The application of ceramic stove cover and loading distance to the performance of water boiling system

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Abstract. Conventional gas stove (CGS) used in the water boiling system (WBS) is quite inefficient if the mechanism is not considered. In the present research, an assessment has been performed to a CGS by applying a ceramic stove cover (CSC) and also investigated the optimum distance between CSC and the loading to obtain very best efficiency of a CGS. Several parameters used to investigate the CGS's performance such as water temperature, heating value of the fuel and temperature of CSC have been used in reference to the definition of efficiency. In this study the distance between CSC and the loading is varied by 1 mm to 7 mm by increment of 1 mm. The results show that at a distance of 4 mm, the performance of a CGS in a certain fuel rate of 12.5 cc/s increase significantly indicated by the best efficiency of 46.4 %. It is because of an optimum condition is accomplished simultaneously in heat transfer processes such convection and radiation in the WBS. Although the fuel rate itself have an influence to the flame structure heating the loading, however, the used of ceramic cover have an effect to the exchange between fresh air and flue gas to the combustion process.

1 Introduction

The main fuel for households in Indonesia was subsidy kerosene or decades. The subsidy of oil for domestic gas stove was hundred billion only in years of 2006 – 2008. This subsidy was overwhelming to the PDB of Indonesia. For this reason, the government of Republic of Indonesia furthermore applied oils to gas conversion program start in year 2007 [1]. The use of LPG also has advantages in relatively clean combustion products. The use of LPG as domestic heating appliances shows cost reduction about 60% cheaper compared to those of using oil [2]. However, if the CGS mechanism is observed there are opportunities to improve its efficiency.

Many efforts have been performed to increase CGS's efficiency and to reduce emission as in Hou [3, 4, 5]. To improve efficiency, modification, and implementation some devices by Gohil [6] into a CGS yield an increasing efficiency of 66% from previously 48%. An addition of a heat collector device or a pyramidal stove cover has also increased by 10 % of the efficiency of a CGS respectively compared to a CGS without cover [7].

The influence of oblique angle and heating on an impinging laminar jet flame applied in domestic gas burner was investigated by Hou [8]. The results show that the oblique angle and heating height have a great influence to temperature field, flame structure, and efficiency of domestic gas burner. A maximum efficiency is obtained at the beginning and then decreased, as the heating height is increased for a fixed oblique angel.
Materials and CGS's design are also have a contribution to develop efficiency. Khan [9] conducted an experiment related to material and CGS's design. By replacing a head burner made from brass instead of cast iron, the efficiency of a CGS increase about 4 %. The efficiency of a CGS also increased around 8 % as a design of a CGS substituted by flat face burner instead of flower brass burner. Commercial CGS which is used in Indonesia is a CGS standard without any modification. Widiandra [10] investigated the used of stove cover and varied the material of stove cover and furthermore applied to a CGS. An indication has also been identified that the application of a CSC to CGS able to prevent heat release from combustion chamber at initially process of heating system. At the initial time of boiling process, CSC have a good efficiency compared to other stove covers due to CSC have a low thermal conductivity compares to others. Thus the CSC will prevent radiation heat transfer from combustion chamber into surrounding as shown in figure 1.

Figure 1(a) is total efficiency per unit time of a CGS without and using stove cover on various materials. From a CGS with and without cover, the time obtained to boil water is equal to 553 seconds without cover, 521 seconds for CSC, 530 seconds aluminum stove cover and 552 seconds for iron stove cover respectively. It indicates that CSC has the best efficiency compared to other stove cover with material of iron or aluminum. The higher efficiency of CGS reaches 46.4%. The value of efficiency for this case is relatively different with the efficiency obtains by Gohil [6], a maximum efficiency of 66% as a result because of different design of the stove cover and how to define the term of efficiency. Other information obtains from figure 1(a) is that the used of stove cover made from

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iron have insignificant influence on the efficiency of the CGS. Aluminum stove cover relatively has a good efficiency compared to iron stove cover with maximum efficiency of 45.8%.

