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Investigation of Melting Materials from an Innovated Mini -Melting Foundry Furnace

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ABSTRACT: At first, this study built a set-up and investigated the functionality of mini melting foundry furnace utilizing oil and water as fuel. This described the relationship between the weight and the time of melting of materials using used lubricant oil and water; and establish the typical melting time for different materials using water as the source of fuel. The functionality of the set up was investigated and was then quantified with known amount water and oil. This study found that the flame burning inside the furnace did not function well if the ratio between the speed of the droplet of oil against the speed of the droplet of water (do/dw) is equal or lesser to 2. It was also found to function with sustainability if do/dw varies from more than 2 to 20. However, with do/dw at above 20 is already dangerous for the furnace to continue the burning operation since the height of the burning flame could reach the extreme level. In contrast with bronze and aluminium plastic materials and lead melted using used lubricant oil as fuel. The reason could be attributed that plastic and lead materials have lower melting temperature compared to aluminium and bronze. When used lubricant oil was incorporated with water droplets, only the plastic materials were melted. The plastic materials generally have lower melting points compared to metals like lead, bronze, and aluminium. When the heat from the oil was combined with any generated friction, the melting point of the plastic is sufficient to be reached and surpassed causing it to melt. Oppositely, the thermal conductivity of metals like lead, bronze, and aluminium are higher compared to plastics which means they can dissipate heat more efficiently helping them to resist melting when exposed to heat sources like used lubricant oil. Plastic materials are susceptible to melting under certain conditions due to its chemical composition so that when the materials are exposed to heat, the polymer can break down leading to softening and eventually melting. It was established that the plastic material melts faster in used lubricant oil compared to when it was incorporated with water droplets.

KEYWORDS: Melting materials, furnace, water, oil, plastic, aluminium, bronze

I. INTRODUCTION

Melting furnace is substantial that an economical design is needed with enhanced heating mechanism to support the traditional foundries [1]. Metal melting is a relatively complex phenomenon that numerous authors investigate that process both experimentally and numerically. In particular, the free surface shape, the convection flow and the temperature field of the molten metal are the scope of the various studies [2]. Some of the studies presents the development of a cylindrical gas-fired furnace, which could be used for recycling aluminum in small-scale foundries and observed that there were large energy losses, which could be reduced by proper furnace sealing and the use of a recuperator to recycle heat from exhaust gases to preheat the air for combustion [3]. The search for alternative fuels for firing crucible furnace for low temperature melting metals has become mandatory, as a result of the pollution problem associated with the use of fossil fuels, the expense of electricity and also deforestation as a result of the use of charcoal [4]. In the operation of solid fuel such as coal, fuel oil and gas fired furnaces, carbon dioxide, carbon monoxide, Sulphur dioxide, oxides of nitrogen and other gases that have adverse effect on both humans and the environment [5]. The increased use of fossil fuels leads gradually to their depletion, environmental problems, and higher procurement cost that has adverse effect on the industries where non-ferrous products are produced [6]. As a prelude to necessary industrialization, foundries are springing up in various parts where most of these foundries rely on oil fired furnaces in their operation. This study established a setup of a furnace by which the combination of oil and water was used. The actual melting of material was also observed.

11. OBJECTIVE OF THE STUDY

This study investigated the functionality of mini melting foundry furnace utilizing water, oil as fuel. This determined the relationship between the weight and the time of melting of materials using used lubricant oil and water. This established the typical melting time of different materials.

111. METHODOLOGY

On this study an economically fuelled foundry furnace was constructed. It established a set-up of a furnace with injectors to use water and oil as fuel (Figure 1). Metal pipes and tube are provided to facilitate thermal energy transfer from the source to the furnace. The furnace has the following parts:

A. The body as a melting chamber

The body is formed from a cylindrical tank as a steel sheet functioning as a melting chamber. It is inside the chamber that the crucible will be placed to melt metal.

B. The burner

The burner is attached to the body which was positioned to burn the supplied changed oil, air and water as an energy source of the melting chamber.

Figure 1. The designed set-up

C. The pipe and tube system

The pipe and the tube are attached to convey the supplied water, oil and air coming from the injection chamber.

D. **The crucible**

The crucible (Figure 2) made of graphite pot was placed in the melting chamber serving as the holder of the molten metal during the time of casting.

Figure 2. The Crucible

Among the metallic materials that were tested are bronze, aluminium and lead while plastic materials are also tested. The materials were prepared individually by cutting them into pieces and put inside the crucible (Figure 3). The crucible is made of graphite material that it can attain good heat transfer performance for high temperature. It has an inner diameter of 38 mm, outer diameter of 58 mm and height of 88 mm.

