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Liquid hydrocarbon flow meters calibration with high flow and viscosity: Conceptual design of a new facility☆

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ABSTRACT

The oil and natural gas production market is heavily regulated with specifications that are almost always defined and valid for each producing country. In all the focus is to ensure accurate and complete results in volumes produced but with specificities of each location. In Brazil this regulation was created in the year 2000 (Joint Ordinance No. 001 between the National Petroleum Agency - ANP and the National Institute of Metrology, Quality and Technology - INMETRO) and in the 2013 review it was specified that liquid hydrocarbon flow meters should be calibrated with fluid under the conditions closest to those found in the operation considering density, viscosity, flow, pressure and temperature. However, the type of oil produced in Brazilian fields typically has high viscosity and there is an additional aspect due to the use of FPSO (Floating Production Storage and Offloading) type production platforms: flow to tankers occurs at high flow rates. There are several restrictions in laboratories worldwide to meet these conditions (high viscosity with high flow) and so the purpose of this paper is to present a proposal that technically meets the conditions imposed by Brazilian regulations and that will serve as a reference for operations in other similar fields. The project considers the laboratory should be able to perform calibrations up to 3200 m^3/h, oil densities above 0.88, with flexibility for changing calibration fluid, pressure and temperature control and viscosities up to 700 cP. To this end, a broad evaluation was carried out with solution providers and a research group within the university to technical support

1. Introduction

In accordance with the International Vocabulary of Metrology [1], calibration “establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication”. In this context, it is evident the importance of adequate metrological control of equipment within the Quality System which the measurement results affect directly or indirectly the quality of the product, process or service. This is the situation found in metering systems designed to custody transfer or fiscal measurement for liquid and gaseous hydrocarbons because they involve high value-added products [2].

Producer countries has created metering regulations for the oil and gas market because the accuracy or flow meter directly affects the product valuation and royalty payments when applicable. The metrological control requirements typically consider the meter calibration frequencies, procedures and the maximum uncertainty for the acceptance of metering system [3].

For reliable operation, the flowmeters should be therefore calibrated close to operating conditions [4] - several standards and regulations recommend calibration with the use fluid in similar working pressure and temperature, density and viscosity: it is the case of Brazilian rules [5].

The project considered operating ranges compatible with the

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Table 1
Requirements for oil flow meter calibration according to Brazilian law.

Calibration Fluid Conditions in Relation to Meter Operating Conditions	
Viscosity	±20%
Density	±20%
Temperature	±5 °C
Flow	±10%
Pressure	±10%
Maximum Calibration Frequency for Fiscal Measurement	
Coriolis Technology	6 months
Ultrasonic Technology	6 months
Rotating Technology	3 months
Other Technology	3 months
Maximum Calibration Frequency for Custody Transfer	
Coriolis Technology	12 months
Ultrasonic Technology	12 months
Rotating Technology	18 months
Other Technology	12 months
Maximum Uncertainty	
Fiscal Measurement	±0.3%
Custody Transfer	±1.0%

Source: ANP [5].

demand of the Brazilian market (flow rate up to 3200 m^3/h, pressure from [0.2 to 2] MPa, temperature controlled from [40 to 100] °C, oil densities above 0.88, flexibility for changing calibration fluid and viscosities up to 700 cP). State-of-the-art Effect Coriolis-based measurement technology has been defined with dynamic pressure and temperature compensation to minimize their effects on final uncertainty. Also, the fact that this technology is not influenced by viscosity variations that will be found in the laboratory was decisive in this decision.

Currently the flow meters to ranges above 1200 m^3/h have been calibrated abroad as Brazilian laboratories do not have accreditation for larger ranges. For these low range meters calibrated in Brazil, uncertainties of 0.12% have been practiced and abroad, 0.1% is obtained even though Brazilian legislation allows up to 0.3%. As there are not international laboratories for operation with the type of oil found in the country, the Brazilian metrological agency has provisionally accepted the calibration with low viscosity fluids and without temperature and pressure control. The project presented would be a definitive solution to this demand.

Note that the project focus to comply with the Brazilian regulation of the liquid hydrocarbon market, which requires the flowmeters calibration with the process fluid under the closest possible operating conditions. Thus, the object is not on obtaining low uncertainty values but on meeting the requirements of the process conditions but with a maximum of 0.3% of total uncertainty that is the limit of this legislation.

Understanding local requirements and finding technical solutions to meet them is critical and for it, this paper is organized as follows: Section 2 briefly describes the current situation for liquid hydrocarbons (oil) flowmeter calibration, Section 3 details the research method considered in this work, Section 4 describes the main components of the project and the solutions defined.

2. Brazilian oil flowmeter calibration – the current situation

Table 1 specifies some of these requirements of Brazilian rules [5] applicable for oil in-line metering systems (most common) and which may vary among different countries that have these regulations.

Particularly Brazil has two important aspects that make the calibration of these meters even more complex: a) the large production in deep water fields and; b) the extraction of oil with high viscosities. The vast majority of the large hydrocarbon production fields in Brazil occur on the continental platform with water depths of up to 2000 m. For this reason, Brazil uses FPSO (Floating Production Storage and Offloading) type production units. FPSOs are preferred in frontier offshore regions as they are easy to install, and do not require a local pipeline infrastructure to export oil. A FPSO vessel is designed to receive hydrocarbons produced by itself or from nearby platforms or subsea template, process them, and store oil until it can be offloaded onto a tanker or, less frequently, transported through a pipeline. For economic reasons the oil transferring oil process from FPSO to the tanker should be performed at high flow rates to reduce transport time. Thus, process lines of [16 to 20]" are used with flow rates [2000 to 5000] m^3/h [6]. In addition, these main producing fields operate with density oil above 0.720 (middle/heavy oil) as shown in Table 2.

Table 2
Characteristics of produced oil in Brazil (2018).

