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Evaluation of James Lip Pressure Method for Low Flow Rate Geothermal Well: ML-5 Case Study

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ABSTRACT

Currently, there are six exploration wells in Muara Laboh field. One well where the James lip pressure method has been applied is ML-5. The interesting feature of this well is the low flow rate characteristic that has been demonstrated after drilling. This feature is suspected to have influenced the accuracy of James lip pressure method.

Beside James lip pressure method, other intensive well testing surveys had been conducted at ML-5 during flow performance test, including tracer flow test (TFT). The TFT is a reliable method able to give accurate analysis for flowing enthalpy and mass flow rate of geothermal wells.

The work is accomplished to evaluate the accuracy of James lip pressure method for ML-5. Results of the method are analyzed and compared to the results of TFT method. Possibilities of error are identified. Several aspects that may contribute to the errors are elaborated upon. The correction process is conducted and sensitivity analysis is performed.

This case study at well ML-5 shows that relative error of James lip pressure method falls in a 10 – 14 % error margin relative to the result of TFT method. The work clearly demonstrates that accuracy of the method is very sensitive to the measurements on brine water level at the weir box. Further investigation shows that it is still possible to maintain the accuracy in the range of ± 2 % error margin by improving the measurement on brine water level at the weir box. Furthermore, the work also suggests that TFT survey is important as benchmarking to guarantee the reliability and accuracy of James lip pressure measurement.

1. INTRODUCTION

Muara Laboh is located in South Solok Regency, West Sumatera, Indonesia. This place is a geothermal working area which is being explored by Supreme Energy. Currently, six exploration wells have been drilled in Muara Laboh to prove and delineate the existence of a geothermal system beneath the Muara Laboh area. Some of the wells have been discharged and flow performance tests have been performed.

The James lip pressure method has been applied in Muara Laboh field to assess performance of the wells during discharge tests. One of these wells is ML-5. There is interesting feature of this well which needs to be investigated. This feature is the low flow rate characteristic that is suspected to have influenced the accuracy of James lip pressure method.

James lip pressure method is a well-known technique to estimate the flowing enthalpy and total mass flow rate from a discharging geothermal well. Enthalpy and total mass flow rate are required to calculate dryness of the fluid, steam mass flow rate, and estimate productivity of the wells at a given well head pressure. This method is derived from the empirical experiment by James (1966).

James lip pressure method has been widely used in the geothermal industry. This method is preferred since it is cost efficient and easy to be performed in the field. The simplicity in both hardware and instrumentation are the advantages of this method. Furthermore, the method is able to provide real-time monitoring on the well production data. The James lip pressure method is a suitable method for long-term production test of new exploratory wells when compact surface facilities are not available yet. These features are the primary consideration to apply the James lip pressure method in Supreme Energy fields.

Accuracy of the James lip pressure method has been frequently reviewed. Results are usually within 5% error margin for both total mass flow and enthalpy. However, another study by Karamaraker and Cheng (1980) showed that this method gives the results with 8% error margin (Grant, 2011).

The objective of this paper is to evaluate the accuracy of the lip pressure method for low flow rate geothermal wells with a case study of ML-5. Indeed, when fluid enthalpy and steam mass flow rate are relatively low, small difference between calculated and actual value will result in significant impacts on estimating the well productivity.

2. REVIEW OF THE LIP PRESSURE METHOD

The James lip pressure method is implemented to geothermal wells being discharged to atmospheric conditions. The atmospheric flash tank (AFT) is used to separate brine and steam fraction. Steam will be flashed to the atmosphere and brine is flowed to the weir box. A short-closed pipeline is built to make the connection between well head and AFT. The pressure is measured at well head point and at the extreme end of the pipeline as it enters the AFT which is called "lip pressure". Brine flow rate is measured at the weir box.

Grant (2011) presented the procedures to calculate flowing enthalpy and total mass flow rate by using the James lip pressure method. The measured parameters are well head pressure in bar absolute, lip pressure in bar absolute, and height of brine from the base of triangular-notch in the weir box which is usually measured in centimeter in the fields. The design parameter is the cross-sectional area of the "lip-pipe" in cm^2.