The weight of plastic materials that was placed in the crucible was 25 grams while for bronze, aluminium and lead materials were equally weight into 65 grams. After the materials were placed in the crucible, the melting time was observed by putting the container in the furnace with the following set ups: the furnace was fuelled with used lubricant oil, the furnace was fuelled with used lubricant oil incorporated with water drops, and the furnace was fuelled with used lubricant oil which is incorporated with water drops and air flow. The time consumed for the materials to melt was recorded using a timer. The relationship between weight and time was computed milligrams per second (mg/s) which was done by dividing the weight with time.

Figure 3. The crucible as positioned in the furnace

1V. RESULT AND DISCUSSION

The functionality of the set up: melting of the materials; weight and the melting time of the materials using water oil were discussed as follows:

A. Functionality of the set up

Looked into this part are the height that the burning flame could reach and the duration of burning. It was done by putting 2.5 ml of used oil inside the furnace. The functionality

Table 1. Functionality of the set up

Parameters	Height (cm)	Duration (minutes)
Oil with no water & no fan	23	10.53
Oil with water & no fan	78	1.23
Oil with no water but with fan at minimum speed	19	10.38
Oil with no water but with fan at maximum speed	12	5.42
Oil with water and fan at minimum speed	54	2.27
Oil with water and fan at maximum speed	46	3.3

was investigated using the following situation: a) oil as fuel with no fan, b) oil as fuel with fan at minimum speed c) oil as fuel with fan at maximum speed, c) oil with water but no fan, d) oil with water and fan at minimum speed, and e) oil with water and fan at maximum speed. Water supplied on each situation are droplets at unknown amount. The result is shown in Table 1.

The table reveals that different burning performance of the furnace was demonstrated using different content of oil, water and air as the fuel. The burning flame reaches the highest peak at 78 cm. when the furnace was supplied with oil and water but with no fan to supply the furnace with air. However, it has the shortest duration time for burning flame. The highest peak of burning flame was attained since it was not resisted by any outside forces such as air to flow in other direction. The height has a significant effect on flame and burning behaviors of the whole burning process that during the initial development stage, the total flame length and burning rate increase rapidly after the fuel was ignited [7].

a) Oil with water and no fan b) oil with water and fan at minimum speed c) oil with water and fan maximum speed

Figure 4. Continuous burning with mixture of oil and water

The height was at lowest level at 12 cm was when the furnace was fueled with oil but with no water and with fan at maximum speed. This occur since the direction of the burning flame was redirected by the airflow to circulate within the interior chamber of the furnace instead of moving freely upward. In this case the energy exerted by the air is dominantly affecting the fuel feed rate. Due to decrease of fuel feed rate, flame height decreases constantly and was correlated with mass loss rate per unit area [8]. The heat transfer process between the water layer and the fuel layer has a significant effect on the burning behaviors. Under certain conditions, the burning of a thin fuel layer can develop into a special phenomenon known as boil over characterized by violent burning [9], [10], that its occurrence can change significantly the heat transfer process and increase the fuel burning rate.

It may be noted that in most cases the flame is high when the burning flame in the furnace are supplied with droplets of water, However, these are the time that the burning flame occurs at the shortest duration. The duration for the burning flame in the furnace supplied with oil and water but with no fan is the shortest at 1.23 minutes followed by oil with water and fan at minimum speed at 2.27 minutes and oil with water and fan at maximum speed at 3.30 minutes. This occur since the quantity of the water was about to surpass the quantity of oil. With the increase of the water amount, the flame expansion was gradually weakened until it disappeared completely [11]. Water mist extinguishes fires mainly by physical means such as cooling the flame, wetting or cooling the fuel, displacing the oxygen and fuel vapor available for combustion and radiant heat attenuation [12]. To attain a desirable operation, maximizing the burning flame for melting foundry furnace is necessary. That is the amount of water droplet mixed to the burning oil is exactly quantified.

B. Functionality with quantified amount of water mixed with oil and air as fuel

Several scenarios were observed to describe the height of the burning flame when the quantified amount of water is mixed with the burning oil. The result is shown in Table 2.

