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Effect of Honeycomb Thickness of Charcoal Cooking Stove on Thermal Efficiency

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Abstract

The effect of honeycomb thickness of charcoal cooking stove is studied to investigate the thermal efficiency (η_{th}). The high efficiency cooking stove (HECS) of Thai Ministry of Energy is used but the honeycomb holes are modified to be inclined (θ) at 10 degree from vertical direction defined as modified high efficiency cooking stove (MECS). The fuel is variant grade of charcoal. Low heating value (LHV) of approximate 22,600 kJ/kg is determined by the bomb calorimeter. Three honeycomb thicknesses (H) consisting of 32, 36 and 40 mm are examined. Hole-diameter ratio between upper and lower honeycomb plate (d:D) is kept at 13:14. Water volume of 3.6 kg filled in a vessel of 26 cm diameter is adopted in examination. The investigated procedure of η_{th} is based on Volunteers in Technical Assistance Standard (VITA). Moreover, the η_{th} of two commercial cooking stoves, i.e., CCS1-34 and CCS2-36, are also observed and compared to the present stove. From experiment, it is found that the value of η_{th} trended to increase with H increasing from 32 to 36 mm. but the η_{th} is decreased at H = 40 mm. Thus, the maximum η_{th} become 46.7% at H = 36 mm. In the comparison case, modified stove is higher than the commercial cooking stoves.

Keywords: Honeycomb plate; Charcoal cooking stove, Thermal efficiency

1. Introduction

In the most of the developing countries, wood or charcoal are still the primary sources of energy for cooking in household. Commonly, the efficiency of conventional cooking stove or bucket stove in Thailand, which wood or charcoal are usually used as fuel, is not over 20% [1]. The significant parameters affected to the stove efficiency are stove shape, configuration of honeycomb plate, stove mass, manufacturing materials and the quality of fuel (wood or charcoal). These parameters are considered on the one objective; namely a combustion mechanism between fuel and air are improved. Thus, in the last decade, the Thai stove are modified by many researchers [2-7] in order to raise the efficiency and, also, to reduce emission gases.

A high efficiency cooking stove (HECS) having efficiency of 29% was proposed by the cooperation between department of Alternative Energy Development and Efficiency (Thai Ministry of Energy) and Ubon Ratchathani University [2]. The prominent point of HECS were three vessel supporters (Fig. 1) because the bottom vessel do not contact with stove resulting to the fresh or secondary air flow easily into combustion zone and a better combustion can be achieved. Moreover, honeycomb thickness, number of hole's grate and hole-diameter ratio (d:D) were 36 mm, 61 holes and 13:14 mm respectively. Limsuwan and Lee [3] improved the efficiency of the super cooking stove process. They recommended that there were 4 major fators, i.e., insufficient number of heating ovens, limited work area, low technology machines, and an uncertain work procedure, causing to low productivity. The adjustments to the work procedure, changes in design and production of tools to reduce delays in the work area, and assignment of job descriptions and responsibilities for workers were conducted to overcome the problem. Thus, Limsuwan and Lee [3] reported that the reduction of standard time of the stove process was about 30.87%. Steps in the work procedure were reduced from 10 to 8. Productivity was increased with 62%. Phomdon and Sriveerakul [4] tested the thermal efficiency of HECS of Ref. [2]. The hole-diameter ratio (d:D) was varied (12:13, 12:14, 12:15, 13:14, 13:15 and 13:16) and . The grate of 37 and 44 holes were examined. They presented that the highest thermal efficiency (41.78%) was found at the HECS with the grate of 61 holes and its d:D of 12:15. On the other hand, the lowest one was obtained at d:D of 13:14 (37.02%). They suggested that the number of hole's grate had a little effect on thermal efficiency of the HECS. Recently, CFD method was employed to improve both the thermal efficiency and emission characteristics [5, 7]. The computational results, particularly in the configuration of honeycomb plate, were acceptable agreement with experimental data. Thus, the CFD model was one of choice for study and design the optimization of the stove geometry.

