



# The Thickness Effect of Exothermic Sleeve Made From Rice Husk on Its Performance as A Riser in Steel Casting

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## ABSTRACT

Exothermic sleeves are useful to be applied in the steel foundry for minimizing the size of the riser and increasing its efficiency. This paper describes the effect of the thickness of the exothermic sleeves made of rice husk and the modulus of the riser to the feeding efficiency of riser for the casting of metal. The series of thermal analysis of carbon steel (GS20Mn5) under the conditions of various thicknesses of exothermic sleeve at the same modulus and various geometry modulus of the riser at the same thickness of sleeve were carried out. Direct Thermal analysis of the cooling rate of the riser was conducted for the temperature during the cooling down to the solidus temperature were conducted. Based on the cooling curves, Modulus Extension Factors as an indicator of the effectiveness of the exothermic sleeves were determined and compared. By comparing the cooling rates, it was found that a 25 mm thick sleeve produced the highest MEF value (1.90) for the riser modulus of 1.6 cm and a solidification time of 285 seconds. Riser modulus of 1cm produces MEF value of 1.90, which is higher than the modulus of 1.6 cm and 3 cm at the sleeve thickness of 15mm

**Key words :** Casting of metal, Exothermic sleeves, modulus the riser, Rice husk,

## 1. INTRODUCTION

### 1.1 Feeding

The main problem in the steel foundry industry is the low yield of casting products (under 50% on average) since riser is to be used to compensate for the relatively large shrinkage of around 7% [1]. During the solidification process of liquid metal in the mold, shrinkage may occur in the product due to temperature changes. The liquid metal becomes solid by experiencing three stages of shrinkage, namely liquid shrinkage, crystal shrinkage, and solid shrinkage (solid shrinkage) [2]. Hardin et al. said that increasing the efficiency and modulus of the riser can be done by increasing the

solidification time [3], which is understood as the cooling time between pouring temperature and solidification temperature. A sleeve is a material that covers the liquid in the riser and provides longer solidification time so as to provide a liquid supply for the purpose of feeding.

### 1.2 Potential of rice husk as a sleeve

Based on how it works, the exothermic sleeve must be made of a material that is easily flammable or has exothermic properties when exposed to metal liquid. Materials that have these properties are carbonaceous materials and thermite materials [4]. Carbonaceous materials are organic materials with a very high amount of carbon content. While thermite materials are flammable materials that release an amount of heat in a short time. Based on this, Idamayanti et al. [5] conducted research on the substitution material of exothermic sleeve using rice husk material. This material has a calorific value of 15.3 kJ / gram, which is higher than that of a typical exothermic sleeve with a value of 11.35 kJ / gram [5]. Exothermic rice husk sleeve is able to extend the solidification rate from 215 to 454 seconds. The modulus extension factor (MEF) obtained from exothermic rice husk is 1.69. This value meets the minimum requirement of MEF value based on Indian Standard IS 15865: 2009, which is 1.60 [6]. Idamayanti et al [5] showed that the Modulus Extension Factor (MEF) value of the rice husk sleeve was still below the MEF value of the primarily produced exothermic sleeve

Rice husk is an abundant amount of biomass in an agrarian country. Biomass itself is a kind of material derived from living things that can be renewed in a relatively short time [7]. As biomass, rice husk has a huge hydrocarbon content of around 44%, as shown in Table 1 [8]. The hydrocarbon content can furthermore be used as fuel to provide the required heat. The higher the carbon content of a material, the more energy (heat) the material can produce. Rice husk has a fuel value of around 3000-3600 Kcal/kg, Fuel value is the number of calories that is produced by the material.

This level of fuel value enables rice husk to be defined as exothermic material [9]. The refractory nature of rice husks

depends on their alkaline oxide content. But normally it can withstand temperatures up to 1600°C. Rice husks are porous and lightweight, with a bulk density of around 210-300 kg / m<sup>3</sup> [9].

