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Impacts of metering technology, BS&W and temperature on the metrological performance of oil fiscal flowmeters

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1 INTRODUCTION

After more than 40 years of oil and gas exploration and production, Brazilian mature offshore fields have been producing more water than ever. Besides the effects of the high amount of water on the oil processing, the oil metering system performance is also impacted by this condition.

According to the Brazilian Technical Regulation for Petroleum and Natural Gas Measurement (RTM), which is a joint resolution from Brazilian Regulatory Agency (ANP) and Brazilian National Institute of Metrology (INMETRO), for an oil fiscal metering system, the oil must be stable and with a BS&W value lower than 1%.

Therefore, if the daily BS&W is above the 1%, it is considered a metering failure event which needs to be electronically communicated to ANP within 3 days from its detection. In addition to that, according to ANP guidance, for all fiscal metering of oil with BS&W above 2%, correction factors ranging from 1,44% to 10,89% must be applied on the oil volumes, depending on the daily BS&W, regardless the technology of the metering system or any other process condition.

Table 1 – BS&W correction factors for oil fiscal metering

BS&W	Correction Factor
2% < BS&W ≤ 30%	1,0144
30% < BS&W ≤ 50%	1,0780
BS&W ≥ 50%	1,1089

The RTM also determines that any oil fiscal metering system must have an accuracy class 0.3 (maximum flowmeter error equals to 0,2%) to comply to OIML R 117 standard and its flowmeter needs to have a type/model approval issued by INMETRO.

Another RTM requirement is that any oil fiscal metering system must be installed before any storage facility (e.g., FPSO cargo tanks). Since not all FPSOs are able to reprocess the produced oil to comply with the BS&W limit, short and atypical process problems may incur additional costs for oil and gas operators in the order of thousands of dollars in payment of royalties and causing operational problems related to stock differences due the application of arbitrary correction factors.

To evaluate if metering technology and other process conditions such as BS&W, fluid temperature and flow rates impact the metrological performance of the flowmeter, an experiment was conducted by an independent laboratory with four of the most used technologies for oil flow rate measurement: positive displacement, ultrasonic, turbine and coriolis.

2 EXPERIMENTAL FACILITY AND METERING SCHEME

The experimental setup consisted of a closed loop where the flowmeters were placed in serial with the prover on a horizontal line. To mitigate issues of calibrating ultrasonic and coriolis meters directly against a prover, a positive displacement master meter was also used as a reference for all meters.

All flowmeters used in the experiment have type/model approval issued by INMETRO for fiscal metering (accuracy class 0.3). Table 2 shows the details for each flowmeter.

Table 2 – Flowmeter details

Flowmeter Technology	DN Size (mm)	Q_{min} (m^3/h)	Q_{max} (m^3/h)
Positive Displacement	100	7,2	72
Ultrasonic	150	12,6	630
Turbine	200	100	1000
Coriolis	100	21	415

The ultrasonic and turbine meters were placed together right at an upstream straight pipe since both typically depend on the flow profile and/or swirl effects. Since the positive displacement meter used in the experiment worked in lower flow rates than the other meters, it was installed in a bypass line to avoid any damage while operating in higher flow rates.

On the loop, there were also a hydraulic pump, valves, and a compensation tower to mitigate any changes in volume of the fluid and piping due to thermal expansion. The control of the fluid temperature was done using a heat exchanger. To increase the temperature, the heat generated by the hydraulic pump was enough, however, to cool the fluid, a water chiller was used.

To monitor and ensure a homogeneous and fully developed flow during the experiment, two glass tubes were installed on the loop along with several fluid sampling points. Also, the fluid density was monitored using the coriolis meter readings and the velocity profile was evaluated using the ultrasonic flowmeter diagnostics functions.

Figure 1 shows the schematics of the flow loop.

