The Effect of Upper and Lower Limit Pressure on the Thermal Performance of Liquefied Petroleum Gas Stove

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The Effect of Upper and Lower Limit Pressure on the Thermal Performance of Liquefied Petroleum Gas Stove

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Abstract: The paper presents the effect of the LPG's upper and lower limit working pressure on the thermal performance of an LPG single-burner gas stove. The measurement method for determining LPG stove thermal performance is based on Indonesian National Standard (SNI). The recent standard is SNI 8660:2018 about low-pressure LPG and LNG/NG gas stoves for households. According to the SNI, the working pressure required by the standard is 280 ± 5 mmH$_2$O (2.8 ± 0.05 kPa). In this study, the effect of gas stove thermal performance for the upper limit pressure was carried out at a working pressure of 290 mmH$_2$O, and the lower limit pressure was carried out at a working pressure of 270 mmH$_2$O. A regression method was applied to determine the effect of upper and lower limit pressure on the thermal performance standardization of single-burner gas stoves. At the 95% confidence level, the input pressure significantly affects the heat input but has no significant effect on the thermal efficiency. The results show that the range of input gas pressure on the heat input measurement is 280 ± 5 mmH$_2$O with special attention to pressure stability, while the thermal efficiency measurement can expand to 280 ± 10 mmH$_2$O.

Keywords: working pressure, thermal performance, gas stove; national standard, heat input, thermal efficiency

1. Introduction

Due to economic considerations, lack of fossil fuels, and environmental problems, decreasing energy consumption is currently among the major human concerns[1,2]. Since a country's development depends on energy supply, natural energy resources are highly demanded[3]. As an energy carrier with the largest portion of consumption growth, natural gas has steady energy consumption ratio growth among other types of primary energies[4]. Globally, there is an increase in gas consumption by 4.8% in 2021[5], and it is predicted to increase by around 37% in 2040[6].

As one of the ASEAN countries with the highest natural gas consumption, Indonesia has implemented a fuel conversion program from kerosene to liquefied petroleum gas (LPG) since 2007[7]. Domestic energy consumption is used significantly for the cooking process[8–10], so saving energy consumption for cooking will affect nationwide energy consumption[11,12]. In 2011, Indonesia completed the megaproject energy program to convert cooking fuel from kerosene to LPG with benefits such as user costs, cleanliness, convenience, and environment[13].

A product to be marketed in Indonesia must go through the stages of testing according to the applicable Indonesian national standards (SNI) to meet safety, health, security, and environmental requirements[14,15]. Therefore, market access and product quality will increase, which are the standard implementation positive impacts[16]. In the context of certifying LPG gas stove for Indonesian market there is a ministerial decree that regulates the testing shall be carried out in an accredited laboratory[17,18]. Such laboratory should ensure the equipment traceability and the method validity[19,20]. By 2021, there will be 12 test laboratories registered with the national accreditation committee, both government and private, that can test gas stoves. National Standardization Agency of Indonesia (BSN) has issued several SNIs for LPG gas stoves, including SNI 7368: 2011, SNI 7469:2013, and the latest are SNI

8660:2018 and SNI 7613-2019. Gas stove testing based on SNI 8660:2018, about low-pressure LPG and LNG/NG gas stoves for households, consists of 12 types of tests, such as dimension test, flame test, temperature rise test, stability test, strength test, physical test, rust resistance test, leak test, valve resistance test gas and lighter, gas pressure test, and thermocouple test. Four out of 12 tests were carried out using working pressures of 280 ± 5 mmH_2O, such as the flame test, temperature rise test, gas pressure test, and thermocouple test[21)].

The thermal performance of the LPG gas stove can be determined by heat input and thermal efficiency testing of the gas stove. The test method shall comply with the energy test procedure. An evaluation of the thermal performance test method of SNI 7368: 2011 has been carried out with an evaluation method through the comparative interpersonal test according to BS EN ISO/IEC 17043: 2010. The results show that the thermal performance is satisfactory for the heat input and thermal efficiency aspects. The measured heat input should not deviate more than 10% from the value specified by the manufacturer. Measured thermal efficiency should not less than 50%. These values are required by all the mandatory standards[22,23)]. Still, the thermal efficiency has different results because the results between temperature rise, gas consumption, and test duration are varying over consecutive tests. This variation is due to the lack of a method for ensuring the gas composition during the test[24)].