**Table 1 :** Elemental Test Results on Rice Husk [8]

LOI	Element, %s					
	N	Fe	Al	Mg	Si	K
Carbon (organic)	0.67	0.0055	0.0070	0.051	6.82	0.36

**1.3 Thermophysical calculation**

According to Joseph Black theory, if there is a mixing of two substances, the amount of heat released by the substance with higher temperature is equal to the amount of heat received by the substance with lower temperature [10]. Since casting processes to deal with higher temperatures, the amount of the heat energy produced is proportional to the mass of the sleeve and its specific heat. Differences in the size of the sleeve caused dissimilarity subsequently in the mass of liquid metal, which at the end will affect the amount of energy received by the sleeve itself. This will also affect the cooling/solidification rate that occurs in the casting process. The cooling rate is defined as the function of heat absorbed or released by objects against other surrounding objects that have differences in temperature with time [11]. The greater heat received by the sleeve will affect the duration of the cooling process.

The geometry modulus of the riser, as well as of casting, is used to determine the location of the riser in the casting design. Modulus is a function of the solidification rate of an object and is defined as the volume (V) of the object divided by the area of the heat releasing section (A). When the modulus of the object is getting bigger, more liquid metal is available so that the cooling/solidification process takes longer. Based on this, the greater the modulus, the slower the cooling [12]. According to its thermal properties, the sleeve is divided into 3 types: exothermic, insulating, and exothermic-insulating sleeve [2].

Sleeve thickness is one of the factors that greatly affect the performance of the sleeve. The use of sleeves with a thickness of 15% of the diameter of the riser and the use of hot toppings on the top of riser produce a flat shrinkage form [12]. The increased efficiency of the riser is caused by the slowing down of the cooling rate due to the higher thickness of the sleeve.

**1.4 Characterization**

Modulus extension factor (MEF) is the ratio of the geometrical modulus of the sand riser and the geometric modulus of the sleeved riser [6] so that the sleeved riser is considered to have the same modulus as the sand riser modulus. The thickness and modulus of the exothermic sleeve

have a great influence on the MEF value of the sleeve, which is normally assessed based on the solidification rate of the riser [6].

Therefore this research was conducted by measuring and analyzing the solidification rate of the riser sleeve and calculating MEF at various modulus and thickness. The effects of these on the thermophysical properties of the exotherm sleeves are then to be observed.

**1.5 Research aim**

This study is aimed to analyze the effect of different modulus and thickness on the thermophysical properties of the rice husk exothermic sleeve and to produce a rice husk exothermic sleeve that meets the sleeve standard specifications of the Indian standard [6].

**2. 2. DESIGN OF EXPERIMENT**

**2.1 Sleeve material and casting material**

Sleeve in this study has a composition of 60 mesh rice husk as much as 89%, 11% of polyvinyl acetate as a binder, and methanol as much as 180% of the amount of polyvinyl acetate. Methanol is used as thinner for the polyvinyl acetate. When methanol is mixed with polyvinyl acetate, this polymer will stabilize and form a surfactant, which act as an active substance on the surface of the solution, so that it will adsorb strongly at the liquid and air interface [13]. The material used in this study is GS30Mn5.

**2.2 Sleeve shape and dimension**

This study uses a tubular sleeve with 3 modulus variations, which are 1 cm, 1.6 cm, and 3 cm, with a height and diameter ratio of 1: 1. Based on the IS 15865:2009 [6], the riser diameter (D) is five times the modulus (M). Then the diameter of the sleeve for MEF testing is 50mm, 80mm, and 150mm.

To determine the effect of the thickness of the exthermic sleeve on the riser, an experiment with two variations of thickness of 15 mm and 25 mm on a riser with a modulus of 1.6 cm was also carried out (Figure 1).



