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EVALUATION OF WEIRS CALCULATION TO ESTIMATE WELL CAPACITY: A NUMERICAL STUDY

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ABSTRACT

To assess a two-phase well capacity in early well testing stage, James Lip Pressure for horizontal discharge is generally applied. The objective of the measurement is to calculate total mass flow rate and enthalpy in order to estimate well capacity. During measurement, two-phase fluid from well is directed horizontally to silencer (atmospheric separator) and water flow rate measured by weir. Simplified weir formula is commonly used for field application rather than the original equation proposed by Kindsvater and Carter (1957). Different equations to calculate water flow rates will lead to different result, therefore it affects calculated total mass flow and enthalpy which represent well capacity. How significant simplified weir calculation for well capacity estimation and comparison of water flow rate calculation between simplified weir calculation and original weir calculation are compared. The result showed, calculation using simplified equation for trapezoidal weir has the biggest error compared to other simplified weir equations, while simplified equation for V-notch has the smallest error.

INTRODUCTION

For highly productive two-phase geothermal wells, the most versatile and economical method of testing is James Lip Pressure. In this method, two-phase fluid from well is directed horizontally to silencer (atmospheric separator). The pressure is measured at an extreme end of the discharge pipe using gauge and separated water flow from the silencer is measured using weir near the silencer outlet.

A measuring weir is simply an overflow structure built perpendicular to an open channel axis to measure the water flow rate. Weirs are commonly classified by the shape of their blade overflow opening shape or control section shape such as rectangular, trapezoidal (Cipolletti) and triangular (V-notch) as shown in Figure 1. Each weir has its own equation to calculate water flow rate within specific water flow rate range in its field application. Simplified weir formula is commonly used for field application rather than the original equation.

To give an idea how significant calculation result is, calculated water flow rate using simplified weir equation and original weir equation are compared. The calculation results and synthetic data then used as inputs in James Lip Pressure calculation to estimate well capacity.

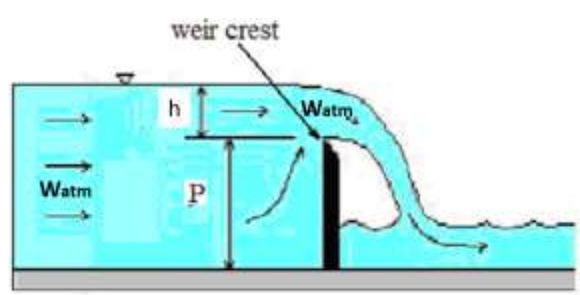

Figure 1. Longitudinal Section, Flow Over a Sharp-crested Weir[1]

WEIRS

Contracted Rectangular Weir

The contracted rectangular weir has a rectangular opening where the sides are straight up and down as shown in Figure 2. The design is good for measuring high water flow rates. The general equation for water flow rate calculation is shown in Equation (1):

$$W_{atm} = \frac{2}{3}\sqrt{2g} * C_e * (k_b + l) * (h_u + 0.0001)^{1.5} * \rho \quad (1)$$

Where :

Watm : Water Mass Rate (kg/s)
C_e : Effective Free Flow discharge coefficient ($m^{0.5}$)
l : Effective Width of Weir (m)
h_u : Head Water Measurement (m)
k_b : Width Correction (m)
g : Gravity Force (m/s^2)
ρ : Fluid Density (kg/m^3)
h_u : Max head water (m)

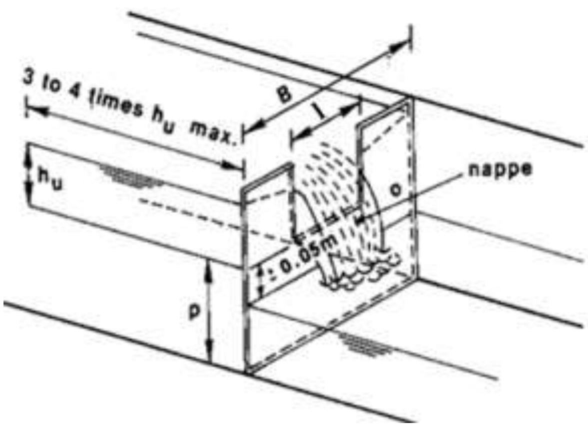

Figure 2: Basic definition sketch of the rectangular and trapezoidal weir (after Bos, 1976)

The effective coefficient of discharge (C_e), is a function of relative depth ($\frac{hu}{P}$) and relative width (l/B), of approach channel.

