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Characterisation of Specially-designed Cooking Stoves Capable of Carbonising Pulverised Coal during Cooking

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Abstract

Specially-designed, carbon-steel cooking stoves, in which pulverised coal was being carbonised while cooking, were fabricated and examined. The combustion chamber of the stoves was double-walled, and a gap between the inner and outer walls is the carbonisation chamber, into which pulverised coal was loaded. The stoves were found to be durable, and the performance efficiencies of the stoves were comparable to that of the traditional one (~31 vs. 33 %) and that of the one made of stainless steel (~31 vs. 32 %). The performance efficiency increased with the amount of charcoal in the combustion chamber; however, when the amount of heat generated from the combustion of charcoal exceeded the level that the stove could utilise, the performance efficiency began to decrease. The amount of pulverised coal loaded into the carbonisation chamber slightly affected the performance efficiency. An increase in the amount of charcoal resulted in a decrease in the amount of remaining volatile matter in the resulting pulverised coal, whereas an increase in the amount of pulverised coal loaded into the carbonisation chamber caused the amount of remaining volatile matter to increase. The performance efficiency was significantly enhanced (from ~24 vs. 31 % on average) when gaseous products from the carbonisation chamber were recycled to a burner located just below the combustion chamber. An attachment of fins to the inner wall of the carbonisation chamber was found to have little effect on the performance efficiency, but resulted in a decrease in the amount of remaining volatile matter in the resulting pulverised coal. It was also found that the combustion of coal briquettes, manually produced from the resulting pulverised coal, generated a little smoke and odour and that the performance efficiency was comparable to that of charcoal (~29 vs. 31 %).

Keywords: carbonisation, coal briquettes, cooking stove

1. Introduction

In an attempt to reduce the consumption of charcoal and firewood, during the past two decades, a number of researchers [1-3] have developed coal briquettes to be used for household cooking. However, most coals in Thailand usually contain a high amount of volatile matter, and the release of volatile matter, especially in the early stage of the combustion, makes the use of coal briquettes unsafe and unattractive, as cooking stoves in Thailand are generally operated without chimneys.

Additionally, the use of coal briquettes for household cooking has also suffered from the fact that sulphur contents of coals in Thailand are often high. A number of studies [4-5] have been done in an attempt to reduce the emission of sulphur (mostly in the form of sulphur dioxide, SO_2) from the combustion of coal briquettes containing a high amount of sulphur.

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It was found that, by mixing lime (containing mainly CaO) with coal fines before briquetting, the emission of sulphur from the combustion of the resulting coal briquettes could be reduced by 50-95 %, and that the optimal CaO/S mole ratio was ~2-3 [4-6].

The reduction of volatile matter in coal can be done by a process called *carbonisation*, in which coal is heated to high temperatures in an inert (oxygen-free) atmosphere [7-8]. At high temperatures, coal decomposes, evolves water and a mixture of gaseous and liquid products (*e.g.*, hydrogen, carbon monoxide, hydrocarbons, tar), and leaves behind a solid residue, whose composition and properties depend upon the temperatures to which it is exposed [7-8]. Optimal temperatures for producing coal suitable for household cooking are in the range of 400-700 °C [8]. Generally, carbonisation processes with this range of temperatures are regarded as low temperature (LT) carbonisation [7-8]. The amount of volatile matter obtained from the LT carbonisation is usually within 15-17 % [8].

Suchart Areerungruang [9] found that a considerable amount of heat loss during the use of a cooking stove took place through the wall of the combustion chamber. With a proper design, heat loss through the wall of the combustion chamber could be used to carbonise coal or coal fines. Tanin Tantakasem [10] devised a newly-designed stove capable of carbonising coal fines at the time of cooking. The stove is a double-walled, cylindrical stove, made of stainless steel, and the space between the inner and outer walls is the carbonisation chamber. Heat generated from the combustion of fuel in the combustion chamber transfers through its wall to carbonise coal fines in the carbonisation chamber at the temperature of, approximately, 450 °C. The amount of volatile matter in the resulting coal fines obtained from the carbonisation chamber was found to be lower than 20 wt.%, which is similar to that obtained from the LT carbonisation. The average efficiency of the stove was found to be higher than 30 %. However, this stove has two major drawbacks:

1) Since the stove is made of stainless steel, the total cost of the stove (*i.e.* the costs of material and fabrication) is considerably more expensive (~4-5 times that of a traditional one)
2) The door of the carbonisation chamber, which is used to load coal fines into and out of the carbonisation chamber, is on the outer wall of the carbonisation chamber. This is very inconvenient, as it is difficult to spread coal throughout the carbonisation chamber. Additionally, it is also difficult to take carbonised coal fines out of the carbonisation chamber.

Therefore, the stove is modified, and a cheaper fabricating material is used, in order to reduce the cost of the stove. In this research, two carbon-steel stoves, similar to that used in the work of Tanin Tantakasem [10], were designed and fabricated. The details of the stoves are described in the subsequent section. Carbon-steel was chosen as it ~3-4 times less expensive than stainless steel. The way that coal was loaded into and out of the carbonisation chamber was also modified, in order that a user can conveniently load pulverised coal (or coal fines) into and out of the carbonisation chamber. The performance efficiencies of the stoves were determined and compared with that of the traditional one and that of the stove used in the work of Tanin Tantakasem [10]. The durability of the stoves used in this research was also determined. Additionally, the ignition and burnout times, the performance efficiency, smoke, and odour of the coal briquettes produced from pulverised coal obtained from the carbonisation chamber, were evaluated and compared with those of charcoal.

2. Materials, Apparatus, and Procedure

Two cylindrical, carbon-steel cooking stoves, similar to that in the work of Tanin Tantakasem [10], as illustrated in Figure 1, were designed and fabricated. The combustion chamber of each stove was double-walled, and a gap (~30 mm) between the inner and outer walls is the carbonisation chamber. The outer wall of the carbonisation chamber was insulated by ceramic wool and then wrapped by an aluminium sheet.

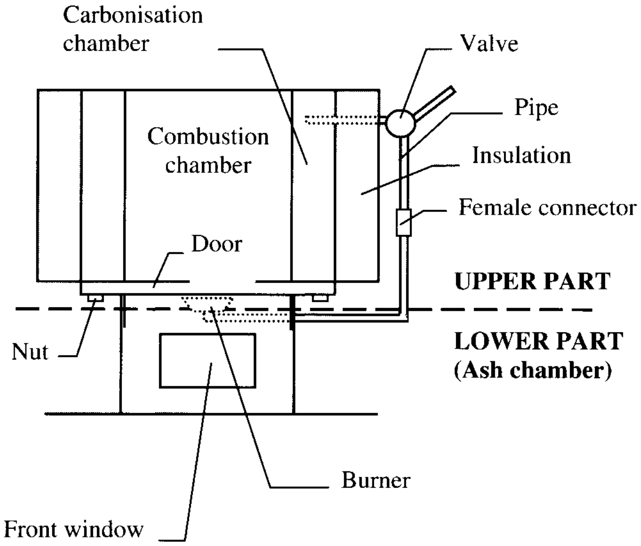

Figure 1: A schematic diagram of the stove used in this research, illustrating the upper part, comprising the combustion and carbonisation chambers; and the lower part or the ash chamber. The grate cannot be seen as it is blocked by the door. Note: not to scale.

Each stove has a pipe to recycle gaseous products from the carbonisation chamber to be burned at a burner located just below the combustion chamber. The gaseous products can either be vented into the atmosphere or recycled to the burner by adjusting a valve. The pipe can be separated into two parts: the upper and the lower parts, and these two parts can be connected to (or separated from) each other by a female connector. The separation of the pipe enables the upper part of the stove, comprising the combustion and the carbonisation chambers, to be disconnected from the lower part (or the ash chamber) of the stove. The separation of the upper part from the lower part is necessary when pulverised coal is to be loaded into and out of the carbonisation chamber (this will be described in detail later). The front window of the ash chamber allows air to flow into the combustion chamber. The combustion and the ash chambers are divided by a grate, on which fuel is placed and burned.