Field	Density (ref. water @ 4 °C)	Production (MMm^3/d)	Oil Type
Lula	0.871	42,966.519	Middle
Sapinhoá	0.876	14,709.453	Middle
Roncador	0.917	14,189.895	Heavy
Jubarte	0.906	11,428.812	Heavy
Marlim Sul	0.933	9563.091	Heavy
Marlim	0.932	8205.467	Heavy
Cabiúnas Mistura	0.901	4699.399	Heavy
Marlim Leste	0.906	3885.074	Heavy
Peregrino	0.975	3879.355	Extra Heavy
Cachalote	0.911	3459.913	Heavy
Barracuda	0.906	2932.601	Heavy
Albacora	0.894	2917.862	Heavy
Albacora Leste	0.940	2864.326	Heavy
RGN Mistura	0.900	2618.577	Heavy
Baleia Azul	0.880	2439.928	Middle
Lapa	0.916	2073.512	Heavy
Other		19,305.577	

Source: ANP [7].

Finally, there is a question of the facilities availability to meet these requirements. According ISO/IEC 17025 [8], laboratories that can perform this service must demonstrate competence, metering capacity and traceability. The formal competence recognition is defined by its accreditation that, in Brazil, it is only performed by INMETRO but is acceptable any laboratory that are signatories to the ILAC Mutual Recognition Agreement Accreditation Cooperation) or IAAC (Inter-American Accreditation Cooperation). Table 3 summarizes the major international laboratories and Table 4 presents those in Brazil for use with liquid hydrocarbons which are the main object of this work.

It can be observed that Brazilian laboratories are limited to ranges of up to 1200 m^3/h and even international ones do not operate above 1260. m^3/h. In these tables it is possible to verify there is little flexibility in the use of different viscosities, pressure and temperature control of the test line.

In short, there is a high demand for oil flow meter calibration services, there are requirements under Brazilian law that must be met and the operating conditions for performing these calibrations are not available in existing laboratories - which justifies the study to find a solution to this problem.

3. Methods

The objective of this paper is to describe a solution developed for a laboratory construction with purpose of flowmeters calibration with high flow and high viscosity. This solution can be implemented in Brazil and can be reproduced in other countries with similar conditions. A working group was created within the university using the necessary expertise in conjunction with equipment manufacturers to prepare the conceptual project.

Table 3
International laboratories for liquid hydrocarbons flow.

Country	Linked Metrology Institute	Flow Range (m^3/h)	Uncertainty (%)	Test Fluid	Temperature Range (°C)	Pressure Range (MPa)	Viscosity (mm^2/s)	Calibration Method	Standard
Austria	BEV	0,0018 to 90	0.07 to 0.1	Gasoline, Light oil	14 to 17	0.05 to 0.6		Volumetric	Calibrated Tank
Taiwan	CMS	18 to 360	0.05	Light Oil	10 to 45	<0,5	2.5 to 150	Gravimetric	Tank Weight
Cuba	INMET	3 to 300	0.1 to 0.2	Gasoline, Kerosene, Light Oil	Ambient Temperature	<0.8		Volumetric	Calibrated Tank
Czech Republic	CMI	0.29 to 396	0.15 to 0.30	Kerosene, Light Oil	0 to 85	0.1 to 3.5		Volumetric	Pipe Prover
Denmark	FORCE	0.4 to 400	0.03	Oil Derivates				Volumetric	Pipe Prover
Germany	PTB	0.6 to 250	0.1	Oil Derivates	Ambient Temperature	0.35	0.77	Volumetric	Calibrated Tank
Italy	IMGC	0.0036 to 3.5	0.1	Kerosene, Light Oil	Ambient Temperature	0.15		Volumetric	Pipe Prover
Japan	NMIJ	15 to 300	0.03	Kerosene, Light Oil	15 to 35	0.1 to 0.7	1.4 to 1.9; 4.4 to 7.8	Gravimetric	Tank Weight
Korea	KRISS	1 to 14.8	0.11	Mineral Oil	15 to 30	0.1 to 0.3	600 to 2200	Gravimetric	Tank Weight
Mexico	CENAM	0.002 to 340	0.06 to 0.08	Oil Derivates	0 to 82	0.1 to 0.4	0.5 to 10	Volumetric	Pipe Prover
Poland	GUM	0.4 to 400	0.1	Light Oil	Ambient Temperature		0.3 to 300	Volumetric	Pipe Prover
Sweden	RISE	0.36 to 1260	0.1	Light Oil	20 to 120		300	Volumetric	Pipe Prover
Netherlands	NMI	0.001 to 250	0.04	Gasoline, Kerosene, Light Oil		0.4	0.7 to 8,5	Volumetric	Calibrated Tank
UK	NEL	0.00012 to 720	0.03 to 0.08	Kerosene, Light Oil, Heavy Oil	5 to 50	0.8	22 to 30	Gravimetric	Tank Weight

Source: Shimada et al. [9].

Table 4
Brazilian laboratories for liquid hydrocarbons flow.

Laboratory	Linked Metrology Institute	Test Fluid	Flow Range	Uncertainty (%)
CONAUT	INMETRO	Mineral Oil	[0.5 to 40] m^3/h	0.19%
			[40 to 700] m^3/h	0.16%
			[700 to 1200] m^3/h	0.12%
METROVAL	INMETRO	Mineral Oil	[0.002 to 0.1] m^3/min	0.04%
			[0.1 to 10] m^3/min	0.1%
			[0.514 to 10] m^3/min	0.1%
			[0.002 to 0.025] m^3/min	0.09%
			[0,025 to 0.050] m^3/min	0.042%
			[0.05 to 10] m^3/min	0.04%
			[20 to 25] m3^min	0.1%
IPT	INMETRO	Mineral Oil	[0.004 to 0.09] m^3/h	0.08%
			[0.09 to 0.8] m^3/h	0.05%
			[0.8 to 800] m^3/h	0.03%

Source: INMETRO [10].