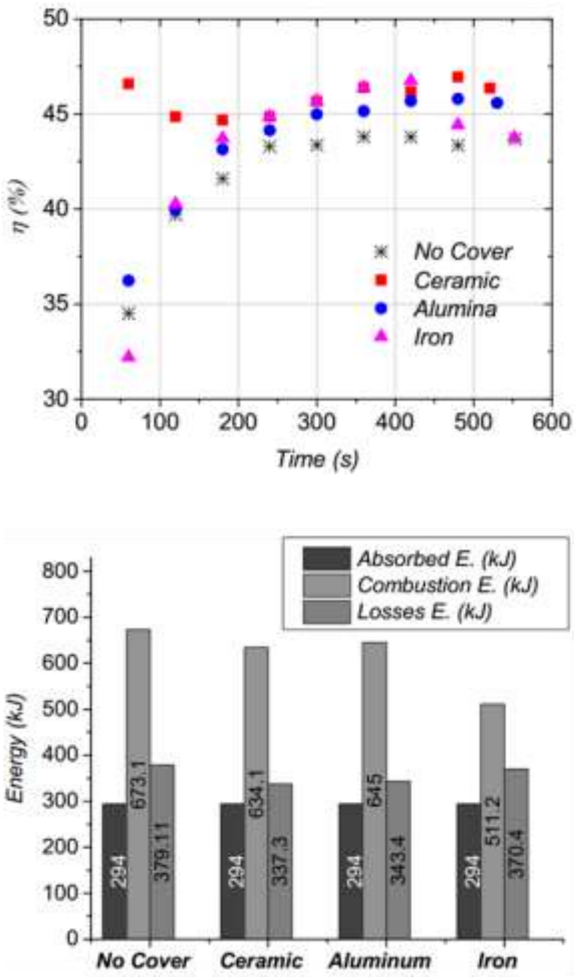

Fig 1. (a) Efficiency of a CGS per unit time with and without stove cover; (b) Energy distribution without & using a stove cover

Figure 1(b) also shows a distribution of energy absorbed by water, energy from fuel and losses energy during boiling process. At equally energy absorbed by the water, it is shown that a CGS without cover use more energy compared to a CGS using a CSC. Losses energy coming from a CGS without cover also show a larger value compared to a CGS using CSC.

Effects of heating height on flame appearance, temperature field and efficiency in a single impinging laminar jet flame used in domestic gas stoves without covering the flame inside the combustion chamber also have been investigated by Hou [5]. Hou categories flames into three different type of flames impinging the loading. It means there will be three different height of heating flame. The result showed that the highest efficiency is by using a C-type of flame which inner premixed and outer diffusion flame were opened and diverged.

An indication has been identified that as the distance between the stove cover and the loading is too close, the efficiency of the CGS tends to decrease. As conduction, convection and radiation heat transfer are elaborate, further investigation is needed. Thereby, the aim of this research is to investigate the optimum distance between loading and stove cover to improve efficiency of a CGS in a certain flow rate of fuel. In addition, in this research, the CSC is made as simple as possible for applicable and manufacture reason.

1.1 Efficiency of a CGS

The term efficiency in a CGS is defined by fraction of the heat input coming from combustion process produced by fuel which is converted to desired output of energy absorbed by water with ignoring the heat absorbed by the loading material as shown in the equation (1).

$$\eta = \frac{m_w C_{p,w} \Delta T}{m_f . LHV_f} x\, 100\% \qquad (1)$$

where is efficiency, mw is mass of water, $C_{p,w}$ is specific heat constant of water, ΔT is initial and end temperature differences, Q_f is energy produced by fuel, m_f is mass of fuel, LHV_f is lower heating value of fuel.

Definition of efficiency in (1) is used for its relationship between energy losses in the heating system. The energy losses in the system are relatively complicated to identify because of the complexity of geometry of the heating system and heat transfer processes mechanism. The easiest way to identify one of the energy losses is radiation heat transfer from the CSC.

1.2 Energy of Heating Systems

Energy conservation in a WBS can be seen in equation (2). Identification of heat transfer processes in this research such as conduction and convection are difficult to be performed due to the complexity of the geometry of installation. It means that only radiation energy is explicated in the energy conservation.

$$E_C = E_{ab} + E_{r,cov} + E_l \qquad (2)$$

where E_c is energy contained in the fuel, LPG, E_{ab} is energy, which is absorbed by water, $E_{r.cov}$ is radiation energy that is emitted by stove cover and E_l is energy losses instead of radiation energy. Efficiency of WBS is determined using definition of input and output in (1). Efficiency is calculated per unit time until the entire water start boiling and plotted with variations of the distance.

2 Data Acquisitions

To obtain data in this research, variables as water temperature, radiation heat transfer, and fuel rate of LPG were set up in an experimental installation as illustrated in figure 3.

