Review of the technologies used in fiscal oil measurements in Brazil

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Abstract. Brazil's oil and gas industry has a relevant presence in the sector's global market as it is one of the largest oil producers in Latin America and the world. The creation of the National Agency for Petroleum, Natural Gas and Biofuels (ANP) and the publication of the Technical Regulation for Measurement of Petroleum and Natural Gas (RTM) were government initiatives to regulate the sector and ensure operational control of oil and gas production. The present work seeks to provide detailed information about oil and natural gas measurement technologies, with the objective of assisting in the adequate selection of meters, guaranteeing the efficiency and accuracy of measurements in the oil industry. Therefore, the main technologies of flow meters used in oil and natural gas measurements are presented, such as Turbine, Ultrasonic, Coriolis and Positive Displacement meters. To select the best technology according to the intended application, the SWOT analysis (Strengths, Opportunities, Weaknesses and Threats) was carried out. Detailed information is also presented on how each technology works, as well as its strengths and weaknesses.

1. Introduction

Oil and natural gas production in Brazil plays a crucial role in the country's economy. The discovery of the pre-salt reserves had a positive impact on the national and international market due to the expansion in the production and extraction of oil and gas. Currently, Brazil is one of the largest oil producers in Latin America, and with the expected increase in production with the entry of new production units in the coming years, it is estimated that in 10 years Brazil will be among the 6 largest oil producers in the world.

Second (Petróleo, 2023), Brazilian oil exports accounted for 31% of national production between 2005 and 2022, reaching an average import percentage of 14% in the same period. In 2020, during the pandemic, these numbers reached 47% and 5%, respectively. Since 2013, when national oil production showed good development, the export volume has increased by about 3.5 times and the import has fallen by 32%.

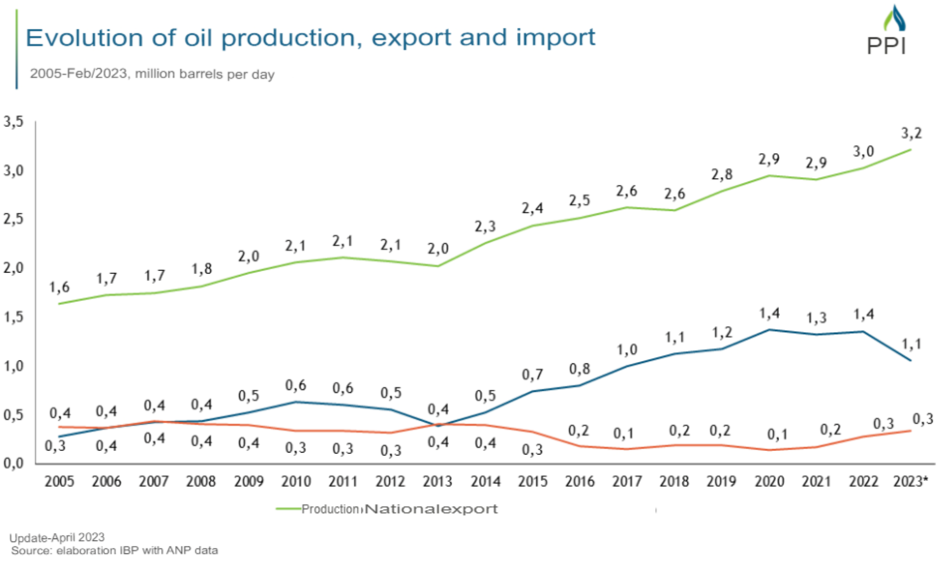

Figure 1 Evolution of oil production, export and import *(Petróleo, 2023)*

Linked to the evolution of the industry, the appeal about the need for increased reliability in determining the quantity being produced and sold is also growing.

Second , with the creation of the National Agency of Petroleum, Natural Gas and Biofuels (ANP), together with Inmetro, the Technical Regulation for Measurement of Petroleum and Natural Gas (RTM) n°001 was developed and published, with the first version published in 200 lines and the last revision on June 10, 2013, the latter being much more detailed. (Oliveira, 2010)The measurement of volumes produced and handled by exploration and production (E&P), in addition to the operational control of production and the determination of transfers, began to serve as the basis for the payment of government participation and payment for occupation or retention of areas, such as signature bonuses, royalties, and special participation.