**Figure 1:** The exothermic sleeve of modulus 1.6 with 2 a thickness of 15mm and 25 mm

### 2.3 Casting

The liquid GS 30 Mn 5 steel was poured at a temperature of  $1600\text{oC} \pm 20\text{oC}$  into the alcaly phenolic mold. Prior to the pouring exothermic sleeves were inserted into the mold. To ensure uniform condition of each trial gating system, as shown in Figure 2, is used. Rice husk is compacted to produce the desired tubular shape and dimension with a constant bulk density of  $0.60195 \text{ gr.cm-3}$ .

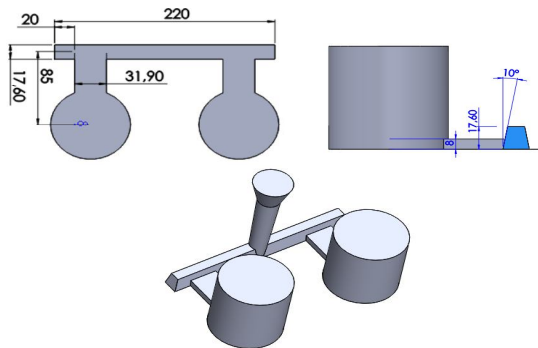


Figure 2 : Gating system of casting

### 2.4 Characterization

To analyze the results of this study, calculation of modulus extension factor (MEF) and Feeding Safety Margin (FSM) is used.

#### A. Determination of Modulus Extension Factor (MEF)

Modulus extension factor (MEF) is the effective ratio of the sand riser and riser sleeve. MEF values are determined by comparing the modulus of the sleeved riser with the modulus of the sand riser by using the solidification rate [6, 12]. If a riser with an exothermic sleeve that has a geometry modulus of A cm demonstrates the same cooling rate as a sand riser that has a geometry modulus of B cm, then MEF is determined as the B / A ratio. MEF value is calculated by comparing the solidification rate on the riser sleeve and sand riser as described in the Indian Standard.

Simplified procedure to determine the MEF value, as suggested by Ignaszak and Prunier, was conducted [14]. The first step is to measure the solidification rate of the rice husk riser sleeve. Temperature measurement is carried out in the range between the pouring temperature and solidus temperature of the material so that the delay time of the solidification can be observed. The temperature detection and measurement were carried out directly on the riser sleeve by using a data logger and thermocouple type R. The measurement position shown in Figure 3 refers to William's research [15].

The solidification rate of the sand riser is obtained through a casting simulation using the SolidCast 8.2.5 application, whereby the data of temperatures was retrieved from the thermocouples, which was positioned as shown in Figure 3.

To determine the solidus temperature of the material, the Fe-Fe 33C phase diagram is used. Since GS30Mn5 steel material is classified as low alloy steel, a carbon equivalent (CE) value is applied in the phase diagram instead of just carbon content. Following is the formula determining the value of CE [16].

$$CE = C + \frac{Si}{38} + \frac{Mn}{6} + \frac{Ni}{12} + \frac{Cr}{1.8} + \frac{Mo}{2.3} + \frac{Cu}{9.1}$$

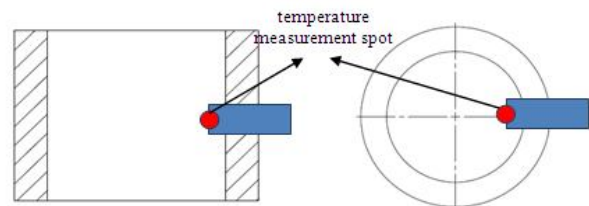


Figure 3 : Measuring temperature at the riser

Based on the composition of the material that has been determined bu applying Optical Emission Spectrometry (OES), the CE value of 0.69% was obtained. According to Fe-Fe3C diagram and the formula derived by Miettinen and Howe, the liquidus temperature is therefore  $1490\text{oC}$ , and solidus temperature is  $1400\text{oC}$  [17].

#### B. Feeding efficiency of a plate casting (plate test)

Volumetric feed efficiency of a sleeve is defined as the percentage of maximum feed metal transferred to the casting during its solidification at the same level of feed safety margin as found in a sand riser of given dimensions mounted on the same casting. The feed efficiency is obtained by calculating the percentage of feed metal supplied to the casting relative to a sand riser [6].