A relation between total mas flow rate (kg/s), enthalpy (kJ/kg), cross-sectional area of the lip pipe (cm^2), and lip pipe pressure (bar absolute) is described by James formula as below:

$$\frac{W \times H^{1.102}}{A \times P_{lip}^{0.96}} = 184 \quad (1)$$

where *W* is the total mass flow rate, *H* is the fluid enthalpy, *A* is the cross-sectional area of lip pipe, and *P* is the lip pressure.

The relation between total mass flow rate and brine flow rate which is measured at the weir box is written as:

$$W = \frac{W' \times H'_{SW}}{H'_S - H} \quad (2)$$

where the parameters with apostrophe are evaluated at the atmospheric pressure.

Substituting the Eq. 2 into Eq. 1 gives:

$$\frac{W'}{A \times P_{lip}^{0.96}} = \frac{184}{H'_{SW}} \times \frac{H'_S - H}{H^{1.102}} \quad (3)$$

Grant (2011) denoted the left side of equation above as *Y* and made the relation between *Y* and enthalpy for atmospheric pressure of 1 bar as below:

$$H = \frac{H'_S + 3329\,Y}{1 + 28.3\,Y} \quad (4)$$

Once the flowing enthalpy has been known, the total mass flow rate can be calculated using Eq. 2.

Assuming an atmospheric pressure of 1 bar, the procedure for calculating the enthalpy and total mass flow rate by using James lip pressure method is:

1. Calculate *Y* using left side of Eq. 3.
2. Calculate enthalpy of fluid using Eq. 4.
3. Calculate total mass flow rate using Eq. 2.

In order to calculate *Y* value, the brine flow rate at the weir box (*W'*) must be calculated first.

3. CALCULATING BRINE MASS FLOW RATE BY USING THE TRIANGULAR-NOTCH THIN-PLATE WEIR

Shen (1981) proposed the semi-empirical correlation to estimate flow rate from the triangular-notch thin-plate weirs. This correlation can be applied to estimate the brine flow rate at the weir box condition in order to calculate *Y* value in Eq. 4.

The proposed equation from Shen (1981) is written as:

$$Q = C_e \frac{8}{15} \sqrt{2g}\, tan\frac{\theta}{2} h_e^{5/2} \quad (5)$$

where Q is the flow rate in m^3/s, *Ce* is the discharge coefficient, *g* is the gravity acceleration in m^2/s, θ is the notch angle, *he* is the effective head in m and defined as:

$$h_e = h + k_h \quad (6)$$

where *h* is the level or height of brine from the base of triangular-notch in the weir box and k_h is the head-adjustment factor to accommodate effects of viscosity and surface tension. Equation (5) is described as the Kindsvater-Shen equation in the international standard (International Standards Organization, 1975) as quoted in Shen (1981).

Shen plotted the average values of *Ce* versus notch angle θ as is illustrated in Fig. 1. Based on the plot, we have made the approximated correlation between *Ce* and θ, which can be written as:

$$C_e = 5.52 \times 10^{-6}\theta^2 - 8.11 \times 10^{-4}\theta + 6.062 \times 10^{-1} \quad (7)$$

Shen plotted the values of k_h versus notch angles θ as is illustrated in Fig. 2. Based on the plotting, we have made the approximated correlation for k_h as function of θ, which can be written as:

$$k_h = 0.032\, \theta^{-0.788} \quad (8)$$

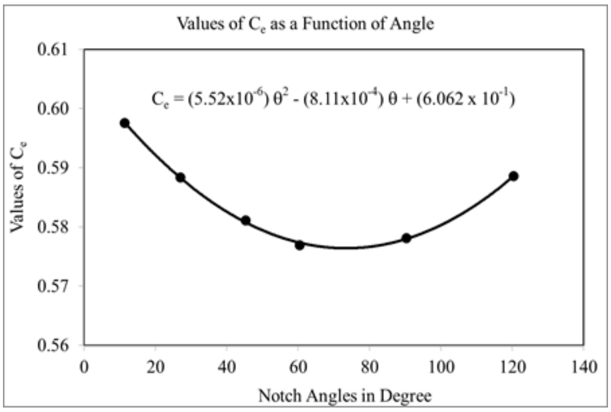

Figure 1. Values of C_e as a Function of Angles.