Essential aspects that may influence the thermal performance of gas stoves include altitude[25,26)], fuel composition[27)], and gas pressure[27,28)]. Since the altitude and fuel composition aspects during the test procedure are well maintained in the laboratory, so that their effects in the results could be minimized. These two aspects are not addressed by the standard, however, for the pressure aspect standard gives a lot of attention. Ko and Lin investigated the influence of natural gas pressure and found that decreasing the gas pressure from 150 mmH2O to 100 mmH2O led to an increase in thermal efficiency [27)]. Wichangarm et al. in 2020 examined the impact of LPG gas pressure (ranging from 0.2-1 bar) on gas flow behavior and thermal efficiency in three different high-pressure LPG burners with various insert wings. They found that as LPG pressure increased, the thermal efficiency decreased due to increased fuel rate and heat flux at the vessel surface, but also higher heat loss to the surroundings[29)]. These findings align with previous experimental studies[27,30–35)]. Furthermore, higher LPG pressure generated increased turbulence intensity, causing hot air detachment from the vessel surface and deteriorating heat transfer. Consequently, fluctuations in gas pressure significantly influence heat input, flame characteristics, and ultimately impact thermal efficiency[29)].

Working pressure has a significant effect on heat input. So, the difference in working pressure will produce a different heat input. The heat input of the stove is one part of the flame test. Therefore, the technician must ensure and control the working pressure when carrying out the test to get an accurate test result and accordance with the requirements of the applicable standard[36)].

The overview presented above highlights the significant role of working pressure in influencing the thermal performance of gas stoves. While previous studies have extensively explored this effect on low-pressure natural gas stoves and high-pressure LPG gas stoves in the wide working pressure range, a gap exists concerning the impact of gas pressure on low-pressure LPG gas stoves, particularly within the narrow range of ±5 mmH_2O from the nominal working pressure (upper limit is 285 mmH_2O and lower limit is 275 mmH_2O).

The importance of the upper and lower limits of working pressure lies in their potential impact on obtaining accurate and reliable measurements of heat input and thermal efficiency in gas stoves. Inaccurate heat input and thermal efficiency data may result in misleading assessments of the stove's thermal performance, making it challenging to compare results across different stoves or conduct reliable energy-saving evaluations. There is a chance to widen the limit range if the examination of standard-required limit does not show significant different for the assessment.

This study seeks to address this gap by conducting a thorough examination of how working pressure range precisely affects the thermal performance of low-pressure LPG gas stoves and to provide evidence of the consistency of gas stove thermal performance even though the working pressure used in the procedure are outside of the allowable range. This study is important in helping testing laboratories that has obligation to ensure the validation of their methods and to examine any disturbance aspect during the testing sequences.

In this study, a gas stove performance test was carried out based on SNI 8660:2018 to determine the effect of working pressure on heat input and the thermal efficiency of the gas stove. The upper limit pressure was carried out at working pressure of 290 mmH_2O, and the lower limit pressure was carried out at working pressure of 270 mmH_2O. The result obtained is expected to expand the working pressure range.

2. Methodology

2.1 Material

This study uses a single-burner gas stove. The method for heat input and thermal efficiency energy of liquefied petroleum gas stove was determined according to SNI 8660:2018 about low-pressure LPG and LNG/NG gas stoves for households. A commercial LPG was used as fuel in this experiment. We used one commercial LPG for one input pressure variation in the measurement. A digital pressure gauge was used to measure the working pressure. The digital pressure gauge has a 0-3.5 bar measurement range with an accuracy of 0.02 %FS. A commercial low-pressure gas regulator was used on the LPG gas to ensure a stable input pressure level during measurement. The testing setup can be seen in Fig. 1.