A flat ring of carbon steel acts as a door of the carbonisation chamber (see Figure 1). The door is ~0.5 cm thick, and has inner and outer diameters of 22 cm and 25 cm, respectively. During the use of the stove, the bottom of the carbonisation chamber is securely closed by the door. This can be done by fastening 8 nuts to bolts that are welded to the bars connecting the inner and outer walls of the carbonisation chamber (see Figure 2).

Two stoves are identical except that one has fins attached to the inner wall of the carbonisation chamber, while the other one does not (see Figure 2).

In each test run, pulverised coal, prepared by crushing (using a hammer mill) raw coal from Banpu Public Company (proximate analysis of raw coal is shown in Table 1) to the size of less than 1 mm, was loaded into the carbonisation chamber. This can be done by

1) loosening the female connector of the pipe;
2) separating the upper part of the stove from the lower part;
3) turning the upper part upside down;
4) loosening all nuts of the carbonisation chamber door using a wrench, and removing the door from the carbonisation chamber;
5) filling a known amount of pulverised coal into the carbonisation chamber;

6) closing and tightening the door of the carbonisation chamber; and

7) putting the upper part of the stove onto the lower part, and connecting the pipe.

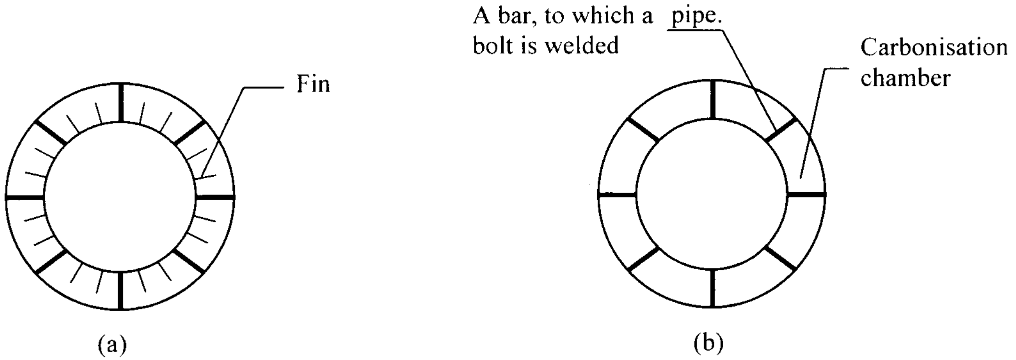

Figure 2: Cross-sections of the stoves (a) with fins and (b) without fins attached to the inner wall of the carbonisation chamber. Note: not on scale.

After the stove was already set-up, a small amount of wood (~20-30 g) was ignited on the grate, and when it was well burned, a known amount of fuel was loaded into the combustion chamber. In order to assist the ignition of fuel, a small electric fan was used to enhance the flow of air into the combustion chamber, through the front window (in a real situation, an enhancement of the flow of air into the combustion chamber, through the front window, was done manually). When fuel was well burned, the fan was turned off. In the early stage of the research, charcoal, bought locally, was used as fuel. Proximate analysis of charcoal is shown in Table 1. The amount of charcoal and the amount of pulverised coal loaded into the carbonisation chamber were in the range of 350-500 g and 700-1,100 g, respectively.

Table 1: Proximate analyses of raw coal (from Banpu Public Company) and of charcoal

List of analysis	Raw coal	Charcoal
Proximate analysis (wt.%)		
• Moisture	18.5	4.8
• Ash	12.5	2.1
• Volatile matter	39.8	17.6
• Fixed carbon (by diff.)	29.2	75.5
Heating value (MJ/kg)	16.3	28.6
Rank of coal	Subbit B	-

The performance efficiency of the stove was determined by heating and evaporating a known amount of water (= 2,000 g in this study), and then compared with that of the traditional cooking stove (as reported in [6]) and that of the stainless steel stove used in the work of Tanin Tantakasem [10]. It is noteworthy that this method was chosen since it is similar to the way that the stove is used for daily household cooking. In each test run, after fuel was well burned, an aluminium pot, covered by a lid, containing 2,000 g of water, was placed on top of the combustion chamber. When water in the pot started to boil, the lid of the pot was then removed, in order to allow water to evaporate. The test run ended when the temperature of water in the pot was lower than 70 °C (it was pre-determined that when the temperature of water in a pot was lower than 70 °C, the combustion of fuel in the combustion chamber extinguished (or nearly extinguished)).