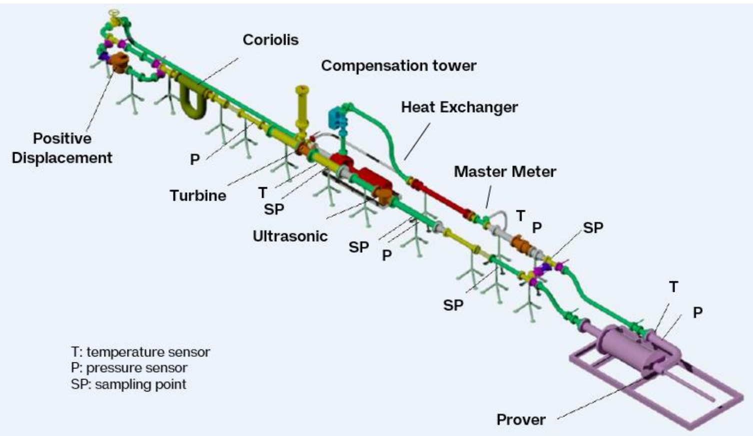

Figure 1 – Flow loop schematics

3 TEST MATRIX AND PROCEDURES

Each flowmeter was evaluated under different process conditions. Table 3 shows the test matrix used on the experiment.

Table 3 - Test matrix

<table>
<tr><th>Meter</th><th>BS&W
(%)</th><th>Temperature
(°C)</th><th>Flow Rate
(m³/h)</th></tr>
<tr><td>Positive Displacement</td><td rowspan="4">0
2
5
10</td><td rowspan="4">25
34
43</td><td>35, 50, 65, 80</td></tr>
<tr><td>Ultrasonic</td><td rowspan="3">100, 125, 150, 175</td></tr>
<tr><td>Coriolis</td></tr>
<tr><td>Turbine</td></tr>
</table>

To initiate the experiment, the loop was filled with pure mineral oil, that is, BS&W = 0%. Table 4 details this initial load.

Table 4 – Initial load

Mass	1030,8 kg
Density @ 25 °C	0,8508 kg/L
Volume @ 25 ° C	1211,5 L

Since the fluid was heated by the operation of the hydraulic pump, the fluid was set initially to 25 °C and data was collected starting by the higher flow rates. Using the water chiller to cool down and control the fluid temperature, data for the lower rates was acquired. For each experimental condition, at least 3 metering points were acquired.

Once changing the BS&W condition was an irreversible process, the fluid was heated to 34 °C and data was acquired for all flow rates, also starting by the higher flow rates. Once completed, the fluid was heated to 43 °C and the procedure repeated.

Despite having several temperature sensors along the loop, the one associated with the master meter was used to set the reference temperature, since it was one closest to the heat exchange.

To run the experiment with the next BS&W condition, 2% of the mineral oil was removed from the loop and later added water in the same proportion. To ensure the homogeneity of the fluid, before starting the test, the pump was set to 50 m³/h and all bypasses on the loop were opened. After the observing the fluid at the glass tubes and the stabilization of the density measured by the coriolis meter (figure 2), the tests were initiated. This procedure was applied for all changes regarding the BS&W condition.

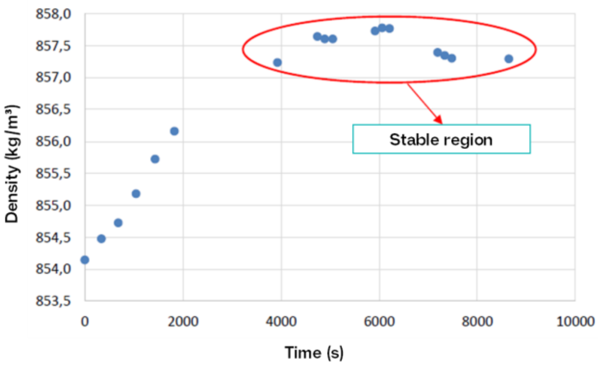

Figure 2 - Density stabilization after changing BS&W condition

To collect the data, fluid temperature was set at 25 °C. The same procedure applied for BS&W = 0% was repeated by starting the experiment with the higher flow rates and then heating the fluid until the next temperature condition.

To reach the BS&W = 5% condition, it was necessary to consider that, when removing a volume of fluid from the loop, now part of this fluid is oil and part is water. Therefore, before removing any fluid from the loop, the pump was set to 50 m³/h and the fluid was observed through the glass tubes (Figure 3). Once the fluid became homogeneous, it was removed from the loop and water was added to achieve the desired BS&W condition. Also, the flow profile was monitored during this procedure using the diagnostics features provided by the ultrasonic flowmeter (Figure 4).