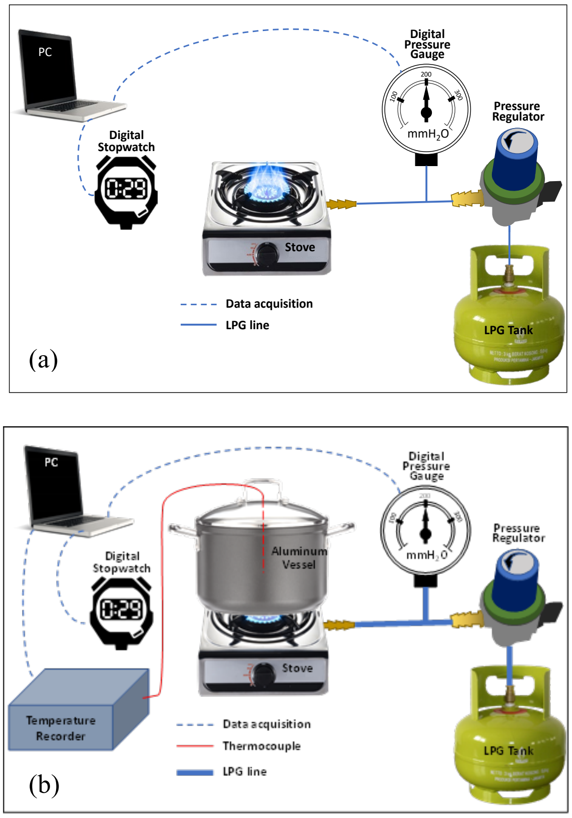

Fig. 1: (a) Experimental setup for heat input measurement, (b) Experimental setup for the estimation of thermal efficiency at the working pressure reference (280 mmH_2O) is 2.30 kW.

For the thermal efficiency determination, the vessel and vessel lid used in the water mass determination have a thickness of 0.5 ± 0.1 mm. Meanwhile, the dimension of the vessel used to determine the thermal efficiency depends on its heat input value, as shown in Table 1. The measurement of water mass was carried out using a digital mass scale with a resolution of 0.5 gr, and the maximum mass that can be weighed is 15kg. The measurement of water temperature inside the vessel becomes one of the crucial steps in thermal efficiency determination. This measurement uses a type-K wire thermocouple with a diameter of 0.3 mm in compliance with CTL-OP 108. The instruments used in this research have been calibrated.

Table 1. The heat input corresponds to the diameter of the vessel and water mass[21)]

Heat Input (kW)	Diameter of Vessel (mm)	Heigh of Vessel (mm)	Minimum Water Mas (kg)
≤ 1,15	200	130	2,6
1,16 – 1,64	220	140	3,7
1,65 – 1,98	240	150	4,8
1,99 – 4,20	260	160	6,1
4,21 – 4,50	280	170	7,2
4,51 – 4,80	300	180	8,3
4,81 – 5,00	320	190	9,5

2.2 Method

According to the SNI 8660: 2018, the determination of the working pressure used is 280 ± 5 mmH_2O. In this measurement, five variations of working pressure are used to determine the effect of working pressure on heat input and the efficiency of the gas stove. The upper limit pressure was carried out at working pressure of 290 mmH_2O, and the lower limit pressure was carried out at working pressure of 270 mmH_2O. Other possible disturbance factors, such as room temperature and humidity, fuel composition, and wind velocity, are maintained. While operator, instruments, and measurement configuration, are the same throughout the measurement. The measurement carried out in a laboratory that equipped with hood to release the flue gas and air conditioning to maintain the room condition.

Following the SNI 8660: 2018, the heat input was estimated by determining LPG consumption for one hour. The gas consumption is calculated to determine the gas mass flow rate. The method of determination of LPG consumption was carried out by measuring the initial and final mass of LPG with a weighing method using a digital mass scale. Then, the heat input was calculated based on Equation (1)[21)]:

$$Q_n = \frac{1000 \times M_n \times H_s}{3600} \quad (1)$$

Where Q_n (kW) is the heat input, 1000 is a factor, M_n (kg/hour) is the gas mass flow rate, and H_s (49.14MJ/kg) is the caloric value of gas.