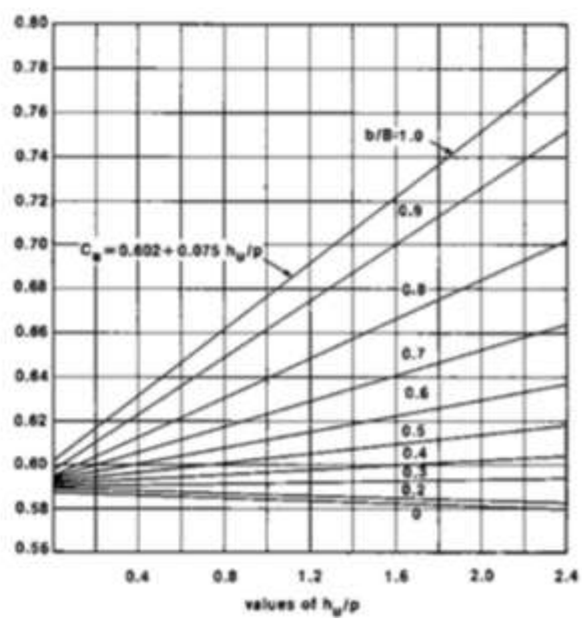

Figure 3. Definition of the C_e coefficient for rectangular thin-plate weir (Kindsvater and Carter, 1957)

$$C_e = C_1 * \frac{h}{P} + C_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (2)$$

Where,

$$C_1 = 0.11094 * \left(\frac{l}{B}\right)^2 - 0.03431 * \frac{l}{B} + 0.00087 \dots\ (3)$$

and,

$$C_2 = -1.40857 * \left(\frac{l}{B}\right)^6 + 4.52970 * \left(\frac{l}{B}\right)^5 - 5.56108 * \left(\frac{l}{B}\right)^4 + 3.26748 * \left(\frac{l}{B}\right)^3 - 0.93778 * \left(\frac{l}{B}\right)^2 + 0.13008 * \frac{l}{B} + 0.58227 \dots\dots\dots\dots\dots\dots\dots\dots\dots . . \dots (4)$$

Width correction (k_b) is correction factor of crest width to weir width. The correction factor follows diagram as shown in Figure 4.

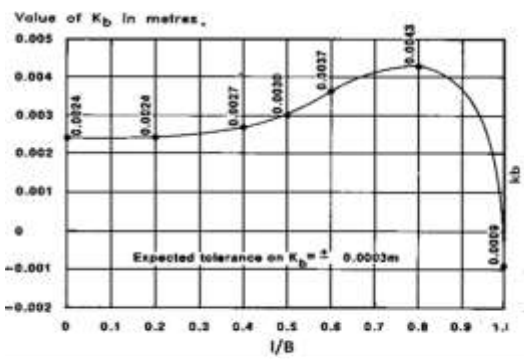

Figure 4. Width correction (K_b) (Kindsvater and Carter, 1957)

For $0 \le l/B \le 0.5$

$$k_b = 0.01466 * \left(\frac{l}{B}\right)^2 - 0.00358 * \left(\frac{l}{B}\right) + 0.00798 \dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots\ (5)$$

For $0.5 < l/B \le 0.8$

$$k_b = -0.03034 * \left(\frac{l}{B}\right)^2 + 0.05438 * \left(\frac{l}{B}\right) - 0.00994 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (6)$$