Figure 3 - Fluid observation at the glass tubes

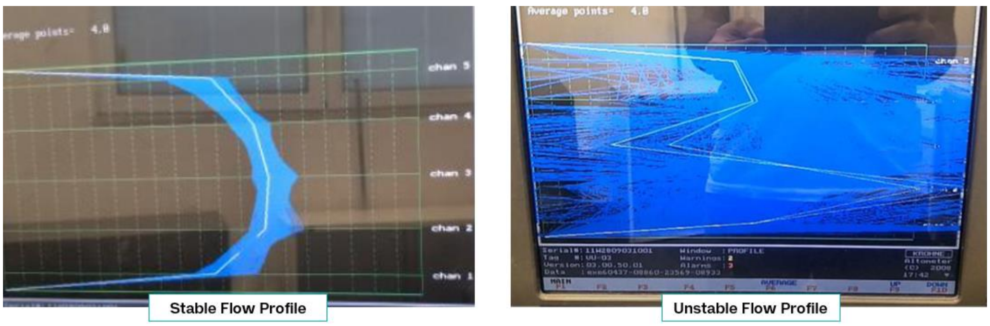

Figure 4 - Examples of flow profile diagnostics by the ultrasonic flowmeter

The same procedure used for the other BS&W conditions were used to acquire data for BS&W = 5% and BS&W = 10% in all temperatures and flow rates.

4 RESULTS

The objective of the experiment was to evaluate the impact on the metrological performance of each flowmeter technology under different conditions of BS&W, fluid temperature and flow rates. Therefore, the results for BS&W = 0%, which is the ideal metering condition, were considered as the baseline.

For each condition, the difference (error) between the flow rate indicated by the master meter and by the flowmeter under evaluation was registered. The flow rates were compensated by the fluid pressure (***CPL***) and temperature (***CTL***) using API standards for oil, despite the percentage of water in the fluid.

$$Error_{meter} = \frac{Q_{meter} - Q_{master}}{Q_{master}}$$

Later, this error was compared to the error indicated for the same temperature and flow rate but acquired for BS&W = 0%, in terms of the absolute difference.

$$\Delta_{\mathrm{BS\&W}} = |Error_{BS\&W=0\%} - Error_{BS\&W}|$$

The results for each flowmeter technology are presented below.

4.1 Positive Displacement

Table 5 – Results for the positive displacement flowmeter

Temperature (°C)	Flow Rate (m^3/h)	$\Delta_{BS\&W}$		
		2%	**5%**	**10%**
25	35	0,12	0,06	0,07
	50	0,06	0,03	0,07
	65	0,21	0,10	0,12
	80	0,08	0,09	0,10
34	35	0,01	0,03	0,07
	50	0,05	0,09	0,12
	65	0,12	0,04	0,03
	80	0,20	0,04	0,08
43	35	0,02	0,16	0,08
	50	0,18	0,08	0,04
	65	0,03	0,03	0,04
	80	0,10	0,14	0,01
Min($\Delta_{BS\&W}$)		**0,01**	**0,03**	**0,01**
Max($\Delta_{BS\&W}$)		**0,21**	**0,16**	**0,12**
$\overline{\Delta_{BS\&W}}$		**0,10**	**0,07**	**0,07**

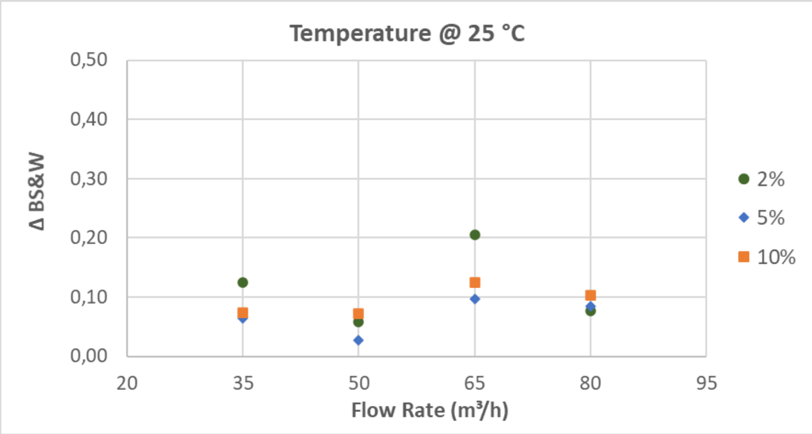

Figure 5 – Results for positive displacement flowmeter (T=25 °C)

