

## IMPROVEMENTS IN THERMAL EFFICIENCY FOR MODIFIED GEOMETRY IN COMMERCIAL COOK-TOP BURNERS (LPG FUEL)

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**Abstract.** *This paper presents experimental results for domestic gas burners, operating on LPG – Liquefied Petroleum Gas, with modification in its original geometry commercially available. The main objective is to identify improvements in performance when evaluating changes in its geometry for LPG passage (end-holes diameter, radial and axial positions) at different thermal power conditions (TP1 up to TP5). Considering the large number of cooker-top burners currently being used, even a slight improvement in thermal performance resulting from a better design and/or operational condition will lead to a significant reduction of energy consumption and costs for the final user. The methodology applied was based on regulations from INMETRO – National Institute for Metrology, Quality and Technology via CONPET program for energy conversion efficiency in cooktop and kilns, ABNT – Brazilian Society for Standard Normatives (testing of household gas burning devices) and ANP – National Agency of Petroleum, Natural Gas, and Biofuels. Appropriate instrumentation was used to measure fuel mass consumption (weighing scale and chronometer), temperature (thermocouple, K type) and water mass (weighing scale) in the heating vessel. The results obtained are analyzed and discussed when varying Thermal Power (kW), for each combination of fuel mass rates (kg/s), Reynolds number (Re, dimensionless), thermal efficiency ( $\eta$ , %) and  $\Delta T_{\text{water}}$  for a standard vessel and time (°C/s). The main findings are: a) Maximum and minimum TP are, respectively, for B-30 and B-10; b) Original burner has the worst efficiency in comparison to the modified ones; c) As Reynolds increases, efficiency for B20 and B-30 also increases, until it reaches its maximum and then, it drops for higher Reynolds values and the opposite for B-00 and B-10.*

**Keywords:** Energy efficiency, gas cooker, firing rate, combustion, labelling programs.

### 1. INTRODUCTION

Industrial and residential burners are thermal equipment that supports the combustion process, allowing a controlled and stable burn of different fuels. For industrial use, equally liquid and gas fuel are considered, while that for residential use, gas fuel is preferable in order to have complete combustion what is safer for indoor air pollution and lowers CO<sub>2</sub> emissions and other greenhouse gases. Other than energy conversion efficiency, concerns on environmental and emission when performing combustion of fossil fuels, non-renewable fuels, are also of great importance.

It is well known that is extremely important to rationalize the energy utilization to minimize costs and environmental issues. That is evidenced in progressive price increase to the final consumer for 13 kg LPG pressure vessel, the most important fuel in the Brazilian domestic appliances, that grew 19.1% when comparing March 2016 to 2015 (MME, 2016). Besides, must be considered the problems related to the petroleum exploration and their products, as for example the risk of accidents on the extraction platforms and the damage to ecosystems around the exploration sites. However, the commercialized models of the cooker top burners still present operating conditions that induce to the inefficient use of the equipment, though were designed quite a long time ago.

Aiming to improve the efficiency of burners, Hou et al. (2007) analyzed the swirl and radial domestic LPG fueled burner behavior. Swirl flow, loading height, primary aeration, gas flow rate (heat input), gas supply pressure and semi-confined combustion flame was study parameters related to thermal efficiency and CO emissions of those burners. The results showed that the swirl burner presented higher efficiency than the conventional burners (radial flow burner). In addition, the increase of the loading height induced a decrease of CO emissions, and the reduction of the gas pressure from 330 mm H<sub>2</sub>O to 230 mm H<sub>2</sub>O increased the efficiency. First aeration did not affect burner efficiency. Ultimately, increasing the thermal input resulted in the decrease of efficiency and increase of CO emission.

Moreover, Li et al. (2006) studied a cook-top-burner with gas-fired-impinging-flame fueled with LPG to analyze the influence of the Reynolds number, equivalence ratio, nozzle-to-plate distance and the jet-to-jet spacing. These authors have evidenced that the burner's thermal efficiency decreased at a constant rate as the Reynolds number increased. Elsewhere, as the equivalence ratio increased, the thermal efficiency rose to a minimum value and then increased. In contrast, the thermal efficiency rose to a maximum value and then decreased as the nozzle-to-plate distance was increased. Lastly, increasing the jet-to-jet spacing caused a higher efficiency.

In this work, different geometry burners were evaluated in order to obtain the best geometric configuration for thermal efficiency. The authors submitted to testing a cook-top-burner operating with LPG with four different geometry burners and five heating power conditions. Nominal thermal power, mass flow rate, Reynolds number and thermal efficiency were parameters of this study. Identifying which design and thermal power condition is most effective is one

of the motivations of this work. In other words, it is intended to look for the lowest fuel consumption and better performance (efficiency) to circumvent the increasing price of fossil fuels and contribute to the environment.

## 2. METODOLOGY

A residential gas burner, cooker-top type (Atlas, model: Tropical plus) was used in the tests. Additional technical data is available in the manufacture’s manual (Atlas, 2014): LPG and fuel gas; weight 20.90 kg; automatic electric ignition; 127/200 voltage; external dimensions (mm) 483 x 570 x 884; INMETRO classification is "A" for the burner and the "A" for the oven according to CONPET – National Program to Rationalize the use of Petroleum and Natural Gas Derivatives. According to ABNT (2003), all the cooker-top burners are classified as ‘semi-fast’ ( $1.16 \text{ kW} \leq TP < 2.30 \text{ kW}$ ). Figure 1 presents the experimental apparatus where the tests were carried out in this work.

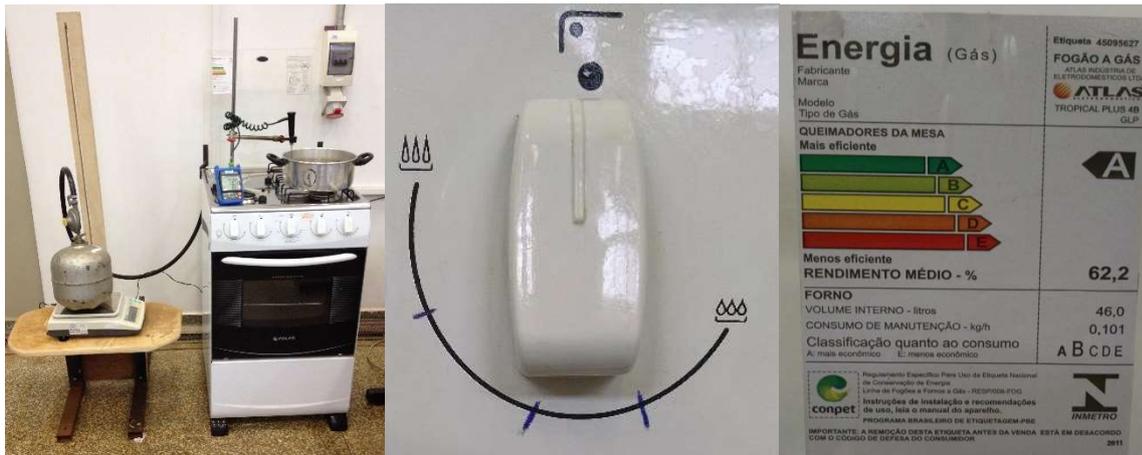


Figure 1: Experimental apparatus, TP levels and INMETRO/CONPET (energy efficiency labelling program).

Four burners with different geometries and five Thermal Power (TP) conditions were tested. TP1, TP2, TP3, TP4 and TP5 correspond from minimum to maximum fuel mass flow rates (kg/s) set from the cook-top, providing five different thermal power (kW) levels. Details are shown in Fig. 1, 2 and Tab. 1.

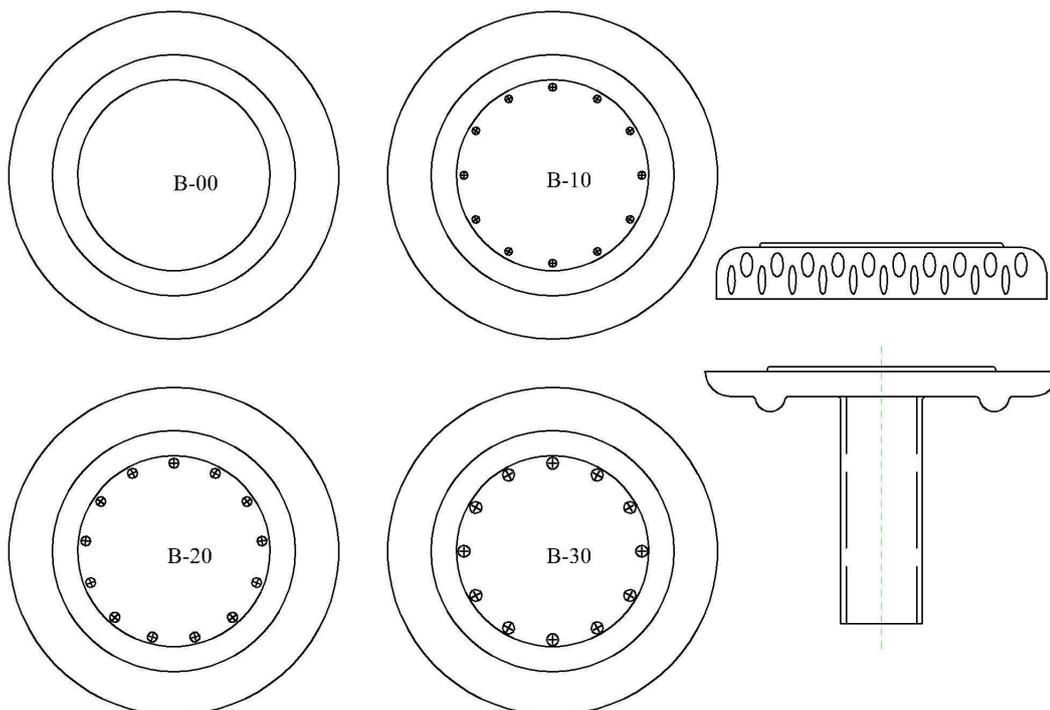


Figure 2. Burners - top and frontal views.

Table 1. Burners geometry differences

Burner	Number of axial holes	Axial hole diameter (mm)	Area decrease (%)
B-00 <sup>1</sup>	-	-	-
B-10	12	1.50	10
B-20	13	2.00	20
B-30	13	2.50	30

<sup>1</sup> Original burner geometry.

## 2.1 Instrumentation for measurements

LPG heating values considered in this work are indicated in Tab. 2. Mean values were adopted by the authors considering that the main components in the commercial LPG are propane/propene and butane/butene in variable compositions (Petrobrás, 2013). Table 3 presents instrumentation required for the experimental measurements in this work.

Table 2. Fuel properties<sup>1</sup>. Turns (2013)

Gas Fuel	HHV (kJ/kg)	LHV (kJ/kg)	T <sub>boiling</sub> (°C)/(K)	T <sub>adiabatic</sub> (°C)/(K)	ρ (kg/m <sup>3</sup> ) <sup>2</sup>
Propene (C <sub>3</sub> H <sub>6</sub> )	48936	45784	-47.40 / 225.75	2071 / 2344	514
Propane (C <sub>3</sub> H <sub>8</sub> )	50368	47357	-42.10 / 231.05	1994 / 2267	500
Butene (C <sub>4</sub> H <sub>8</sub> )	48471	45319	-63.00 / 210.15	2049 / 2322	595
Butane (C <sub>4</sub> H <sub>10</sub> )	49546	45742	-0.50 / 272.65	1997 / 2270	579
Mean values in this work	49330	46050	-38.25 / 234.90	2028 / 2301	547

<sup>1</sup>measured at T = 298.15 K and P = 0.1 MPa      <sup>2</sup>gases at boiling temperature (liquefied gas)

Table 3. Instrumentation and technical specification

Instrument (Manufacturer, Model)	Measurement	Range	Resolution	Instrument Uncertainty
Weighing scale (GEHAKA, model: BK8000 Class "II"/2011)	Mass Measurements	5–8100 g (at 15–35 °C)	0.1 g	±0.1 g
Thermocouple (Politerm, model: TM-364)	Temperature	-200 up to 1372°C	0.1°C	±0.1°C
Chronometer (Cronobio, model: SW2018)	Time	23h59'59"	1/100"	±1/200"
Thermo-Hygro-Anemometer-Barometer (Instrutherm, model: THAB-500)	Barometric pressure	999.9 hPa	0.1 hPa	±10 Pa
Manometer (Famabras, model: FSA 62, Class "B")	Pressure	0–20 kgf/cm <sup>2</sup>	0.5 kgf/cm <sup>2</sup>	±0.25 kgf/cm <sup>2</sup>
Water container (Aluminum)	Water mass (~2 kg)	-	-	-
Gas pressure vessel for LPG (P-2)	Gas mass (2 kg)	-	-	-

## 2.2 Laboratory Condition

Ideal laboratory conditions for data acquisition, recommended by ABNT (1999 and 2003), is temperature, T<sub>lab</sub> = (25±5) °C. UFGD facilities have no control of ambient parameters, so tests were performed as close as possible under the recommended ones. LPG pressure inside the vessel (P-2 pressure vessel) must be, according to ABNT (1999 e 2003), higher than 1.96 kPa. Results in this work were obtained under the following laboratory conditions: 25.5°C ≤ T<sub>lab</sub> ≤ 19.6 °C, 245.2 kPa ≤ P<sub>LPG</sub> ≤ 343.2 kPa, and only for registration, 56% ≤ RH<sub>lab</sub> ≤ 68%, 95.6 kPa ≤ P<sub>lab</sub> ≤ 95.9 kPa. Small differences below the recommended ambient temperatures occurred only to one test run, and do not interfere in the overall discussions and conclusions.

## 2.3 Experimental Procedures

### 2.3.1 Fuel mass flow and thermal power

Fuel mass flow – m<sub>gas</sub> (kg/s) – thermal power – TP (kW) – and its respective uncertainties, are determined by Eqs. (1) and (2). Measured values are: Δm (kg) is a total mass variation of the pressure vessel and Δt (s) is the time elapsed during a single test. Fuel properties from Tab. 3: LPG high heating value is HHV (kJ/kg) and ρ (kg/m<sup>3</sup>) is the specific mass.

$$\dot{m}_{gas} = \Delta m / \Delta t \text{ and } u_{\dot{m}_{gas}} = \sqrt{(u_{\Delta m} \cdot 1 / \Delta t)^2 + ((u_{\Delta t} \cdot \Delta m) / \Delta t^2)^2} \quad (1)$$

$$TP = \dot{m}_{gas} \cdot (HHV) \text{ and } u_{TP} = \sqrt{(u_{\dot{m}_{gas}} \cdot HHV)^2 + (u_{HHV} \cdot \dot{m})^2}, \text{ assuming } u_{HHV} = 0 \text{ (HHV = cte)} \quad (2)$$

The following procedure was used:

- 1) Ambient conditions and pressure inside the P-2 vessel is measured and registered at test beginning and ending;
- 2) The mass of the pressure vessel is measured and registered at the test beginning and end to determine the fuel mass consumed;
- 3) Ignition of the burner and shut down after 300 s (5 min);
- 4) Repetition of the steps for each burner and each five TP;

### 2.3.2 Energy conversion efficiency (from fuel to water heating) and water heating

Heat rate (or thermal energy transferred/absorbed during the test) from water and from the gas –  $Q_w$  (J/s) and  $Q_{gas}$  (J/s) –, energy conversion efficiency –  $\eta$ (%) – and its respective uncertainties, are determined by Eqs. (3), (4) and (5). Measured values are:  $m_w$  (kg) is the water's mass inside container,  $h_w = 4.178$  (kJ/kg.K) is the specific heat of the liquid water,  $\Delta T$  (°C) is the water temperature variation, and  $\Delta t$  (s) is the time elapsed during a single test. Eq. (7) gives the Reynolds number for the internal turbulence inside the burner's rod.  $\mu$  (N.s/m<sup>2</sup>) is the kinematic viscosity,  $v$  (m/s) is the fuel velocity inside the rod of the burner and  $D_{i,rod}$  is the internal diameter of the rod.

$$Q_{gas} = \Delta m \cdot HHV \text{ and } u_{Q_{gas}} = \sqrt{(u_{\Delta m} \cdot HHV)^2 + (u_{HHV} \cdot \Delta m)^2}, \text{ assuming that } u_{HHV} = 0 \text{ (HHV = cte)} \quad (3)$$

$$Q_w = m_w \cdot h_w \cdot \Delta T \text{ and uncertainty by } u_{Q_w} = \sqrt{(u_{m_w} \cdot h_w \cdot \Delta T)^2 + (u_{h_w} \cdot m_w \cdot \Delta T)^2 + (u_{\Delta T} \cdot m_w \cdot h_w)^2},$$

$$u_{h_{water}} = 0 \text{ (h=cte)} \quad (4)$$

$$\eta = Q_w / Q_{gas} \text{ and uncertainty determination given by } u_{\eta} = \sqrt{(u_{Q_w} \cdot 1 / Q_{gas})^2 + ((u_{Q_{gas}} \cdot Q_w) / Q_{gas}^2)^2} \quad (5)$$

$$R_{eynolds} = \rho \cdot v \cdot D_{i,rod} / \mu = 4 \cdot \dot{m} / \mu \cdot \pi \cdot D_{i,rod} \quad (6)$$

The following procedure was used:

- 1) Ambient conditions and pressure inside the P-2 vessel is measured and registered at test beginning and ending;
- 2) The mass of the pressure vessel is measured and registered at the test beginning and ending to determine the fuel mass consumption;
- 3) Insert ~2 kg (20±1 °C) of water inside the container;
- 4) Ignition the burner and pre-heating during 600 s (10 minutes). Note: Container at the center of the burner;
- 5) Transfer pre-heated water in another container and, positioning at the same burner again;
- 6) Thermocouple positioned at the water container's volumetric center;
- 7) Burner shut down when water temperature reaches (90±1) °C, register maximum water temperature after shutdown;
- 8) Repetition of the steps for each burner and each five TP either;

## 3. RESULTS AND DISCUSSIONS

The geometry variations of the burners diversified the fuel mass flow and, consequently, the nominal thermal power provided by them. The Fig. 3 evinces the behavior when subjecting each burner to five different mass flow rates. The thermal power presents a linear behavior, with increasing values as high is the mass flow. Moreover, the maximum thermal power was given by burner B-30, ~20.88 10E-1 kW (4.23 10E-5 kg/s) and the minimum was given by burner B-10, ~7.07 10E-1 kW (1.43 10E-5 kg/s). This linear and progressive behavior was already noticed by Rocha et al. (2010), which in the study used industrial burners fueled with LPG and natural gas. Important to notice that, even with increases in flow area for the LPG, there are mass flow rates lower than the ones obtained in the original burner (B10 and B20).

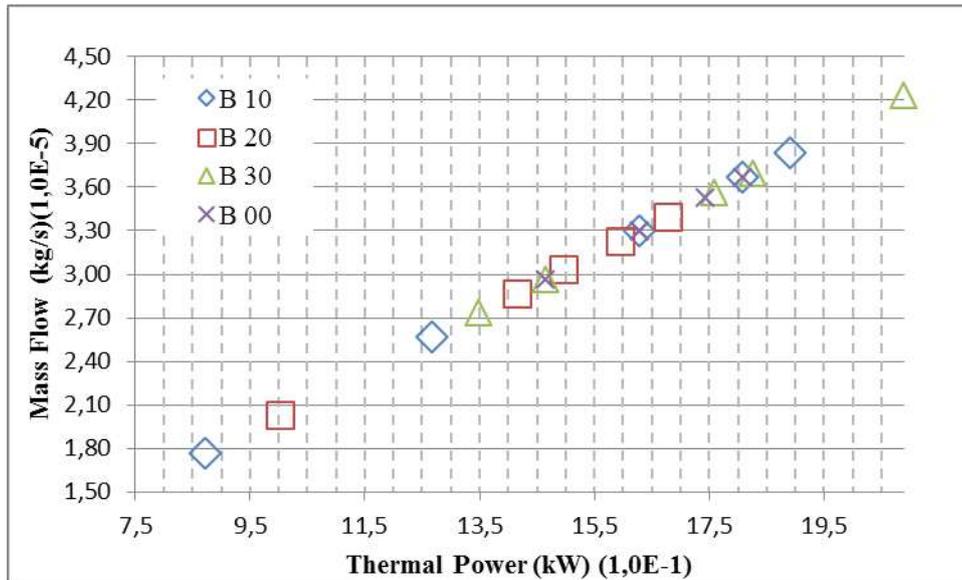


Figure 3. Nominal thermal power and mass flow behavior.

The thermal efficiency of a gas burner is defined as the percentage of the thermal energy input transferred to the loading water (Hou et al., 2007). Hence, it is observed in Fig. 4, the efficiency of the burners and also the trend line behavior represented by a third degree polynomial. Burner B-10, achieved maximum efficiency, showing to be the best design. B-00 presented minimum efficiency, thus it is evidencing that the original design is the worst when compared to the other burners tested. This difference reached 27.9 % between burners B-10 and B-00 in TP1, for example. Moreover, it is observable that starting from TP3, the efficiency is in the same order of magnitude regarding B-10 and B-30 burners. Also, in previous studies, the TP3 supplies the same temperature rate per time ( $\Delta T/\Delta t$ ) as TP 4 and TP 5 (Silva, 2015). In summary, TP3, TP4 and TP5 is the best option as an operational condition for B-10 and B-30 burners, and TP5 is the best operational conditional for B-00 and B-20 burners.

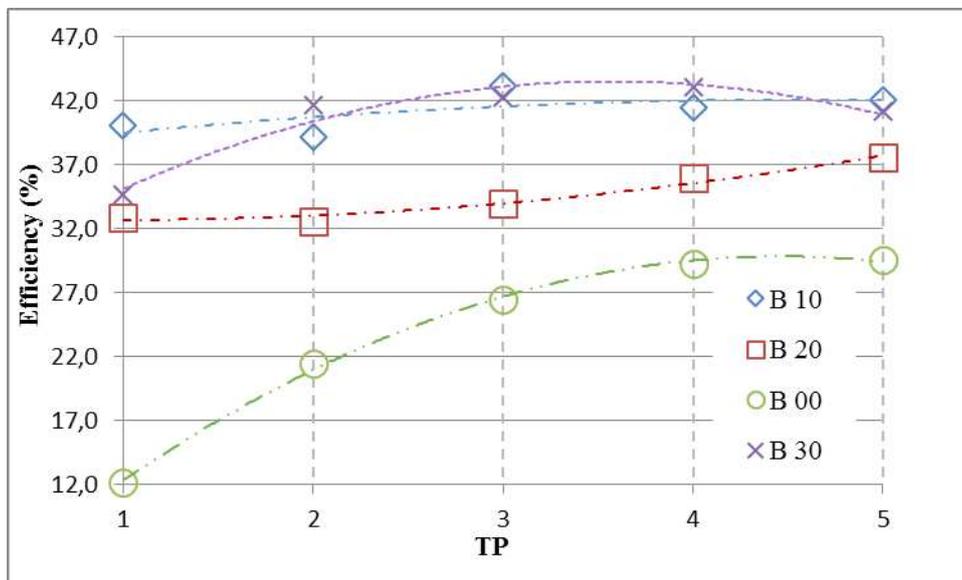


Figure 4. Thermal efficiency experimental data and trend lines for TP levels.

Furthermore, the influence of the Reynolds number in the combustion process was also evaluated in this work. Figure 5 shows the behavior between the efficiency as the Reynolds number increases. B-00 and B-10 burners denote a parabolic behavior that increases to a peak value followed by a drop. According to Li et al. (2006), with an increase of Reynolds number, more air/LPG mixture flows towards the reaction zone to participate in the process, so turbulence ensures and enhances the combustion. Meanwhile, if there is insufficient air for the combustion to be fully completed,

the efficiency declines as occurring to B-20 and B-30. That adverse behavior, when  $250 < Re < 300$ , do not occur for higher values in B-20 and B-30 indicating that both burners are able to sustain combustion with better efficiency for higher Reynolds numbers, but insufficient air is dragged for lower ones. In other words, B-20 and B-30 operate better as  $Re$  increases (TP4 and TP5 conditions, 20-30% area increases), while the opposite occurs B-00 and B10.