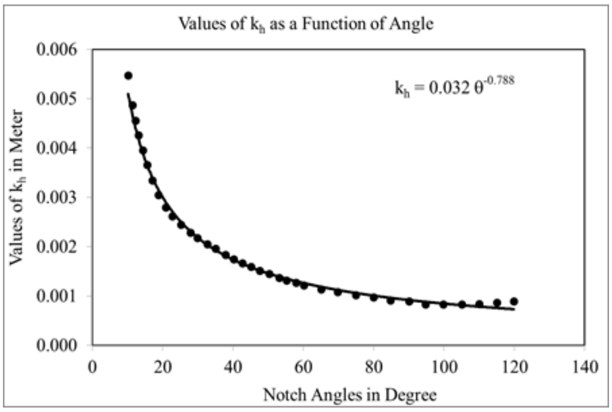

Figure 2. Values of k_h as a Function of Angles.

Equation 7 is valid for $10 < \theta < 120$ degree with error margin less than 1%. Then, Eq. 8 is valid for $10 < \theta < 110$ degree with error margin less than 8%. Having calculated Q value using Eq. (5), brine mass flow rate at the weir box can be calculated as below:

$$W' = Q \times \rho_W(P_{atm}) \quad (9)$$

where $\rho_W(P_{atm})$ is the density of brine water which is evaluated at atmospheric pressure.

When brine mass flow rate at the weir box has been known, then Y value in the James lip pressure method can be calculated as:

$$Y = \frac{W'}{A \times P_{lip}^{0.96}} \quad (10)$$

4. APPLICATION OF LIP PRESSURE METHOD IN ML-5

ML-5 is one of the exploratory wells situated in Muara Laboh geothermal prospect area. This well was spudded on 22nd of June 2013 and completed on 29nd of July 2013. A completion test and intensive well testing surveys have been done. Subsurface information about ML-5 had been well characterized.

On 22nd of September 2013, ML-5 was switched to the flowing condition for the first time. Air injection technique was performed to initiate the flow. This well has been discharged for 88 days or almost 3 months before being switched to shut-in condition on 19nd of December 2013.

Horizontal discharge method has been implemented in ML-5 to reduce effects of direct exposure from geothermal fluid to the environment. Using this method, two-phase fluid has been flowed to the atmospheric flash tank (AFT) through short-closed pipeline. In the AFT, steam has been flashed to the atmosphere and brine has been flowed to the weir box.

Three are three parameters that have been measured continuously during flow performance test of ML-5. These parameters are well head pressure, lip pressure, and height or level of brine water in the weir box. Well head pressure and lip pressure has been measured by using digital pressure gauges. Level of brine in the weir box has been measured manually by using measurement set which had good calibration in the field to make sure that the reading is correct.

Figure 3. Discharging of ML-5 through AFT on October 9, 2013.

Figure 4. Brine in Weir Box on October 9, 2013.

Grant (2011) has made the relation between enthalpy *H* and *Y* values for atmospheric pressure of 1 bar as written in Eq. (4). However, related to high elevation, the atmospheric pressure in ML-5 is less than 1 bar.

Based on the elevation of ML-5, the calculated atmospheric pressure is 0.84 bar. Then we have calculated the modified correlation between enthalpy *H* and *Y* values for atmospheric pressure of 0.84 bar as is presented in Fig. 5.