Feed safety margin (FSM) is the safe limit for liquid supply from a riser to casting. FSM is measured based on the distance between the lowest shrink surface of a riser to the bottom of the riser. FSM value is determined by applying a cube test [6].

## 3. RESULTS AND DISCUSSION

### 3.1 Determination Modulus Extension Factor (MEF)

MEF values were obtained by analyzing the solidification/cooling rate of the sleeved riser and sand riser. The following are the MEF values on various thickness and modulus.

#### A. Determination Modulus Extension Factor (MEF) at various thickness

The solidification rate test was carried out on various thicknesses of the sleeve on the riser with a diameter of 80 mm (modulus 1.6 cm). The cooling rate of GS30Mn5 steel was also observed for the sleeve thickness of 15 mm and 25 mm. Figure 4 confirms that the thickness of the sleeve affects the cooling rate of the metal, where the sleeve with a thickness

of 25 mm has a temperature retarding time longer than a sleeve with a thickness of 15 mm and a sand riser.

The considered working area of a riser is above the solidus line. Therefore the determination of the riser modulus is done by measuring the solidification time of the material up to its solidus point.

Table 2 and Figure 4. Temperature retarding time of riser sleeve up to solidus point. Show the difference in holding time up to the solidus point (freezing time) for each variation. A sleeve with a thickness of 25 mm has the largest working area of 285 seconds, a sleeve with a thickness of 15 mm 188 seconds, and a sand riser of 21 seconds.

Both types of the sleeve have a much larger working area compared to the sand riser, which proves that sleeved riser can perform longer feeding time and more supply of fluid than a sand riser [12].

Figure 4 described the cooling rates of the sand riser, riser sleeve with a thickness of 15 mm and 25 mm. Riser sleeves with a thickness of 15 mm indicate a considerably constant temperature during the cooling process at the temperature of 1460 ° C for up to 120 seconds. Riser sleeve with a thickness of 25 mm experiences a significant increase in temperature from the pouring temperature to a temperature of 1610 ° C, and then it will be followed by a constant decrease starting from 120th second. The graph shows that the heat rate is proportional to the change in temperature with time. It can be seen that riser sleeve with a thickness of 15 mm has a lower cooling rate compared to riser sleeve with a thickness of 25 mm by 1/5 times. 15 mm riser can be considered as slightly better at releasing heat compared to the 25 mm riser.

The amount of heat supply is very influential on the temperature of the material. The variation of thickness causes, therefore, a change of the cooling rate of GS30Mn5. Sleeve with a thickness of 25 mm has a mass of 450 grams, and a sleeve thick 15 has a mass of 235 grams.

Cooling Rate of Sleeve at Various Thickness

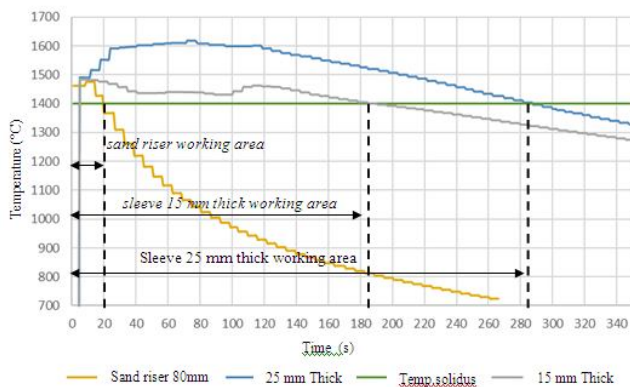


Figure 4 : Temperature retarding time of riser sleeve up to solidus point

The heat produced by each sleeve is determined by its mass and can be calculated as follows

$$Q = m . c . \Delta T, sc$$

$$Q_{15 \text{ thick}} = m . c . \Delta T = \frac{235}{1000} gr \times 1690,71 \frac{J}{KgK} \times (1460 - 1400) = 23,84 J$$

$$Q_{25 \text{ thick}} = m . c . \Delta T = \frac{450}{1000} gr \times 1690,71 \frac{J}{KgK} \times (1610 - 1400) = 159,77 J$$

