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# The influence of measurement uncertainty of associated quantities on the uncertainty of liquefied petroleum gas mass in a dynamic measurement system

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ABSTRACT
Liquefied Petroleum Gas (LPG) is a versatile fuel with high energy content, easy storage, and a lower environmental impact compared to other fossil fuels. It is widely used in industry, commerce, and agriculture, making accurate systems for measuring LPG mass—the product's trading unit—essential. This study evaluates the main factors influencing mass measurement in dynamic systems, considering regulatory standards and calculation algorithms. The measurement function and associated uncertainty calculation are presented, along with the key contributors to expanded uncertainty: corrections for pressure, density, and temperature. These account for approximately 45 %, 43 %, and 9 %, respectively, of the total uncertainty, based on experimental averages. Results show that the uncertainty limits established for secondary quantities by the Brazilian Institute of Metrology, Quality, and Technology have limited practical relevance. Although individual uncertainties exceed prescribed limits, the maximum uncertainty of LPG mass—the primary variable—remains compliant, underscoring the importance of output-focused criteria. Finally, the study recommends future research to refine acceptance criteria for individual calibration, aiming to ensure more efficient and reliable LPG mass measurements.

**Section:** RESEARCH PAPER

**Keywords:** measurement uncertainty; liquefied petroleum gas; measuring station

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## 1. INTRODUCTION

Among petroleum derivatives, liquefied petroleum gas (LPG) stands out due to its distinct physicochemical properties, which make it more susceptible to variations in factors affecting transferred mass measurement [1].

Accurate and reliable measurements are essential for both efficient utilization and commercial transactions. Thus, identifying the factors influencing LPG mass flow calculations and evaluating the associated measurement uncertainty are crucial.

Key factors include pressure and temperature corrections, density, pulse number, K factor, and turbine meter factor, though their influence is not uniform. The pulse number represents the pulses generated by the turbine during the measurement interval; the K factor relates pulses to volume, expressed as pulses per cubic meter; and the meter factor is the ratio between the gross standard quantity passing through the meter and the corresponding indicated volume at standard conditions.

## 2. LIQUEFIED PETROLEUM GAS

LPG, a valuable byproduct derived from petroleum refining processes, has emerged as a vital component in the energy sector. Typically obtained through the fractional distillation process of petroleum, it primarily comprises propane and butane. Figure 1 presents the percentage distribution of petroleum energy derivatives production.

Due to its high energy content, LPG is highly applicable as a fuel, finding extensive usage in domestic, industrial, commercial, and agricultural settings. In addition to its lower environmental impact compared to other fossil fuels, it also offers convenience in handling, storage, and transportation.

The Brazilian Energy Balance (BEM), published by the Energy Research Company (EPE) in 2022, indicates LPG as the

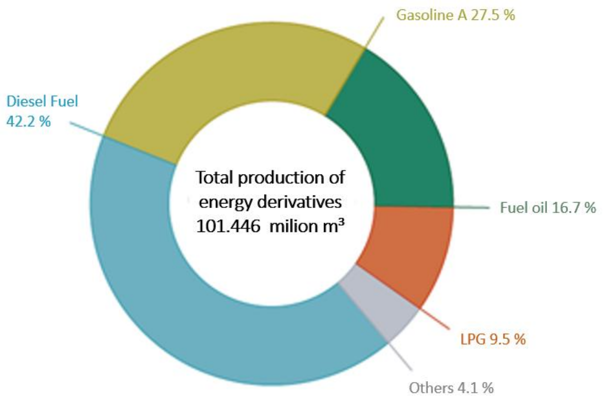


Figure 1. Total production of petroleum energy derivatives. Source: ANP [2]

third most utilized energy source in Brazilian households in 2021, Figure 2 [3].

## 3. MEASUREMENT SYSTEM AND INMETRO ORDINANCE

In this context, standards were created to ensure compliance with storage, transportation, and distribution processes. Among them, the Brazilian Institute of Metrology, Quality, and Technology (INMETRO) Ordinance No. 291, on July 7th, 2021 [4], approved in its text the Brazilian Metrological Technical Regulation, which established minimum conditions for dynamic measurement systems of quantities of petroleum and its liquid derivatives.

Measurement systems for liquefied petroleum gases can utilize volumetric or mass determination methods, which can be applied in static and dynamic conditions. According to Oliveira [5], in Brazil generally, LPG is measured volumetrically using turbine meters and converted to mass basis by density.

The measuring systems, also known as metering stations, are responsible for measuring the flow rate and calculating the mass of LPG. The system, as depicted in Figure 3, is composed of a flow transmitter (FIT), a pressure transmitter (PIT), a temperature transmitter (TIT), a densitometer (AIT), and a flow computer (FQIT).