After each test run, the resulting pulverised coal was withdrawn from the carbonisation chamber, weighed, sampled, and analysed for its proximate analysis and heating value. The remaining pulverised coal was kept in a plastic bag for further briquetting.

The performance efficiency can be calculated from the following equation:

$$\eta = \frac{m_i c(T_b - T) + (m_i - m_f)\lambda}{m_F q_F + m_{VM} q_{VM}} \times 100, \quad (1)$$

where

η = performance efficiency (%);
m_i = initial mass of water (kg);
c = specific heat of water (kJ/kg-K);
T_b = temperature of water at the boiling point (K);

T_i = initial temperature of water (K);
m_f = mass of water at the end of a test run (kg);
λ = latent heat of vaporisation of water (kJ/kg);
m_F = mass of fuel used (kg);
q_F = heating value of fuel (kJ/kg);
m_{VM} = mass of volatile matter that was recycled to be burned at the burner located just below the combustion chamber (kg);
q_{VM} = heating value of volatile matter (kJ/kg).

Mass of volatile matter produced throughout each test run was obtained by performing material balances on the pulverised coal before and after each test run, while a heating value of volatile matter was calculated from the following equation:

$$q_{VM} = \frac{(m_{C_i} q_{C_i}) - (m_{C_f} q_{C_f})}{m_{VM}}, \qquad (2)$$

where

m_{C_i} = initial mass of pulverised coal in the carbonisation chamber (kg);
m_{C_f} = mass of pulverised coal in the carbonisation chamber after each test run(kg);
q_{C_i} = heating value of raw coal (kJ/kg);
q_{C_f} = heating value of pulverised coal obtained from the carbonisation chamber after each test run (kJ/kg);

Equation (2) was based on the assumption that the difference between the total heat of pulverised coal before each test run (*i.e.* of raw coal) and that after each test run was attributed to the total heat of volatile matter that was removed from the pulverised coal matrix (or that was recycled to be burned at the burner located just below the combustion chamber) only. This assumption was justified as it was found that the mass of fixed carbon after each test run was equal (or nearly equal) to that before each test run.

When the amount of pulverised coal was sufficient, it was mixed with clay (10 wt.%), which was used as a binder; lime, in the amount such that the CaO/S mole ratio was 2; and a suitable amount of water in a mixer. The mixture was then briquetted manually using an ice-cube tray as a mould. The resulting coal briquettes, ~2.5 × 3.0 × 2.5 cm^3 in size, ~15-20 g in weight (each), and with an average heating value of 24.4 MJ/kg, were then used as fuel. The amount of coal briquettes used ranged from 516 to 738 g (heat outputs were equivalent to those of 350-500 g of charcoal). The smoke and odour from the combustion of coal briquettes were observed. The performance efficiency of the coal briquettes was determined using the same method for determining that of charcoal, and then compared with that of charcoal. The ignition and total burnout times of the coal briquettes were also measured and compared with those of charcoal.

In order to determine the durability of the stoves, the conditions of the stoves were closely monitored during the course of the research.

It should be noted that, although the emissions of pollutants (*e.g.*, SO_2, NO_x) from the combustion of coal briquettes are of serious concern, it is not the scope of this research to determine the emissions of any pollutants in particular. In this research, the emissions from the combustion of coal briquettes were rather determined in the forms of smoke and odour. The works concerning the emissions of major pollutants (*e.g.*, SO_2, NO_x) from the combustion of coal briquettes, particularly at household cooking level, are available elsewhere [5, 11].

