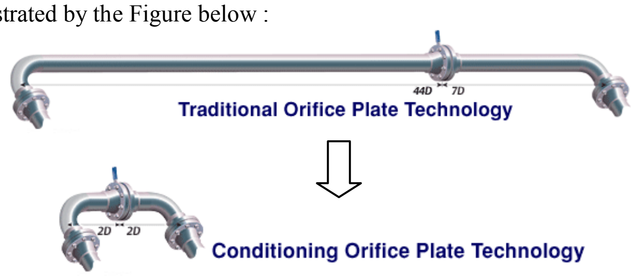

Figure 5: Reduction in Pipe LengthRequirements of ConditioningOrifice (Rosemount Website – ConditioningOrificePlate Technology)

Figure 6 : Total InstalledCostSavings (Rosemount Website – ConditioningOrificePlate Technology)

2. RESULT

Conditoning orifice by Rosemount was applied in production well testing at Lahendong Geothermal Field, especially for LHD-A and LHD-B to measure steam flowing out of separator. The result was compared with the standard orifice measurement. Both orifice types were installed at a steam pipeline 14” outlet separator with different line and different straight pipe requirement as mentioned aboved. Conditioning Orifice used ß of 0.65 because Reynold Number in Lahendong geothermal application more than 10,000.

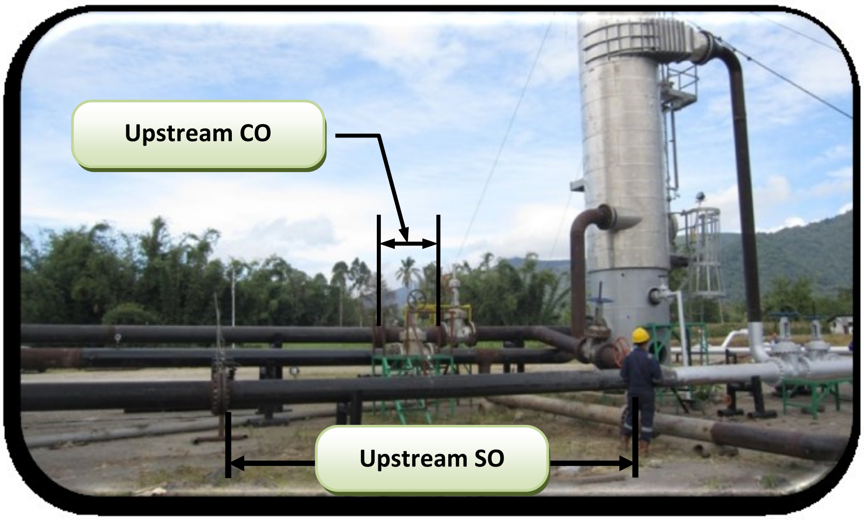

Figure 7: Steam Pipelinefor Both Standard and ConditioningOrifice atLahendongGeothermal Field

Based on production well testing by Separator method appliedat well LHD-A and LHD-B of Cluster-X Lahendong geothermal field, here the data result.

Table 3 : Results of Steam Flowrate by Standard Orifice and Conditioning Orifice LHD-A

WELL	WHP (Kscg)	Steam flowrate (Ton/h)		% ε
		SO	CO	
LHD-A	20.00	16.37	15.62	4.56
	19.00	21.59	21.56	0.14
	18.00	26.22	26.68	1.75
	17.00	30.25	30.97	2.38
	16.00	33.69	34.45	2.24
	15.00	36.54	37.10	1.55
	14.00	38.79	38.94	0.38
	13.00	40.46	39.96	1.23
	12.00	41.53	40.16	3.30

