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Research Paper

The Analysis of Energy Efficiency and Emission Rate of a Cookware coated with Enamel Material

Pramadhony[1]*, Martin Luther King[2], Muhammad Lazim[2], Sukarmansah[2], Helmi Ibrahim[3]

[1]*Student of Doctoral Program, Department of Engineering Science, Sriwijaya University, Palembang 30139, Indonesia*
[2]*Mechanical Engineering Department, University of Tridinanti Palembang, Palembang, 30129, Indonesia*
[3]*Student of Mechanical Engineering Department, University of Tridinanti Palembang, Palembang, 30129, Indonesia*
*Corresponding author e-mail: pramadhony@yahoo.com

Abstract
Metal cookware has been used many people for its better thermal conductivity. However this material also has some weaknesses for its reaction with acidic food which will contaminate the food. Metal-base material coated with enamel is one of the solutions. The hard and non-reactive surface has cause this material has been widely used for processing food. Lower thermal conductivity is one of the problems of enamel cookware. The experimental analysis has been conducted to investigate energy efficiency, emission rate and thermal conductivity. The efficiency is calculated by comparing the useful energy (work) with the input energy. The emission rate is calculated by multiply energy consumption with emission factor. Meanwhile the thermal conductivity is calculated by using simply conduction heat transfer equation. Based on the analysis, enamel cookware has much lower thermal conductivity than aluminum cookware. However this physical property does not much affects the efficiency. The most dominant factors which should considered are type of fuel and technology of stove which consume higher energy inefficiently and emits much higher hazardous gas.

Keywords
Enamel Cookware, Energy efficiency, Emission Rate

1. INTRODUCTION

Commonly metal based materials are used as main material for cookware product because they have good heat conductivity which is good for better energy efficiency and emission reduction. However these materials have some weaknesses. Reaction with acidic food materials and sometime stick with food are the main problems of metal materials. Therefore the development of material technology is needed in order to solve the problems. The emerging of non-stick inner coating PTFE in cookware seems gives a solution. But this material is still to be suspected as a source of toxic gas in very high temperature (Sajid et al., 2014). Another solution is the application of enamel material which can be used to coat metal-base cookware material. Cast iron coated with enamel can increase the resistance of cookware against an oxidation (Martínez-Gomez et al., 2016). Therefore, for the safety reason nowadays many metal packaging is coated with enamel (Oldring and Nehring, 2007).

Enamel is a non-reactive material which makes this material is safe for storing many kind of food. Moreover it has a very hard surface. This property gives some advantages for high durability and the ease for cleaning after the usage. In other side this material also has a significant weakness when applied as a cookware material. The heat conductivity of enamel is far lower than the heat conductivity of a common metal. The addition micro particle such as SiO_2 or TiO_2 in enamel layer apparently doesn't improve the heat conductivity property (Ganesan et al., 2013).

Considering these enamel's properties, it is necessary to investigate the performance and efficiency of this material when applied on a cookware. Since the lower efficiency will cause the increasing of energy consumption, CO_2 and some hazardous gasses which emitted by burning process.

2. EXPERIMENTAL SECTION

2.1 Materials
The investigation is conducted with two different materials of cookware. The first analysis will investigate the performance of an enamel-coated cookware. And the second analysis investigates an analyze aluminum cookware which is commonly used in household.

2.2 Methods

The investigation is begun by measuring the dimension of cook wares. The dimension measurement is conducted with some tools such as:

- Ruler for measuring diameter.
- Vanier Caliper for measuring depth of cookware.
- Micrometer screw gauge measuring the thickness.

The profile dimension of cookware is estimated by measuring the height and radius of water which is filled in cookware. Water is filled in cookware with various volumes. The result of the measurement is shown in Table 1. This profile is needed to estimates the contact area between water and inside wall of cookware. Dimension and the height equation of cookware are shown in Figure 1. In addition volume and contact area of cookware can be estimated by using equation (1) and (2).

$$Q = -kA\frac{dT}{dx} \tag{1}$$

$$E_{in} = m_f HV_f \tag{2}$$

Table 1. Dimension and Contact Area of Cookware in some various volumes

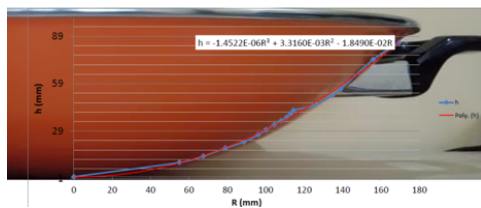| Volume (mL)	Dimension (mm)		Contact Area (cm^2)
	Radius	Height	
0	0	0	0
50	55	9.05	100.61
100	67.5	13.1	145.41
200	79	18.2	203.19
300	88.5	22	247.27
400	96	26.65	302.42
500	100	29.75	339.91
600	104.5	32.9	378.6
700	108	35.5	410.98
800	111	37.8	439.95
900	113	40	467.96
1000	114.5	42.2	496.24

Figure 1. Graphic Surface Profile of cookware

$$Vol = 2.\pi \int_0^R hRdR \tag{3}$$

$$Area = 2.\pi \int_0^R RdS \tag{4}$$

where:

$$dS = \sqrt{1 + (\frac{dh}{dR})^2} dR$$

h = -1.4522E-06R^3 + 3.3160E-03R^2 - 1.8490E-02R

Having obtained the dimensions, the research s continued by setting the mass of water (500, 600, 700, 800 and 1000 gram). Then each mass of water is heated from 31 °C to 100 °C and at the same time the authors are also counting the time needed. During heating the water, the temperatures of flame, outer wall and inner wall of cookware are measured with thermocouple. Each temperature is measured three times to obtain the average temperature.

