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Geothermal Steam Measurement with Orifice Plates, According with the ISO 5167—The Cerro Prieto Case

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ABSTRACT

Since the Comisión Federal de Electricidad (CFE) has changed its operative criteria, in the Cerro Prieto geothermal field, the economical resources to operate it are coming from the steam effectively supplied to the power plants, which are operated by a different team. Delivery steam points have been installed time ago to measure the amount of steam, but there have been some controversies between the power plant group and the field-group. To avoid such controversies, it was decided to certify the measurement points by a third party, and a technical analysis was made to verify whether the requirements established by the ISO 5167 are met or not, including a physical inspection in the delivery points of the Unit 9 (110 MW), on the high and medium pressure steam pipelines. The difficulties of normal geothermal installations to accomplish those standard requirements are presented, as well as the methods to calculate the flow rate using the computer program in a flow totalizer computer.

Introduction

The Comisión Federal de Electricidad (CFE) has installed in the Cerro Prieto geothermal field 720 MW in four power houses. The steam delivered to the units is 5800 tons per hour (t/h) in high, medium and low pressure. The steam is produced by over 150 wells connected to the gathering system and the flow is

measured in each wellhead pad and in the entrance of each power house. Figure 1 shows the gathering system.

At the beginning of the operation of the power plants (1972-1986) the steam was measured at the turbine inlet to calculate the thermal regime and the efficiency in the steam production. The steam transportation through the field was not considered as a problem, because the field was able to produce as much steam as the turbines needs. In early 1995 CFE decided to change the philosophy of the organization and consider each part of the process as a strategic business unit responsible of the financial and economical results, trying to be prepared in the case of an open electrical market could operate in Mexico.

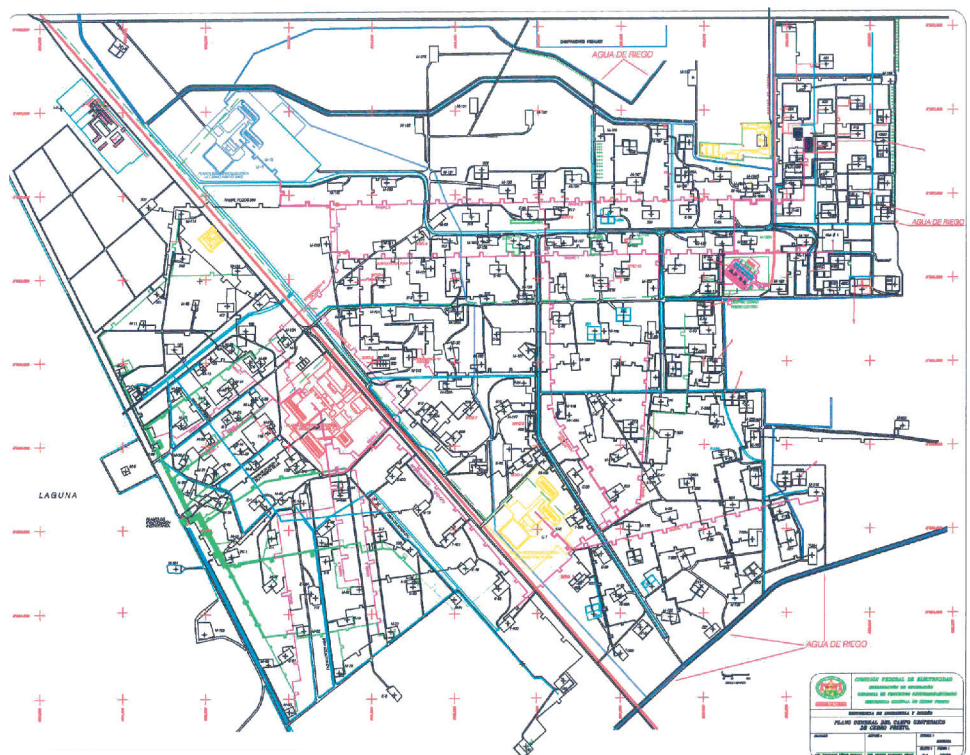


Figure 1. Gathering system in Cerro Prieto Geothermal Field.

The geothermal business was organized in two parts, the field-group being responsible for the steam supply and the operation-group responsible for the operation and maintenance of the power plants and the electrical production. Under this panorama, the incomes for the geothermal field might be calculated according with the steam effectively supplied, and measurement points were installed with this purpose.

Measurements are made in most cases by orifice plates installed in pipes from 24 inches to 46 inches in diameter for the sectors Cerro Prieto II and Cerro Prieto III.

At the present, negotiations to define the amount of steam delivered to the power plant are difficult, and so both organizations decided to analyze the possibility to certify the steam measurement by a third part.