For $0.8 < l/B \le 1$

$$k_b = -23.573 * \left(\frac{l}{B}\right)^4 + 82.192 * \left(\frac{l}{B}\right)^3 - 107.62 * \left(\frac{l}{B}\right)^2 + 62.693 * \left(\frac{l}{B}\right) - 13.69 \dots\dots (7)$$

However, in field application, simplified equation of rectangular weir is commonly used. Equation (8) is obtained by assuming C_e = 0.588 $m^{0.5}$ and water temperature 98°C, while k_b value is ignored.

$$W_{atm} = 6000 * l * h^{1.5} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots (8)$$

Trapezoidal (Cipolletti) Weir

The trapezoidal or cipolletti weir is similar to a rectangular weir except the sides of the trapezoidal opening as shown in Figure 5. The design is good for measuring medium water flow rates.

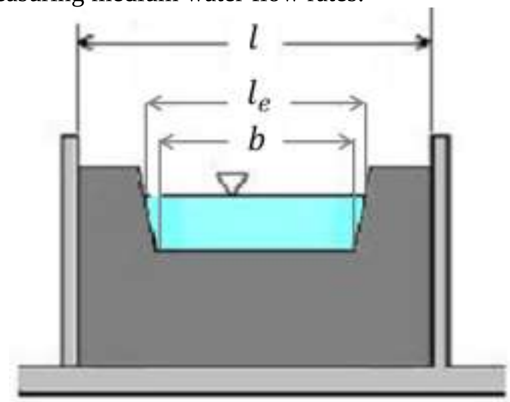

Figure 5. Trapezoidal (Cipolleti weir) sketch (Shen, 1960)

The general equation for water flow rate calculation is same as rectangular (Eq. 1) except the l factor should be corrected to *h* by the following equation.

$$l_e = \frac{\frac{h_u}{h_{u\,max}} * (l - b) + 2b}{2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (9)$$

In field application, the simplified equation for trapezoidal weir sligthly the same as rectangular weir.

$$W_{atm} = 6290 * l * h^{1.5} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (10)$$

Equation (10) is obtained by assuming C_e = 0.616 $m^{0.5}$ and water temperature 98°C, while k_b value is ignored.

V-notch Weir

The V-notch weir design is good to measure low water flow rates. The designed angle could range from 20° – 100°. For standard application, 90° V-notch is commonly used as shown in Figure 6. The general equation for water flow rate calculation at any angle is:

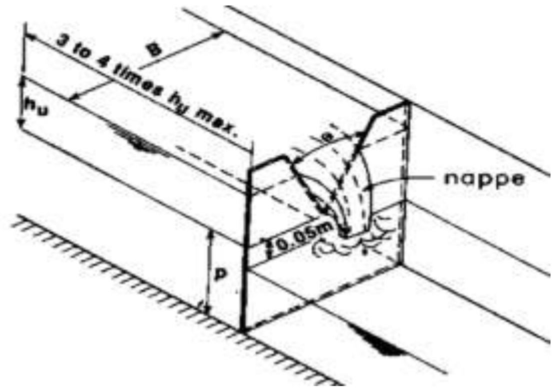

Figure 6. Definition sketch of the V-notch weir (after Bos, 1976)

$$W_{atm} = \frac{8}{15}\sqrt{2g} * \frac{\theta}{2} * C_e * (h_u + k_h)^{2.5} * \rho \dots\dots\dots\dots (11)$$

Where :

- W_{atm} : Water Mass Rate (kg/s)
- C_e : Effective Free Flow discharge coefficient ($m^{0.5}$)
- h_u : Water Head Measurement (m)
- k_h : Head Correction(m)
- θ : Central Angle of V-notch(m)
- g : The Gravity Force (m/s^2)

The effective discharge coefficient (C_e), and the head correction (k_h), both are functions of notch angle (θ).