- note :
- Q = Heat (Joule)
  - m = Mass of sleeve (kg)
  - c = Specific heat of rice husk (Joule/Kg.K) = 1690,71 J/Kg [18]
  - ΔT = Temperature difference (°C)

Table 2 : Ratio sleeve mass to mass of liquid metal

No.	Type of Riser	Solidification time
1	Sand riser	21 seconds
2	Riser with 15mm thick sleeve	190 seconds
3	Riser with 25mm thick sleeve	285 seconds

Based on the above calculations, the amount of heat produced by a sleeve of 25 mm thick is 159,77 J while a sleeve of 15 mm thick produces only 23,84 J. The temperature of GS30Mn5 steel in the sleeved riser with a sleeve thickness of 25 has a higher increase compared to the sleeved riser with a sleeve thickness of 15 mm. During the cooling process of the GS30Mn5, which is wrapped with a 25 mm thick sleeve receives a very large amount of heat energy so that the cooling process will be longer though the relatively similar heat rate. MEF is obtained from the ratio of the solidification rate between the sleeved riser and sand riser. Table 3 presents the sand riser solidification time data, as resulted from the SolidCast 8.2.5 software simulation.

The solidification time required for the material to reach the solidus temperature by the 15 mm thick sleeve (196 seconds) is relatively similar to those of the 140 mm sand riser (190 seconds). Since the riser of 25 mm thick sleeve is associated with a greater supply of heat compared to a riser with 15 mm thick sleeve, in the term of solidification time, it is only comparable with a sand riser of 152 mm diameter (Table 4).

Table 3 : Solidification time of sand riser

No.	Diameter (mm)	Modulus (cm)	Solidification time (s)
1	80	1.6	21
2	136	2.72	163
3	140	2.8	196
4	152	3.04	255
5	156	3.12	271
6	160	3.2	317

**Table 4 :** Solidification time of riser with 15 mm thick sleeve, the sand riser of 140 mm diameter, riser with 125 mm thick sleeve and sand riser of 156 mm diameter

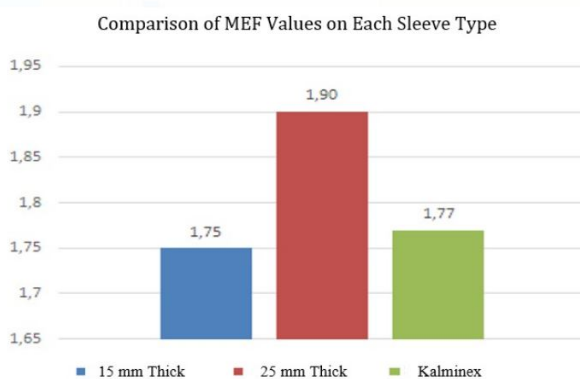
No.	Riser Type	Mod ulus	Solidification time (s)
1	Riser with 15mm sleeve	1.6	190 seconds
2	Sand riser 140mm diameter	2.8	196 seconds
3	Riser with 25mm sleeve	1.6	285 seconds
4	Sand riser 152mm diameter	3.04	280 seconds

Based on the comparison of the solidification time of the two risers, the MEF values of the 15 mm thick sleeve and 25 mm thick sleeve are as follows

$$\text{MEF of riser with 15mm thick sleeve} = \frac{2,8}{1,6} = 1,75$$

$$\text{MEF of riser with 25mm thick sleeve} = \frac{3,04}{1,6} = 1,90$$

For the purpose of a comparative study Idamayanti *et al.* has conducted MEF testing on the Kalminex sleeve riser used in POLMAN Bandung [5]. Based on his research, the Kalminex sleeve riser has a MEF of 1.77. Figure 5 shows that a riser wrapped with a 15 mm thick rice husk sleeve generates a MEF value of 1.75, which is slightly below the MEF value of Kalminex sleeve (1.77). The riser with a rice husk sleeve of 25 mm thick generates a MEF value of 1.90, respectively. This proves that the increasing thickness of the sleeve can expand the MEF value since it produces a higher amount of heat to compensate for the decreasing temperature during the solidification process.