4. Basis of new calibration facility for high viscosity and flow

4.1. Assumptions

Table 5 summarizes the study's assumptions for the main conditions necessary to meet Brazil's demands regarding the flowmeters calibration for fiscal or custody transfer metering systems.

Table 5
Typical project conditions.

Operational Conditions	Density Limits	Flow Range (m^3/h)	Pressure Range (MPa)	Static Viscosity Limits (cP)	Dynamics Viscosity Limits (cSt)
Normal Conditions	0.88 a 0.92	5 to 500	0.5 to 3	5 to 200	6 to 227
Worst Cases in Terms of Oil Density	0.95	1000	0.4	700	750
Worst Cases in Terms of Flow Range	0.95	3000	0.5	140	150

The project considers the laboratory should be able to perform calibrations up to 3200 m^3/h, oil densities above 0.88, with flexibility for changing calibration fluid, pressure and temperature control and viscosities up to 700 cP.

4.2. Overview

Fig. 1 represents a schematic summary of the laboratory project with symbology in accordance with ANSI/ISA 5.1–2009. The facility project consists of five closed loops, and the flow is generated by gear pumps for low/medium/high flow ranges (up to 1000 m^3/h) and centrifugal pumps for the highest flow lines (above 1000 m^3/h). Reference flowmeters are of the mass type by the Coriolis principle. The working fluid will be mineral oil and six tanks are foreseen for the storage with flexibility for fluid change with an automated valve control system. The temperature loop can be controlled from (40–100] °C using a controlled buffer tank and boiler and chiller system. The pressure at the test section is varied from [0.2 to 2] MPa by a control valve system. During operation, the temperature stability is expected around 0.5 °C for one test and the pressure stability is expected around 0.02 MPa. All connections are designed for the pressure rating class 600 in accordance with ASME B16.5 [11]. There will be an in-line calibration system for the reference

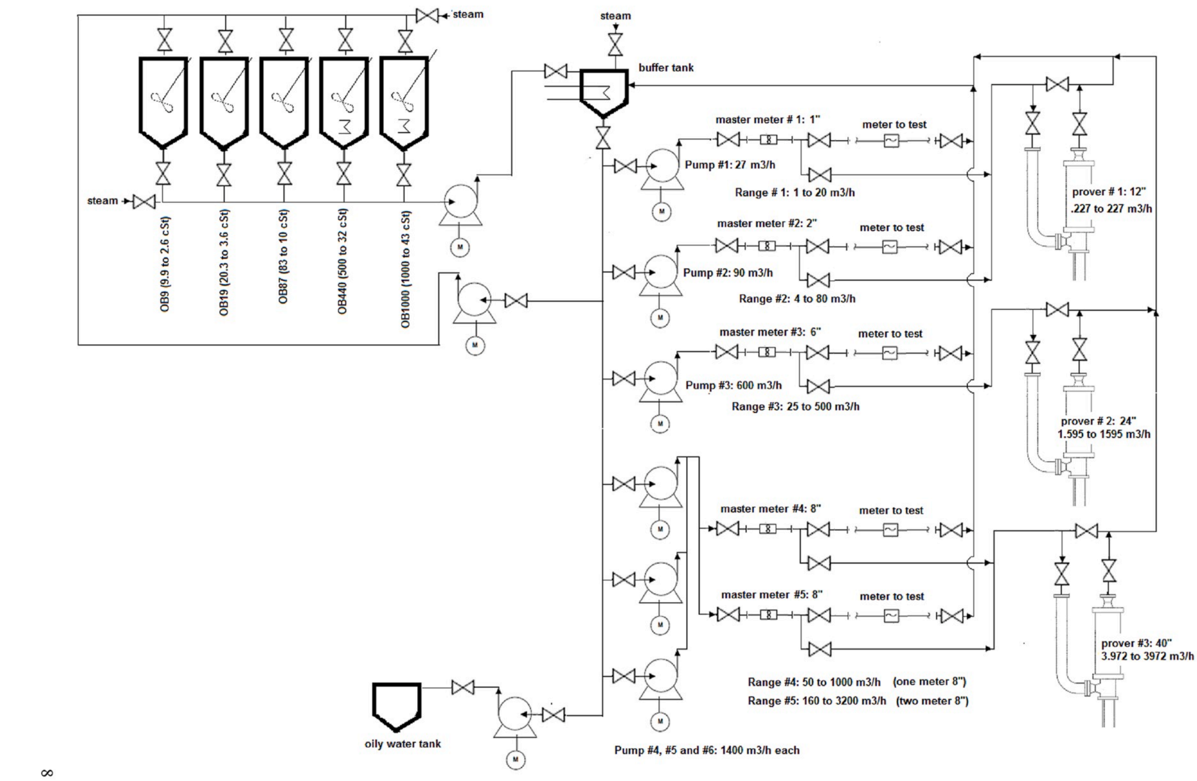

Fig. 1. Schematic summary of the laboratory project.

meters based on compact provers. In order to be able to change the test fluids there will be a steam line cleaning system. All laboratory operation will be done through a modern microprocessor hybrid control system with wired and wireless digital communication.

The project considers the whole assembly in modular structures and subdivided into subsystems:

a) Oil Storage Tanks System;
b) Reference Flowmeters System;
c) Compact Provers System;
d) Buffer Tank System;
e) Meter Test Line and Pressure Control System;
f) Pumps System;
g) Cleaning and Inertization System;
h) Automation System.