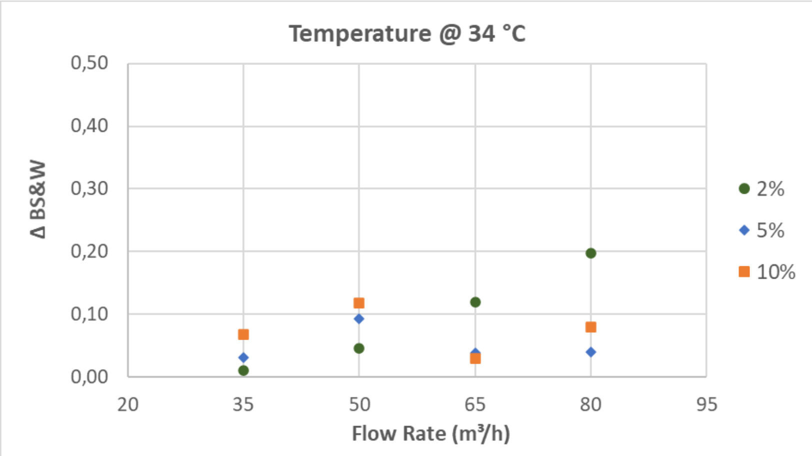

Figure 6 – Results for positive displacement flowmeter (T=34 °C)

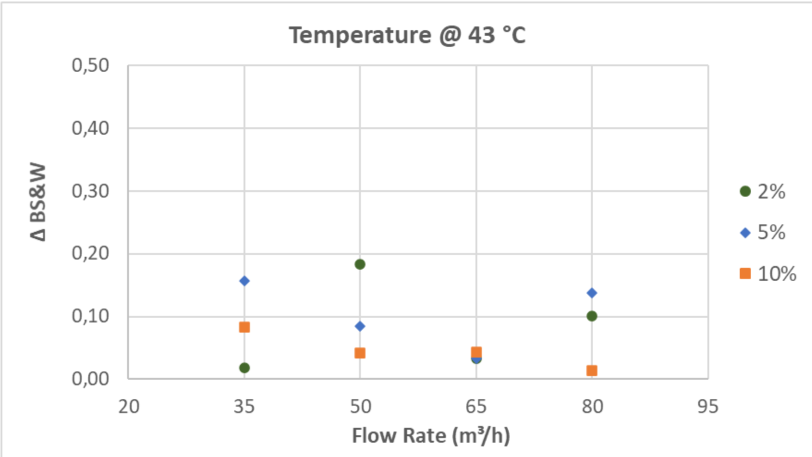

Figure 7 – Results for positive displacement flowmeter (T=43 °C)

Analyzing the results, the minimum difference was close to zero for all BS&W conditions and the average values considering all temperature and flow rates showed little variation as expected for a flowmeter which technology is based on the displacement of a fixed volume.

4.2 Ultrasonic

Table 6 – Results fo the positive displacement flowmeter

Temperature (°C)	Flow Rate (m³/h)	$\Delta_{BS\&W}$		
		2%	**5%**	**10%**
25	100	0,02	0,01	0,05
	125	0,01	0,01	0,02
	150	0,02	0,01	0,04
	175	0,03	0,01	0,03
34	100	0,01	0,03	0,04
	125	0,01	0,01	0,04
	150	0,02	0,04	0,06
	175	0,03	0,04	0,03
43	100	0,01	0,04	0,05
	125	0,03	0,01	0,08
	150	0,02	0,03	0,05
	175	0,02	0,05	0,11
Min($\Delta_{BS\&W}$)		**0,01**	**0,01**	**0,02**
Max($\Delta_{BS\&W}$)		**0,03**	**0,05**	**0,11**
$\overline{\Delta_{BS\&W}}$		**0,02**	**0,02**	**0,05**