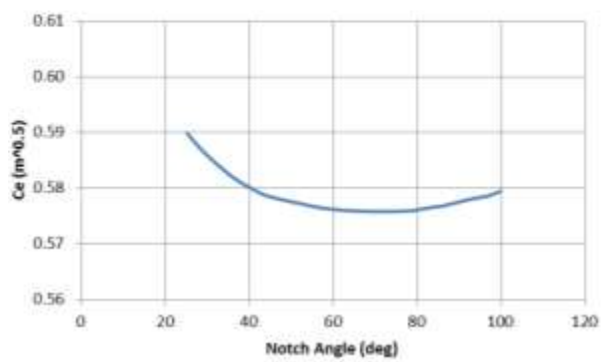

Figure 7. Effective Discharge Factor (C_e), for V-notch weirs (Shen, 1960)

$$C_e = 1.543x10^{-9} * \theta^4 - 4.535x10^{-7} * \theta^3 + 5.294x10^{-5} * \theta^2 - 2.855x10^{-3} * \theta + 6.348x10^{-1} \dots\dots\dots\dots (12)$$

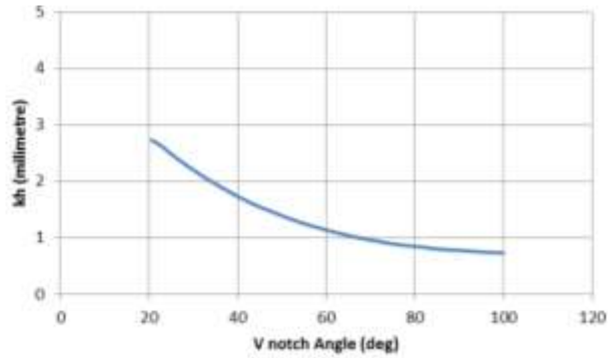

Figure 8. Head correction factor, K_h, for V-notch weirs (Shen, 1960)

$$k_h = 0.0004 * \theta^2 - 0.071 * \theta + 3.984 \ldots\ldots\ldots\ldots\ldots..(13)$$

In field application, the simplified equation is commonly used by assuming C_e = 0.578 $m^{0.5}$ and water temperature 98°C, while k_h value is ignored. It should be noted that the simplified equation is only applied for notch angle (θ) = 90°.

$$W_{atm} = 4720 * h^{2.5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots(14)$$

James Lip Pressure Method

James Lip Pressure method correlates total mass flow rate to enthalpy, cross-sectional area of tube, and lip pressure. Total mass flow rate is related to water flow rate measured in weirbox. As water flow rate measured at atmospheric condition, to convert to separation condition it needs to apply flash correction factor. Common procedure to obtain total mass flow rate (M) and flowing enthalpy (H) using horizontal lip pressure method is as follows.

1. Calculate flowing enthalpy (H) by equation:

$$H = \frac{H_{g\,atm} + 925 * Y}{1 + 7.85 * Y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots(15)$$

2. Calculate Total Mass Flow Rate (M) by equation:

$$M = \frac{W_{atm} * (H_{g\,atm} - H_{l\,atm})}{H_{g\,atm} - H} \ldots\ldots\ldots\ldots\ldots..(16)$$

Where Y variable is calculated by:

$$Y = \frac{W_{atm}}{A * p_{lip}^{0.96}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(17)$$

$H_{g\,atm}$	:	Vapor Enthalpy at atmospheric condition	(kJ/kg)
$H_{l\,atm}$	:	Liquid Enthalpy at atmospheric condition	(kJ/kg)
H	:	Flowing Enthalpy	(kJ/kg)
W_{atm}	:	Water Mass Rate over weir	(ton/hr)
P_{lip}	:	Lip Pressure	(bara)
M	:	Total Mass Flow Rate	(ton/hr)
A	:	Lip pipe cross-sectional area	(cm^2)

NUMERICAL ANALYSIS

The comparison between original and simplified equation are presented in this section. The objective of this comparison is to give an idea how significant simplified equation is regarding to the calculation result. The parameters are given in Table 1 below.