The base calculation of government participation is defined based on fiscal measurement points of produced and transferred volumes. These points characterize the transfer of ownership or custody of oil and natural gas from the Union to the concessionaire that produces and delivers the oil and natural gas.

The RTM also establishes flow measurement technologies that can be used for in-line measurements of Oil and Natural Gas. For in-line petroleum measurements, Coriolis-type mass meters, turbine-type meters, positive displacement meters or ultrasonic meters must be used.

Also according to the RTM, the measuring instruments, the materialized measures and the measurement systems used must be submitted to the metrological control of the National Institute of Metrology, Quality and Technology (Inmetro), when applicable, or prove traceability to Inmetro standards.

When considering the relevance of selecting the technologies involved for measuring Oil and Natural Gas, it is essential to take into account the fluid in question, its specific characteristics (composition, viscosity, specific mass), the temperature and pressure to which it will be subjected and the installation of the measurement system.

This work aims to highlight and describe in detail the Petroleum measurement technologies, evaluating the strengths and weaknesses of each option, contributing to the adequate selection of meters and ensuring efficiency and accuracy in measurements.

2. Materials and methods

The methodology used in this study was primarily based on a systematic review, following a protocol with defined and carefully planned steps. The main objective of this approach was to obtain an in-depth understanding of the current scenario related to the researched area.

In order to gather the necessary information, a detailed analysis of the information available on the ANP website was carried out, in addition to reviewing relevant scientific articles that addressed the technologies associated with authorized flow meters for measuring oil. For this, search terms were defined both in Portuguese ((Petróleo, Gás Natural); (medição de vazão); (Extração); ("Medidor tipo turbina", ou "Medidor tipo ultrassônico", ou "Medidor tipo Coriolis", ou "Medidor tipo Deslocamento positivo")), and in English ((Oil and Gas); (Flow measurement); (Extraction); ("Turbine meter" or " Ultrasonic meter" or "Coriolis meter" or "Positive displacement meter").

Based on the information obtained, it became possible to relate the specific characteristics of the fluid to be measured and to be assertive in choosing the meter/measurement system, avoiding errors and waste. In this context, a management tool was the SWOT analysis (*Strengths, Weaknesses, Opportunities and Threats*), also known as SWOT analysis (Strengths, Opportunities, Weaknesses and Threats), in Portuguese.

In summary, the methodology used in this study proved to be thorough and comprehensive, based on a systematic review, analysis of authorized sources and the application of SWOT analysis to identify and compare the characteristics of flow meters, promoting a complete understanding of the technologies involved and, thus, contributing to the improvement of the oil industry and the optimization of its measurement processes.

3. Main technologies

3.1. Turbine type meters

Turbine-type meters are mechanical devices, whose construction comprises a moving part (rotor), where it is possible to establish a relationship between the velocity of the fluid passing through the instrument and its flow. According to *Manual of Petroleum Measurement Standards Chapter 5* (API, 2005), the drained fluid causes movement in the rotor, with a tangential velocity proportional to the flow velocity, as long as it is possible to neglect the drag on the meter blades. This meter technology can be used to measure liquids or gases using different designs.

Turbine movement is usually detected by means of mechanical, optical or magnetic devices. In the case of magnetic transducers, coils are mounted on the meter body, and are capable of producing pulses, each time one of the meter blades crosses the magnetic field of these coils. Each pulse generated represents a small volume, so that the frequency of these pulses is proportional to the flow rate, and their amount is proportional to the total volume under flow conditions.

It is common to use two coils, in the meter body, out of phase with each other. The presence of two coils guarantees redundancy to the system and allows automatic detection of the flow direction. A comparison of the pulses generated by both coils is also a useful tool to ensure secure data transmission (Crabtree, 2020).

According to (Emerson, 2016), typically, the generated pulses have a small amplitude, and are transmitted with the aid of a pre-amplifier. These signals are used in instrumentation loops, usually with the aid of flow computers, in order to calculate, correct, display and record flows.

In general, according to the materials used in the construction and the shape of the rotor, there is commercial availability of meters capable of measuring flow for fluids of different ranges of viscosity, temperature and flow. Turbine gauges are available in the nominal diameter range of 5 to 600 mm.