3. Results and Discussion

In the early stage of the research, charcoal was used as fuel. The amount of charcoal used and the amount of pulverised coal loaded into the carbonisation chamber were in the range of 350-500 g and 700-1,100 g, respectively.

It was found, as shown in Figure 3, that the performance efficiencies increased with the amount of charcoal. It should be noted, however, that, when the amount of charcoal exceeded 450 g, the performance efficiencies began to decrease.

Since the amount of water used to determine the performance efficiencies of the stoves was kept constant (at 2,000 g) and, during the course of the research, the initial temperature and the temperature at the boiling point of water were relatively constant (~30-33 and ~100 °C, respectively), the first term of the numerator of

Equation (1) was, therefore, found to be relatively constant. Meanwhile, the second term of the numerator of Equation (1) contributed ~80-85% of the total value of the numerator. Thus, the performance efficiency depends mainly on the second term of the numerator. It was found, from the experiments, that, as the amount of charcoal increased, which resulted in an increase in the value of the denominator, mass of water at the end of a test run decreased, thus resulting in an increase in the value of the second term of the numerator. At the amounts of charcoal of 350-450 g, an increase in the value of the numerator was found to be greater than that of the denominator. Accordingly, the performance efficiency increased as the amount of charcoal increased. Nevertheless, at 500 g of charcoal, it was found that the amount of water at the end of the test run was almost empty. This indicated that the amount of heat generated from the combustion of charcoal exceeded the amount of heat that the stove could utilise. Consequently, the performance efficiency decreased. This could be verified by conducting an experiment at the amounts of water and charcoal of 3,000 g and 500 g, respectively (on the stove with fins attached to the inner wall of the carbonisation chamber). The results showed (in Figure 3, as square symbols) that the performance efficiencies were in the same trend as those obtained when the amounts of water and charcoal of 2,000 g and 350-450 g, respectively, were used. This agrees with the results found in previous studies [9-10].

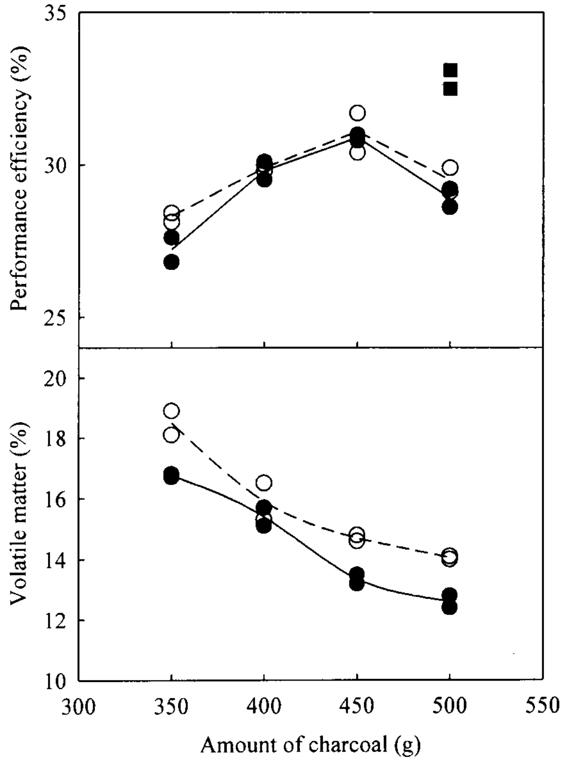

Figure 3: The performance efficiencies and the amounts of remaining volatile matter in pulverised coal of the stove with (solid symbols) or without (open symbols) fins at different amounts of charcoal (350-500 g), when 900 g of pulverised coal was loaded into the carbonisation chamber. The gaseous products from the carbonisation chamber were recycled to be burned at the burner located just below the combustion chamber. Square symbols illustrate the performance efficiencies when the amount of water of 3,000 g was used.

It was also found, as shown in Figure 3, that an increase in the amount of charcoal resulted in a decrease in the amount of remaining volatile matter in the pulverised coal obtained from the carbonisation chamber.