The ISO 5167 is the international standard to regulate the steam measurements using an orifice plate. According to that, the primary element must meet some requirements in order to certify it.

ISO 5167 Requirements

The ISO 5167 defines the formula to calculate the steam flow passing through an orifice plate, and to use this information the user should meet the physical conditions established in the international code. Mainly it is necessary to meet the physical installations conditions because the discharge coefficient is calculated by experimental methods observing this requirement. The more deviated the installation is from the standard requirement, the higher the error from the actual value is the calculated flow-rate.

The general requirements are mentioned briefly, including the tolerance permitted reflected in the uncertainty of the measurement.

Pipe

- The upstream pipeline should have a minimum straight length according with its internal diameter.
- The downstream pipeline should have a minimum straight length according with its internal diameter.
- The pipe should be round and none difference in any diameter measured in a section should be greater than 0.3%, with respect to its average diameter.
- The internal surface of the pipe should have a relative roughness lower or equal than 10×10^{-4} .

Orifice Plate

- The part of the plate inside the pipe should be circular and concentric with the pipe centerline. The faces of the plate shall always be flat and parallel.
- The upstream face of the plate shall have a roughness criterion $Ra < 10^{-4} d$ within a circle of diameter not less than D that is determined from the pipe size and which is concentric with the orifice. If under working conditions the plate does not fulfill the specific conditions, it shall be repolished or cleaned.

- Where possible, it is useful to provide a distinctive mark visible even when the orifice plat is installed, to show that the upstream face on the orifice plate corresponds to the flow direction.
- The thickness (e) of the orifice shall be between $0.005D$ and $0.02D$. The difference between the values of e measured at any point on the orifice shall not be greater than $0.001D$.
- The thickness (E) of the plate should be between e and $0.05D$. If $D > 200$ mm the difference between the values of E measured at any point of the plate shall not be greater than $0.001 D$.

Pressure Tapping (D and $1/2D$ tappings)

For orifice plates with D and $1/2D$ tappings, the spacing of the upstream pressure tapping is normally equal to D , but may be between $0.9 D$ and $1,1 D$ without altering the discharge coefficient.

The spacing of the downstream pressure tapping is normally equal to $0.5D$ but may be between the following values without altering the discharge coefficient:

- a) Between $0.48D$ and $0.52D$ when $\beta \leq 0.6$,
- b) Between $0.49D$ and $0.51D$ when $\beta > 0.6$

The spacing for both upstream and downstream tappings is measured from the upstream face of the orifice plate.

The centerline of the tapping shall meet the pipe centerline at an angle as near 90° from horizontal as possible, but in every case within 3° of the perpendicular,

At the point of break-through, the tap shall be circular. The edges shall be flush with the internal surface of the pipe wall and as sharp as possible.

The diameter of the pressure tappings shall be less than $0.13D$ and less than 13 mm.

Not in Accordance with the Standard and Uncertainty Sources

Some criteria presented in the ISO 5167 requirements must be achieved or the primary element can be considered not in accordance with the standard, and no certification is able under these conditions. Other deviations are reflected in a greater uncertainty of the measure.

Uncertainty of the Measure

Uncertainty is defined as an interval around the result of a measurement that may be expected to encompass approximately 95% of the distribution of values that could reasonably be attributed to the measure.

ISO 5167 proposes a practical computation of the uncertainty from the general equation for the computation of the mass flow-rate:

$$qm = C\varepsilon \frac{\pi}{4} d^2 \frac{\sqrt{2\Delta P \rho_1}}{\sqrt{1 - \beta^4}} \quad (1)$$

The simplified method is based on the assumption that the uncertainties of C , ε , d , D , ΔP , ρ are independent of each other

The practical working formula for the uncertainty of the mass flow-rate is given by the equation as follows:

$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\delta C}{C}\right)^2 + \left(\frac{\delta \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2\beta^4}{1-\beta^4}\right)^2 \left(\frac{\delta D}{D}\right)^2 + \left(\frac{2}{1-\beta^4}\right)^2 \left(\frac{\delta d}{d}\right)^2 + \frac{1}{4} \left(\frac{\delta \Delta P}{\Delta P}\right)^2 + \frac{1}{4} \left(\frac{\delta \rho_1}{\rho_1}\right)^2} \quad (2)$$

Deviations Increasing the Uncertainty

Smaller straight length upstream and downstream of the orifice meter that is determined from the pipe diameter can introduce an error in the calculation. There is a value to accomplish in order to have zero additional uncertainty. A lower length is permitted but an additional uncertainty of 0.5% must be added arithmetically in Equation 2. If this lower value is not achieved, the primary element is not in accordance with the Code.