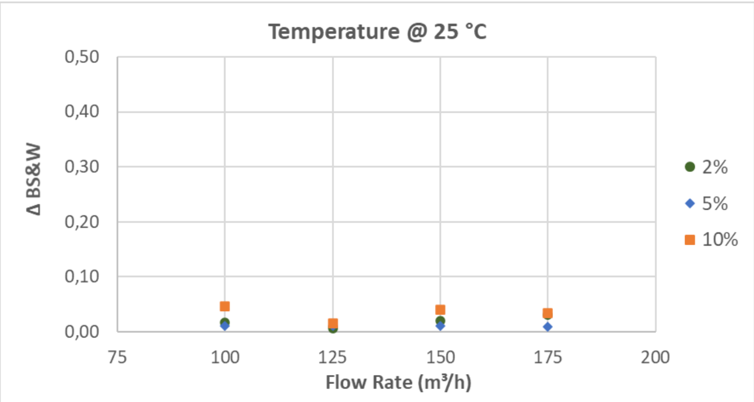

Figure 8 – Results for ultrasonic flowmeter (T=25 °C)

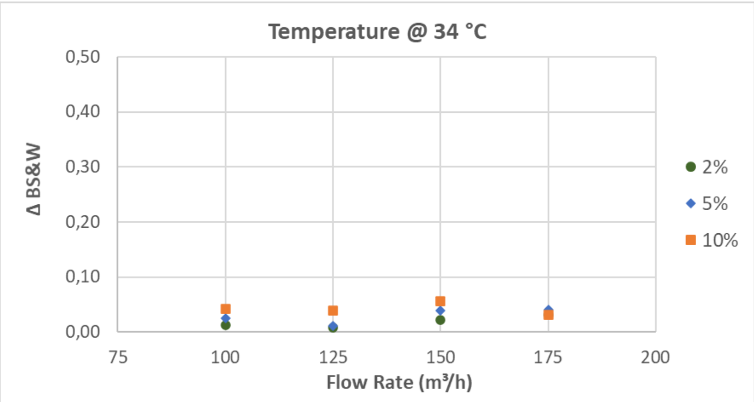

Figure 9 – Results for ultrasonic flowmeter (T=34 °C)

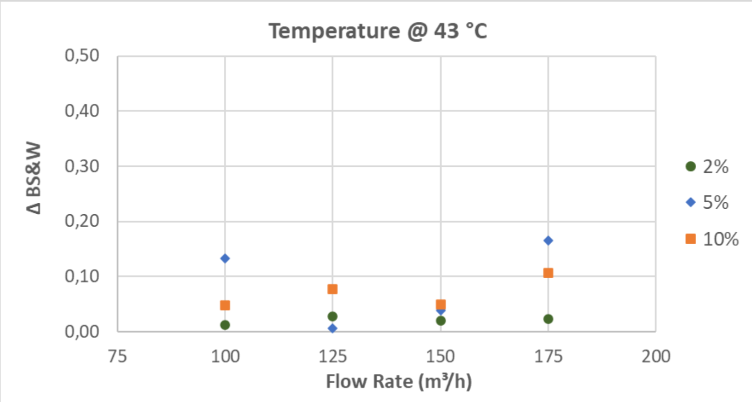

Figure 10 – Results for ultrasonic flowmeter (T=43 °C)

The experiment showed that the minimum difference was close to zero for all BS&W conditions. The difference slightly increases for higher BS&Ws as expected since the metering results are dependent on the flow profile.

4.3 Turbine

Table 7 – Results for the turbine flowmeter

Temperature (°C)	Flow Rate (m^3/h)	$\Delta_{BS\&W}$		
		2%	**5%**	**10%**
25	100	0,14	0,19	0,23
	125	0,08	0,23	0,18
	150	0,02	0,10	0,17
	175	0,08	0,06	0,28
34	100	0,02	0,06	0,26
	125	0,11	0,14	0,19
	150	0,02	0,05	0,30
	175	0,10	0,06	0,40
43	100	0,04	0,13	0,20
	125	0,21	0,01	0,18
	150	0,24	0,04	0,18
	175	0,08	0,17	0,13
Min($\Delta_{BS\&W}$)		**0,02**	**0,01**	**0,13**
Max($\Delta_{BS\&W}$)		**0,24**	**0,23**	**0,40**
$\overline{\Delta_{BS\&W}}$		**0,10**	**0,10**	**0,23**