An increase in the amount of charcoal increases the amount of heat transferred through the wall of the combustion chamber into the carbonisation chamber. As the amount of heat transferred into the carbonisation chamber increases, the temperature of the carbonisation chamber should also increase. When the temperature increases, the amount of gaseous products from the carbonisation (or pyrolysis) also increases, thus resulting in a decrease in the amount of remaining volatile matter [12—13].

The amount of pulverised coal loaded into the carbonisation chamber was found to have little effect on the performance efficiencies of the stoves (see Figure 4), but it was found, as also shown in Figure 4, that the amount of remaining volatile matter increased with the amount of pulverised coal loaded into the carbonisation chamber.

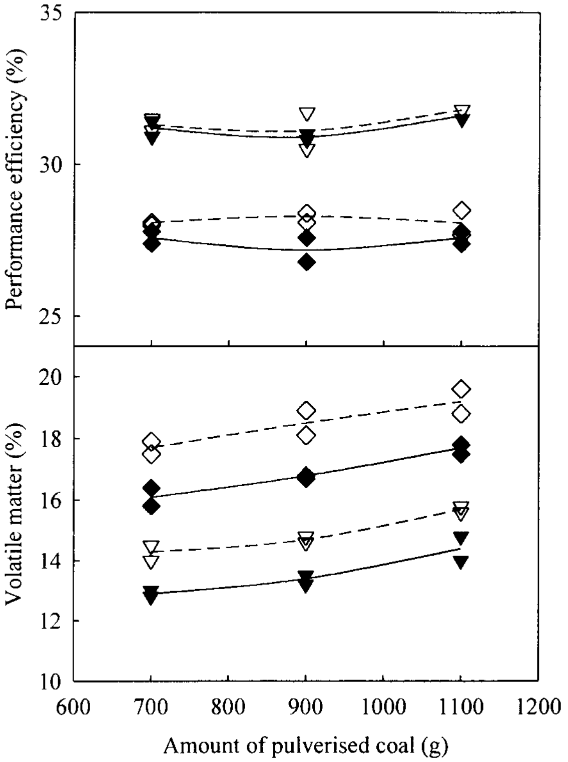

Figure 4: The performance efficiencies and the amounts of remaining volatile matter of pulverised coal of the stove with (solid symbols) or without (open symbols) fins at different amounts of pulverised coal loaded into the carbonisation chamber (700-1,100 g), when 350 (◇) or 450 (▽) g of charcoal was burned in the combustion chamber. The gaseous products from the carbonisation chamber were recycled to be burned at the burner located just below the combustion chamber.

When the amount of pulverised coal loaded into the carbonisation chamber increases, in order to obtain the same amount of remaining volatile matter, the amount of heat transferred into the carbonisation chamber should also increase. However, since the amount of charcoal was kept constant, the amount of heat output from the combustion of charcoal was also constant, thus resulting in the same amount of heat transferred into the carbonisation chamber. While the amount of heat required to remove volatile matter from pulverised coal increases, but the amount of heat provided remains constant, the amount of remaining volatile matter should increase.

The amounts of remaining volatile matter in the pulverised coal obtained from all test runs were found to be lower than 20 wt.%, which are similar to that obtained from the LT carbonisation. Accordingly, it can be assumed that the carbonisation took place in the carbonisation chamber of the stoves used in this research fell within the category of the LT carbonisation. It should be noted that, although there was no attempt to measure the temperature of the carbonisation chamber, it was expected that the temperatures should be ~400-600 °C, as these are typical temperatures of the LT carbonisation.

When comparing the performance efficiency of the stove with fins attached to the inner wall of the carbonisation chamber with that of the one without fins, it was found that an attachment of fins had little effect on the performance efficiency, but resulted in a decrease in the amount of remaining volatile matter (see Figures 3 and 4).

The possible explanation to this phenomenon might be that, an attachment of fins, although it may not result in a substantial increase in the amount of heat transferred from the combustion chamber into the carbonisation chamber, it increases the effective surface area [14]. When the effective surface area increases, the transfer of heat to the pulverised coal matrix is enhanced, thus leading to the lower amount of remaining volatile matter. On the other hand, since the attachment of fins increases the effective surface area, some heat that should be used for heating and evaporating water may be lost through these fins, thus resulting in a slight decrease in performance efficiency.