A CGS is a stove Quantum type QGC-101R. A standard loading with diameter of 24-cm is hanged over a supporter. The loading is equipped with a glass lid for preventing vapor of water to escape. The glass lid is chosen as an observation window as the water start to boil. At the top of the lid, an Alcohol thermometer type Al-30100-010 with range of scale of -10ºC – 110ºC is used to measure temperature of the water. The loading is equipped with a stirrer driven by a motor to ensure uniform temperature distribution obtained inside the loading so that the reading of Alcohol thermometer represent a precisely temperature of the water. Mass fuel rate are measured using a flow meter Omega FL-1501A. Surface temperatures of stove cover are obtained using k-type thermocouple that is plugged to a thermometer-set KRISBOW KW06-278 Single Input Digital Thermometer.

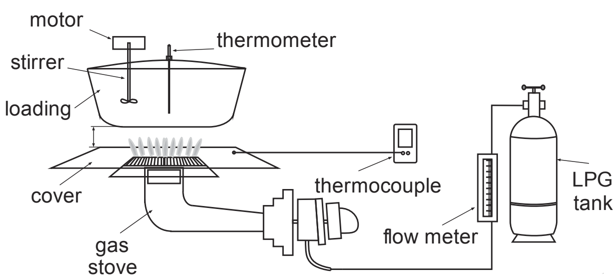

Fig 3. Illustration of experiment installation

3 Experimental Conditions

Many variables have to be collected to develop efficiency of WBS, furthermore experimental conditions are set up as seen in table 1.

Table 1. Experiment conditions

Conditions	Value
water mass [kg]	1
initial temperature of water [ºC]	25
end temperature of water [ºC]	95
$C_{p\ \mathrm{water}}$ [J/kg.ºC]	4196
Q LPG [L/m]	0.75
ρ LPG [kg/L]	0.0021
LHV propane [MJ/kg]	46.1
LHV butane [MJ/kg]	46.5

The LPG used in experiment was commercial LPG in Indonesia with a LHV of 46.44 MJ/kg. This value was obtained from proportionally composition of the fuel 30 % propane and 70% butane by volume. Average atmosphere (room) temperature was 25ºC. The end temperature of water started to boil was 95ºC correspond to the location of experiment in ± 476 from sea level. Reading of thermometer was recorded when the bottom solid interface was covering with bubbles and it rising to the top surface. Specific heat constant of water was obtained in an average operational temperature of boiling system. In every data acquisition, experiments were restarting in room temperature.

4 Results and Discussions

Efficiency of CGS is measured per unit time in various distances compared to a CGS without cover as shown in figure 4. It shows that efficiency tend to lower at the initial heating process because of energy produced from combustion process is absorbed by materials in the heating system including stove cover and loading. However, efficiency tends to be constant at time of 250 seconds exceeding a standard CGS (dash line). Actually, the distance of 5 mm has a good characteristic for covering heat release from combustion chamber. It is shown by the efficiency, which tends to increase at the initial of heating process. However, for after 300 seconds, the distance of 4 mm has a higher tendency characteristic compared to the distance of 5 mm.

Distance of 4 mm shows a maximum efficiency of 46.4 % differ 1 % compare to the distance of 5 mm. This value was identic with 116 secondds time saving equal to 141.2 kJ refer to the WBS without a CGS. The highest efficiency is reached because of the optimum condition is simultaneous achieved in convection and radiation heat transfer processes of the heating system.

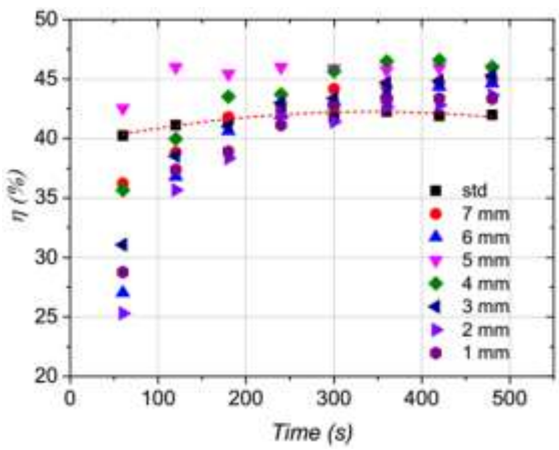

Fig 4. Efficiency of a CGS per unit time with and without stove cover

In a laminar jet flame, maximum temperature is located at the top of flame tip because of buoyancy effect. When the flowrate of the jet is increasing, the flame structure change causing combustion and heat transfer process in a WBS. As the distance between stove cover and loading is too close, there will be conditions as mention above. However, relating with fresh and flue gas exchange, there are two possibilities conditions happened. The first is the shape of the flame is not perfectly developed as a free flame because of the flame is hitting the loading. In such condition, stretch phenomenon is likely appear. Stretch affects the propagation rate by changing the diffusive flux that has significant effect to the flame temperature. Once the flame temperature decrease, it will influence the reaction rate and the burning velocity.