The equipment for measuring the system's flow rate can be a turbine meter. A turbine meter is a flow measurement device that operates based on the principle of fluid flowing through a rotating turbine. The fluid passing through the meter causes the

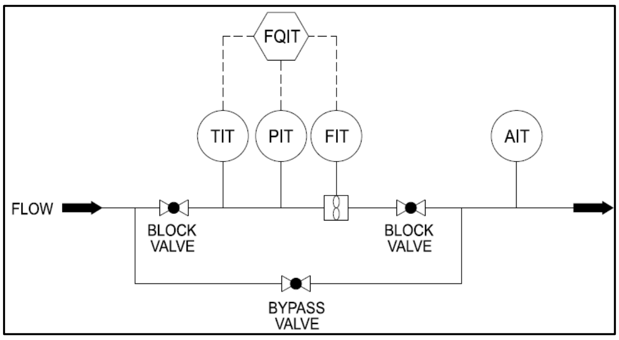


Figure 3. Schematic installation of a flow measuring station.

turbine to rotate, and the speed of rotation is proportional to the flow rate. The rotation of the turbine is detected by sensors or magnets, which generate electrical pulses that are then converted into flow rate readings. Turbine meters are commonly used for measuring the flow of liquids and gases in various industrial applications, due to their accuracy, wide flow range, and low pressure drop.

The measurement of gas flow occurs under unstable pressure and temperature conditions, known as operating or metering conditions, which can change for many reasons. However, the volumetric indications of transferred or received fluid must be referenced to conditions defined by regulatory bodies, known as base conditions. The base conditions are defined as a temperature of 20 °C and a static pressure of 101.325 kPa (or 1 atm).

The temperature, pressure, and density (also known as variable associated or secondary) measurements are transmitted to the correction device for converting the flow rate and the volume measured at metering conditions into a volume at base conditions.

The flow computer, widely used as a correction device, is defined by INMETRO [6] as an electronic device capable of receiving signals from a flow meter and other associated devices, measuring under specific flow conditions, and executing the necessary calculations to convert the flow value to base conditions.

The Brazilian regulation, INMETRO Ordinance No. 291, from July 7$^{th}$, 2021, is based on the International Organization of Legal Metrology's (OIML) International Recommendation R 117-1 [7]. This document states that the Maximum Permissible

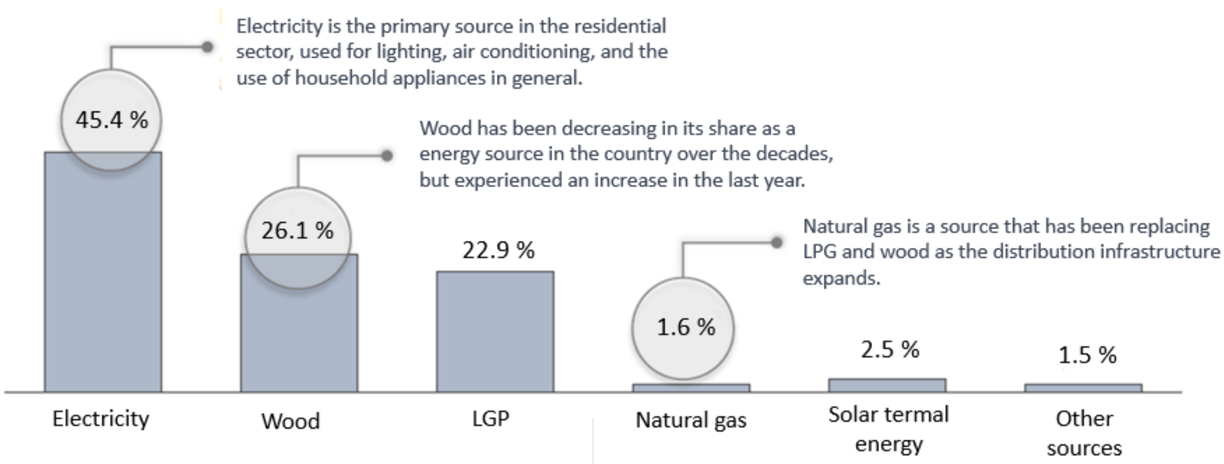


Figure 2. Brazilian residential energy matrix. Source: Balanço energético nacional [3].