Calculation result of rectangular weir using original and simplified equation, and error is shown in Figure 9. At small head value or water rate less than 100 kg/s, the error is relatively small (<5%). The higher head value leads to greater error. The error generated by C_e value which is assumed to be constant, whereas C_e must not constant depends on measured head and weir size. In field application, the simplified equation is only applicable for criteria l/B < 0.5 and $\frac{hu}{P}$ <1.

Table 1: Weirs parameters used for numerical calculation

Parameter	Rectangular	Trapezoidal	V-notch
B (m)	1	1	1
h (m)	1	1	1
p (m)	0.3	0.3	-
l (m)	0.8	0.8	-
b (m)	-	0.4	-
θ (deg)	-	-	90
Temp (degC)	98	98	98

Trapezoidal weir calculation result is shown in Figure 10. The error as a result of simplified equation is quite high when head value more than 20 cm or water flow rate more than 50 kg/s. Compare with rectangular calculation, the error value is higher since head value (h_u) and effective length (l_e) value are not constant on its original equation. In field application, the simplified equation is applicable for criteria $0.4 < l/B < 0.7$ and $\frac{hu}{P}$ < 0.8.

Figure 11 shows calculation result of 90° V-notch. The error goes smaller as higher measured head value. C_e value is only function of notch angle (θ), therefore weir sizing and measured head affects nothing to the calculation result. Although the simplified equation gives same result as original one, the simplified equation must not be used if notch angle $\theta \neq 90^o$.

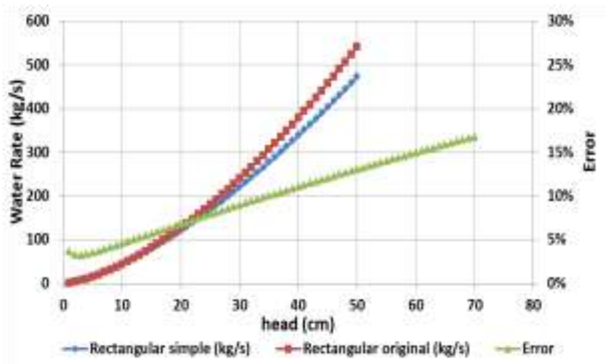

Figure 9. Calculation result of Rectangular Weir

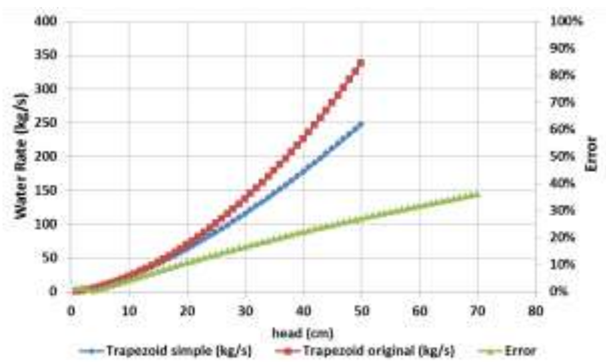

Figure 10. Calculation result of Trapezoidal Weir

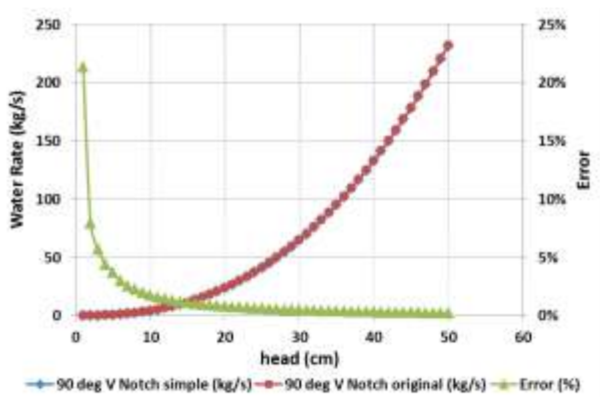

Figure 11. Calculation result of 90^o V- notch Weir

FIELD APPLICATION

The original and simplified weir equations are used as input to calculate generation capacity using James Lip Pressure method. The synthetic data for calculation is presented in Table 2. The objective of this calculation is to give an idea how significant error generated by simplified equation to the estimated generation capacity of a well.