Secondly, the distance between CSC and the loading is a channel of convection heat transfer and also as a channel of the flow of air into fuel to make mixture in a combustion chamber. If the distance is too close, one of thus conditions may happened. In such condition, maximum temperature in combustion chamber is likely decrease and has an impact to radiation heat transfer. Conversely, as the distance is too far, convection and radiation heat energy easily escape from combustion chamber.

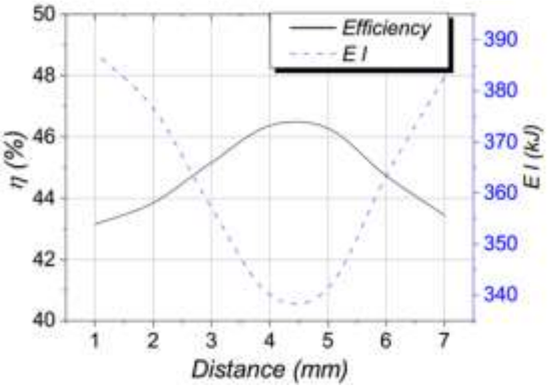

Fig. 5. Efficiency and energy losses;

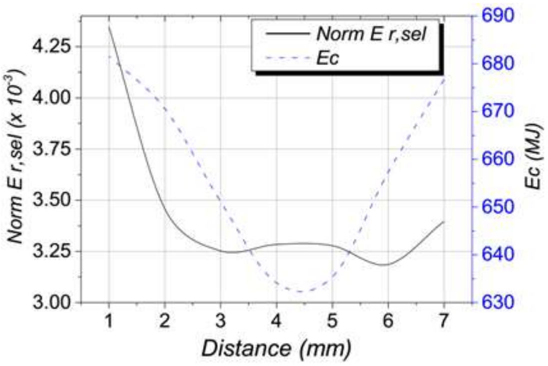

Fig 6. Norm. $E_{r,cov}$ and energy from fuel combustion in various distance

Figure 5 shows polynomial line for efficiency and energy losses in various distances. Maximum efficiency occurs in distance of 4 and 5 mm. The rest of distances indicate a decreasing efficiency as shown by values of E_l that have a minimum value as efficiency reach a maximum value. E_l of 0.34 MJ is the smallest energy losses at the distance of 4 mm. Otherwise, maximum E_l is 0.48 MJ happened in a standard CGS.

To analyze the performance of the WBS, polynomial line also plotted to combustion and radiation energy from the stove cover, $E_{r,cov}$ as shown in figure 6. Term Norm. $E_{r,cov}$ is normalized $E_{r,cov}$ by E_l in various distances. As can be seen in figure 6, distance of 1 mm indicates the highest Norm. $E_{r,cov}$ of 4.31×10^{-3}. It means that although radiation energy has a large value (indicated by surface temperature of 323.3ºC), energy losses coming from convection heat transfer at a distance of 1 mm is relatively small compared to other distances. Distance of 6 mm indicated a Norm $E_{r,cov}$ of 3.17 x 10^{-3} is the smallest one however this value is not referring to the smallest efficiency of the distance of 7 mm. Energy polynomial line which is produced by combustion process, E_C, (dash line in the figure 6) is showing a decreasing trend which is contrast with efficiency line. The highest value is obtained at a distance of 1 mm, meaning that the distance requires higher energy to boil water compare to others. This phenomenon is contrast with combustion energy at a distance of 4 mm.

5 Conclusions

In the present study, efficiency of a CGS has been assessed by varying distance between loading and stove cover in WBS. The used of CSC indicated a good characteristic for covering heat release from combustion chamber. From the discussion it is concluded that distance between pan and cover stove influences efficiency of a CGS. In a certain fuel rate of 12.5 cc/s, maximum efficiency is obtained in a distance of 4 mm. The distance of 4 mm indicates the highest efficiency of 46.4% of a CGS because of the optimum condition is simultaneous achieved in convection and radiation heat transfer processes of the WBS.

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