From above mentioned, to raise the thermal efficiency, several works focused on the modification of honeycomb plate configuration, namely thickness, number of hole's grate and hole-diameter ratio (d:D), owing to the combustion mechanism of cooking stove is depended on this factor more than another factors. Against this reason, the thermal efficiency (η_{th}) of

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HECS is investigated by adjusting the honeycomb thickness (H). Hole-diameter ratio (d:D) was kept at 13:14 but these holes were modified by being as inclined holes (θ) with 10 degree from vertical direction. The fuel is variant grade of charcoal having 22,600 kJ/kg of equivalent low heating value (ELHV).

The experimental procedure of η_{th} was based on Volunteers in Technical Assistance Standard (VITA) [8]. To validate the experiment, the η_{th} commercial cooking stoves were compared to the present stove.

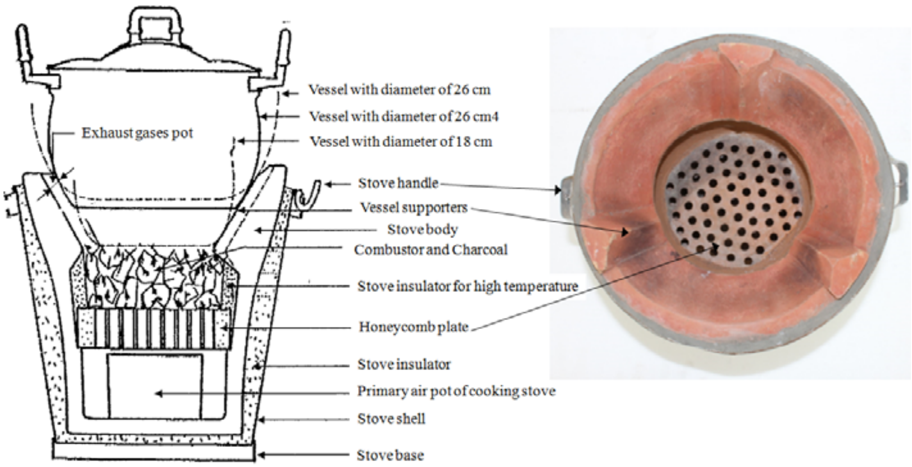

Fig. 1 A high efficiency cooking stove (HECS)

2. Experiment

2.1 The Examined Cooking Stoves

There are four cooking stoves consisting of HECS, the first commercial cooking stove (CCS1), the second commercial cooking stove (CCS2) and the present cooking stove or, hereafter, it called as modified high efficiency cooking stove (MECS), for study in this paper as shown in Fig.2. The MECS is developed from HECS with changing the honeycomb holes as inclined holes (θ) at 10 degree referred from vertical direction. The new honeycomb plate is depicted in Fig. 3 and three honeycomb thicknesses (H), i.e., 32, 36 and 40 mm, are experimented. Hole-diameter ratio between upper and lower honeycomb plate (d:D) of all examined stoves are 13:14. To deeply understand in these stoves, the configuration details (Name code, honeycomb thickness (H), number of hole's honeycomb (n), upper hole diameter (d)) are expressed in Table 1.

Table 1. Configuration of examined stoves

No.	Name code	H (mm)	n	d (mm)
1	MECS-32	32	61	13
2	MECS-36	36	61	13
3	MECS-40	40	61	13
4	HECS-36	36	61	13
5	CCS1-34	34	19	24
6	CCS2-36	36	19	19

(a) MECS (b) HECS

(c) CCS1 (d) CCS2

Fig. 2 Four examined cooking stoves

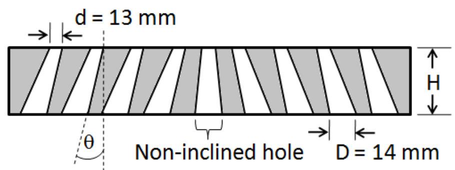

Fig. 3 The honeycomb plate with inclined holes (θ)

2.2 Efficiency Test by VITA

Fig. 4 shows two positions for measuring the water temperature in vessel (T_1) and the combustion temperature in the stove combustor (T_2). In determination of the thermal efficiency (η_{th}), the Volunteers in Technical Assistance Standard (VITA) [8] based on water boiling test (WBT) is applied but the present experiment will be end when the charcoal is completely burnt. Water volume of 3.6 kg is filled in a vessel of 26 cm-diameter for boiling test. Thus, the thermal efficiency estimated from the quantity of water evaporated after complete burning of fuel is calculated following as:

$$\eta_{th} = [m_{w,i}C_{p,w}(T_b - T_i) + m_{v,evap}H_w]/m_f H_f, \qquad (1)$$

where $m_{w,i}$, $m_{w,I}$ and m_f are the mass of water initially in cooking vessel (kg), the mass of water evaporated (kg) and the mass of fuel burned (kg) respectively. T_b is the temperature of boiling water (K) and T_i is the temperature of water in vessel (K). H_w is the latent heat of vaporization of water at 373 K (kJ/kg) and H_f is the equivalent low heating value (ELHV) of variant grade of charcoal determined from the bomb calorimeter test (= 22,600 kJ/kg).