4.3. *Oil Storage Tanks System*

The project considered six 25,000 L storage tanks with five loaded with mineral oil and one will be used as reservoir and thereby enable the use of a specific oil for an application. Oils manufactured by Petrobras were specified with the following characteristics [12]:

a) Oil # 1: Lubrax OB9, code BR0118, naphthenic mineral type with a density of 0.8537 @ 20 °C (reference water @ 4 °C), viscosity 9.90 cSt @ 40 ° C and 2.61 cSt @ 100 ° C;
b) Oil # 2: Lubrax OB19, code BR0119, naphthenic mineral type with a density of 0.9017 @ 20 °C (reference water @ 4 °C), viscosity of 20.38 cSt @ 40 ° C and 3.59 cSt @ 100 ° C;
c) Oil # 3: Lubrax OB87, code BR0123, paraffinic mineral type with a density of 0.8765 @ 20 °C (reference water @ 4 °C), viscosity of 83.95 cSt @ 40 ° C and 10.23 cSt @ 100 ° C;
d) Oil # 4: Lubrax OB440, code BR0126, paraffinic mineral type with density 0.9023 @ 20 °C (reference water @ 4 °C), viscosity 502.1 cSt @ 40 ° C and 32.46 cSt @ 100 ° C.
e) Oil # 5: Lubrax OB1000, code Pb-0051, paraffinic mineral type with a density of 0.9340 @ 20 °C (reference water @ 4 °C), viscosity of 1000 cSt @ 40 ° C and 43 cSt @ 100 ° C.

Table 6 presents the main physicochemical characteristics of the chosen oils and we can observe that both the flash and combustion limits are far above the laboratory operating conditions. However, as oil

Table 6
Oil characteristics.

Oil Type	Combustion Point	Flash Point	Explosive Limits in Air	Specific Hazards	Hazardous Reactions
Lubrax OB9	>202 °C	>182 °C	Non flammable product	Low toxic product	Reacts exothermically when in contact with strong oxidizers (peroxides, chlorates, chromic acid, etc.). Heating above 60 ° C may cause decomposition of the product.
Lubrax OB19	>180 °C	>160 °C			
Lubrax OB87	>202 °C	>268 °C			
Lubrax OB440	>202 °C	>326 °C			
Lubrax OB1000	>340 °C	>290 °C			

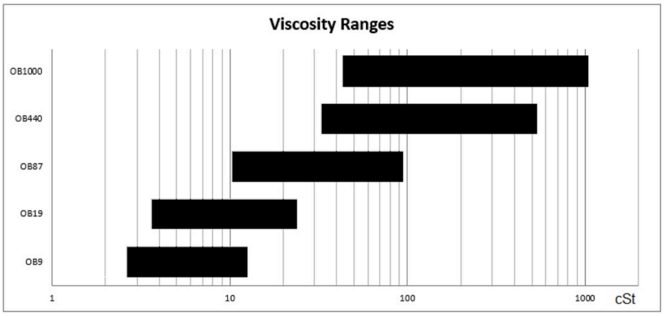

Fig. 2. Viscosity ranges by oil type.

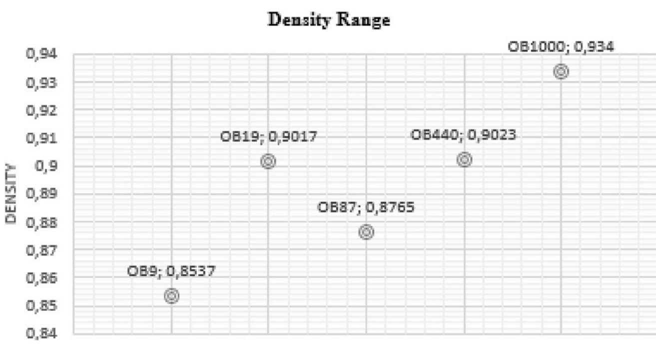

Fig. 3. Density ranges by oil type.

Table 7
Reference meter and loop ranges.

	Master Meter Model	Size	Maximum Flow	Loop Range
Very Low Flow Range	CMF100 M/L	1"	27.2 m3ˆh	[1 to 20] mˆ3/h
Low Flow Range	CMF200 M	2"	87.1 mˆ3/h	[4 to 80] mˆ3/h
Medium Flow Range	CMF400 M	6"	545 mˆ3/h	[25 to 500] mˆ3/h
High Flow Range	CMFHC2M	8"	1470 mˆ3/h	[50 to 1000] mˆ3/h
Very High Flow Range	2 x CMFHC2M	8"	3940 mˆ3/h	[160 to 3200] mˆ3/h

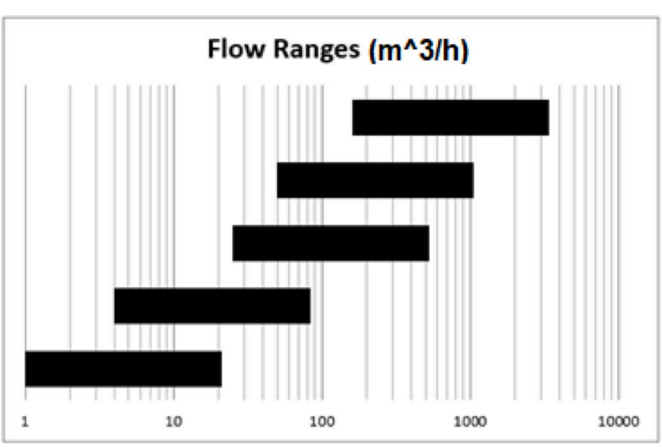

Fig. 4. Flow ranges.

degradation above 60 will occur, constant chemical analysis is foreseen for the need to discard them whenever there is operation at high temperatures. Regardless of the low oil hazard, appropriate protections are provided in the laboratory such as foam systems for hydrocarbons, water fog, chemical dust and dioxide of carbon (CO2).

Fig. 2 summarizes the operating ranges of these oils in terms of viscosity and Fig. 3 summarizes the density ranges.