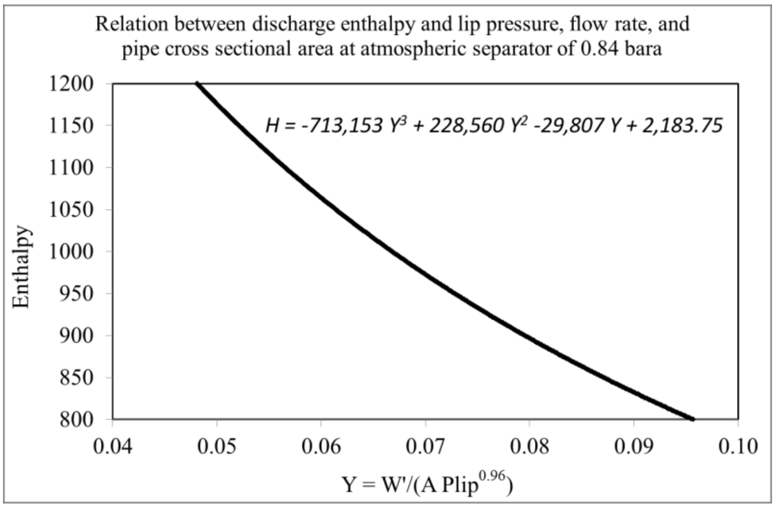

Figure 5. Relation between *H* and *Y* for atmospheric of 0.84 bar and $800 < H \leq 1200$ kJ/kg.

The modified correlation between enthalpy *H* and *Y* values for atmospheric pressure of 0.84 bar can be written as:

$$H = -aY^3 + bY^2 - cY + d \qquad (11)$$

where,

for $800 < H \leq 1200$

$a = 713{,}15$

$b = 228{,}560$

$c = 29{,}807$

$d = 2{,}183.75$

for $1200 < H \leq 1600$

$a = 3{,}420{,}808$

$b = 616{,}748$

$c = 48{,}739$

$d = 2{,}497.75$

for $1600 < H \leq 2000$

$a = 10{,}990{,}795$

$b = 1{,}191{,}905$

$c = 63{,}607$

$d = 2{,}628.45$

for $2000 < H \leq 2400$

$a = 28{,}114{,}652$

$b = 1{,}827{,}360$

$c = 71{,}725$

$d = 2{,}664.12$

The correlation which is described in Eq. 11 is valid under the enthalpy conditions quoted above with error within ± 0.4 kJ/kg. This correlation was used in the James lip pressure method to calculate the enthalpy and mass flow rate of ML-5.

5. EVALUATION AND METHODOLOGY

The tracer flow test (TFT) method has been conducted in ML-5 in order to obtain the accurate estimation for enthalpy and mass flow rate. The TFT method is able to determine the enthalpy and mass flow rate of the two-phase flow stream of geothermal well in the production line. The method requires the injection of separated chemical tracers for the liquid and vapor phase into flow stream. Samples are taken downstream from the tracer injection point. Mass flow rate of each phase can then be calculated, and by knowing the pressure in the pipeline, enthalpy can also be calculated.

TFT method is considered able to give the most reliable and accurate estimation for the enthalpy and mass flow rate. Hirtz and Lovekin (1995) were performed field validations of TFT results based on experiences in Roosevelt, Salton Sea, and Heber geothermal fields. Validation process was done by using orifice meter measurement as reference. The validation result has shown that greatest deviation is 4.37 % for steam flow rate, 4.61 % for liquid flow rate, and 4.10 % for enthalpy.

In Muara Laboh geothermal field, TFT had been implemented as benchmarking method to check the accuracy of measurement from the James Lip pressure method. In high productivity wells that had been drilled in Muara Laboh, the difference between TFT and James lip pressure method is in the range of ± 5 %. However, a different result was found in low productivity wells.

In case of ML-5, two TFT surveys have been performed to get the accurate values of the enthalpy and mass flow rate and at the same time to validate the results of James lip pressure method. These TFT surveys were performed on October and December 2013. Result of these TFT was also supported by result from pressure – temperature (PT) logging. It had been found that TFT result has shown good consistency with PT logging result. Enthalpy from the TFT result was close to the feedzone temperature from PT logging data.

Enthalpy and mass flow rate which have been calculated by using James lip pressure method are compared to the TFT result as reference. Deviation of James lip pressure method to the TFT results is calculated as relative error which is defined as:

$$\varepsilon_r = \frac{|\zeta_{LPM} - \zeta_{TFT}|}{\zeta_{TFT}} \times 100\% \qquad (12)$$

where ε_r is the relative error, ζ_{LPM} denotes the quantity from the lip pressure method, ζ_{TFT} denotes the quantity from the TFT.