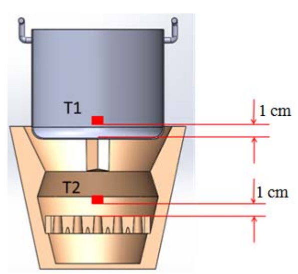

Fig. 4 The position of measured temperature in the present study

3. Results and Discussions

3.1 Effect of Honeycomb Thickness (*H*)

The effect of honeycomb thickness (H) of MECS on the water temperature in vessel (T_1) is shown in Fig. 5. The trend of T_1 can be divided into two zones. The first zone is heating & high power zone which is the period of sensible and latent heat of water [9]. After the fuel is completely burnt, the heat transfer process of flame to water is decreased gradually. This period is cooling zone or second zone. With increasing H from 32 to 36 mm, the level of T_1 in the heating & high power zone is increased. This is described by the ability of heat conduction flowing throughout honeycomb plate similar with Fourier's law of conduction [10]. The thickness of honeycomb plate for the case of H = 32 mm. (MECS-32) is thinner than the case of H = 36 mm. (MECS-36) resulting to the heat loss from combustion zone in cooking stove is down is easily flow into primary air port zone located under the honeycomb plate. It is exact that the heat loss flowed through the plate in the case of MECS-36 is more difficult. However, the level of T_1 is decreased in spite of H become 40 mm (MECS-40) because of an over thickness of honeycomb plate. It is correspondence with the theory of critical thickness [10]. Although the heat loss is difficultly transferred, in the same time, a lot of energy is also stored for a thicker honeycomb plate. For the results of cooling zone, the level of T_1 of MECS-36 is quickly decreased and the T_1 is less than another stove for t > 70 min. This is a practical phenomenon of combustion due to the hot water must be cool down if no energy transfer to the vessel. The amount of burned charcoal in the case of MECS-36 is almost completed and there exist minimum, in comparison with another stove, after end of heating & high power zone. For t > 70 min, the charcoal is burned out while MECS-32 and MECS-40 have still fuel.

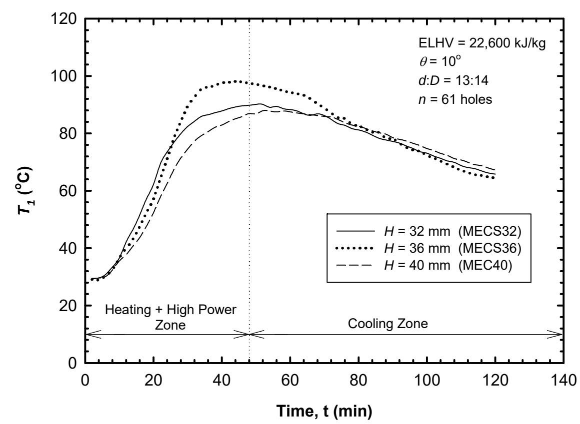

Fig. 5 Relation between the T_1 and H

Fig. 6 shows the effect of H on thermal efficiency (η_{th}) based on the Volunteers in Technical Assistance Standard (VITA) which the end of experiment is at the completed burn of charcoal. As seen in Fig. 6, it is found that the MECS-36 (H = 36 mm) yields the highest η_{th} of 46.7% followed by MECS-32 (42.5%) and MECS-40 (39.8%) respectively. The η_{th} of the present study is calculated by Eq. (1). Therefore, the quantity of η_{th} is depended directly on T_b (Temperature of boiling water) depicted by T_1 (Water temperature in vessel) from Fig. 5. Referring to Fig. 5, the T_1 (T_b) in the case of MECS-36 (H = 36 mm) gives highest level and the quantity of T_1 (T_b) of MECS-32 (H = 32 mm) is in middle between MECS-36 and MECS-40 (H = 40 mm). This phenomenon is thoroughly described in Fig.5.