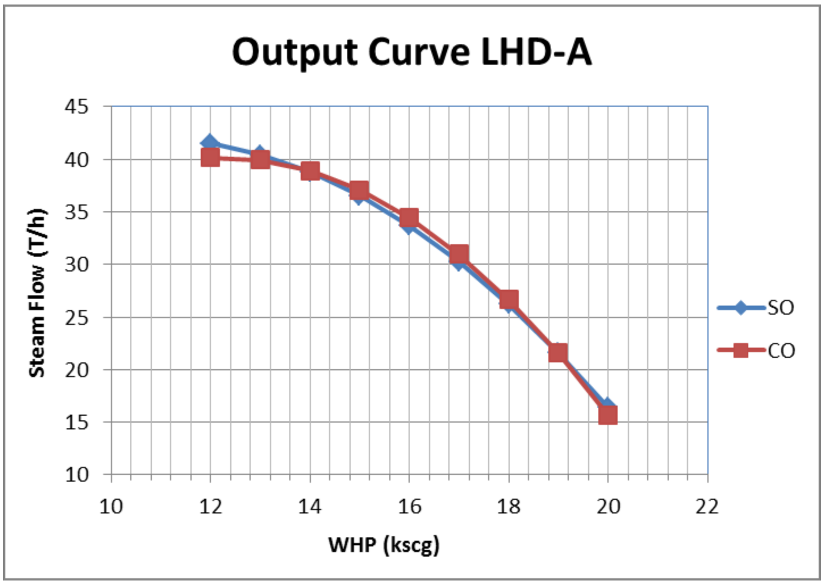

Figure 7: Output Curve LHD-A by Standard Orifice and Conditioning Orifice

Table 4: Calculation Result of Steam Flowrate by Standard Orifice and Conditioning Orifice LHD-B

WELL	WHP (Kscg)	Steam flowrate (Ton/h)		% Ɛ
		SO	CO	
LHD-B	34.00	28.67	27.24	4.98
	33.00	37.76	37.21	1.47
	32.00	46.10	46.26	0.34
	31.00	53.69	54.40	1.31
	30.00	60.54	61.62	1.80
	29.00	66.63	67.94	1.96
	28.00	71.97	73.34	1.90
	27.00	76.56	77.82	1.64
	26.00	80.41	81.39	1.23
	25.00	83.50	84.05	0.67
	24.00	85.84	85.80	0.05
	23.00	87.43	86.63	0.92
	22.00	88.28	86.55	1.95
	21.00	88.37	85.56	3.18

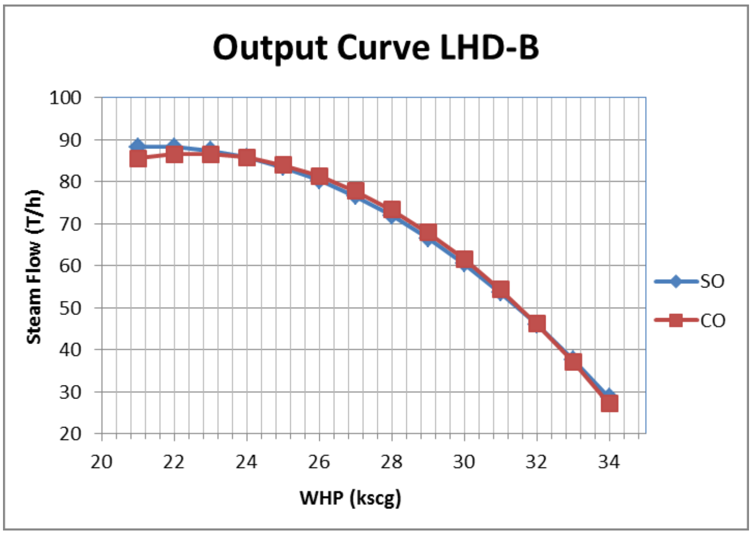

Figure 8 : Output Curve LHD-B by standard orifice and conditioning orifice

Reduction on cost due to conditioning orifice application in steam flow measurement are given below