6. RESULTS

Two TFT were performed on 20th of October 2013 and on 12th of December 2013. The calculated enthalpy and total mass flow rate from James lip pressure method and results from the TFT are presented together in Fig. 6 and Fig. 7, respectively.

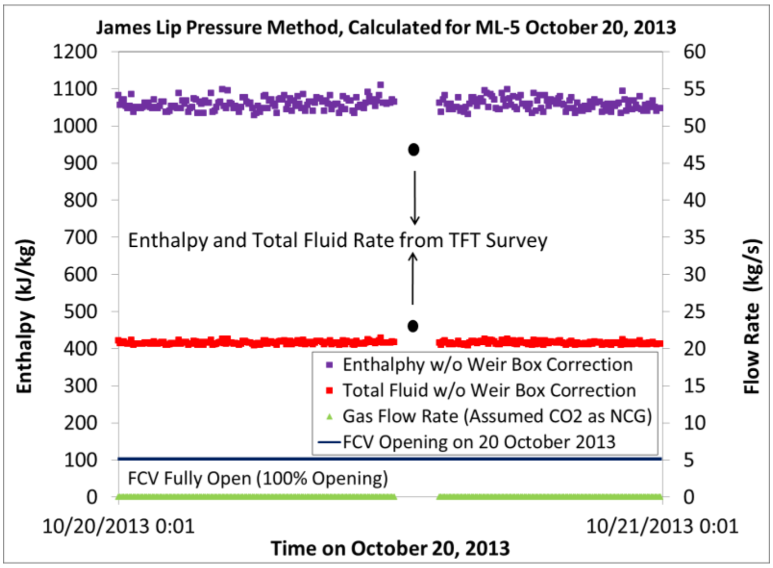

Figure 6. Lip Pressure Results - Data October 2013.

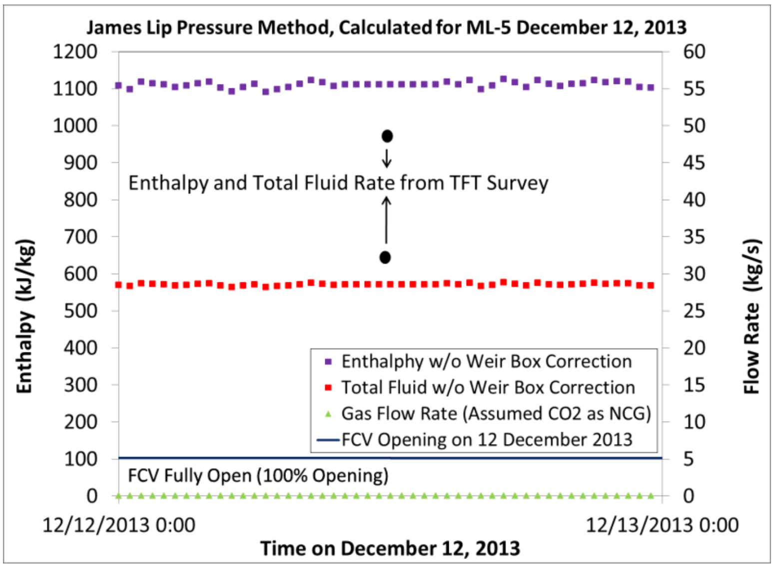

Figure 7. Lip Pressure Method Result - December 2013.

As can be seen in Fig. 6 and Fig. 7 above, there are deviation of James lip pressure results compared to the TFT results. Calculated error for enthalpy and total mass flow rate are 13.25 % and 10.00 % on data 20th of October 2013 and 14.50 % and 10.50 % on data 12th of December 2013, respectively. These results show that average error for enthalpy falls in value of 14 % and average error for total mass flow rate falls in value of 10 %. Considering the average deviation of TFT is 4 % for enthalpy and 4.5 % for mass flow rate as presented in Hirtz (1995), it can be calculated that in case of ML-5, the average error for enthalpy is 15 % and average error for total mass flow rate is 11 %. Furthermore, it also indicates that accuracy which has been obtained in this case is less reliable than accuracy that has been mentioned in Grant (2011) where the James lip pressure method usually gives the error margin within value of $5 - 8$ %.