Table 1. MPE values covered by INMETRO Ordinance No. 291 and respective expanded uncertainties. The considered pressure value refers to the operating range between 1 MPa and 4 MPa, which was taken as a reference for the conducted experiments.

| Measuring object | MPE | Expanded uncertainty |
|---|---|---|
| Measuring system (mass of LPG) | 1.0 % | 1.2 % |
| Temperature | 0.5 °C | 0.6 °C |
| Pressure | 5.0 % | 5.8 % |
| Density | 2.0 kg/m³ | 2.3 kg/m³ |

Error (MPE) for liquefied gas measuring systems under pressure, measured at a temperature equal to or above -10 °C, is 1.0 % (included in accuracy class 1.0). Based on [1], the $MPE$ can be converted into expanded uncertainty ($U$), according to equation (1). This value corresponds to the expanded uncertainty of the measuring system:

$$U = \frac{2 \times MPE}{\sqrt{3}} . \tag{1}$$

In addition to specifying the Maximum Permissible Error value for the measuring system, that is, the calculated mass of LPG, the Ordinance also establishes an $MPE$ for measuring devices (temperature, pressure, and density), as shown in Table 1.

## 4. MASS UNCERTAINTY BASED ON THE MEASUREMENT FUNCTION

The volume calculation, based on the standards of the American Society for Testing and Materials International (ASTM), the Institute of Petroleum (IP), the International Organization for Standardization (ISO), and the American Petroleum Institute's Manual of Petroleum Measurement Standards (API-MPMS), relies on factors such as the K factor, density, pulse number, turbine meter factor, and temperature and pressure corrections. [5]

The MPMS, in chapter 14, section 8 [8], titled Liquefied Petroleum Gas Measurement, presents the measurement function or mathematical model in equation (2) for the transferred mass, in tons. The model converts the volume to mass using the corrected density at base conditions of 101.325 kPa and 20 °C.

$$M = \frac{MF \times VCF \times CPL \times N_p \times D_4^{20} *}{K} , \tag{2}$$

where:

- $M$ = mass of LPG;
- $MF$ = meter factor;
- $VCF$ = correction factor for the effect of temperature on the liquid to the reference temperature;
- $CPL$ = correction factor for the effect of pressure on the liquid to the reference pressure;
- $N_p$ = pulses number generated by the turbine during the measurement interval;
- $D_4^{20} *$ = corrected density;
- $K$ = conversion factor of a number of pulses to volume, it is given in number of pulses per cubic meter.

Considering that the input quantities are not correlated, the combined standard uncertainty of LPG mass measurement is obtained based on ISO GUM [9], see equation (3):

Table 2. Expanded uncertainty data for the experiment.

| Variable | Expanded uncertainty | Unit |
|---|---|---|
| Meter factor | 0.00042 | - |
| Temperature | 1.0 | °C |
| Pressure | 50.0 | kPa |
| Density | 1.0 | kg/m³ |

$$u_c(M) = \left[ \left( \frac{\partial M}{\partial MF} \times u(MF) \right)^2 + \left( \frac{\partial M}{\partial VCF} \times u(VCF) \right)^2 + \left( \frac{\partial M}{\partial CPL} \times u(CPL) \right)^2 + \left( \frac{\partial M}{\partial N_p} \times u(N_p) \right)^2 + \left( \frac{\partial M}{\partial D_4^{20} *} \times u(D_4^{20} *) \right)^2 + \left( \frac{\partial M}{\partial K} \times u(K) \right)^2 \right]^{1/2} . \tag{3}$$

The degree of freedom ($\nu_{\text{eff}}$) is calculated using equation (4):

$$\nu_{\text{eff}}(M) = u_c^4(M) \cdot \left[ \frac{\left( \frac{\partial M}{\partial MF} \times u(MF) \right)^4}{\nu_{\text{eff}}(MF)} + \frac{\left( \frac{\partial M}{\partial VCF} \times u(VCF) \right)^4}{\nu_{\text{eff}}(VCF)} + \frac{\left( \frac{\partial M}{\partial CPL} \times u(CPL) \right)^4}{\nu_{\text{eff}}(CPL)} + \frac{\left( \frac{\partial M}{\partial Np} \times u(N_p) \right)^4}{\nu(N_p)} + \frac{\left( \frac{\partial M}{\partial D_4^{20} *} \times u(D_4^{20} *) \right)^4}{\nu_{\text{eff}}(\partial D_4^{20} *)} + \frac{\left( \frac{\partial M}{\partial K} \times u(K) \right)^4}{\nu(K)} \right]^{-1} . \tag{4}$$

## 5. RESULTS AND DISCUSSION

The present study did not aim to develop the uncertainty equation, but rather to present the relevance of each variable's contribution.

To verify the influence of the presented variables, an experiment based on the mathematical model was conducted. The input values for the experiments are the measurement uncertainties on the calibration of the instruments, Table 2, which can be obtained from their respective calibration certificates. These uncertainties are directly linked to the sources of uncertainty used in the mathematical calculation presented in equation (2).