It can be observed that the mineral oils chosen to cover the range of [2.61 to 750] cSt in terms of viscosity and 0.8537 to 0.935 which meets the project's operational needs. An inerting system is provided in each tank to minimize the evaporation of mineral oils and an oil heating system is also provided for the high viscosity tanks.

Table 8
Process effect at reference meter.

Master Meter Model	Process Temperature Effect at Mass Flow (note 1)	Process Temperature Effect at Density (note 2)	Process Pressure Effect at Mass Flow (note 3)	Process Pressure Effect at Density
CMF100 M/L	±0.0001	±0.015	−0.003	±0.0870
CMF200 M	±0.0005	±0.0005	−0.009	±0.0145
CMF400 M	±0.0008	±0.0008	−0.016	±0.1450
CMFHC2M	±0.000075	±0.000075	−0.023	±0.0406

Note 1: % of maximum mass flow rate per °C difference from calibration temperature.
Note 2: kg/mˆ3 per °C difference from calibration temperature.
Note 3: % of rate per 0,1 MPa difference from calibration pressure without dynamic pressure compensation.
Note 4: kg/m3 per 0,1 MPa difference from calibration pressure without dynamic pressure compensation.
Source: Micro Motion [13].

4.4. Reference Flowmeters System

In this facility project, calibration of the test meter is carried out by comparison with mass flowmeters by the Coriolis principle. Micro Motion Elite CMF model meters [13] were chosen due to low uncertainty (±0.05% of rate), repeatability (0.025% of rate) and rangeability 20:1. In Table 7 we have the specified model for each laboratory flow range. The laboratory considered five ranges of operation covering from [1 to 3200] mˆ3/h as presented in Fig. 4.

In Table 8 we have a summary of process pressure and temperature effects for these reference models, Whilst temperature is a critical parameter for flow measurement, this Coriolis flow meter model has an onboard live temperature measurement via the RTD (Resistance Temperature Detector) and incorporates temperature correction algorithms to correct its effects on the flow tube material so it is not affected by temperature process. In this table we also have the effect of the process pressure under the meter without dynamic pressure compensation. Although laboratory operation will occur at relatively low-pressure ranges ([0.2 to 2] MPa) and with that we would already have a negligible impact on uncertainty, we are considering the laboratory design with the use of dynamic pressure compensation and the algorithms implementation provided by the manufacturer. Also, the fact that this technology is not influenced by viscosity variations that will be found in the laboratory was decisive in this decision [14].

Fig. 5 represents the schematic of the reference system for low range line calibration with the location of the secondary instrumentation.

Note that the uncertainty of the standards is ± 0.05% of rate and as the specifications of Brazilian law is ± 0.3% for the entire measurement system and ± 0.2% only for the meter there is therefore a comfortable range to meet the requirements. We have not yet the expanded laboratory uncertainty which will be the next project phase, but the goal is to reach a final value of ± 0.3% according to local law.

It is also important to emphasize that according to Brazilian law all calibrations must be performed in volumetric units. Thus, we are considering Master Meter calibrated by volume although originally provide the values in mass terms. The models chosen measure both mass

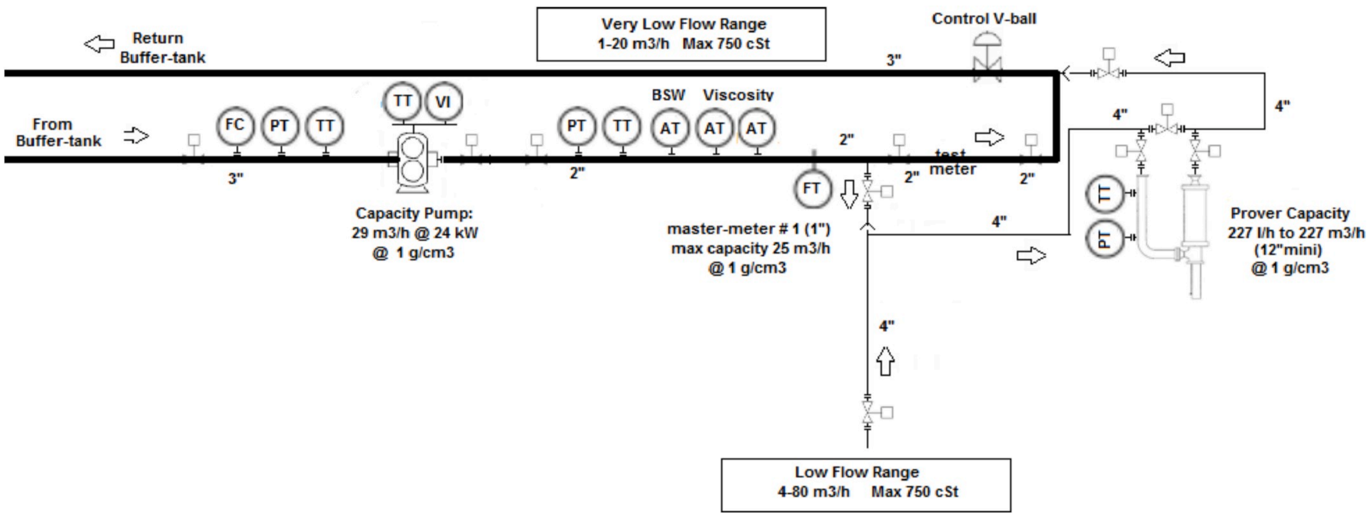

Fig. 5. Very low flow range detail.

Table 9
Compact prover and loop ranges.