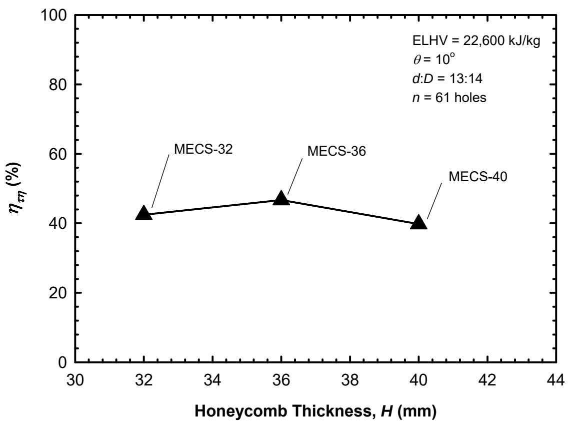

Fig. 6 Relation between the η_{th} and H

3.2 Comparison of Examined Cooking Stoves

To understand the combustion phenomena of the MECS, the water temperature in vessel (T_1) and thermal efficiency (η_{th}) of HECS and two commercial cooking stoves, consisting of CCS1-34 and CCS2-36 are compared as illustrated in Fig. 7 and Fig.8.

As seen in Fig. 7, the quantity of T_1 in the heating and high power zone of MECS-36 becomes maximum or is greater than another examined stove. It can be claimed by the effect of inclined angle of honeycomb holes. The flow pattern of primary air below the honeycomb plate is changed with the inclined holes. The inclined feature can be sum the almost air flowing into the center of combustor or the position of charcoal leading to a higher velocity and a higher concentration of air attack to fuel followed by the intensive combustion. A better combustion is obtained in the case of MECS-36. For the cooling zone, the decreasing level of T_1 of MECS-36 is faster for t < 70 min and the T_1 is less than another stove if t > 70 min. This result can be explained by the same reason in Fig. 5. There exist a little charcoal in the case of MECS-36 and the charcoal in the case of other stoves (HECS-36, CCS1-34 and CCS2-36) has higher than MECS-36.

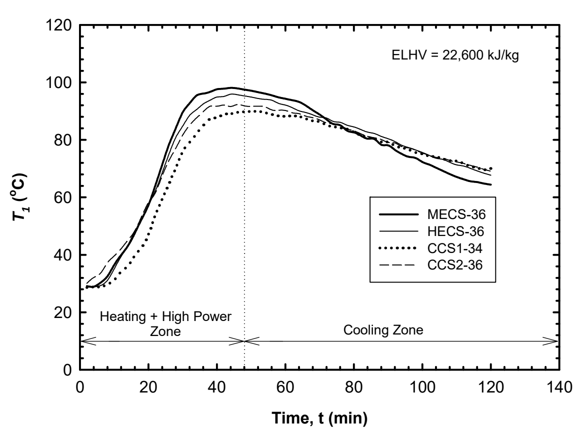

Fig. 7 Comparison of T_1 in several cooking stoves

As seen in Fig. 8, the thermal efficiency (η_{th}) in the case of MECS-36 is greater than another examined stove. The value of η_{th} of HECS-36, CCS1-34 and CCS2-36 become 41.6%, 32.5% and 35.8% respectively. The reason to clarify this result is similar to Fig. 6 that is the quantity of η_{th} is depended directly on T_b or T_1 from Fig. 7. Referring to Fig. 7, the T_1 (T_b) in the case of MECS-36 gives highest level followed by HECS-36, CCS1-34 and CCS2-36 respectively. Remarkably, the η_{th} of three modified stoves (MECS-32, MECS-36 and MECS-40) are greater than all compared stoves. It is benefit from inclined holes of honeycomb plate as thoroughly described in Fig.7.