It was found, as shown in Figure 5, that the recycling of gaseous products from the carbonisation chamber to be burned at a burner located just below the combustion chamber (or the grate) enhanced the performance efficiency by ~30 % on average (from ~24 to 31 %).

Gaseous products from the carbonisation (or pyrolysis) comprises mainly hydrogen, carbon monoxide, and hydrocarbons [7-8, 12-13]. Since these gases are combustible, and their heating values are relatively high, when they are burned, a considerable amount of heat is generated. This heat, when combined with the heat generated from the combustion of fuel, increases the total heat output from the combustion chamber, thus leading to a significant increase in the performance efficiency.

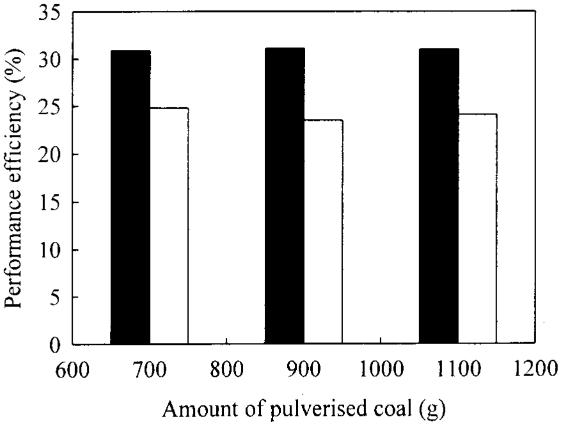

Figure 5: Performance efficiencies of the stove (without fins attached to the inner wall of the carbonisation chamber) at different amounts of pulverised coal loaded into the combustion chamber (700-1,100 g), when gaseous products from the carbonisation chamber were recycled (■) or were not recycled (□) to be burned at the burner located just below the combustion chamber. The amount of charcoal was 400 g.

The performance efficiency of the stove (either with or without fins) used in this research was compared with that of the traditional one (as reported in [6]) and that of the stainless steel stove used in the work of Tanin Tantakasem [10]. The amount of remaining volatile matter in the pulverised coal obtained in this research was also compared with that reported in the work of Tanin Tantakasem [10]. The comparisons are summarised in Table 2.

The performance efficiencies of the stoves used in this research were found to be comparable to that of the traditional one and that of the stainless steel stove used in the work of Tanin Tantakasem [10]. It was also found that the amount of remaining volatile matter found in this research were similar to that found in the work of Tanin Tantakasem [10].

Table 2: The combustion efficiencies of the carbon steel stove used in this research (either with or without fins), the traditional one (as reported in [6]), and of the stainless steel stove used in the work of Tanin Tantakasem [10]; and the amount of remaining volatile matter in pulverised coal obtained in this work and that obtained in the work of Tanin Tantakasem [10]

Type of stove	Performance efficiency (%)	Amount of remaining volatile matter (%)
• Carbon steel[(a)]		
○ with fins	30.0	14.4
○ without fins	30.8	15.7
• Stainless steel[(a)]	32.1	15.3
• Traditional[(b)]	32.9	-

(a) The performance efficiency was averaged from those at different amounts pulverised coal (700-1,100 g) at the amount of charcoal of 400 g, while the amount of remaining volatile matter was averaged from all values obtained in each research.

(b) The amount of charcoal is 400 g.

In addition to the performance efficiency and the amount of remaining volatile matter, the durability of the stoves used in this research was also determined. This was done by closely monitoring the conditions of the stoves throughout the course of the research, which lasted ~6 months. It was found, from observation, that the stoves were still in good condition even after extensive use. There were no signs of major corrosion and damage.

Hence, it can be concluded that the specially-designed cooking stoves, such as those used in this research, could satisfactorily be used for household cooking.