In this research, Liquid Petroleum Gas (LPG) is used as source of energy. Mass of LPG is measured in each heating process in order to calculate energy released during the combustion process.

3. RESULTS AND DISCUSSION

The result of Temperature and Time measurements during heating water with Enamel and Aluminum cookware are shown in Table 2 and Table 3 respectively. Water with various masses are heated from 31 °C to 100 °C. During heating process, some parameters are measured such as Temperature (flame, outer wall and inner wall), fuel consumption and heating time. Then these data's are processed to calculate the amount of heat transfer, energy consumption, emission rate and efficiency.

3.1 Energy Consumption

The analysis is begun by calculating energy consumption for each material of cookware. Heat Energy input is taken from the LPG burning process. The fuel is used on stove to heat up water from 31 °C to 100 °C. Mass of LPG consumption is measured and then multiplied with its caloric value. In this calculation, LPG is assumed has caloric value of 11.254,61 kcal/kg or 47.089 MJ/kg (ESDM, 2013). The calculation result of energy consumption is shown in Table 4.

3.2 Energy Adsorption

Thermal energy is adsorbed by water and causes the increasing of water temperature. Each kg of water needs to adsorb 1 kcal or 4.184 kJ of energy to increase its temperature by 1 °C at constant pressure. The amount of energy adsorption is depending on heat transfer between heat source and heated media. The smaller difference between input energy and adsorbed energy means it has better efficiency. The amount of energy adsorbed by water is shown in Table 5.

Table 2. Experimental Result of Boiling Water with Enamel Cookware

m_{water} (gram)	mLPG (gram)	Flame	Temperature (°C) Outer Cookware	Inner Cookware	Time (s)
500	4.53	601	230	225	160
600	5.43	603	233	227	191
700	6.3	602	234	228	218.7
800	6.7	603	234	229	233.3
1000	8.63	616	239	233	260

Table 3. Experimental Result of Boiling Water with Aluminum Cookware

m_{water} (gram)	mLPG (gram)	Flame	Temperature (°C) Outer Cookware	Inner Cookware	Time (s)
500	4	604	234	233	150
600	5	628	236	235	187.8
700	6	626	237	236	211.7
800	6.7	627	242	241	233.3
1000	7.5	628	243	242	250

Table 4. Energy Consumption for heating water with Enamel cookware

m_{water}	Enamel Cookware mLPG	Energy	Aluminium Cookware mLPG	Energy
(gram)	(gram)	(kJ)	(gram)	(kJ)
500	4.53	213.31	4	188.36
600	5.43	255.69	5	235.45
700	6.3	296.66	6	282.54
800	6.7	315.5	6.7	315.5
1000	8.63	406.38	7.5	353.17

Table 5. The amount of Energy adsorption by water and its energy efficiency.

m_{water} (gram)	Caloric Value (kJ/kg)	Energy adsorb (kJ)	Efficiency Enamel Cookware (%)	Aluminum Cookware (%)
500	4.18	144.35	0.68	0.77
600		173.22	0.68	0.74
700		202.09	0.68	0.72
800		230.96	0.73	0.73
1000		288.7	0.71	0.82

3.3 Energy Efficiency and Emission rate

Based on the calculation, apparently the cooking efficiency for both cook wares is increased as the increasing of water in cookware. Based on Table 1, 2 and 3 all temperature is relatively constant in each experiment, but the contact area is increased when the volume of water is increased. It is accordance with conduction heat transfer equation which implies that the heat transfer will be increased when the contact area is enlarged. The graph the efficiency is shown in Figure 2.

The average efficiencies which are yielded by enamel and aluminum cookware are 69.95 % and 75.34 % respectively. Even though these materials have significant different thermal conductivity (discussed in next part of this paper), their efficiency is not too significantly different. Apparently, the Energy efficiency is not only determined by thermal conductivity. There are many factors which affecting the efficiency of heat transfer, such as thickness and shape of cookware.

Generally aluminum has weaker mechanical properties than cast iron and stainless steel. It is causing aluminum cookware needs a thicker surface than other cookware materials.

Because of that, there are many solutions to increase the heat transfer efficiency. The example solutions are by reducing the ratio of cookware diameter to flame diameter or decreasing cookware's distance to its heat source (Hannani et al., 2006). Other research also reveals that a thin enameled cast iron can have better efficiency than aluminum cookware (Villacís et al., 2015).