The preheating procedure for thermal efficiency testing of the gas stove was performed by operating the gas stove at the maximum position for 10 minutes without a vessel. Successively, the determination of thermal efficiency was carried out, after preheating procedure, by boiling water inside a vessel. The water mass inside the vessel and the dimension of the vessel used for thermal efficiency testing were determined based on the heat input value, as shown in Table 1. Before boiling the water, it is crucial to ensure that the water temperature inside the vessel is 20 ± 0.5°C. The gas stove was turned off immediately when the temperature of the water inside the vessel reached 90 ± 1°C. The thermal efficiency value was calculated by obtaining the water temperature inside the vessel after the gas stove was turned off. Meanwhile, the consumption of LPG gas was obtained by determining the initial and final mass of LPG. Finally, the thermal efficiency was calculated by Equation (2)[21)]:

$$\eta = \frac{4.186 \times 10^{-3} \times M_e \times (t_2 - t_1)}{M_c \times H_s} \times 100 \quad (2)$$

Where η(%) is thermal efficiency, M_e (kg) is the total mass of water, vessel, and vessel-lid. t_1 (20±0.5°C) is the initial water temperature, and t_2 (°C) is the maximum water temperature. M_c (kg) is the mass of gas consumption used to heat water up in the vessel from temperature t_1 to t_2, and H_s (49.14 MJ/kg) is the caloric value of gas.

3. Result and Discussion

3.1 Heat Input

Heat input is one of the parameters for determining the thermal performance of an LPG gas stove. Heat input is the maximum gas fuel consumption required to ignite a gas stove at a particular duration [36]. The relationship between the heat input and the pressure can be seen in Fig. 2 that is obtained from a previous study and experiments from this study.

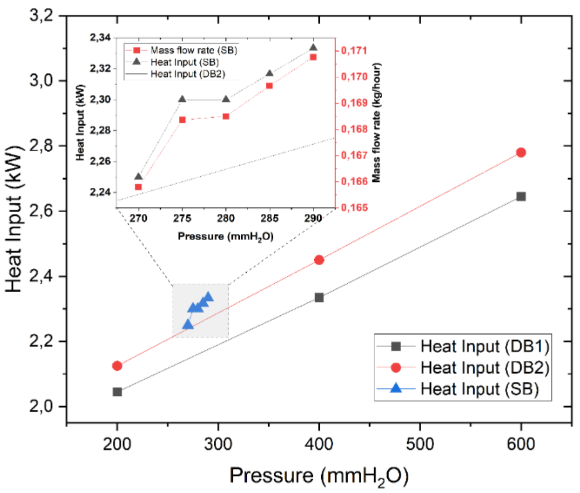

Fig. 2: Measurement result of heat input (blue triangle), compared to a previous result (red dot and black square)[36]. Inset: detail of heat input and flowrate measurements in this study.

The previous study performed an experiment at a wider pressure range, which is 200 to 600 mmH$_2$O, using double burner gas stove with three distinct measurement points (200, 400, and 600 mmH$_2$O). Each burner (DB1 and DB2) gives an increasing heat input trend against pressure. On the contrary, this study is focused on a narrow pressure range (270 to 290 mmH$_2$O) using a single burner gas stove. Detailed result can be seen in the inset of Fig. 2. The measurement is carried out at the working pressure 270, 275, 280, 285, and 290 mmH$_2$O. The inset in Fig. 2 also shows the gas mass flow rate at each working pressure variation.

It can be seen on Fig. 2 that the higher the working pressure, the higher the gas mass flow rate. This means that gas consumption will increase with increasing working pressure. It was found that the gas mass flow rate is 0.166 kg/hour for the lower limit working pressure (270 mmH$_2$O) and 0.171 kg/hour for the upper limit working pressure (290 mmH$_2$O). The gas mass flow rate affects the obtained heat input value. The heat input at the lower limit pressure is 2.25 kW, and that at the upper limit pressure is 2.33 kW. Meanwhile, the heat input at the working pressure reference (280 mmH$_2$O) is 2.30 kW.

Furthermore, regression analysis to determine the effect of input pressure on the heat input is carried out by entering ambient temperature (Temp), humidity (*RH*), and input pressure (*P-in*) as independent variables to the heat input (*HIP*) value as the dependent variable. The intended independent variable is only the input pressure based on literature review elaborated in introduction. The ambient temperature and humidity are unintended independent variables since in this research the two variables are maintained in a specified range. However, it necessary to seek out the effect the fluctuation of the two variables within the specified range on thermal performance result.

In this case, the test was carried out at the 95% confidence level, so the significance level (α) value is 0.05. The results of the regression from the Minitab output can be seen in Table 2.