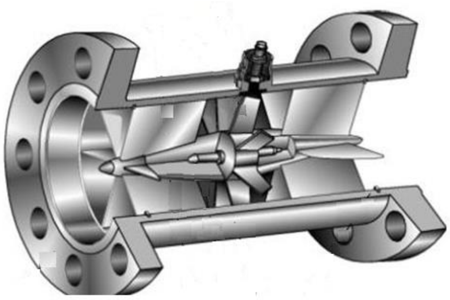

Figure 2. Turbine-type meter in horizontal section (Silver A. I., 2019)

3.2. Ultrasonic type meters

second (Santos, 2016) flow measurement using ultrasonic signals has become one of the most used technologies by organizations. These meters have a wide range of flow, require little maintenance and meet with certain flexibility the needs of the market related to the measurement of different fluids. The ultrasonic pulse flow measurement technology is applied in two types of meters: Doppler type and transit time type.

Ultrasonic transit time meters are composed of several sensors inside, which emit and receive ultrasonic signals, these sensors are called transducers and are arranged in pairs. The transducers produce and receive high frequency acoustic pulses (ultrasound) that are emitted in order to cross the flow in a pipe, the pulse crosses the flow and the signal sent is received by the other transducer in opposition, this acoustic signal is converted into an electrical signal and sent to an electronics that processes the signal, measuring the time that the signal took to transit between the pair of transducers. This sequence occurs several times for each pair of transducers, in both directions (each transducer emits and receives signals alternately.

The transducers are positioned on the walls of the pipe, so that the trajectory between the transducers that emit and receive the signals crosses the flow at an angle to its direction, so that the acoustic pulse can transit for or against the flow direction. Because of this, the signal that transits in favor of the flow arrives faster at the receiver, and the one that transits against the direction of the flow takes longer to arrive at the receiver. When sound signals that are sent from opposite directions on the same path arrive at your receiver at the same time, it means that there is no flow at that moment.

The fluid velocity in the pipe is not uniform throughout the diameter, and may have a laminar flow (where the flow is more sensitive to viscosity and the velocity profile has a parabolic profile from zero near the wall to a maximum at its center) for a Reynolds number < 2000, or turbulent flow that occurs for Reynolds numbers >4000 when the flow is faster and less sensitive to viscosity, having a flatter profile in the central part of the pipe

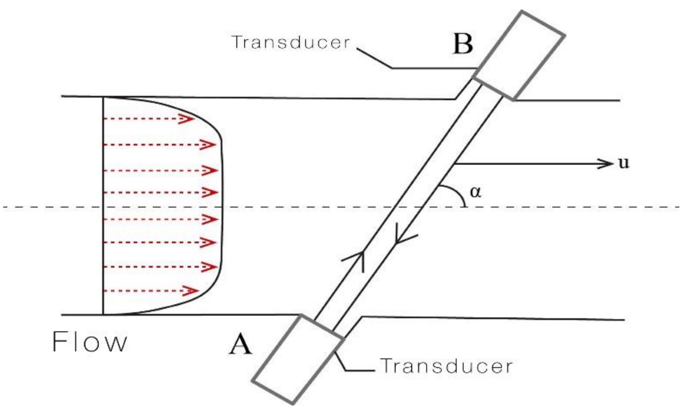

Figure 3. Fluid flow inside the meter (Source: Author)

According to (Dalmée, 2003), the application of ultrasonic Doppler effect meters becomes more effective in fluids that have a higher concentration of impurities during their flow, whether particles or bubbles. In short, the ultrasonic signal will reflect on these particles and will be forwarded to your receiver. The speed of the flow causes a variation in the frequency of the acoustic pulse that transits for and against the flow, this phenomenon is known as the "Doppler effect" (wave phenomenon).

The flow of meters based on this technology is calculated by measuring the two frequencies obtained through the difference between the sound pulse of the transmitter transducer and the receiver, which produce a beat (wave phenomenon). Finally, the calculation is performed using the frequency of the beats. These meters are not considered very accurate and because of this they are not widely used in the area of fiscal measurement, as the emitted signal reflects on the impurities of the fluid, and depending on the position of these particles the result may not be very reliable, because if it is positioned in the center, for example, the speed will be faster increasing the frequency, and on the walls of the pipe, the speed is slower decreasing the frequency.