Loop Range	Maximum Flow	Calibration Scheme				
		Compact Prover Model	Size	Nominal Prover Volume Base	Minimum Flow Range	Maximum Flow Range
Very Low Flow Range	27.2 m^3/h	Compact Prover12" - mini	12"	0.040 m^3	0.227 m^3/h	227 m^3/h
Low Flow Range	87.1 m^3/h	Compact Prover12" - mini	12"	0.040 m^3	0.227 m^3/h	227 m^3/h
Medium Flow Range	545 m^3/h	Compact Prover 24"	24"	0.250 m^3	1.595 m^3/h	1595 m^3/h
High Flow Range	1470 m^3/h	Compact Prover 40"	40"	0.650 m^3	3.972 m^3/h	3972 m^3/h
Very High Flow Range	2 × 1470 m^3/h	Compact Prover 40"	40"	0.650 m^3	3.972 m^3/h	3972 m^3/h

flow and density simultaneously and can thus be configured for volume processing. These models have a density uncertainty of +/0.02 kg/m^3 which is quite low to affect the system final performance. It is worth noting that local law defines 12 months for density meter calibration and so we are considering that annually this variable for Coriolis flow meter will be made externally in accredited laboratories in Brazil.

Observe in the loop diagram that BSW (Basic Sediment and Water) and viscosity in-line measurement is planned simultaneously and independently of the flow meters. These measurements are important for analyzing oil properties during the operation. Periodic oil analysis routines are also scheduled to check their integrity as operating temperatures above 60 °C may cause degradation of their characteristics.

4.5. Compact prover system

The calibration of reference flowmeters will be carried out by comparison with compact prover that provides high accuracy, rapid operation and proving without interrupting flow. It was chosen the Daniel Compact Prover [15] with 1000:1 flow rangeability and repeatability of 0.02% or better by comparison of the prover volume base with a

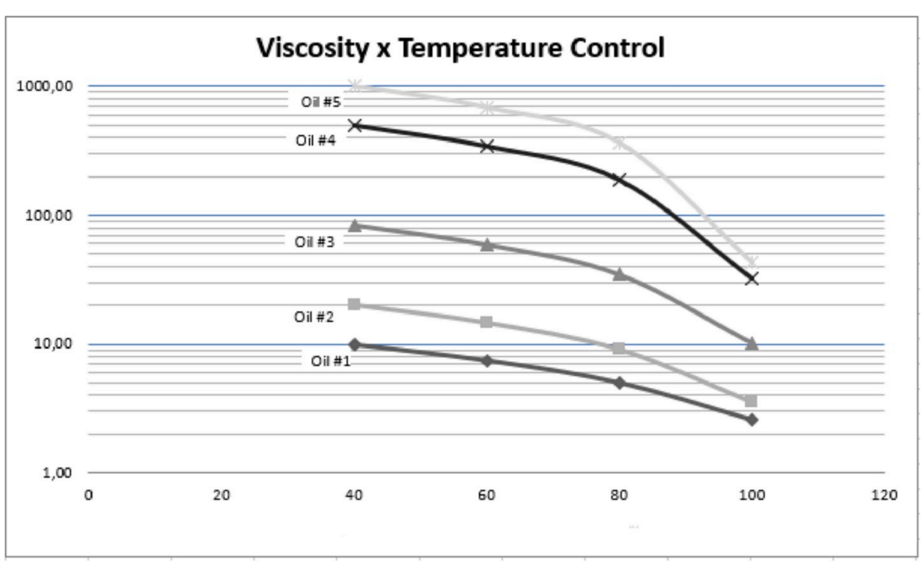

Fig. 6. Viscosity and temperature variation.