When the amount of pulverised coal obtained from carbonisation chamber was sufficient, it was mixed with clay, lime, and water (as described in detail previously), and then briquetted manually using an ice-cube tray as a mould. The resulting coal briquettes were then used as fuel. In order to evaluate the suitability of the coal briquettes, the ignition and burnout times, the performance efficiency, smoke, and odour of the coal briquettes were compared with those of charcoal, which is widely used for household cooking. The results (only the ignition and burnout times, and the performance efficiency) are summarised in Table 3.

It was found that the performance efficiency of the coal briquettes was comparable to that of charcoal. Smoke and odour from the combustion of the coal briquettes, although relatively stronger than those of charcoal, were found to be small. However, the major disadvantage of the coal briquettes was that the ignition time was found to be significantly longer than that of charcoal. This is a drawback and, therefore, needs to be improved. The ignition time can be shortened by adding an oxidiser (*e.g.*, KNO_3, $NaNO_3$) and/or biomass (*e.g.*, pulverised charcoal, sawdust) to the coal briquettes. The addition of an oxidiser and/or biomass was also found to reduce smoke, especially in the early stage of the combustion. The works related to this matter are available elsewhere [4, 15].

It should be noted that, although determining the emissions from the combustion of coal briquettes in the forms of smoke and odour may seem to be arbitrary or subjective, it is a suitable way of evaluating the suitability of coal briquettes (or any other fuels) for household cooking. It was reported [16] that the major concern of people, especially in rural areas, on the use of coal briquettes for household cooking is smoke and odour from the combustion of coal briquettes. It was also found [16] that coal briquettes produced from low-sulphur-content (< 3 wt.%) coal, mixed with lime (CaO/S mole ratio ~2-3), were acceptable to be used for household cooking. Additionally, the results from a previous study [11] showed that the concentrations of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emitted from the combustion of coal briquettes with sulphur contents and CaO/S mole ratio of less than 2 wt.% and 2, respectively, were lower than 150 and 50 ppm (corrected to 7% O_2), respectively, which are within the acceptable limits of U.S. emission standards for these gases (*i.e.* 150 ppm (corrected to 7% O_2) for both SO_2 and NO_x). The sulphur content of raw coal used in this research was well below 2 wt.% and the CaO/S mole ratio of the coal briquettes was 2. Hence, with some improvements, as described previously, coal briquettes, such as those produced in this research, should be able to be used for household cooking.

Table 3: The ignition and burnout times, and the performance efficiencies (η) of the coal briquettes produced in this research (for the stove without fins attached to the inner wall of the carbonisation chamber) and of charcoal

Type of fuel	Ignition time (min)	Burnout time (min)	η (%)
• Coal briquettes	6-8	70-80	28-30
• Charcoal	3-5	60-70	28-32

4. Conclusions

- The designed and fabricated, carbon-steel cooking stoves, in which pulverised coal was being carbonised while performing cooking, were found be durable. Their conditions were still good even after extensive use.
- The performance efficiencies of the carbon-steel stoves used in this research were comparable to that of the traditional one and that of the one made of stainless steel.
- The performance efficiency increased with the amount of charcoal in the combustion chamber; however, when the amount of heat generated from the combustion of charcoal exceeded the amount of heat that the stove could utilise, the performance efficiency began to decrease.
- An increase in the amount of charcoal caused the amount of remaining volatile matter in the pulverised coal obtained from the carbonisation chamber to decrease.
- An increase in the amount of pulverised coal loaded into the carbonisation chamber was found to have little effect on the performance efficiency, but led to an increase in the amount of remaining volatile matter.
- An attachment of fins to the inner wall of the carbonisation chamber, had little effect on the performance efficiency, and resulted in a decrease in the amount of remaining volatile matter.
- The performance efficiency of the stove was significantly enhanced when gaseous products from the carbonisation chamber was recycled to be burned at the burner located just below the combustion chamber.
- The performance efficiency of the coal briquettes manually produced from the pulverised coal, obtained from the carbonisation chamber, were comparable to that of charcoal. Smoke and odour from the combustion of the coal briquettes, although relatively stronger than that of charcoal, were found to be acceptable.

5. Acknowledgements

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