Air emission is other issue relates to fuel consumption. The emission can be categorized by the impact of pollutant to the environment. The degradation of ambient/indoor air quality and the increasing of ambient air temperature has become the biggest issue. Since the energy efficiency of cooking by using enamel and aluminum cookware do not different significantly, the percentage increase in emission rate is also relatively low at 8,18 %. Considering the health

Table 6. Emission rate of cooking activity by using gas stove and traditional stove.

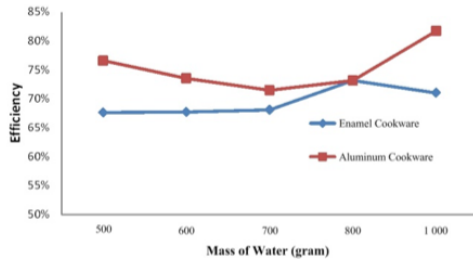| Type of Stove	FC (KJ)		Emission Rate		
	EFP	AFP	Prameter	EFP	AFP
Gas Stove	297.51	275	CO_2 (g)	18.77	17.35
			CO (mg)	5.95	5.5
Traditional wood Stove	5435.51	5024.28	CO_2 (g)	608.78	562.72
			CO (mg)	21742.04	20097.11

Figure 2. Graph of Energy Efficiency of the cookwares

Table 7. Thermal Conductivity of Water Heating with Enamel Cookware

ΔT (°C)	Time (s)	Q (kW)	A (m^2)	k (W/m°C)
5	160	0.903	3.40E-02	15.94
6	191	0.908	3.79E-02	11.99
6	218.7	0.925	4.11E-02	11.25
5	233.3	0.991	4.40E-02	13.51
6	260	1.111	4.96E-02	11.2
Average				12.78

Table 8. Thermal Conductivity of Water Heating with Aluminum Cookware

ΔT (°C)	Time (s)	Q (kW)	A (m^2)	k (W/m°C)
1	150	0.963	3.40E-02	84.99
1	187.8	0.923	3.79E-02	73.14
1	211.7	0.955	4.11E-02	69.73
1	233.3	0.991	4.40E-02	67.55
1	250	1.156	4.96E-02	69.86
Average				73.06

tween aluminum ($\pm$ 1 °C) and enamel (5 - 6 °C) cookware. The calculations state the average of Aluminum thermal conductivity is 73.06 (W/m °C) and enamel cookware is 12.78 (W/m °C).

Actually thermal conductivity value is depend on temperature and phase of the material. Aluminum material thermal conductivity would be decreased when the temperature is increased. In Solid phase, aluminum thermal conductivity is 150 - 210 (W/m °C) (Valencia & Quested, 2008). This range value is different to the result in Table 7 and 8. The difference result with the standard value could be caused by the limitation of thermometer. In order to obtain better result, it needs a more accurate and precise thermometer especially in high temperature.

4. CONCLUSIONS

An experimental study has been conducted to investigate the influence of enamel coating on a cookware. There are two different material of cookware investigated in order to find out the performance. The parameters described in this research involve energy efficiency, thermal conductivity and the emission rate. In addition this research also comparing the emission when the cooking activity use traditional wood stove which is still used by many people in Indonesia.

Energy efficiency is calculated by divides energy input from burning process by useful energy which adsorbed by water. Based on the calculation above the efficiency of enamel and aluminum cookware are 69.95 % and 75.34 % respectively. The efficiencies of enamel and aluminum cookware above are influenced by thermal conductivity, where the

benefit of enamel coating on cookware, this cookware is very feasible to be used especially for cooking acid food.

In addition, the focus consideration of emission rate should be focused on the technology and type of fuel. In Indonesia there are many people still use traditional wood stove. It has bad efficiency and emits a huge hazardous gas concentration. According report of emission inventory in Prabumulih, the consumption of wood is 18.27 higher than LPG (KLHK, 2016). The emission rates in four conditions are shown in Table 6.

3.4 Thermal Conductivity

Enamel coating affects cookware's thermal conductivity property. This property is simply calculated by using Heat Transfer equation (Eq. 1). Based on the calculation in Table 7 and Table 8, Aluminum cookware has better thermal conductivity than Enamel Cookware. The temperature difference between outer wall and Inner wall of cookware proves the significant difference of thermal conductivity be-

average thermal conductivity of enamel and aluminum cook wares are 12.78 (W/m °C) and 73.6 (W/m °C) respectively. Furthermore, all these efficiencies are increased when the amount of water on cookware increased. The addition of water enlarges the contact area between outer wall and inner wall of the cookware. As a consequence, the conduction heat transfer which occurred in solid material is also increased.

Even though thermal conductivity of enamel cookware is much lower than aluminum cookware, the efficiency between two cookwares is not so different because the efficiency is influenced by many factors such as thickness, shape of cookware and distance between flame and cookware. The most dominant factors on efficiency and emission rate which should be considered are type of fuel and technology. The using of traditional wood stove is should be replaced, because it consumed large of energy inefficiently and emits much higher of carbon monoxide.

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