Unlike Doppler effect meters, in meters that use transit time as a technology it is advisable to use cleaner fluids, resulting in greater accuracy of your results . (Dalmée, 2003)

In transit time meters, it is observed the travel time that the signal radiated in an inclined manner by the emitting transducer, takes to cross the entire diameter of the meter, reach the receiving transducer and return to the initial point, taking into account the velocity of the fluid. For this reason, it is of great importance to clean the fluid being used in this meter, so that impurities do not disturb the flow rate. The time difference between the signal sent upstream and downstream is directly proportional to the current velocity.

In short, for more accuracy in volumetric measurement, the ultrasonic meter must have more pairs of transducers, and through the average of their readings, the liquid velocity is achieved, since the internal area of the meter is known.

3.3. Coriolis type meters

The Coriolis meter is an instrument that performs mass flow measurements, this equipment has one or more tubes inside it that vibrates due to the natural frequency of its material and when there is a fluid, even if it is stopped inside, it begins to suffer a lag.

With the passage of the fluid, it begins to have a deformation, as the fluid will exert a force on the inside of the tube that will respond with an opposite force (figure 3). These acting forces will generate a deformation that will increase along with the flow that is passing inside the meter and will be captured by the sensors.

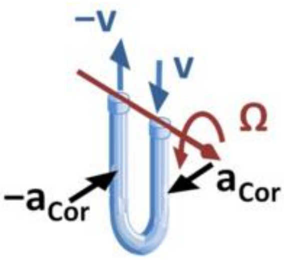

Figure 4. Fluid flow in Coriolis meter (Brews, 2012)

These meters have high measurement accuracy rates and are low maintenance meters. There are different formats of gauges currently on the market, in gauges smaller than 1" it is usual to have only one inner tube, but because it has a very rigid plate structure it is difficult to make it for larger diameters. Meters with two internal tubes and an actuator that captures the difference in the vibration signal are usually used, however it is already seen the manufacture of meters with more than two tubes internally. With this second technology , Coriolis meters can measure liquids, even those with entrained gases, liquids with solids, dry gases (provided in high volume for a better response) and a wide dimension in sizes. (Ribeiro, 1997)

Figure 5. Different formats of Coriolis gauges(Silver C. A., 2019)

As much as they are good meters, they have disadvantages to be considered at the time of purchase, such as sensitivity to vibration, as vibration can end up interfering with the vibration of tubes with fluid. These meters have high diagnostic technology, being able to identify failures in the electronic circuit, tube ruptures in internal welding, due to corrosion of the material and, among other factors, clogging of the tubes by secondary phases.

3.4. Positive Displacement type meters

Volumetric meters, also known as positive displacement meters, are devices whose fundamental function is the measurement of volumes, that is, they are used to measure the amount of fluid that passes through a certain point of the system. In these devices, the flow is calculated through mechanical or electronic accessories, in a constant way, mathematically deriving the volume in time. These instruments contain mechanical elements that form a volume chamber, as the fluid passes through the meter, it shifts the position chambers causing a filling and emptying cycle in each chamber.

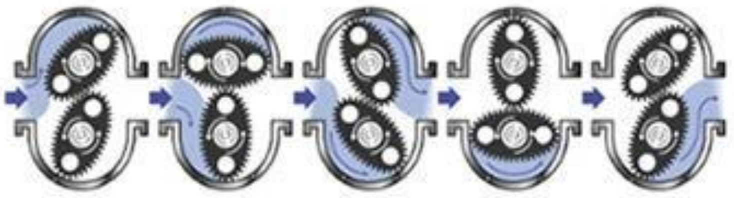

Figure 6. Rotary Positive Displacement Meters (OMEGA, 2015)

There are several models of positive displacement meters, each meter has its own operating principle, each type has specific characteristics and may be more suitable for a particular use, to know the best meter to be used will depend on the fluid to be measured, the physical state of matter, its viscosity, among other factors.

During the measurement process, three distinct phases that occur in sequence can be identified:

a) Inlet phase: In this phase, the fluid enters through an opening and fills the measuring chamber.

b) Measuring chamber isolation phase: The measuring chamber is isolated, preventing the entry or exit of fluid.

c) Escape phase: In this phase, the fluid leaves the measurement chamber and flows towards the outlet. Manufacturers seek to minimize the possibility of fluid leakage through mechanical clearances, which are necessary for the movement of moving parts with low friction.