The errors that are stated above are the relative errors which are calculated relative to the TFT result. One possibility could be that TFT result not reliable. Regarding this issue, TFT result was then validated with pressure-temperature (PT) survey under shut-in condition and wellbore modeling of pressure-temperature-spinner (PTS) survey under flowing condition. Previous PT shut-in survey has been done on 20th of September 2013 and PTS shut-in surveys have been conducted on 30th of October 2013 and 17th of December 2013. Calculated feedzone enthalpy based on these surveys is falls in the temperature range of 220 – 220 ^{0}C under condition of compress liquid. Enthalpy from the TFT is also falls in this range. It confirms that TFT result is reliable.

Based on the analysis, several aspects might have contributed to the error of the James lip pressure method result in the case of ML-5. The aspects have been identified as below:

1. The significant amount of non-condensable gas (NCG) in the wellhead may have led the calculated enthalpy to a less reliable value.
2. The unstable well condition may have led the calculated mass flow rate to a less reliable value.
3. Unreliable pressure gauge measurements.
4. Deposition of mineral inside the U-pipe of measurement set in the weir box.
5. The manual reading process on the weir box may have led the reading of brine water level to a less reliable value.

A geochemistry survey had been conducted on ML-5. Non-condensable gas (NCG) was determined from the survey by analysis of samples of steam condensate from the two-phase flow line. The analysis yield NCG concentration of 0.025 – 0.037 weight %. These concentrations were corrected to total discharge. This correction was performed because gas concentration in steam will vary with sampling pressure but the total discharge will not. Furthermore, the calculated NCG flow rate at the wellhead of ML-5 is showed in Fig. 6 and Fig. 7. It clearly shows that NCG flow rate is very low (less than 0.05 kg/s) and tends to be zero under flowing condition. Therefore, the NCG effect can be excluded from the list of possible aspects that may contribute to the error.

The unstable well condition can lead the calculated mass flow rate to a less reliable value. However, in the case of ML-5, even the well has shown a slight increase of performance every month, and it has been observed that reading of wellhead pressure on 20th of October and 12th of December 2013 stabilized at certain value. Therefore, contribution of this aspect to the error can be ignored.

The other possibility that may have contributed to the error is the unreliable pressure gauge instruments. However, based on the field investigation, it was found that the digital pressure gauges which were used at the well head and lip-pipe of ML-5 had given reliable measurements. There was no significant contribution from these pressure gauges to the errors.

Mineral deposition if occurred inside the U-pipe of measurement set in the weir box can obstruct and reduce the inside diameter of the pipe. Based on the capillary principle, this occurrence will influence the height or brine water level in the measurement set. This phenomenon can lead to an unreliable brine water level measurement. However, in the case of ML-5, regular clearing had been done to make sure there was no mineral deposition left in the U-pipe.

Figure 8. Simple measurement set with U-pipe principle to measure the brine water level in the weir box.

Further investigation has been addressed to the measurement of level or height of brine water from the base of triangular-notch in the weir box. Brine water level in the weir box had been measured manually. Calibration for this set had been done and frequently checked in the field.

During the calibration of measurement in the weir box, however, it had been observed that brine water level in the weir box was never smooth. Brine water level in the measurement set had fluctuated and slight isolation phenomenon had been observed in the reading. In the case of ML-5, reading had been simplified by taking the average values of brine water level in the measurement set. Based on this situation, it was considered that level of brine water measurement had the most potential to lead the result of James lip pressure to less reliable values.

Sensitivity analysis is performed to investigate the impact of brine water level to the calculated enthalpy and total mass flow rate. The process is done by adding relatively small values as corrections to the measured brine water level, as is presented in Fig. 9 and Fig. 10, and then re-calculating the enthalpy and total mass flow rate by using those new values. Then results are compared to the TFT results and relative errors are calculated by using Eq. (12). The results of sensitivity analysis are showed in Fig. 9 and Fig. 10 below.