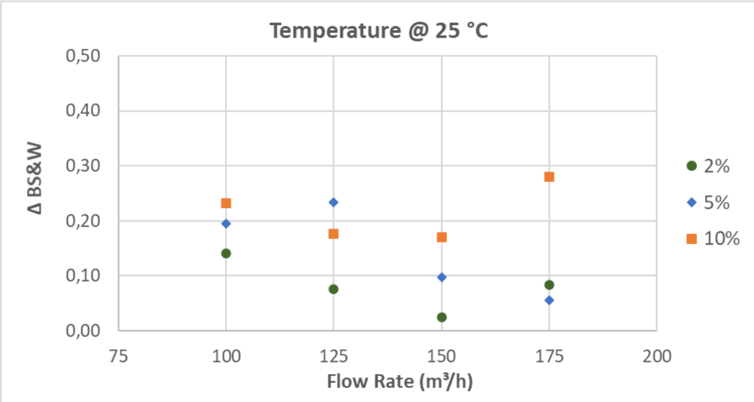

Figure 11 – Results for turbine flowmeter (T=25 °C)

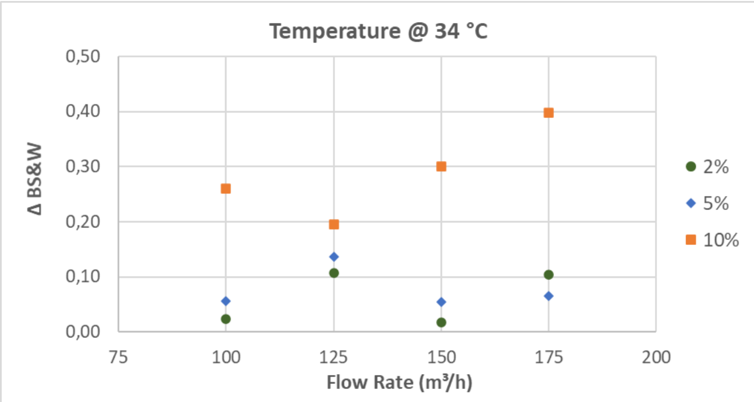

Figure 12 – Results for turbine flowmeter (T=34 °C)

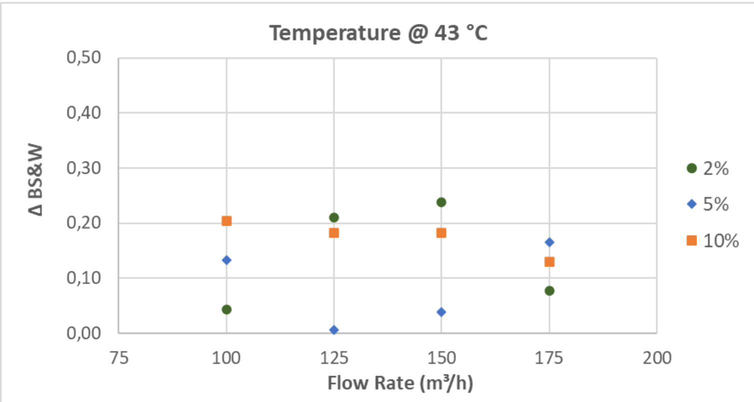

Figure 13 – Results for turbine flowmeter (T=43 °C)

For the turbine flowmeter, in comparison with lower BS&W values (2% and 5%) the difference for BS&W=10% was higher. This was expected since this technology is sensitive to fluid properties and flow disturbance effects.

4.4 Coriolis

Table 8 – Results for the Coriolis flowmeter

Temperature (°C)	Flow Rate (m^3/h)	$\Delta_{BS\&W}$ 2%	5%	10%
25	100	0,12	0,03	0,16
	125	0,09	0,03	0,13
	150	0,16	0,06	0,08
	175	0,09	0,06	0,07
34	100	0,08	0,06	0,00
	125	0,02	0,03	0,02
	150	0,03	0,02	0,01
	175	0,02	0,00	0,03
43	100	0,05	0,00	0,21
	125	0,07	0,04	0,02
	150	0,03	0,02	0,04
	175	0,07	0,04	0,00
Min($\Delta_{BS\&W}$)		**0,02**	**0,00**	**0,00**
Max($\Delta_{BS\&W}$)		**0,16**	**0,06**	**0,21**
$\overline{\Delta_{BS\&W}}$		**0,07**	**0,03**	**0,06**