Table 2: Synthetic data for generation capacity calculation

P_{atm}	1	bara
ID_{lip}	10	in
P_{lip}	50	psia
Pseparator	12	bara
$h_{rectangular\ weir}$	15	cm
$h_{trapezoidal\ weir}$	22	cm
$h_{90^o\ V\text{-}notch}$	33	cm

Generation capacity calculation is done by using parameters in Table 1, Equation (15), Equation (16) and Equation (17). The result is shown in Table 3.

Calculation using simplified equation for trapezoidal weir leads the biggest error among other simplified weir equations while simplified equation for V-notch has smallest error. It is clearly seen that calculated error in water flow rate calculation using simplified equation is proportional with error in estimated generation capacity.

Table 3: Generation capacity calculation

		Simplified Equation	**Original Equation**	**Error**
h (cm)	Rectangular	15.00	15.00	-
	Trapezoidal	22.00	22.00	
	90^o V-notch	33.00	33.00	
W_{atm} (kg/s)	**Rectangular**	**77.46**	**82.05**	**5.6%**
	Trapezoidal	**72.12**	**81.74**	**11.8%**
	90^o V-notch	**82.02**	**82.37**	**0.4%**
H (kJ/kg)	Rectangular	1221.77	1185.78	3.0%
	Trapezoidal	1266.80	1188.12	6.6%
	90^o V-notch	1186.02	1183.38	0.2%
Total Mass (kg/s)	Rectangular	120.36	124.41	3.3%
	Trapezoidal	115.64	124.14	6.8%
	90^o V-notch	124.38	124.69	0.2%
Estimated MW @ 12 bar	**Rectangular**	**12.84**	**12.14**	**5.7%**
	Trapezoidal	**13.65**	**12.19**	**12.0%**
	90^o V-notch	**12.15**	**12.10**	**0.4%**

CONCLUSIONS

1. Simplified equation for rectangular weir is applicable for criteria $l/B < 0.5$ and $h/P < 1$.
2. Simplified equation for trapezoidal weir is applicable for criteria $0.4 < l/B < 0.7$ and $h/P <$

0.8.

3. Simplified equation for V-notch is applicable if notch angle $\theta = 90^o$.
4. Simplified equation for trapezoidal weir leads the biggest error among other simplified weirs.
5. Calculated error in water flow rate calculation using simplified equation is proportional with error in estimated generation capacity.
6. The use of original equations are strongly suggested to minimize error since the calculation result will be used for James lip calculation to estimate well capacity.

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REFERENCES

Bengtson, Harlan H. Sharp Crested Weirs for Open Channel Flow Measurement. *Continuing Education and Development*. New York.

Bos, M. G., ed. (1976). "Discharge measurement structures." Publ. No. 161, *Delft Hydr.*, The Netherlands.

Grant, M.A. and Bixley, P. F. 2011. Geothermal Reservoir Engineering – Second Edition. *Elsevier.Inc*, 131-169.

Kindsvater, C.E. and R.W.C. Carter. 1957. Discharge Characteristics of Rectangular Thin-Plate Weirs. Journal of the Hydraulics Division, *Proceedings of the American Society of Civil Engineers, Vol. 83, No. HY6. Paper 1453.*

Saptadji, Nenny M. Teknik Panasbumi. *Departemen Teknik Perminyakan, Institut Teknologi Bandung.*

Shen, J.A., "Preliminary Report on the Discharge Characteristics of Trapezoidal-Notch Thin-Plate Weirs," July, 1959. *U.S. Geological Survey*.

United States Department of the Interior Bureau of Reclamation. Revised Reprint 2001. Water Measurement Manual. *http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm*