COOKER-TOP GAS BURNERS (LPG) DESIGN PARAMETERS EXPERIMENTAL ANALYSIS

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Abstract. *The paper presents results for experimental tests in burners for residential use (home stoves), operating on LPG – Liquefied Petroleum Gas, with eight different geometries (diameter, height, etc) and five thermal power levels (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 operational condition will lead to a significant reduction of energy consumption (LPG). Appropriate instrumentation was used to carry out the measurements of the quantities of interest, namely fuel mass consumption (weight device), time (chronometer), temperature (thermocouple K type) and also water mass (weight device) in the heating vessel. Methodology applied was based in regulations from INMETRO (CONPET program for energy conversion efficiency in cook top and kilns), ABNT (testing of household gas burning devices, part 1: performance and security; part 2: rational energy use) and ANP – National Agency of Petroleum, Natural Gas and Biofuels. Results obtained are analyzed and discussed when varying thermal power (kW), for each combination of mass fuel rates (kg/s), Reynolds number, thermal efficiency (dimensionless) and* ΔT_{water} *versus time (°C x s).*

Keywords: *Burners, Experimental engineering, Energy conversion efficiency, Gaseous fuel.*

1. INTRODUCTION

Burners are thermal equipment destined for the final routing of gas or gas/air mixture to the combustion zone, allowing a controlled and stable burn (NBR 10148, 2011). Therefore, most ones support the combustion process of different fuels, which in an exothermic process that transforms chemical energy from the fuel molecules bonds into thermal energy (Turns, 2013). Presently, cooker-top-burners ratify the importance of the flame's management due to it's high control efficiency of the combustion process.

The most frequent fuel used in domestic burners is LPG (Liquefied Petroleum Gas), mainly composed of propane and butane. These fuels, according to LI *et al* (2006) are widely employed because of their rapid combustion and high heating-rates. Besides that, Hou *et al* (2007) proposes its domestic utilization because their products are relatively clean, thus it can be directly related with people.

Although cooker top burners were designed quite a long time ago, the commercialized models present operation conditions that induce to the inefficient use of the equipment. According to the MME (2015), in May 2015, the price to the final consumer of the 13 kg of LPG (pressure vessel) grew 7.7% compared to 2014, while in September 2015, the the prices at Petrobras refineries were increased by 15% (SINDIGAS, 2015). Besides, problems related to the petroleum exploration and their products have to be considered, as for example the risk of accidents on the extraction platforms and the damage to ecosystems around the exploration sites. So, it is extremely important to rationalize the energy utilization to minimize environmental issues and costs.

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 were study parameters related with thermal efficiency and CO emissions of that burner. 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 gas pressure reduction from 330 mm H_2O to 230 mm H_2O conceived the increase of efficiency. First aeration did not affect burner efficiency. Ultimately, the thermal input growth resulted in the decrease of efficiency and increase of CO emission.

Moreover, Li *et al* (2006) studied a cooker-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, the growth of the jet-to-jet spacing caused efficiency increase.

In this work, burner aspect ratios were evaluated in order to obtain the best geometric configuration for thermal efficiency. The authors submitted to testing a cooker-top-burner operating with LPG with eight different geometries burners and five heating power conditions. Nominal thermal power, mass flow rate, adiabatic temperature, 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, we intend to look for the lowest fuel consumption and best performance (efficiency) to circumvent the increasing price of fossil fuels and contribute to the environment.

2. METHODOLOGY

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. Figure 1 presents the experimental apparatus where the tests were carried out in this work.

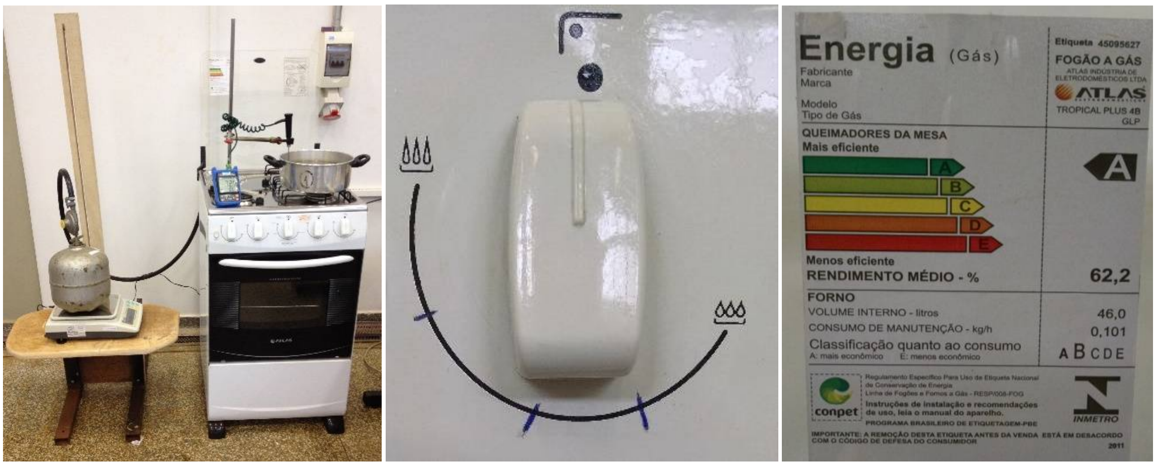

Figure 1: Experimental apparatus, TP levels and INMETRO/CONPET label.

Eight 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 by the cooker-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. Burner Geometry and the Aspect Ratio

Burner	Rod Length (mm)[1]	D, Diameter (mm)	Combustion zone's Diameter (mm)[2]	Aspect Ratio (Rod /Combustion zone)
2-α	20	13.30	70	0.28
3-α	30	13.94	70	0.43
4-α	40	14.10	70	0.57
5-α [1]	45	13.50	70	0.64
2-β	20	13.50	80	0.25
3-β	30	13.80	80	0.37
4-β	40	14.00	80	0.50
5-β[3]	45	14.02	80	0.56

[1] 120,30,40 and 45 mm are referenced as 2,3,4 and 5,respectively.[2] 70 and 80 mm are referenced as α and β. Burners original 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/butane in variable compositions (Petrobrás, 2013). Table 3 presents instrumentation required for the experimental measurements in this work.

Table 2.Fuel properties[2]. Turns (2013)

Gas Fuel	HHV (kJ/kg)	LHV (kJ/kg)	T_boiling (ºC)/(K)	T_adiabatic (ºC)/(K)	ρ (kg/m³) [3]
Propene (C_3H_6)	48936	45784	-47.40 /225.75	2071 / 2344	514
Propane (C_3H_8)	50368	47357	-42.10 / 231.05	1994 / 2267	500
Butene (C_4H_8)	48471	45319	-63.00 / 210.15	2049 / 2322	595
Butane (C_4H_{10})	49546	45742	-0.50 / 272.65	1997 / 2270	579
Mean values in this work	49330	46050	-38.25 / 234.90	2028 / 2301	547

[2] measured at T = 298.15 K and P = 0.1 MPa [3] gases at boiling temperature (liquefied gas)

Table 3. Instrumentation and technical specification

Instrument (Manufacturer, Model)	Measurement	Range	Resolution	Instrument uncertainty
Weigh device (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 1372ºC	0.1ºC	±0.1ºC
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/cm²	0.5 kgf/cm²	±0.25 kgf/cm²
Water container (Aluminum)	Water mass (~2 kg)	-	-	-
Gas pressure vessel for LPG (P-2)	Gas mass (2 kg)	-	-	-

2.2 Experimental Procedures and Laboratory condition

Ideal laboratory conditions for data acquisition, recommended by ABNT (1999 and 2003), is temperature, T_{lab} = (25±5) ºC. UFGD facilities have no control of ambient parameters, so tests were performed as close as possible under the recommended ones, but unfortunately some of the results were obtained for T_{lab}> 25ºC. LPG pressure inside the vessel (P-2 pressure vessel) must be, according to ABNT (1999 e 2003), higher than 1.96 kPa.

2.2.1 Fuel mass flow, thermal power and adiabatic temperature

Fuel mass flow – m_{gas} (kg/s) – thermal power – TP (kW) – and its respective uncertainties, are determined by Eqs. (1) and (2). Measured values are: Δm (kg) is total mass variation of the pressure vessel and Δt (s) is time elapsed during a single test. Fuel properties from Tab. 3: LPG high heating value is HHV (kJ/kg) and ρ (kg/m³) is the specific mass.

Adiabatic temperature -T_g(K)- was calculated by Eq.3. Where, T_{air} (K) is the air temperature, m_f (kg/s) is the mass of the burned fuel and LHV (kJ/kg) is the low heating value. m_g (kg/s) is the mass of exhaust gases and Cp_g (kJ/kg.K) is the specific heat of theirs.

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

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

$$T_g = T_{air} + (\dot{m}_f.LHV)/(\dot{m}_g.Cp_g) \quad (3)$$

Adiabatic temperature is a theoretical value calculated assuming that all the heat resulted from combustion process is converted into enthalpy of the combustion products. This means that there is no heat transfer to the environment or heat loss by fuel dissociation (Garcia, 2002).

Results in this work were obtained under the following laboratory conditions: 25.5ºC $\leq T_{lab} \leq$ 31.6ºC, 49% $\leq RH_{lab} \leq$ 65% , 95.43kPa $\leq P_{lab} \leq$ 96.35 kPa and 490.33 kPa $\leq P_{LPG} \leq$ 735.50 kPa. The following procedure was used:
1) Ambient conditions and pressure inside the P-2 vessel are measured and registered at test beginning and ending;
2) Mass of pressure vessel is measured and registered at the test beginning and end to determine the fuel mass consumed;
3) Ignition of the burner and shutdown after 300 s (5 min);
4) Repetition of the steps for each burner and each five TP;

2.2.2 Energy conversion efficiency (from fuel to water heating) and water heating

Heat flux (or thermal energy transferred/absorbed during the test) from water and from gas – Q_w (J/s) and Q_{gas} (J/s) –, energy conversion efficiency – η(%) – and its respective uncertainties, are determined by Eqs. (4), (5) and (6). 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, ΔT (K) is the water temperature variation, and Δt (s) is the time elapsed during a single test. Eq. (7) gives the Reynolds number for the internal turbulence inside the burner´s rod. μ (N.s/m²) is the kinematic viscosity, v (m/s) is the fuel velocity inside the burner´s rod and $D_{i,rod}$ is the internal diameter of burner's rod.

$$Q_{gas} = \Delta m.HHV \quad u_{Q_{gas}} = \sqrt{(u_{\Delta m}.HHV)^2 + (u_{HHV}.\Delta m)^2} \text{ , assuming that } u_{HHV} = 0 \text{ (HHV=cte)} \quad (4)$$

$$Q_w = m_w.h_w.\Delta T \text{ and uncertainty by } u_{Q_w} = \sqrt{\left(u_{m_w}.h_w.\Delta T\right)^2 + \left(u_{h_w}.m_w.\Delta T\right)^2 + \left(u_{\Delta T}.m_w.h_w\right)^2} \text{ , } u_{h_{water}} = 0 \text{ (h=cte)} \quad (5)$$

$$\eta = Q_w/Q_{gas} \text{ and uncertainty determination given by } u_\eta = \sqrt{\left(u_{Q_w}.1/Q_{gas}\right)^2 + \left(u_{Q_{gas}}.-Q_w/Q_{gas}^2\right)^2} \quad (6)$$

$$R_{eynolds} = \rho.v.D_{i,rod} / \mu = 4.\dot{m} / \mu.\pi.D_{i,rod} \quad (7)$$

These results were not obtained under controlled laboratory conditions: 22.9 ºC $\leq T_{lab} \leq$ 31.0 ºC, 59.5% $\leq RH_{lab} \leq$ 68 %, 95.63kPa $\leq P_{lab} \leq$ 96.21 kPa and 196.13 kPa $\leq P_{LPG} \leq$ 686.47 kPa. The following procedure was used:
1) Ambient conditions and pressure inside the P-2 vessel are measured and registered at test beginning and ending;
2) 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 ºC) of water inside the container;
4) Ignition the burner and pre-heating during 600 s (10 minutes). Note: Container at the center of burner´s flame;
5) Transfer pre-heated water to another container and, positioning at the burner´s flame again;
6) Thermocouple positioned at the water container´s volumetric center;
7) Burner shutdown 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;

2.2.3 Temperature evolution over time

Direct measurements for water temperature, T_w (°C), and time elapsed, t(s), were performed by using a thermocouple and a chronometer. These results were not obtained under controlled laboratory conditions: 26,9 ºC $\leq T_{lab} \leq$ 34,1 ºC, 37 % $\leq RU_{lab} \leq$ 73 %, 95.59kPa $\leq P_{lab} \leq$ 95.89kPa and 588,40kPa $\leq P_{LPG} \leq$ 686,47 kPa. The following procedure was applied:
1) Ambient conditions and pressure inside the P-2 vessel were measured and registered at test beginning and ending;
2) Insert ~2 kg (20±1 ºC) of water inside the container;
3) Ignition of the burner positioning the container at the center burner´s flame;
4) Thermocouple positioning at the water container´s center;
5) Burner´s shutdown after 600 s (10 minutes), and water temperature registering each 30 s;
6) Repetition of the steps for each burner and each five TP either;

3. RESULTS AND DISCUSSIONS

Regarding the water's temperature, the Fig. 3 represents the temperature (°C) variation over time (s) as a result of the combustion process provided by burners β. Thereby, the highest temperature variation in a fixed period of 600 s was achieved by TP 5 (higher thermal power) and the lowest was given by TP1 (lower thermal power) for all burners. Uncertainties are the same as ones of the instruments (thermometer, $u_T = \pm 0.1$ °C; chronometer, $u_C = \pm 0.005$ s), since data acquisition was obtained directly.

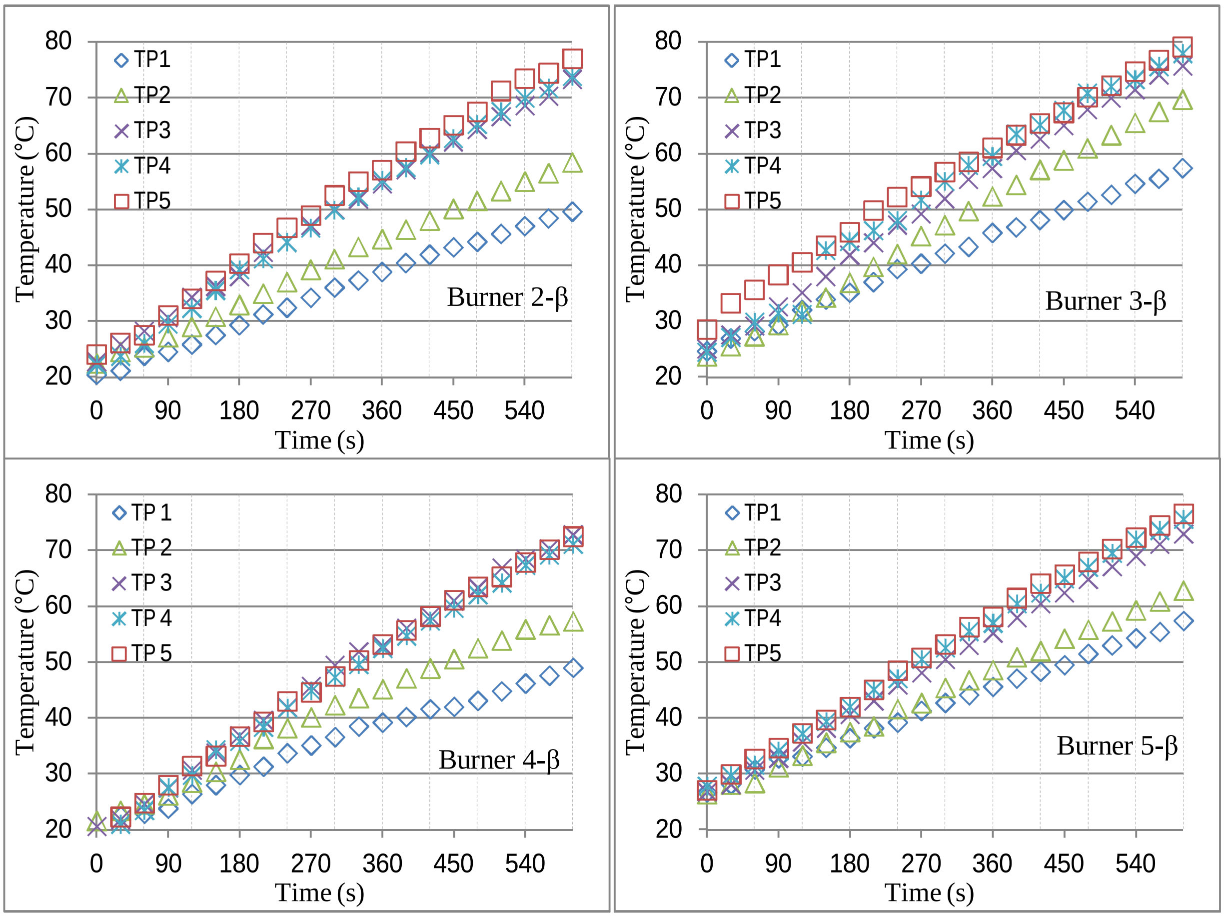

Figure 3.Heating capacity tests - Water temperature (°C) over time (s) for "β" burners.

Also, it's observable in Tab. 4 that temperature variations per second were in the same order of magnitude when operating conditions are TP 3, TP 4 and TP 5. So, it implies that there are no relevant differences in the ΔT/Δt slope when comparing maximum thermal power (TP 5) and intermediate thermal power (TP 3 and TP 4). In summary, TP3 is the best option as an operational condition.

Table 4. Temperature slope over time.

	2-β (±0.008 °C/s)	3-β (±0.008 °C/s)	4-β (±0.008 °C/s)	5-β (±0.008 °C/s)
TP 1	0.049	0.055	0.049	0.051
TP 2	0.060	0.077	0.060	0.061
TP 3	0.084	0.085	0.087	0.077
TP 4	0.086	0.089	0.086	0.080
TP 5	0.088	0.084	0.088	0.083

The burner geometries variations diversified the fuel mass flow and, consequently, the nominal thermal power conceived by the burners. The Fig. 5 evinces the behavior when each burner was subjected to five different mass flow rates. Thus, it can be noticed that the thermal power presented a linear behavior which increased with the mass flow. Moreover, the maximum thermal power was given by burner 2-α and 5-α, ~18.09 10E-1 kW (3.67 kg/s) and the minimum was given by burner 5-β, ~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.

In addition, regarding burner β, the maximum thermal power was provided by the burner with rod's size of ~20 mm (2-β) and lowest thermal power was given by the burner with ~45 mm (5-β). Therefore, it was verified that the smallest rod size benefits the thermal power's increase in this kind of burner. However, the burners α did not show this behavior. According to ABNT (2003), all the cooker-top burners are classified as 'semi-fast' (1.16 kW ≤ TP < 2.30 kW) and the burner 2-β can be classified as 'fast' (2.30 kW ≤ TP <3.50 kW).

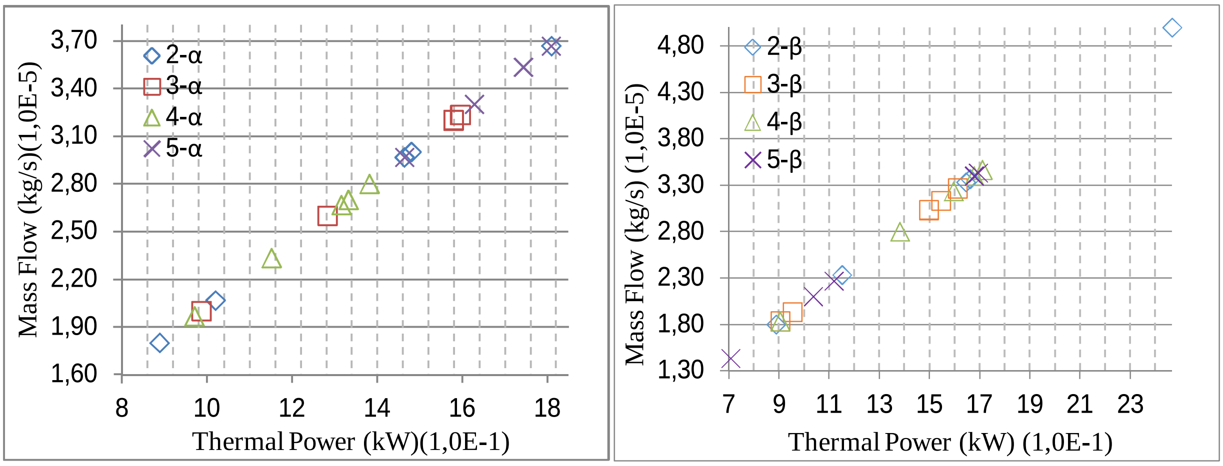

Figure 4. Nominal thermal power and mass flow behavior - Burners "α" (left) and "β" (right).

Adiabatic temperature was calculated considering that the LPG was composed entirely by propane and butane at the same ratio and the air composed by 23.13% of O_2 (in mass), Eq. (3). It resulted in a constant value of 2031.5 K (2304.6 °C) for all burners studied, representing 89.5% of the real propane/butane average value (Tab.2: 2268.5 K – 2541.6 °C). According to Nabi (2010) the lower adiabatic temperature obtained can be attributed to the heat losses during the combustion process as for example, the air-fuel equivalence ratio greater than one.

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. 5 and Fig. 6, the burner's efficiency and also the trend line behavior represented by a third degree polynomial. It is evident the burners β behavior (except burner 3-β): slight increase in TP 2, sudden decrease in TP 3, the trend decrease again at TP 4 and finally increase at TP 5. These curves were not manifested with the burners α. In other words, burners α seemed to be more sensitive to the distinguished rod's sizes than burners β. Moreover, the efficiency of both kind burners (α and β) converge to a single value when subordinated to high TP levels. It implied that the venture sizes were irrelevant when related to higher TP's. The average values in the TP 5 are 30.9% for burners α and 36.6% for burners β. This behavior is comparable to Silva *et al* (2014) which studied burners with two different combustion zones and one size of rod.

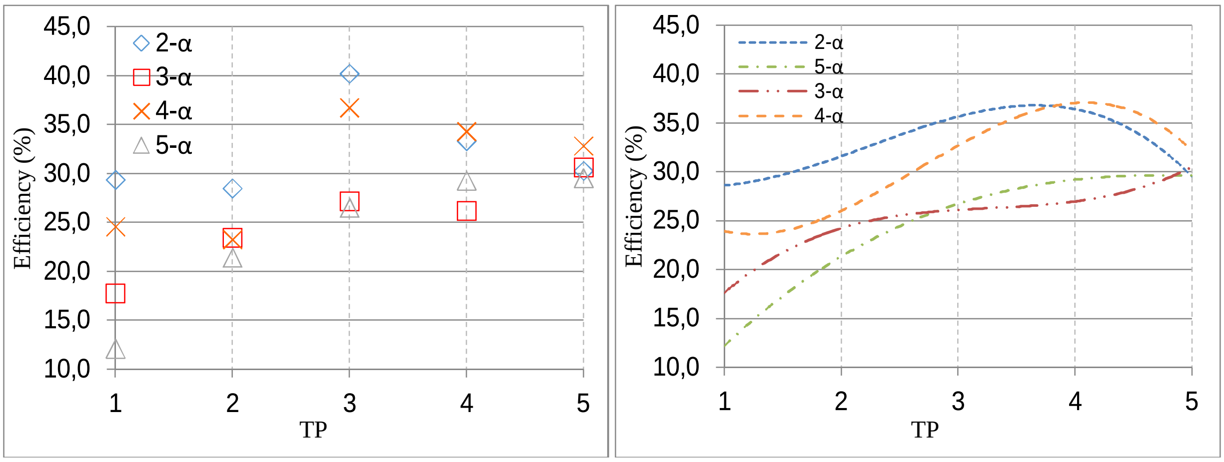

Figure 5. Thermal efficiency experimental data and trend lines for TP levels - "α" burners.

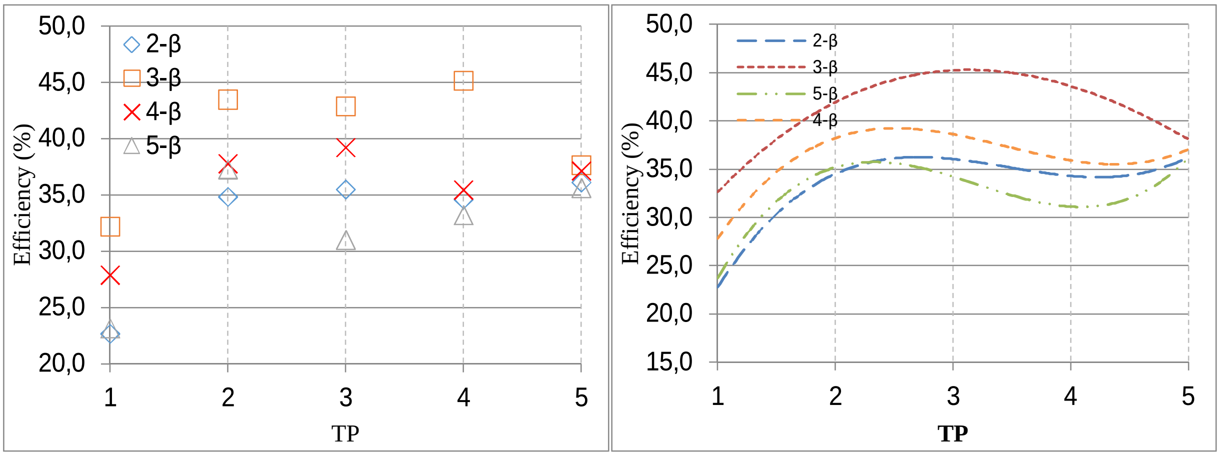

Figure 6. Thermal efficiency experimental data and trend lines for TP levels - "β" burners.

Maximum burners' efficiency was achieved by burner 3-β, showing the best design. In contrast, minimum efficiency was presented by burner 5-α. Elsewhere, it is evident that the original burners (5-α and 5-β) presented the worst efficiency performance compared to the other burners. This difference reached 13.7 % between burners 2-α and 5-α in TP 3 and 11.9 % between 3-β and 5-β at the same thermal power condition. Finally, as discussed above, the intermediate thermal power provides the same temperature variation per second compared to TP 5, besides the results from efficiency shown that this thermal power offers less fuel consumption than the TP 5 to vary the temperature evolution.

According to MME (2015), the price of 13 kg of LPG was ~ R$ 46.00 in the first half of 2015 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 2-α and 3-β instead the 5-α and 5-β (original burners) it will have a 13.7% and 11.9%, respectively, of efficiency improvement as noted previously. It implies a saving of ~9 kg /~11 kg of LPG and ~R$ 33.00 / ~ R$ 38.00 for burners 3-β and 2-α, respectively.

Furthermore, the influence of the Reynolds number in the combustion process was also studied in this work. Figure 7 shows the behavior between the efficiency and the Reynolds number, represented by a trend line of a second degree polynomial. Thus, even burners α and β denote a parabolic behavior which 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.

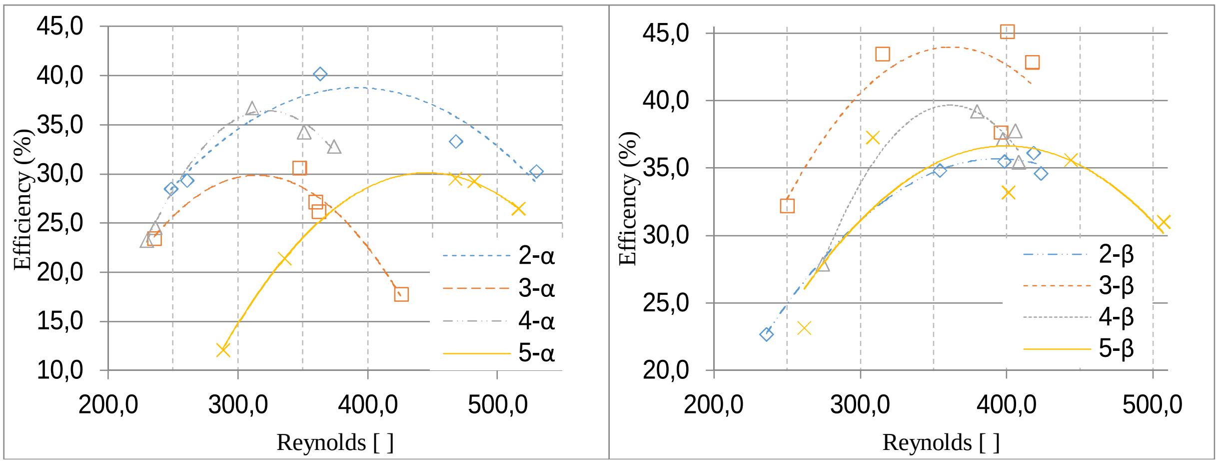

Figure 7. Influence of Reynolds in the heating efficiency test.

4. CONCLUSIONS

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

a) There were no relevant differences in the ΔT/Δt slope when comparing maximum thermal power (TP 5) and intermediate thermal power (TP 3 and TP 4), and these conditions presented less fuel consumption. In summary, TP 3 or TP 4 is the best option as an operational condition.
b) The maximum thermal power was given by burner 2-α and 5-α, ~18.09 10E-1 kW (3.67 kg/s) and the minimum given by burner 5-β, ~7.07 10E-1 kW (1.43 10E-5 kg/s). Also, the smallest size of the rod was beneficial to the thermal power in the β burners. However, the burners α did not show this behavior.
c) Adiabatic temperature calculated resulted in a constant value of 2031.5 K (2304.6 °C) for all burners studied, that can be compared to literature, 2268.5 K (2541.6 °C).
d) Maximum burner efficiency was achieved by burner 3-β, which showed the best aspect ratio. In contrast, minimum efficiency was presented by burner 5-α. Moreover, the efficiency of both kind burners (α and β) converge to a single value when subordinated to high TP levels. It implies that the rod sizes are irrelevant when related to higher TP's.
e) Regarding the influence of the Reynolds number in the process efficiency, even burners α and β denote a parabolic behavior which increases to a peak value and then drops. This behavior can be explained by the turbulence and consequently the air/LPG mixtures reaching a maximum efficiency value which 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 operational conditions for cooker-top gas burner at better efficiency and lower fuel consumption, what results in money savings and lowers greenhouse gases emissions.

5. ACKNOWLEDGEMENTS

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