The data were collected from three real measurement stations in the Brazilian Northeast (Table 3). Figure 4 illustrates the results, while the contributions from the measurement stations are summarized in Table 4.

The experiment showed which variables are relevant to the LPG mass uncertainty. In descending order, considering the arithmetic average, the relevant contributions were the correction factor for the effect of pressure ($CPL$) with almost 45 %; the corrected density ($D_4^{20} *$) that overtakes 40 %; and the correction factor for the effect of temperature ($VCF$), that is around 10 %.

Considering the low contribution value of the meter factor, the $Np$ and the $K$ factor were not considered relevant.

Table 3. Data for measuring stations.

| Measuring Station | Variable / Factor | Value | Associated uncertainty source | Contribution on expanded uncertainty LPG Mass | Expanded uncertainty of LPG Mass |
|---|---|---|---|---|---|
| 1 | Meter Factor | 1.0010 | *MF* | 2.76 % | 0.79 % |
| | Temperature | 24.82 °C | *VCF* | 13.63 % | |
| | Pressure | 1306.7 kPa | *CPL* | 39.34 % | |
| | Density | 538.5 kg/m³ | $D_4^{20}*$ | 44.26 % | |
| 2 | Meter Factor | 1.0011 | *MF* | 2.83 % | 0.79 % |
| | Temperature | 22.06 °C | *VCF* | 6.20 % | |
| | Pressure | 1354.1 kPa | *CPL* | 50.30 % | |
| | Density | 510.1 kg/m³ | $D_4^{20}*$ | 40.68 % | |
| 3 | Meter Factor | 1.0011 | *MF* | 3.12 % | 0.75 % |
| | Temperature | 19.61 °C | *VCF* | 6.82 % | |
| | Pressure | 1282.4 kPa | *CPL* | 45.22 % | |
| | Density | 510.5 kg/m³ | $D_4^{20}*$ | 44.84 % | |

The use of transmitters that would initially not meet the established limits, and, in this way, optimizing the acceptance criteria in the calibration of the instruments prevents improper disposal of the equipment, providing financial, bureaucratic, and operational benefits.

Future work is being developed using the Design of Experiments methodology associated with the Response of Surface Methodology to optimize the individual acceptance criteria calibration of secondary transmitters of static pressure, temperature, and density, as the calibration input data of an LPG measuring system.

## 6. CONCLUSION

The results demonstrate that the uncertainty measurement value of density, pressure, and temperature are critical for LPG mass uncertainty. On the other hand, the uncertainties of the K factor, pulses number, and turbine meter factor do not significantly impact it. The method considered is the volumetric on a dynamic measurement system, which is then converted to mass by density using a standard procedure.

This study suggests that the prescribed uncertainty limits established by INMETRO regulations for secondary (or associated) quantities have limited practical significance. This occurs because, even if the uncertainty values for individual quantities exceed the prescribed limits, they can still meet the maximum uncertainty requirement for the output variable, which is the critical aspect of LPG mass measurement.

Table 4. Data for comparison off all measuring station.

| Variable | Contribution on expanded uncertainty LPG Mass | | | |
|---|---|---|---|---|
| | Measuring Station 1 | Measuring Station 2 | Measuring Station 3 | Arithmetic average |
| *MF* | 2.76 % | 2.83 % | 3.12 % | 2.90 % |
| *VCF* | 13.63 % | 6.20 % | 6.82 % | 8.88 % |
| *CPL* | 39.34 % | 50.30 % | 45.22 % | 44.95 % |
| $D_4^{20}*$ | 44.26 % | 40.68 % | 44.84 % | 43.26 % |

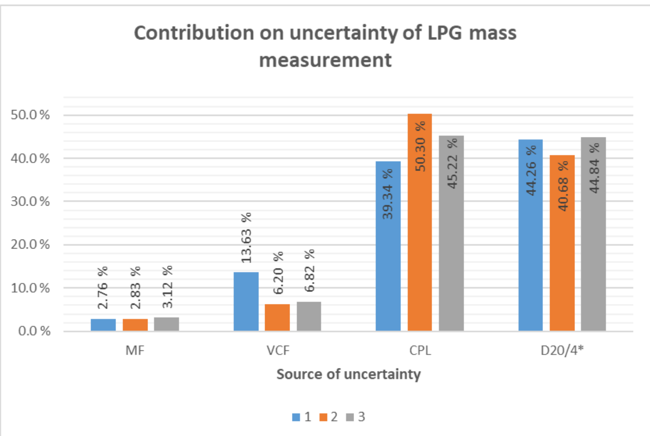


Figure 4. Contributions of *MF*, *VCF*, *CPL* and $D_4^{20}*$ on uncertainty of LPG mass measurement

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