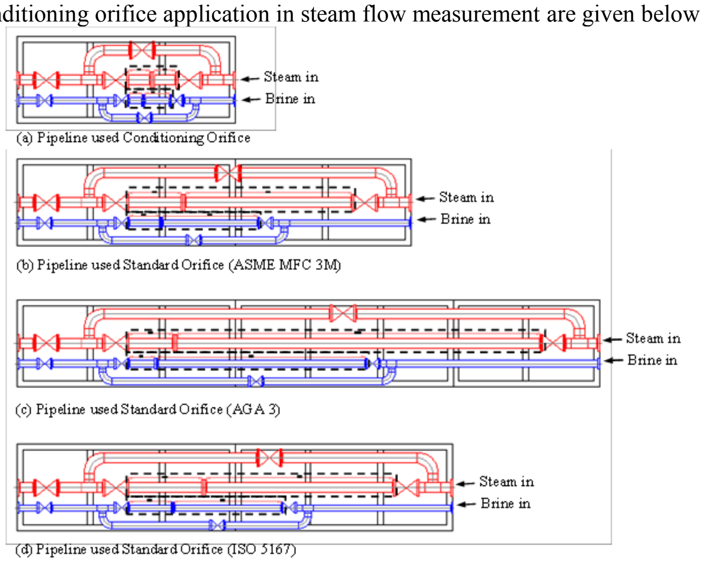

Figure 9: Comparison of Pipeline Used for Conditioning Orifice and Standard Orifice

Table 5 : Material Efficiency Result by Conditioning Orifice Compared with Standard Orifice

NO	POINT OF EFFICIENCY	CONDITIONING ORIFICE		ASME			AGA 3			ISO 5167		
		x Pipe ID	Actual (mm)	x Pipe ID	Actual (mm)	Ɛ (%)	x Pipe ID	Actual (mm)	Ɛ (%)	x Pipe ID	Actual (mm)	Ɛ (%)
1	**Straight Pipe Requirement (Upstream), after**											
	- Single 90° Bend	2	712	22	7832	90.91	44	15664	95.45	44	15664	95.45
	- Single Tee	2	712	22	7832	90.91	44	15664	95.45	36	12816	94.44
	- Two or more bend in same plane	2	712	32	11392	93.75	44	15664	95.45	44	15664	95.45
	- Two or more bend in different plane	2	712	54	19224	96.30	95	33820	97.89	60	21360	96.67
	- Reducer	2	712	12	4272	83.33	11	3916	81.82	12	4272	83.33
	- Valve (actual)	2	712	16	5696	87.50	35	12460	94.29	18	6408	88.89
2	**Straight Pipe Requirement (Downstream)**	2	712	5	1780	60.00	4.2	1495.2	52.38	7	2492	71.43

Table 6: Cost EfficiencyResult by Conditioning Orifice Compared with Standard Orifice

NO	POINT OF EFFICIENCY	CONDITIONING ORIFICE	ASME		AGA 3		ISO 5167	
		Cost (IDR) Total	Cost (IDR) Total	Ɛ (%)	Cost (IDR) Total	Ɛ (%)	Cost (IDR) Total	Ɛ (%)
1	**Straight Pipe Requirement (Upstream), after**							
	- Single 90° Bend	10,641,814	88,759,952	88.01	175,594,904	93.94	175,594,904	93.94
	- Single Tee	10,641,814	88,759,952	88.01	175,594,904	93.94	144,627,649	92.64
	- Two or more bend in same plane	10,641,814	127,469,021	91.65	175,594,904	93.94	175,594,904	93.94
	- Two or more bend in different plane	10,641,814	213,603,973	95.02	373,986,156	97.15	237,529,414	95.52
	- Reducer	10,641,814	50,050,883	78.74	46,879,976	77.30	50,750,883	79.03
	- Valve (actual)	10,641,814	65,534,510	83.76	140,756,742	92.44	73,976,324	85.61
2	**Straight Pipe Requirement (Downstream)**	10,641,814	22,954,535	53.64	20,557,809	48.23	31,396,348	66.10

3. CONCLUSION

Conditioning orifice by Rosemount as new orifice innovation technology has a good accuracy in steam flow measurement, as shown by well testing of well LHD-A and LHD-B Cluster-X at Lahendong geothermal field. Moreover, Conditioning orifice also offers many advantages in cost and material efficiency. Based on those, that it is worthy to apply this new technology for steam flow measurement especially in Pertamina Geothermal fields in Indonesia.

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