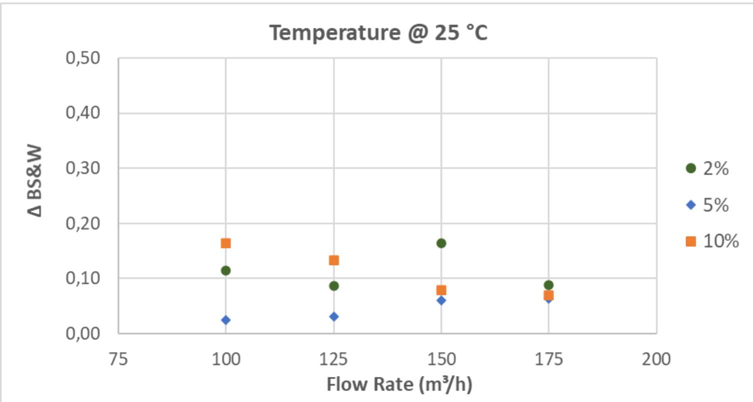

Figure 14 – Results for coriolis flowmeter (T=25 °C)

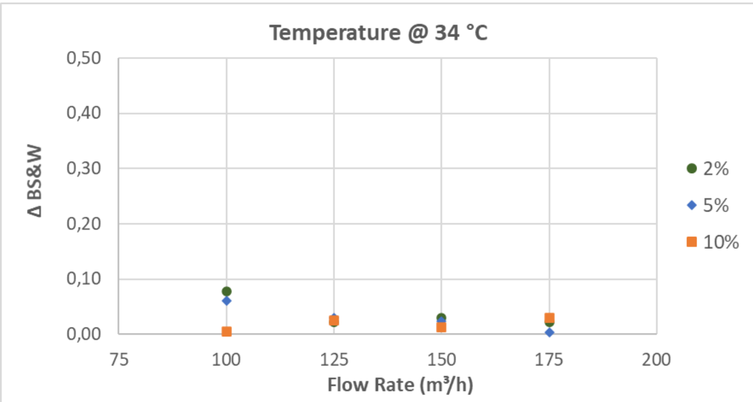

Figure 15 – Results for coriolis flowmeter (T=34 °C)

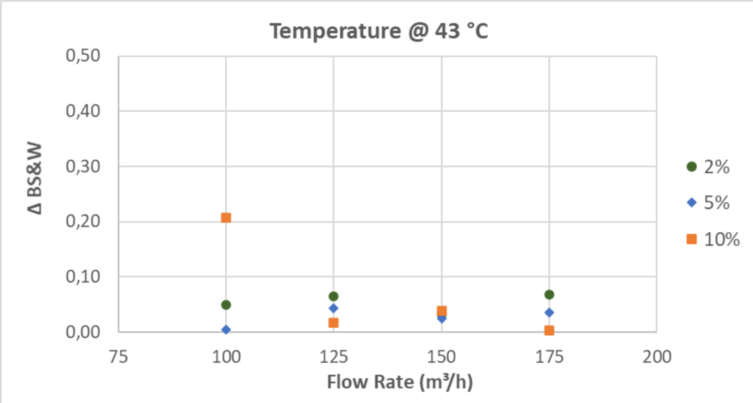

Figure 16 – Results for coriolis flowmeter (T=43 °C)

Since the coriolis is a mass flowmeter, as expected, it showed to be very robust to deal with different BS&W conditions. Even for higher BS&W, the difference was very low.

5 CONCLUSIONS

The experiment showed that the flowmeter technology plays a key role on the flowmeter performance when the BS&W varies.

For BS&W values below 5%, the error is very low for all flowmeters. Therefore, applying correction factors from BS&W greater than 2% can be extremely conservative. Also, the maximum error obtained for the whole test matrix (0,40) is lower than the minimum correction factor currently in place in Brazil (1,0144).

Despite evaluating the most used oil flow metering technologies, this experiment alone is not suitable to define new corrections factors. It is recommended to carry out more tests, contemplating a test matrix closer to real operational conditions (higher flow rates and crude oil) and the evaluation of more models of each metering technology.

6 REFERENCES

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