The upstream straight pipeline can be manufactured welding two or more lengths. However the step in the junction must be smaller than 0.3% beyond 2D and 10D. For lengths bigger than 10D the accepted step is lower than 2%. If the step is higher an uncertainty is added in the Equation 2.

If the orifice plate is not centered with respect to the centerline of the pipeline, but within the maximum value, an uncertainty is added in the Equation 2.

Not in Accordance with the Standard

Other requirements as defined in ISO 5167 not met by the primary element are considered as Not in accordance with the Standard. There is no way to certify a primary element if this is the case if the meter is not in accordance with the standard.

The Cerro Prieto Case

In the case of the Cerro Prieto geothermal field, one of the delivery steam points was inspected to check how far it could be from the standard requirements, and evaluate the possibility to certify the primary element. At this point two pipelines were inspected, since high and intermediate pressure steam is measured. The general information recorded before the inspection is as follows:

High Pressure Measurement

Internal diameter of the pipe	1136.7 mm (44.75 in)
Diameter of the orifice plate	847.6 mm (33.37 in)
Diameters relationship (β)	0.746
Diameter of the pressure tappings	19 mm (3/4 in)
Upstream straight length	40.8 m
Downstream straight length	8.0 m
Upstream pressure tapping location	1180 mm
Downstream pressure tapping location	560 mm

Intermediate Pressure Measurement

Internal diameter of the pipe	692.2 mm (27.25 in)
Diameter of the orifice plate	517.3 mm (20.37 in)
Diameters relationship (β)	0.747
Diameter of the pressure tappings	19 mm (3/4 in)
Upstream straight length	39 m
Downstream straight length	6.0 m
Upstream pressure tapping location	680 mm
Downstream pressure tapping location	300 mm

The pipe information was taken from the ASTM technical information when the pipe was installed. The orifice plate was measured by the local manufacturer, before the installation. The tapping location and the straight length were measured on site at the present.

Physical Inspection

The last April 30th the measure points were inspected in the high and intermediate pressure collectors and calibrated after a few years of continuous operation.

The target of this work was focused in the internal pipe conditions, by checking the roughness of the pipe and the internal diameter, to know how different the supposed diameter is from the initial diameter after years of operation. The objective was also to check the steel attacked by the sulphydric acid and the final thickness after cleaning the pipe. Finally, the physical condition of the orifice plate and the sharpness in the upstream edge was an important point to check.

High Pressure Pipeline

This pipeline is of 46 inches in diameter. The expected attack by the sulphydric acid was not evident at all. The pipe was found relatively clean and with very low scale on its wall. Picture 1 shows the internal aspect of the tube before cleaning. Some water runs were observe on the bottom of the pipe and



Picture 1. Internal aspect of the pipeline before cleaning job. High pressure pipeline.

this water is dragged by the steam in the orifice plate. Most of the time the drain installed before the orifice plate remains closed and the water is not frequently drained from this portion of the pipe. No drip pots are accepted by the code in the straight pipe length required for the meter run. The last drip pot is located 300 m before the measurement point.



Picture 2. Steel cleaned with low corrosion attack.

Mechanical tools removed the scale in the pipe easily and the final aspect of the wall pipe is shown in Picture 2. It is possible to distinguish some pitting corrosion, and the required roughness can not be achieved.

The internal diameter was measured in three sections and the final average was 1136.8 mm (44.76 in), which is very close to the internal diameter referred in the literature, and the maximum difference between diameters was 0.29%. But it was only a random result because the ASME A-134 lets an oval-shape of 1% between the major and minor outside diameter. The API 5-L has a tolerance of +1/4 and -1/8 in (+6 mm and -3.175 mm), which means the total difference between diameters could be 3/8 in (9.5 mm). The ISO 5167 accepts only 0.3% of difference, equivalent to 3.41 mm.

High Pressure Orifice Plate

The orifice plate was inspected and physically it was in good conditions with the following remarks:

- Some roundness was detected in the edge of the upstream face.
- The roughness in the upstream face is not what the code requires.
- The measured average orifice diameter was 845.4, 2.2 mm smaller than the initial measurement. The difference is probably due to the fact that the initial value was not averaged and only one measurement was made.

Orifice plate must be re-machined and polished in order to meet the code requirements.



Picture 3. New pressure arrangement with four taps.

High Pressure Taps

Due to the fact the pressure taps were not made with precision mechanical tools, it was decided to build new ones, considering 4 taps per location at 90° of separation. The new 1/2 in diameter was observed. Picture 3 shows the new pressure tapings.

Important Remark

The physical inspection showed a strong erosion problem in the downstream pipeline: almost the half of the wall thickness was lost because the contract vane is impacting the pipe. This affected zone correlate very well with theory because it was located 5 pipe diameters downstream of the orifice plate.