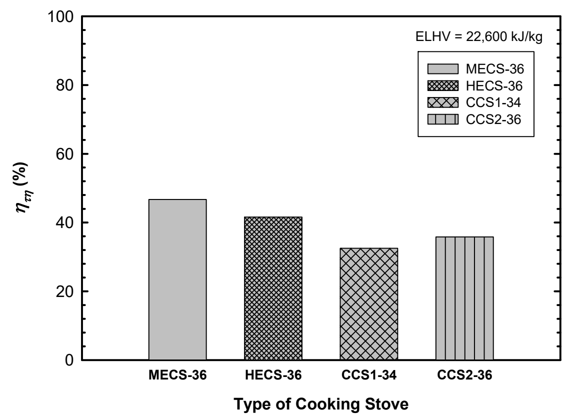

Fig. 8 Comparison of η_{th} in several cooking stoves

4. Conclusion

The thermal efficiency (η_{th}) of cooking stove used charcoal as fuel is investigate by focusing on the effect of honeycomb thickness (H). A high efficiency cooking stove (HECS) of Thai Ministry of Energy is developed by modifying the honeycomb holes as the inclined (θ) holes with 10 degree from vertical direction and defined as modified high efficiency cooking stove (MECS). The experimental procedure of η_{th} is based on Volunteers in Technical Assistance Standard (VITA) which the end of experiment is at the completed burn of charcoal. The level of the water temperature in vessel (T_1) in the heating & high power zone is increased with H increasing from 32 (MECS-32) to 36 (MECS-36) but the T_1 is decreased at H = 40 mm. (MECS-40). For the cooling zone, the level of T_1 of MECS-36 is quickly decreased for t < 70 min. owing to the fuel is burned almost. From this result, the value of η_{th} trended to increase with H increasing from 32 to 36 mmbut the η_{th} is decreased at H = 40 mm. Thus, the maximum η_{th} become 46.7% by MECS-36 (H = 36 mm.). In the comparison, the T_1 (Heating & high power zone) and η_{th} three MECS are higher than the HECS and two commercial cooking stoves (CCS1-34 and CCS2-36).

5. Acknowledgement

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6. References

[1] Koopmans, A. (1993). Thailand improved charcoal bucket stove technology and dissemination, Report No: FAO-RAPA-GCP/RAS/131/NET, Regional Energy Resources Information Center, Asian Institutute of Technology.

[2] Department of Alternative Energy Development and Efficiency (Thai Ministry of Energy) and Ubon Ratchathani University. (2007). Manual of manufacturing processes and application for high efficiency cooking stove (HECS). (in Thai)

[3] Limsuwan, S. and Lee, A. (2010). Efficiency improvement of the super cooking stove process, *Journal of Academics Ubon Ratchathani University*, vol.12(2), May 2010, pp. 17 – 28. (in Thai)

[4] Phomdon, A. and Sriveerakul, T. (2012). Thermal efficiency test of high efficiency cooking stove (HECS) with variations on the number and diameter ratio of the grate's holes, paper presented in *the 26th Conference of Mechanical Engineering Network of Thailand*, Chiang Rai, Thailand.

[5] Wicha-ngam, M. and Sriveerakul, T. (2012). Simulation of air flow though a high efficiency cooking stove's grate using CFD, *Journal of Science and Technology, Ubon Ratchathani University*, vol.14(2), April 2012, pp. 24 – 34. (in Thai)

[6] Kumar, A., Prasad, M. and Mishra, K. P. (2013). Comparative study of effect of different parameters on performance and emission of biomass cook stoves, *International Journal of Research in Engineering and Technology*, vol.1(3), August 2013, pp. 121 – 126.

[7] Sowgath, M. T., Rahman, M. M., Nomany, S. A., Sakib, M. N. and Junayed, M. (2015). CFD study of biomass cooking stove using Autodesk simulation CFD to improve energy efficiency and emission characteristics, *Chemical Engineering Transactions*, vol.45, pp. 1255 – 1260.

[8] Cook stove Emission and Efficiency in a Controlled Laboratory Setting. (2009). *The water Boiling Test Version 4.1.2*, *Merhods.bioenergylists.org*, URL:http://www.hedon.info/tikidownload_item_attachment.php?attId=320 accessed on 1/10/2009

[9] Charles, E. B, Jr. (2003). The John Zink Combustion Handbook, ISBN: 1420038699, CRC Press, Boca Raton.

[10] Cengel, Y. A. and Ghajar, A. F. (2011). Heat and Mass Transfer: Fundamental and Applications, 4th edition, ISBN: 978-0073398181, McGraw-Hill Inc., Singapore.