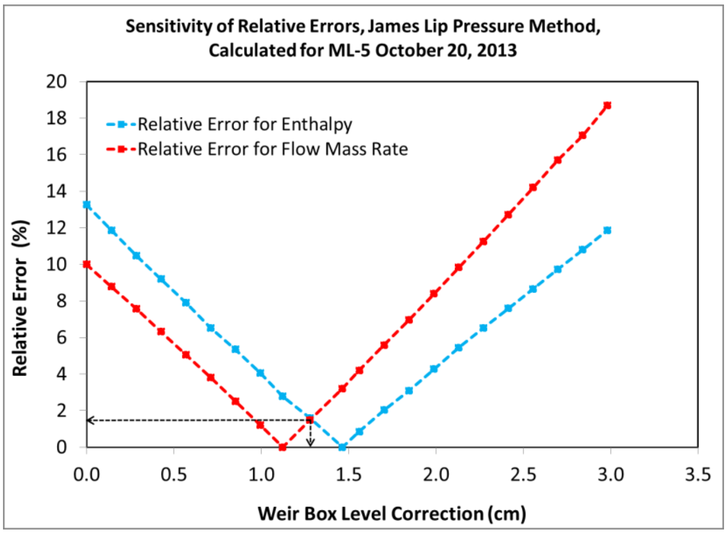

Figure 9. Sensitivity Analysis - Data October 2013.

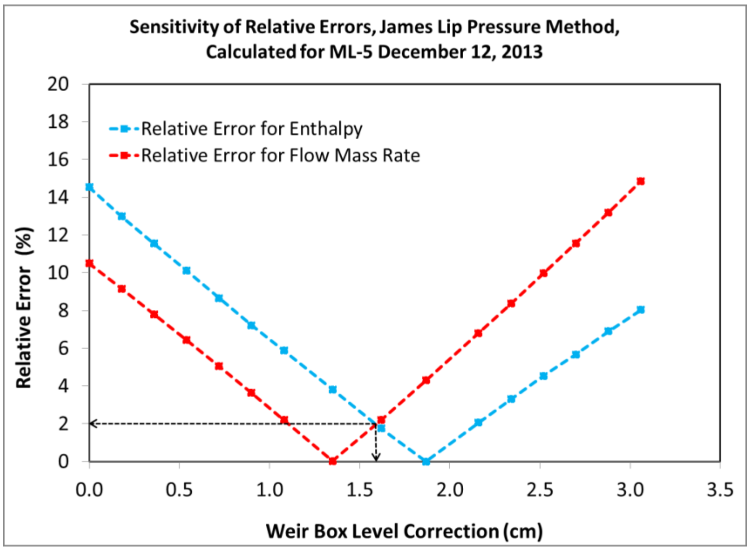

Figure 10. Sensitivity Analysis - Data December 2013.

As can be seen in Fig. 9 and Fig. 10, adding small values to the measured brine water level in the weir box, until a specific number, lead to the significant decreasing of the relative errors. Then, if this process is continued, the relative errors start to increase consistently. Below of a specific number, the relative errors for total mass flow rate are less than enthalpy. On the contrary, above of a specific number, the relative errors for total mass flow rate are more than enthalpy.

As can be seen in Fig. 9 and Fig. 10, there is one specific number where the relative error for enthalpy is exactly same with the relative error for total mass flow rate. This number is considered as minimum correction value that can be reached to achieve the optimum relative errors for both enthalpy and total mass flow rate at the same time. For data on 20[nd] of October 2013 illustrated in Fig. 9, this minimum correction value of 1.2842 cm can give the optimum relative error of 1.52 %. Then for data on 12[nd] of December 2013 is presented in Fig. 10, the minimum correction value of 1.5947 cm can give the optimum relative error of 1.99 %.