Intermediate Pressure Pipeline

The intermediate pressure pipeline was inspected before cleaning and no corrosion problems were detected. As assumed, the low gas content in the steam is not a problem for corrosion. Picture 4 shows the inside pipeline.



Picture 4. Inside pipeline intermediate pressure before cleaning job, with no evidence of corrosion problems.

The pipeline was cleaned and measured. The internal average diameter was 699.7 mm, 7 mm greater than the initial one and the difference between diameters was smaller than 0.3%. However, we remarked the same that for the high pressure pipe.

Orifice Plate and Pressure Tappings

The general comments for these points are similar than the high pressure ones.

The other code requirements were met by the installation.

Flow-Meter

A flow-meter is installed at the delivery points and values are taken each 5 seconds to calculate the amount of steam delivered by the field to the power plants. Because of the nature of the steam source and the geothermal installations, some variations can be recorded in the steam delivered. However, the frequency of the measurements makes these variations integrated in an acceptable manner.

The main problems in this measurement are related with the gas contents and the difference in density between the value considering the steam as a pure substance and the value as a mixture of gases. No corrections nor considerations are made in the flow computer to take into account the geothermal fluid characteristics.

Obviously the difference in density considering a pure substance and a mixture depends on the amount of gases produced in each field. For Cerro Prieto, the gas content is different from one zone (Cerro Prieto I with 1.3 % of NCG) to another (Cerro Prieto III with 3.2% of NCG). Also some steam transfer is made from one zone to other, so the gas content can be different with the time in the same power house, depending of the management of the field.

At the present, flow calculations continue be performed with the electronic equipment that only uses the density of pure steam.

Conclusions

1. The Cerro Prieto geothermal field needs to accurately measure the steam flow delivered to the power plants, since the budget for field operations is now determined according with the amount of steam measured in the delivering point of the power plants.

2. Both parties (generation-group and field-group) decided to find the best solution and certify the measurement points.

3. The ISO 5167 was revised in order to have a good knowledge about the requirements established by this international standard.

4. The measurement points in the Unit 9 (110 MW), high and intermediate steam pressure, were inspected during the maintenance outage to check the physical conditions of the pipelines, orifice plates and pressure tappings.

5. The pipelines were found in good conditions, but the roughness is higher because the pitting corrosion suffered by

the pipe. However, the corrosion is not severe. To meet this requirement is not easy and the internal wall of the pipe must be polished if the required roughness want be achieved.

6. The internal diameter was measured in 12 points in 3 sections and the average diameter is very close to the specifications in the literature. The tolerance established in the manufacture specification, it is very difficult to accomplish with the difference in diameter as the ISO indicates (less than 0.3%). The ASME and API have a tolerance higher than this value for the manufacturing process.

7. Special pipe must be supplied for the measure points with a closer tolerance in agreement with the manufacturer.

8. The orifice plate is not a problem except for a good method to assure the orifice is installed centered with respect to the axis of the pipe.

9. New pressure tappings were manufactured to assure the edge in the internal wall of the pipe and the correct size required by the code (1/2 inches). Four tappings were installed in order to minimize blockage problems. Also, in this way it could be possible to evaluate the benefits to have multi-tappings.

10. Severe erosion was checked in the downstream high pressure pipe, exactly 5 pipe diameters from the orifice plate, where the steam impinged against the wall of the pipe in the vena contracta end. Care must be taken to inspect this point in all the other measure points.

11. The flow-meter furnished to integrate the flow in the delivery point is not taking into account the gas content in the steam. The possible error in the measure is related directly with the amount of gas content in the steam. In Cerro Prieto this amount of gas is between 1.3% and 3.2% by weight depending on the resource.

12. The information exchange with the manufacturer and possible modification in the algorithm to calculate the density is not an easy task. It is necessary to modify the algorithm of the flow totalizer.

13. Certifying a measurement point in geothermal fields could represent an expensive operation, specifically obtaining the required roughness inside the pipeline. Each time a work-over of the power plant is programmed, also a cleaning job inside the pipe must be programmed to reduce this effect. However, the influence of the roughness in the accuracy of this measurement is not evaluated.

References

- International Standard Organization 5167:2003.- Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full.- Part 1.- General principles and requirements. ISO 5167-1
- International Standard Organization 5167:2003.- Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full.- Part 2.- Orifices Plates.
- Flow of Fluids Through Valves, Fittings and Pipe.- Crane Co.
- ASTM A-134:1996.- Standard Specification for Pipe, Steel, Electric-Fusion (Arc)-Welded (Size NPS 16 and Over).
- American Petroleum Institute.- API Specification 5L:2000.- Specification for Line Pipe. Forty-Second Edition.