Table 2. Regression Analysis: *HIP* versus *Temp, RH,* and *P-in*

Predictor	Regression Coefficient	Std. Error Coefficient	P-value
Constant	1.4027	0.1903	0.000
Temp	-0.003891	0.002716	0.180
RH	-0.0008028	0.0008707	0.376
P-in	0.37447	0.06396	0.000

The regression equation:

```
HIP = 1.40 - 0.00389 Temp - 0.000803 RH + 0.374
P-in
Std. Error of Regression, S = 0.0139819
Coefficient of determination, R-Sq = 83.0%
```

From the regression analysis results, it was found that the variables *Temp* and *RH* have P values of 0.180 and 0.376, respectively ($P \geq \alpha$). It can be concluded that from this experiment, the room temperature and the humidity have no significant effect on the value of the resulting heat input because both variables are controlled. Meanwhile, at the variable *P-in*, with P value = 0.000 (<< 0.05), it shows that the input pressure during measurement significantly affects the value of the gas stove heat input. This result agrees with the conclusion obtained in Kusnandar's study[36].

Comparing this research to the previous study, both yield positive regression coefficient, however, the coefficient in this research (regression coefficient of 0.374) is greater that that of the previous one (regression coefficient of 0.146) which was caused by differences in the test samples. The greater the value of the regression coefficient, the greater the heat input range. In heat input measurement, there is a deviation of 2.17% and 1.3% for the lower and upper working pressure limits, respectively, when compared to the heat input obtained by applying the nominal working pressure (280 mmH$_2$O).

To see how much input pressure affects the heat input value, the regression model was remade by only entering the input pressure (*P-in*) as the independent variable. Table 3 shows the results.

Table 3. Regression Analysis: HIP versus P-in

Predictor	Regression Coefficient	Std. Error Coefficient	P-value
Constant	1.2874	0.1522	0.000
P-in	0.36127	0.05433	0.000

```
The regression equation:
HIP = 1.29 + 0.361 P-in
Std. Error of Regression, S = 0.0148796
Coefficient of determination, R-Sq = 77.3%
```

The regression coefficient value of 0.361 means that in this experiment, a change (increase) in gas pressure of 1 kPa will cause an increase in the value of heat input of 0.361 kW. In addition, the regression model also shows that the magnitude of the effect of the input gas pressure on the heat input is quite dominant, which is 77.3% according to the resulting *R-sq* (coefficient of determination). Given the significant effect of the input gas pressure on the heat input, maintaining the stability of the input gas pressure value during the heat input testing process is a factor that needs attention.

3.2 Thermal Efficiency

Some experimental studies show that fuel consumption in domestic stoves can be reduced by modifying the burner geometry[34,35,37–39]. The literature revealed that the thermal efficiency of the gas stove is available between 67% and 69%[40–42].

Based on the measurement result, the graph was prepared to compare the parameters of consumed gas, duration to reach the set temperature, temperature rise, and thermal efficiency for each variation of working pressure, as shown in Fig. 3.

It was found that the gas consumption at the upper limit pressure was the same as the gas consumption at the reference pressure (280 mmH_2O), although, at the upper limit pressure, it took less time to reach the set temperature. The gas consumption at the lower limit pressure is smaller than gas consumption at the reference pressure with a longer time to reach the set temperature. The duration to reach temperature 90°C is range from 22-23 minutes. Thermal efficiency was found 62.19% at lower limit pressure, 61.70% at reference pressure, and 61.71% at upper limit pressure.

Regression analysis to determine the effect of input pressure on the thermal efficiency is carried out by entering ambient temperature (*Temp*), humidity (*RH*), input pressure (*P-in*), consumed gas (M_c), and temperature rise (*dT*) as independent variables to the thermal efficiency (*Eff*) value as the dependent variable. The results of the regression from the Minitab output can be seen in Table 4.

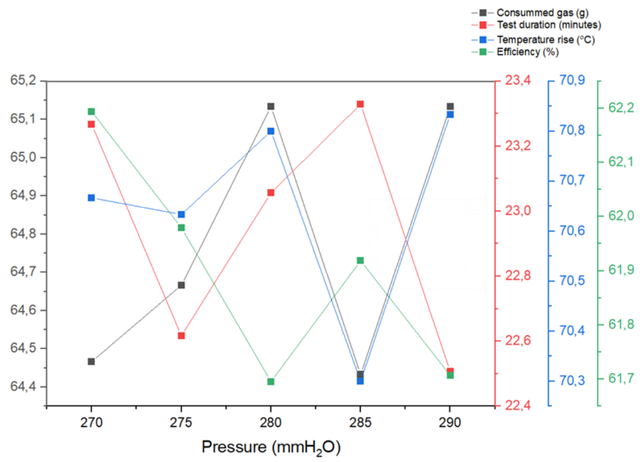

Fig. 3: Comparisons of different parameters on variations of working pressure.