These meters are commonly used in different types of industries such as oil and gas, chemical, food and beverage. They provide accurate and reliable measurements of fluid flow, which is of utmost importance for controlling and monitoring industrial processes.

Among the most common examples of different models of positive displacement meters, we can mention: gear meters, diaphragm meters, vane meters and piston meters.

Gear Meters

These meters consist of two gears that mesh and shift as fluid passes through them. The displacement of the gears is proportional to the volume of the fluid being measured. Gear meters are commonly used to measure the flow of viscous liquids.

Diaphragm Meters

These meters use a flexible diaphragm to measure fluid displacement. As the fluid flows, the diaphragm deforms and registers the displaced volume. Diaphragm gauges are commonly used in low cost, low viscosity applications.

Vane Meters

These meters use either rotating or sliding vanes to measure fluid displacement. As the fluid flows, the vanes move and the displacement is recorded. These gauges are widely used to measure the flow of liquids in applications such as fueling.

Piston Meters

These meters use one or more pistons to measure fluid displacement. As the fluid flows, the piston moves and registers the volume displaced. Piston gauges are often used in applications where high measurement accuracy is required.

It is worth mentioning that despite being quite efficient, positive displacement meters may have some limitations, such as flow range restrictions and the influence of the type of fluid on the measurement accuracy.

4. SWOT Analysis

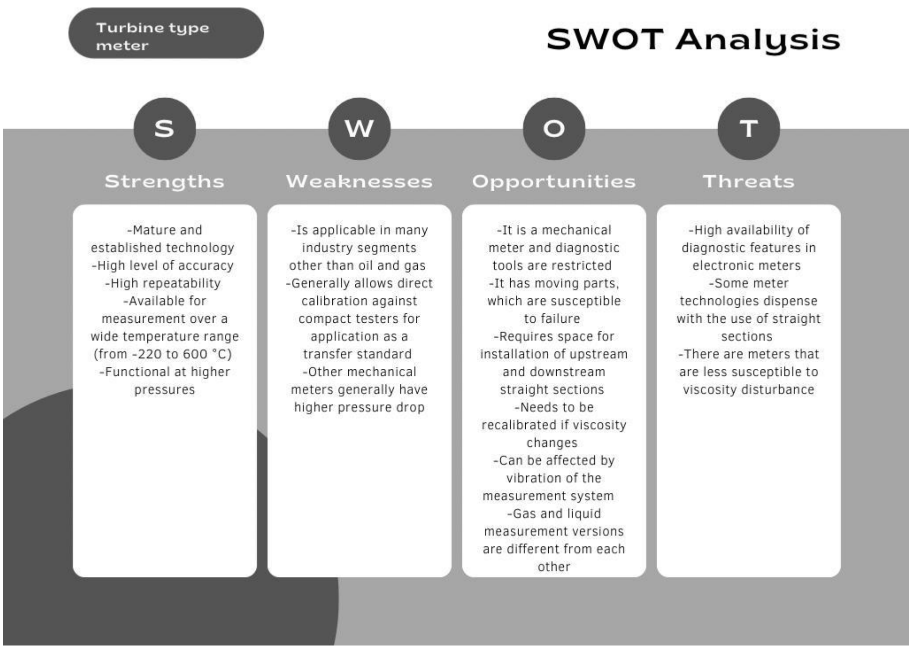

Figure 7. SWOT analysis turbine meter (SOURCE: Author)