**Figure 5 :** MEF value of sleeves

**B. Modulus Extension Factor (MEF) fo various modulus**

The solidification rate test was carried out on three types of sleeved risers with a variation of modulus, which was 1 cm, 1.6 cm, and 3 cm with the same sleeve thickness of 15 mm. Riser sleeve with a diameter of 50 mm (modulus 1 cm), 80 mm (modulus 1.6 cm) and 150 mm (modulus 3 cm) has a solidification time in the following sequence: 48 seconds, 190 seconds and 434 seconds. Riser sleeves with larger modulus

consequently have longer solidification time [12] due to a more significant mass of liquid.

As previously discussed, MEF of a riser sleeve with a modulus of 1.6 cm (diameter 80) is 1.75. The MEF value is obtained from the ratio of the sleeve solidification rate to the sand riser solidification rate. Table 5 presents the sand riser solidification times resulted from the SolidCast 8.2.5 software simulation.

**Table 5 :** Solidification time of sand riser

No.	Diameter (mm)	Modulus (cm)	Solidification time (s)
1	90	1.8	39
2	95	1.9	50
3	240	4.8	408
4	244	4.88	431

**Table 6 :** Retarding time of sleeved riser modulus 1 cm dan sand riser 95 mm

N o.	Riser Type	Modulus	Retarding Time
1	Sleeved Riser modulus 1cm	1.0 cm	48 seconds
2	Sand riser 95mm	1.9 cm	50 seconds
3	Sleeved riser modulus 3cm	3 cm	434 seconds
4	Sand riser 244 mm	4.88 cm	431 seconds

The solidification rate lines of the sleeved riser with a geometry modulus of 1 cm and the sand riser with a diameter of 95 mm intersect the solidus temperature line at almost the same time. Likewise, the solidification rate lines of the sleeved riser with a modulus of 3 cm intersect the solidus temperature line at almost the same time as the solidification rate line of the sand riser with a diameter of 244 mm. Based on these, the MEF value of the sleeved riser with a modulus of 1 cm is 1.9, and the sleeved riser of the modulus 3 cm is 1.63.

MEF values of rice husk sleeved riser in various modulus exceed the minimum MEF value, as stated in the Indian Standard, which is 1.60 [16]. At the same sleeve thickness, increasing the modulus of the riser decreases the MEF value. A higher modulus can be understood as an increase in the liquid mass, which means that the amount of heat to be supplied is also increasing. However, the MEF value continues to decline. This is caused by the amount of liquid that needs to be supplied by the sleeve, where the greater the geometric modulus of the sleeve, the greater the amount of liquid that needs to be supplied. So the ratio between the weight of the sleeve and the weight of the liquid becomes smaller, as shown in Table 7.

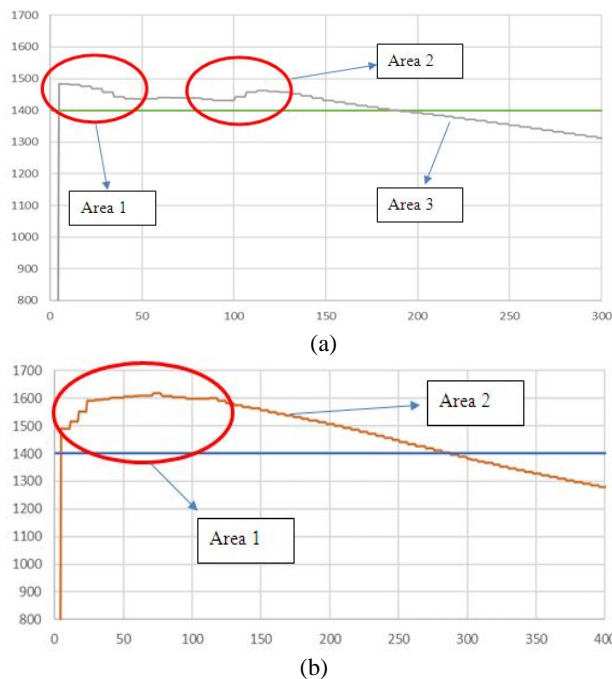
**Table 7 :** Ratio sleeve mass to mass of liquid metal