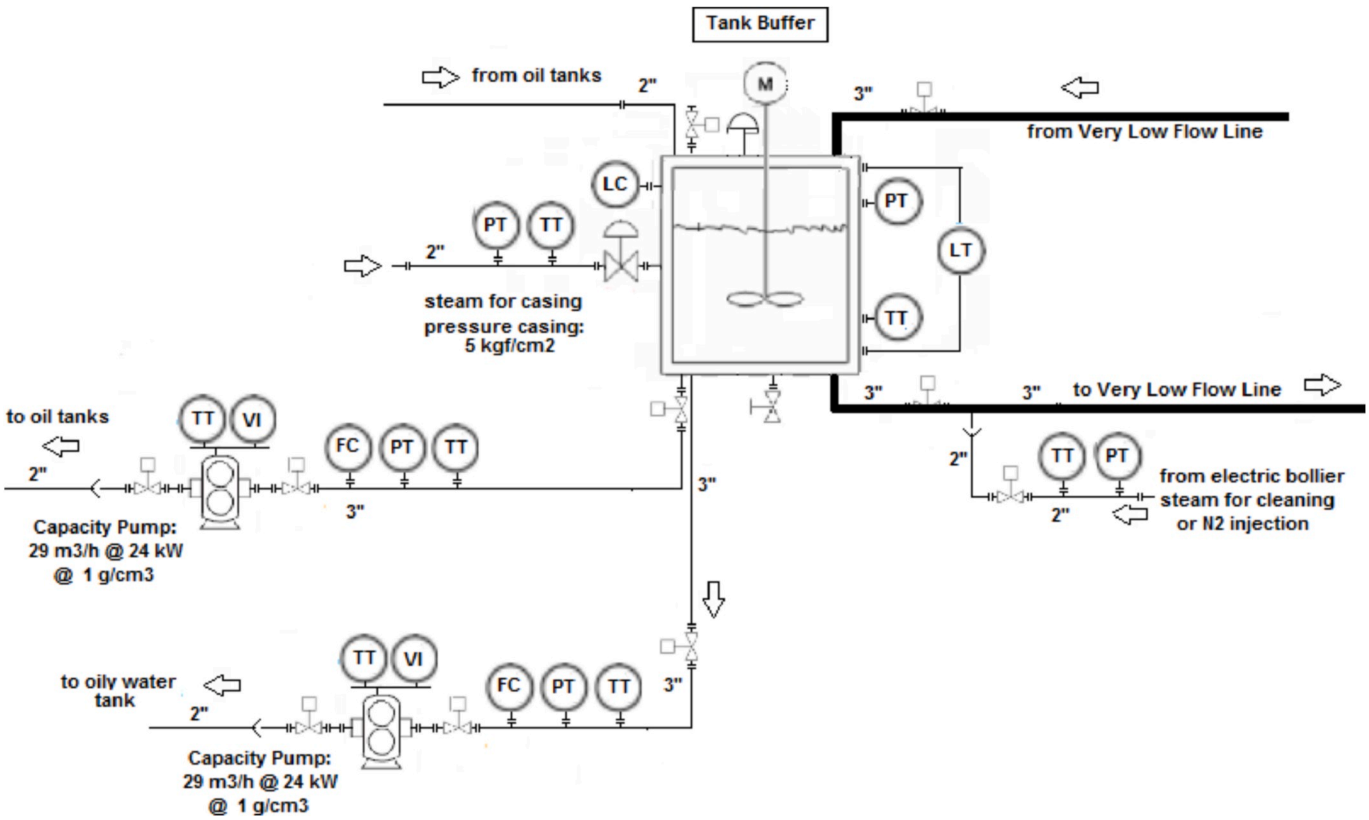

Fig. 7. Viscosity and temperature variation.

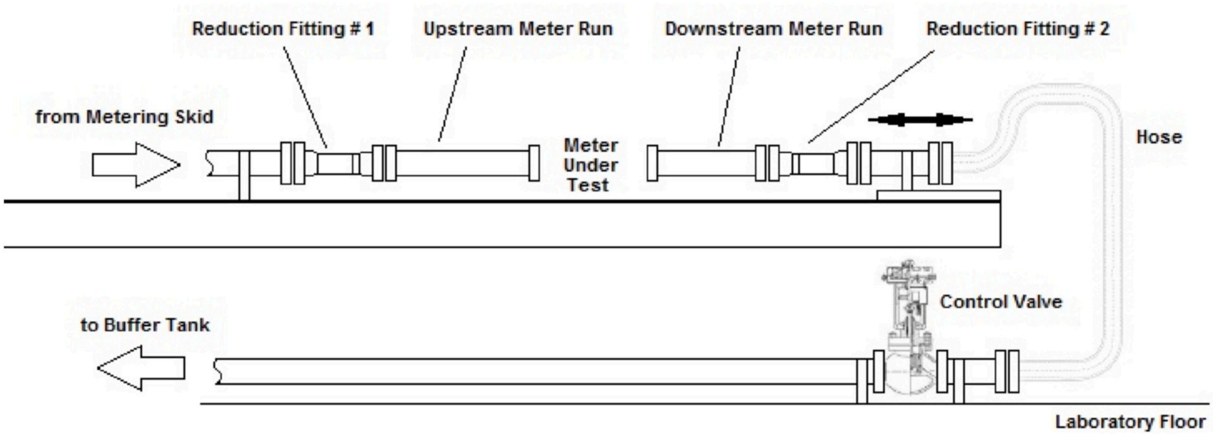

Fig. 8. Meter test line and pressure control system.

certified water weighing system (water draw). Table 9 summarizes the calibration scheme of the reference meters with the chosen provers.

The compact provers will be calibrated by static gravimetric method using external laboratories - it is not critical because Brazilian law defines the calibration of the compact every 36 months. The compact provers calibration can be performed in Brazil as there are accredited laboratories with volumetric capacity up to 5 mˆ3 and uncertainty of 0.009% - which is quite acceptable compared to the prover uncertainty.

4.6. Buffer Tank System

The solution considered the use of a buffer tank that will be responsible for filling the test lines and control of oil temperature. This tank was designed with a capacity of 20 mˆ3 and for the heating system was considered a steam injection from a boiler and a chiller system. Fig. 6 represents the variation in viscosity behavior with temperature.

The project considered a variation in the oil temperature from [40 to 100] °C which allows the control of the viscosity of the test oil in the range from [2.61 to 1000] cSt.

Fig. 7 shows the operation diagram of the tank buffer with the oil heating temperature control system using steam injection by tank casing.

4.7. Meter Test Line and Pressure Control System

Pressure control is accomplished by installing a control valve on the return line of each one of the test flows lines. Control valves will be used on 2" (very low flow loop), 4" (flow low loop), 8" (medium flow loop),

Table 10
Pump system.

Flow Line	Model/ Manufacturer	Capacity (@ 1 g/ cm^3)	Size	Motor
Loop Test Very High Range	RDL/KSB	1400 m^3/h	12"	600 kW
Loop Test High Range	ZH 400/ Zeilfelder	600 m^3/h	8"	112 kW
Loop Teste Medium Range	ZH 400/ Zeilfelder	600 m^3/h	8"	112 kW
Loop Test Low Range	ZH 100/ Zeilfelder	90 m^3/h	3"	80 kW
Loop Test Very Low Range	ZH 80/Zeilfelder	45 m^3/h	2"	20 kW
Flow to Loading the Buffer Tank	ZH 80/Zeilfelder	45 m^3/h	2"	20 kW
Flow to Return to Oil Tank	ZH 80/Zeilfelder	45 m^3/h	2"	20 kW
Flow to Oily Water Tank	ZH 80/Zeilfelder	45 m^3/h	2"	20 kW

12" (high flow loop) and 20" (very high flow loop). The control valves have been sized to allow pressure control between [0.02 and 2] MPa and this limitation is given by the pressure class of the connection between the meter floor and the return line as shown in Fig. 8.

In this project, the straight pipe length of over 50D is maintained upstream of the test flowmeter, a fully developed flow is expected at the test flowmeter. Moreover, one of the main reasons for using Coriolis effect mass technology as a reference flowmeter is precisely the fact that velocity profile effects are usually negligible to the project conditions [16].

The laboratory design assumes the focus to calibrate meters normally found in onshore and offshore production units. Typically, these meters are turbine, mass and ultrasonic type with varying diameters from [4 to 24]".