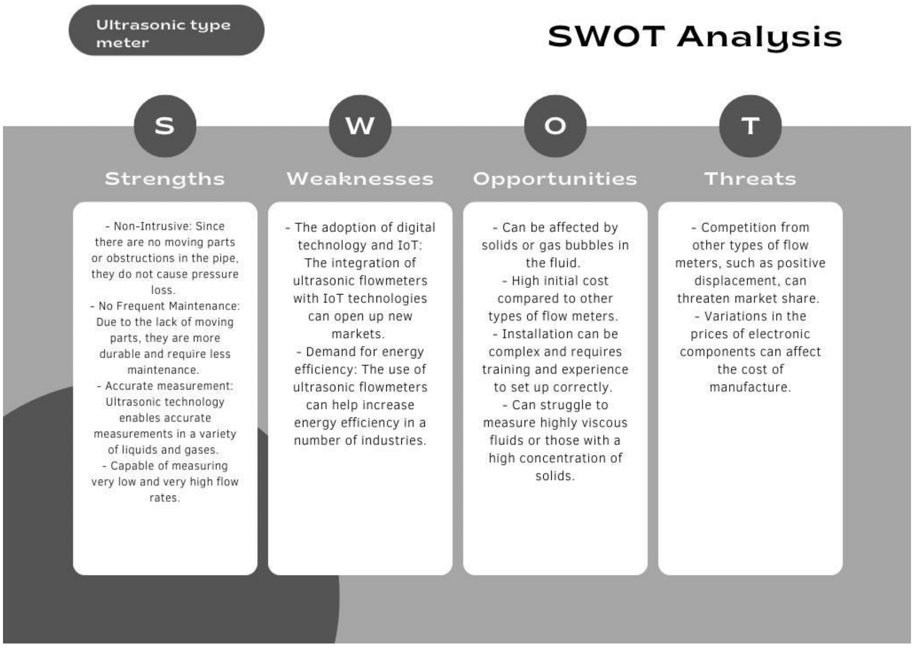

Figure 8. SWOT Analysis Ultrasonic type meter (SOURCE: Author)

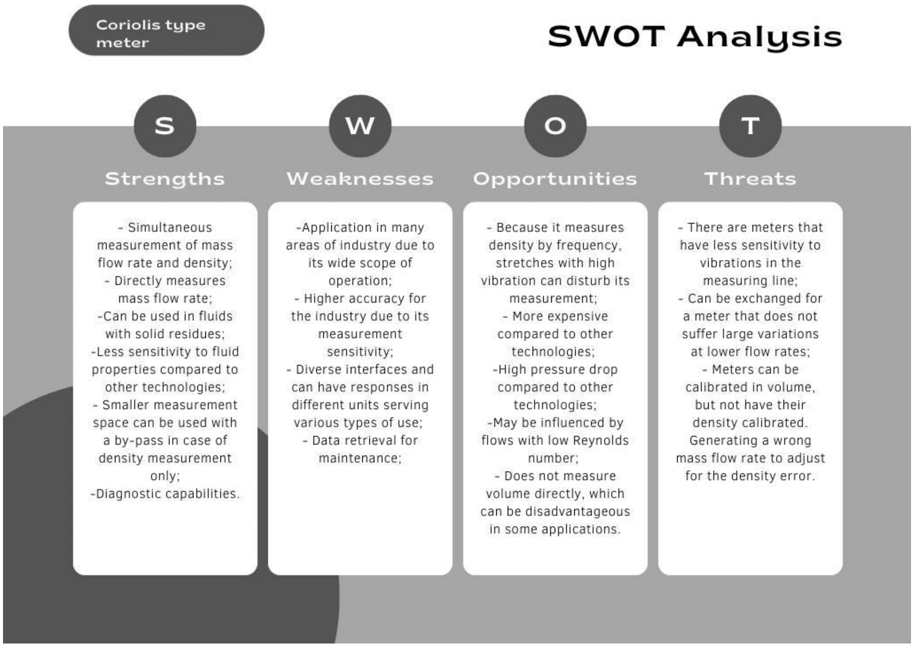

Figure 9. SWOT analysis Coriolis type meter (SOURCE: Author)