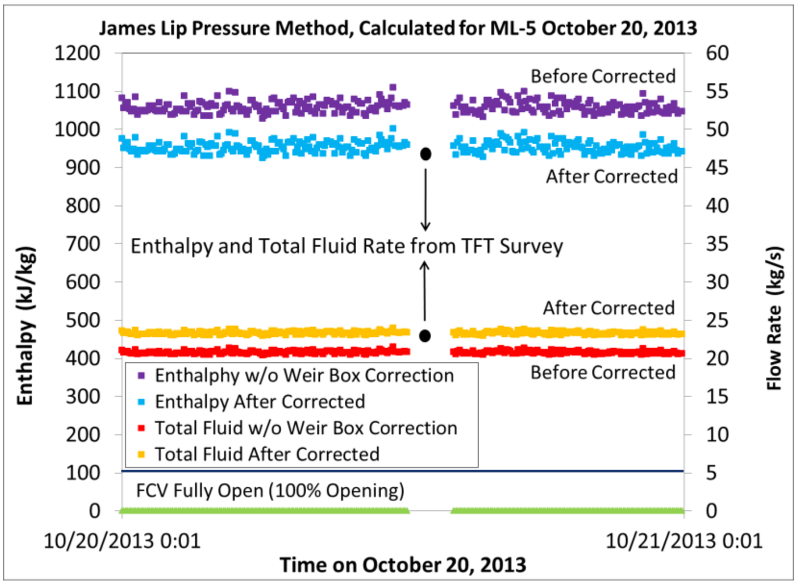

Figure 11. Corrected Results - Data October 2013.

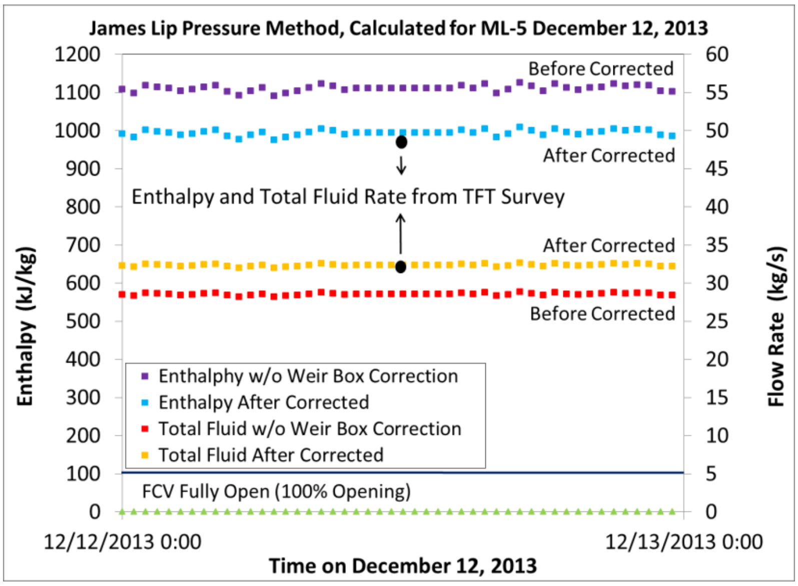

Figure 12. Corrected Results - Data December 2013.

The minimum correction values that have been obtained above are implemented to re-calculate the enthalpy and total mass flow rate of ML-5. These calculated enthalpy and total mass flow rate are presented in Fig. 11 and Fig. 12.

Fig. 11 and Fig. 12 clearly show that correction process that has been done to the measured brine water level has significantly increased the accuracy of James lip pressure method in ML-5. This result indicate that if measurement of brine water level can be precisely and accurately done in the field, more reliable calculated enthalpy and total mass flow rate can then be obtained by using the James lip pressure method with relative error within $\pm$ 2 % for both of them.

7. CONCLUSION

The conclusions that can be drawn from the accomplished work are summarized below:

1. The James lip pressure method, with standard measurements on brine water level in the weir box by using simple measurement set, may lead to relative error margin of more than 10 %. In case of ML-5, we have obtained relative error margin of 15 % for enthalpy and 11 % for total mass flow rate.

2. Accuracy of the James lip pressure method is very sensitive to the measurements on brine water level in the weir box. Case of ML-5 shows that correction that has been made was able to improve the accuracy of James lip pressure method until relative error margin less than 2 %. This correction was done by adding correction factor of 1.3 – 1.6 cm to the reading of brine water level in the weir box.

3. Accuracy of James lip pressure method is still possible to be maintained in the range of relative error margin around $\pm$ 2 % by improving the measurement of the brine water level in the weir box. This is possible to be conducted by applying the precision real time electronic measurement.

4. Benchmarking with other standard methods is important to be performed to guarantee the reliability and accuracy of the results obtained. In case of ML-5, TFT method was used to provide a comparison to James lip pressure method.

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