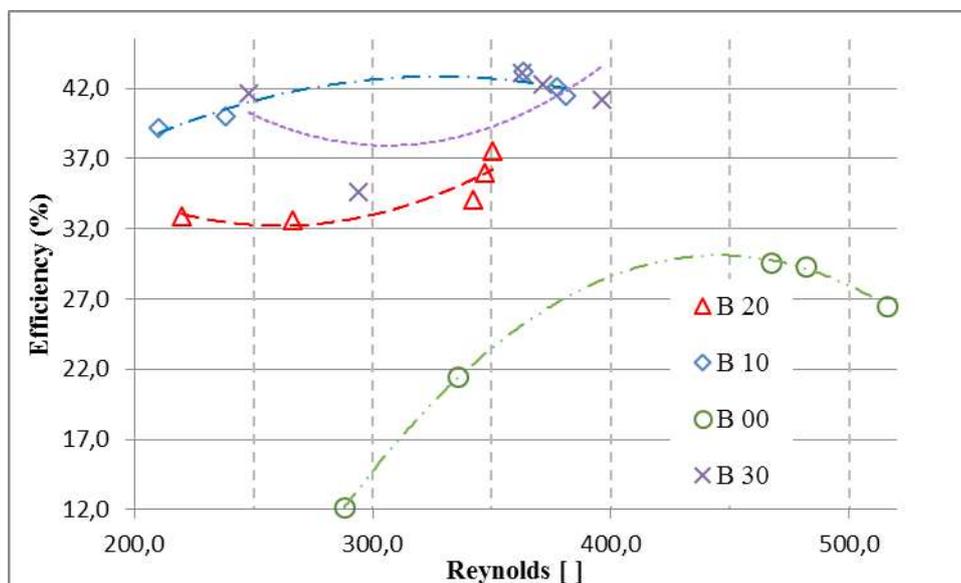


Figure 5. Maximum and minimum efficiencies identified according to Reynolds.

According to MME (2016), the price of 13 kg of LPG was ~R\$ 53.90 in the first half of 2016 for Brazilian consumers and it lasts usually 60 days (two months). Considering that households use burners in the third thermal power condition instead of the maximum thermal power and use the burner B-10 or B-30 instead the B-00 (original burner) it will have a 16.7 % of efficiency improvement. It implies a saving of ~13kg of LPG and ~R\$ 54.00 for burners B-10, per year.

#### 4. CONCLUSIONS

From the results obtained in this work, it was possible to evaluate the nominal thermal power, mass flow rate, Reynolds number and thermal efficiency in a cooker-top gas burner with four different geometries with the purpose of establishing an efficiency improvement. The main findings are pointed out next:

a) The maximum thermal power was given by burner B-30,  $\sim 20.88 \cdot 10^{-1}$  kW ( $4.23 \cdot 10^{-5}$  kg/s) and the minimum was given by burner B-10,  $\sim 7.07 \cdot 10^{-1}$  kW ( $1.43 \cdot 10^{-5}$  kg/s). According to ABNT (2003), all the cook-top burners are classified as 'semi-fast'.

b) The original burner presented the worst efficiency performance compared to the other burners. Burner B-10 achieved the best average efficiency, showing the best design.

c) Regarding the influence of the Reynolds number in the process efficiency, B-20 and B-30 burners denoted a parabolic behavior that increased to a peak value and then drops, and the opposite for B-00 and B-10. This behavior can be explained by the turbulence and consequently the air/LPG mixtures reaching a maximum efficiency value that declines when there is insufficient air for the combustion process to be fully completed.

Therefore, it was possible to show that it is possible to define better operating conditions for cooker-top gas burner at better efficiency and lower fuel consumption, what results in money savings and lowers greenhouse gas emissions.

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