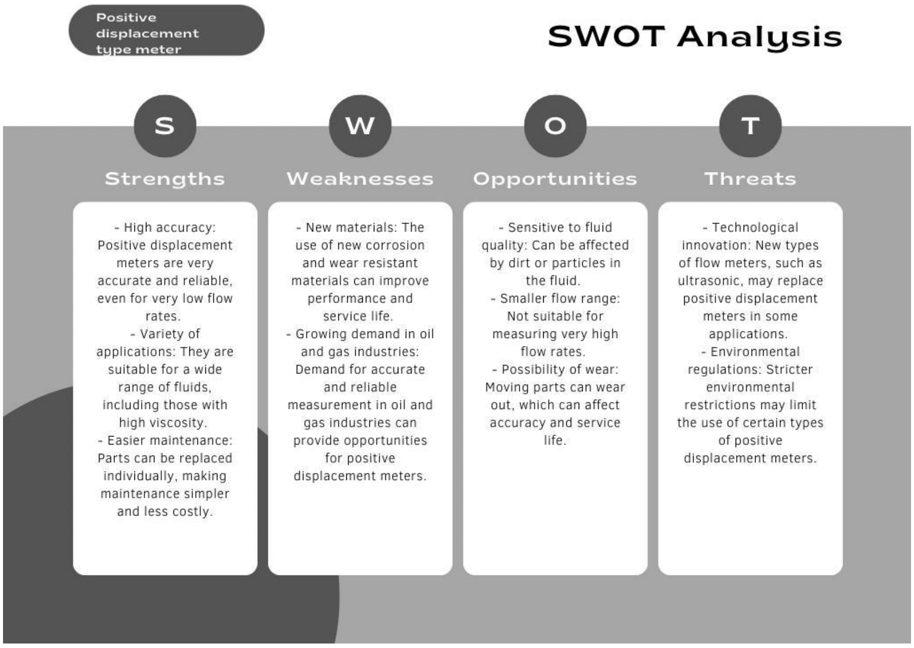

Figure 10. SWOT Analysis Positive Displacement Type Meter (SOURCE: Author)

5. Discussion and conclusions

The present study was systematically conducted using the SWOT analysis, also known as SWOT analysis. Its main objective was to understand in greater depth the technologies of the different types of flow meters for Oil measurement (Turbine, Ultrasonic, Coriolis and Positive Displacement), which are recommended by the RTM jointly developed by ANP and Inmetro.

Through this analysis, it is possible to identify more precisely the strengths and weaknesses of each technology, thus facilitating the choice of the meter that best responds in measurement to the needs of the intended use.

When evaluating this analysis, it is noticeable that no technology is fully comprehensive, presenting its own limitations. In addition to the intrinsic characteristics of the fluid to be measured, such as its composition and physical properties, there are external factors that also influence the choice of meter, such as the space available for installing the measurement line, the viable investment and the temperature to which the measurement line will be exposed.

It is also necessary to highlight the importance of proper installation and regular calibration of meters, in order to ensure the accuracy and reliability of fiscal measurements. It is highly recommended to consult experts and follow industry-specific regulations and standards for fiscal petroleum measurement.

Bibliography

[1] ANP/Inmetro. (2013, June 10). *Metrological technical report.* From Official Gazette of the Union: http://www.inmetro.gov.br/melegal/legislacao-metrologica-em-vigor.asp

[2] API, M.o.-M. (2005, September). Manual of Petroleum Measurement Standards Chapter 5 - Metering. *Section 3 - Measurements of Liquid Hydrocarbons by Turbine Meters* . API American Petroleum Institute.

[3] Brews, JR (2012). Force. *Coriolis Force.* Citizendium.

[4] Crabtree, MA (2020). *The Concise Industrial Flow Measurement Handbook.* Sound Parkway: Taylor & Francis Group.

[5] Dalmée, GJ (2003). *Flow measurement manual.* Edgard Blucher LTDA.

[6] Emerson. (2016, 08). Daniel Liquid Turbine Flow Meters.

[7] Oliveira, TB (2010, September). *Metrological evaluation of the V-cone meter for wet gas flow measurement.* From PUC Rio BR.
[8] OMEGA, EI (2015). *Positive Displacement (PD) Flow Meters* . From OMEGA .
[9] Petroleum, IB (2023). *ibp* . From Sector Observatory: https://www.ibp.org.br/observatorio-do-setor/producao-importacao-e-exportacao-de-petroleo/
[10] Ribeiro, MA (1997). *Flow measurement Fundamentals and Applications* . Savior: Winter.
[11] Santos, JW (2016). Analysis of the influence of Viscosity in the Measurement of Oil flow by ultrasonic meters. *Master's Dissertation* .
[12] Silver, AI (2019, July 2). *Silver Automation Instruments* . From Silver Automation Instruments: https://pt.silverinstruments.com/blog/turbine-flow-meters-tuf-used-in-oil-and-gas-industry-field.html
[13] Silver, CA (2019, February 19). *Copyright Silver Automation Instruments LTD* . From Liquid Mass Flow Meter - Coriolis Flow Meter: https://pt.silverinstruments.com/coriolis-mass-flow-meter/