There is no sufficient correlation between the independent variables included in the regression model, as indicated by the VIF values of each of these variables, which are quite small (less than 10). The absence of multicollinearity indicates that this regression model can be used to analyze what factors affect the thermal efficiency of gas stoves.

Table 4. Regression Analysis: Eff versus *Temp, RH, P-in,* M_c*, dT*

Predictor	Regression Coefficient	Std. Error Coefficient	P-value	VIF
Constant	61.6305	0.5931	0.000	-
Temp	0.004062	0.002904	0.195	1.758
RH	0.0004590	0.0007504	0.556	2.084
P-in	-0.01494	0.05277	0.783	1.205
M_c	-944.993	5.393	0.000	2.050
dT	0.868856	0.009475	0.000	1.356

```
VIF = Variance Inflation Factor
The regression equation:
Eff = 61.6 + 0.00406 Temp + 0.000459 RH -
    0.0149 P-in - 945 Mc + 0.869 dT
Std. Error of Regression, S = 0.0131658
Coefficient of determination, R-Sq = 100.0%
```

The regression analysis results show that only two variables have P values less than $\alpha = 0.05$, namely Mc and *dT*. It can be concluded that at the 95% confidence level, consumed gas and temperature rise significantly affect the thermal efficiency value. As stated in, an inconsistent result between temperature rise and gas consumption may be due to the absence of a method to ensure the composition and temperature of LPG used during the test.

Meanwhile, the effect of input pressure is stated to be insignificant because it has a P value bigger than α. This result shows that in the pressure range of 270 mmH_2O to

290 mmH_2O, the rise and fall of the input gas pressure during the test have no significant impact on the thermal efficiency value of the gas stove produced. This phenomenon is caused by the fact that in this pressure range the flame neither drift away from the burner nor curve more than the vessel bottom perimeter. Thus, in this experiment, the change of gas pressure does not significantly affect the thermal efficiency. If the increase of gas pressure makes the flame curve more than the vessel bottom perimeter the thermal efficiency will significantly reduce.

4 Conclusion

The effect of the upper and lower limit of pressure on the thermal performance of liquefied petroleum gas stove has been performed in this study. The upper limit pressure was carried out at working pressure of 290 mmH_2O, and the lower limit pressure was carried out at working pressure of 270 mmH_2O. The result of regression analysis at the 95% confidence level, there is a significant effect of variations in working pressure during testing on the heat input. The research findings indicate a positive linear correlation between heat input and working pressure in gas stoves. The regression coefficient of 0.374 suggests that for every unit increase in working pressure, there is a corresponding increase in heat input. The relationship between heat input and working pressure leads to deviations of 2.17% and 1.3% for the lower and upper working pressure limits, respectively, when compared to the heat input obtained by applying the nominal working pressure (280 mmH2O). This result shows that the measurement of heat input using working pressures of 280 ± 5 mmH_2O needs to pay more attention to pressure stability. Meanwhile, working pressure, at this narrow range, has no significant effect on thermal efficiency. Despite the slight variations in heat input at the upper and lower working pressure limits, the thermal efficiency remains relatively stable. The thermal efficiency of the gas stove varied less than 1% within this pressure range. It suggests that on the measurement of thermal efficiency, the working pressure range can be expanded to 280 ± 10 mmH_2O. Future research can focus on investigating methods to improve pressure stability during gas stove testing to enhance the accuracy of heat input measurements.

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Nomenclature

Q_n	heat input (kW)
M_n	gas mass flow rate (kg hour^{-1})
H_s	caloric value of gas = 49.14 (MJ kg^{-1})
M_e	total amount of water mass and vessel and lid vessel (kg)
t_1	initial water temperature (°C)
t_2	maximum water temperature (°C)
M_c	mass of gas consumption (kg)

Greek symbols

η	thermal efficiency (%)

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