4.8. Pumps System

As high viscosity oil will be drained, gear pumps were chosen for loop test [17] of very low range, low range, medium and high range. For the very high range centrifugal pumps [18] were chosen that will limit viscosity in 40 cSt in this case. For the other flow lines were chosen gear pumps. Table 10 summarizes the pump capacity and the sizing of the electric motors for it.

As gear pumps are being used that generate large operating noise it has been predicted that the pumping system is located outside the laboratory work area.

4.9. Cleaning and inertization system

As oil of different characteristics will be used there will be a need for periodic cleaning of the lines after the operation. It was considering the use of a steam injection system that will drain oily water residues into a 15 m^3 capacity disposal tank. The oily water stored in this tank will be drained periodically to be treated in outdoor units specialized in this application. Lines after steam cleaning and the oil tanks will be inert with nitrogen for corrosion and hydrocarbon fume control. No contamination of oil from storage tanks is expected as the cleaning liquid will be discarded and nitrogen will keep the lines clean and dry.

4.10. Automation system

The project provides a complete automation system with all the necessary instrumentation for the automation of all laboratory activities including oil selection, line filling, meter calibration routines, proving routines, temperature control in the buffer tank, pressure control of the test lines, line cleaning and inertization system. Fig. 9 represents the complete process and instrumentation flow sheet for the project indicating all systems covered.

The figure indicates the buffer tank, proving system, cleaning system, oily water tank, oil storage tanks, pump system and the calibration lines with reference meters.

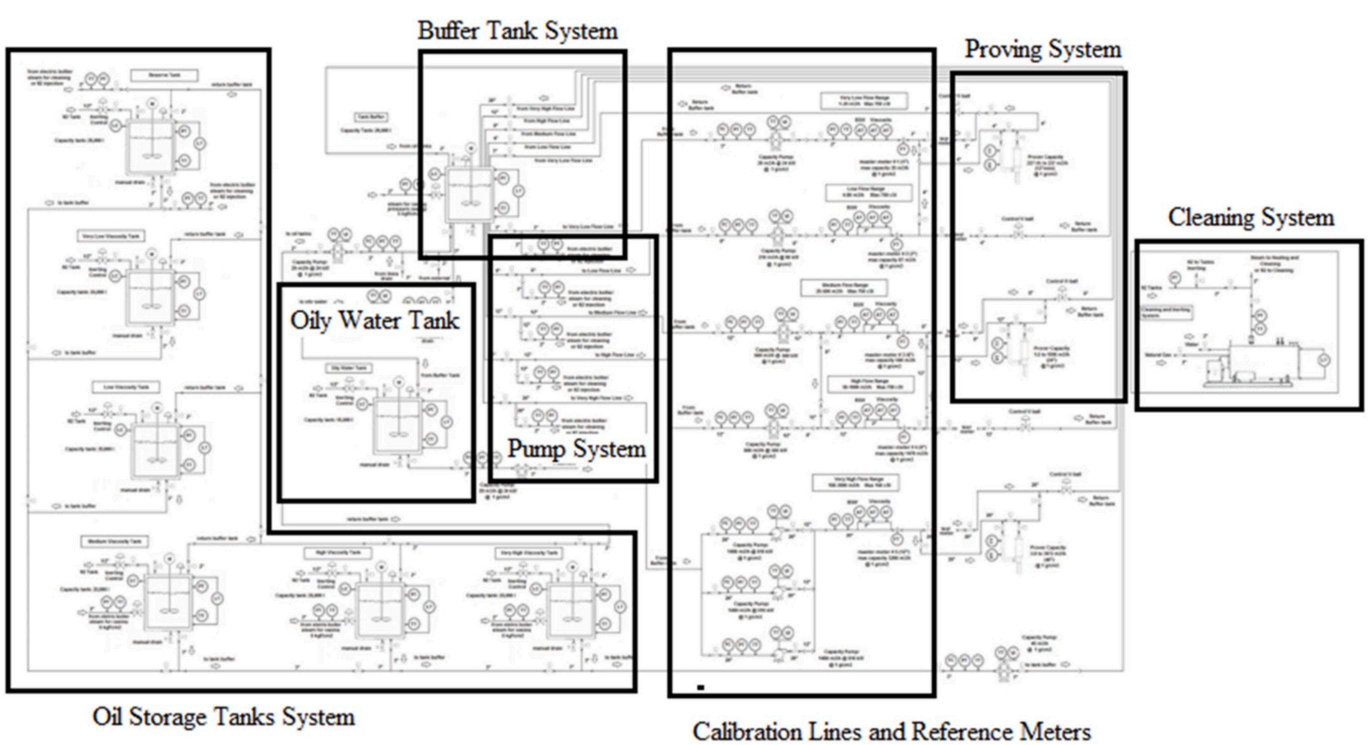

Fig. 9. P&I flow sheet.

5. Conclusion

In the present paper, a project of a new calibration facility for liquid hydrocarbons is described. A maximum flowrate of 3200 m^3/h is achieved with the use of five different types of mineral oil. This facility consists of five calibration loops with mass flowmeters by the Coriolis principle as reference. Compact provers are provided to calibrate the reference meters and a buffer tank where the oil temperature for test line will be controlled. The pressure control is through control valves and the oil changing to be used for calibration will be possible with a steam cleaning system implementation.

The proposed solution meets the requirements of Brazilian legislation but further studies for uncertainty calculations and velocity profile analysis are needed to give robustness to the project.

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This article portrays the basis of a conceptual project for the construction of a new calibration facility for liquid hydrocarbons. The project considers the laboratory should be able to perform calibrations up to 3200 m^3/h, oil densities above 0.88, with flexibility for changing calibration fluid, pressure and temperature control and viscosities up to 700 cP.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.flowmeasinst.2020.101749.

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