No.	Riser Type	Diameter	Mass of Sleeve (S)	Mass of liquid metal	Ratio S/G
1	Modulus 1cm	50 mm	113 gram	0.77 kg	0.14
2	Modulus 1.6cm	80 mm	235 gram	3.14 kg	0.07
3	Modulus 3cm	150 mm	699 gram	20.68 kg	0.03

As shown in Table 7 that the same sleeve thickness of 15 mm creates a less mass ratio of rice husk and liquid metal for higher modulus. The amount of rice husk mass that is aimed to supply liquid metal with exothermic heat per kilogram of the liquid becomes smaller. The increasing modulus of riser causes, therefore, a decrease in MEF value subsequently.

**C. Morphology of solidification curve of the sleeved riser**

The morphology of the solidification rate comes out mainly in two types. The characteristics of these graphs show the reaction or phenomenon that occurs in the riser during the solidification and cooling process.



**Figure 6 :** Solidification and cooling curves of rice husk sleeved riser

The first graphical characteristics, as shown in Figure 6(a), are formed during the cooling process of the rice husk sleeves with a diameter of the riser of 80 and 150 and a sleeve thickness of 15 mm. It describes that there are three different working areas. Suharto [7] explains that rice husks may experience two times exothermic reactions, namely the pyrolysis reaction and the oxidation reaction [7]. Area 1 is the area where the first exothermic reaction occurs, which is the pyrolysis reaction. Pyrolysis combustion reaction may occur

even in the absence of oxygen from the adjacent environment because rice husks already have oxygen as a constituent element itself. This reaction causes the cooling rate to be slower than without the sleeve. Area 2 After the pyrolysis reaction occurs, a few moments later, an oxidation reaction or combustion takes place. At this stage, a reaction occurs between biomass, charcoal, and pyrolysis products. This reaction is exothermic so as to produce adequate heat and cause a temperature surge, as shown in the graph. Area 3 is where all of the reaction has completely finished so that at this stage, only a consistent temperature decrease occurs.

The second type of cooling curve is shown in Figure 6(b). This graph is remarked with just two working areas. Area 1 on the riser with a sleeve thickness of 25 mm does not indicate clearly the occurrence of two reactions. There is a combustion process in area 1, whereas, according to Suharto [7], rice husks experience two exothermic reactions. This is caused by the thickness of the burning sleeve so that the pyrolysis and oxidation reactions do not occur at the same time. The pyrolysis reaction takes place gradually and alternately with the oxidation reaction causing a rise in temperature simultaneously and significantly, as shown in the graph. In area 2, the exothermic reaction is completed. Some applications and integration can be considered for further exploration [19] [20].

**4. CONCLUSION**

The thicker the sleeve at the same geometry modulus of the riser, the more heat is produced during the burning of the sleeve, and the solidification time becomes longer. Sleeve with a thickness of 25 mm, the longest solidification time of 285 seconds. Increasing the geometry modulus of the rice husk sleeved riser at the same sleeve thickness will decrease the MEF value of the riser since the amount of heat to be supplied gets intensified. By applying various thicknesses, the rice husk sleeve produces the highest MEF value at a sleeve thickness of 25 mm with a MEF value of 1.90. The rice husk sleeve that produces the highest MEF value is a sleeve with a modulus of 1 cm with a MEF value of 1.90, while risers with higher geometry modulus at the same sleeve thickness of 25 mm produce lower MEF value.

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