Table 2. Functionality quantifying water and oil as fuel

Parameters	Height of burning flame (cm)		
	No air fan was supplied	With air fan at minimum speed	With air at maximum speed
$d_o = 2d_w$	3	3	0
$d_o = 10d_w$	20	35	20
$d_o = 20d_w$	30	45	27

C. Droplets of oil is two (2) times faster than the droplets of water ($d_o = 2d_w$)

The table show that when the droplets of oil is two times faster than the water droplets or with mathematical relationship of $d_o = 2d_w$ the burning flame is not functioning well attaining a height of 3.0 cm only even if supplied with air at minimum speed. The flame was dead a when supplied with air at maximum speed. On this case, the water droplets make the burning of oil weaker. As the water amount in the mixtures were increased, the reaction and peak temperatures shifted to lower temperatures [13]. However, inefficiency of the burning process could be attributed to other factors such as: burning of water and oil as fuel without preliminary preparation causes disturbance of burning process down to extinction of the flame [14] while it was suggested that for successful implementation it is necessary to homogenize the mixture of fuel and moisture in special device and effectively mix water-fuel emulsion with an air oxidant in a burner [15]. The experimental set up was not continued anymore at lower ratio for it will not function well anymore.

D. When droplets of oil is ten (10) times faster than the droplets of water ($d_o = 10d_w$)

The height of the burning flame reaches 20 cm when not supplied with an air fan, 35 cm with air fan at minimum speed and 20 cm at maximum speed. Combustion is found to have a profound impact on the mixing characteristics [16]. Based from the result, it seems that after the length or height of the flame reaches the maximum level, it will decrease as the velocity of the supplied air continue to increase. On this event, the combustion is positively affected by the aerodynamic characteristics of the fuel and air mixture [15]. The geometrical spacing between the flames can also plays a vital role in flame stabilization while the increased spacing between the flames causes a reduction in flame length by promoting the mixing of oxygen and air [16]. The air jet produced led to a short flame and a significant increase in combustion achieved by internal recycling [17].

E. When droplets of oil is twenty (20) times faster than the droplets of water ($d_o = 20d_w$)

The height of the burning flame on this scenario is 20 cm when not supplied with an air fan, 45 cm when supplied with air fan at minimum speed, and 27 cm when supplied with air fan at maximum speed. The fluctuation of the burning flame fluctuates similarly in the case of $d_o = 10d_w$, however, the magnitude was increased. The experimental set up at higher level was not continued anymore for the reason that it is dangerous anymore.

F. Height of burning flame versus do/dw

It is through the ratio between the velocity of the droplets of oil and water (d_o/d_w) that the functionality of the furnace may be established to sustain the stabilization of burning flame as water is continuously mixed with oil. Height of burning flame versus d_o/d_w is shown in Figure 4.

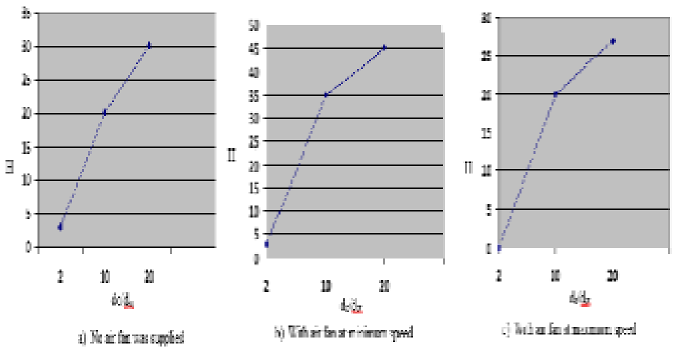

Figure 4. Height of burning flame versus d_o/d_w

The figure shows that if do/dw is less than two (2) the burning flame will not perform well. The water content on this ration is high that it affects the efficiency of burning. It was cited that increase of the water content of fuels has a significant effect on the effective heat of combustion decrease and a moderate effect on combustion efficiency decrease [18]. Therefore, it can be deduced that if,

$$\frac{d_0}{d_w} < 2$$

the burning process will not perform efficiently.

As d_o/d_w ranges from 2 to 20 the height of the burning flame increases from 3cm to 30cm. On that case no air fan was supplied to the furnace while it increases from 3cm to 45 cm when the furnace was supplied with air fan at minimum speed and 0 to 20 cm at maximum speed. It can also deduce that if:

$$2 < \frac{d_o}{d_w} < 20$$

the ratio is typical for burning oil and water

It can be noted in the figure that the height of the burning flame increases as d_o/d_w increases. However, if no air fan was supplied the magnitude is greater than when air fan is supplied at minimum and maximum speed. The air supplied by the fan changed the direction of the flame for it is affected by the aerodynamic characteristics of the fuel and air mixture. The ratio do/dw was not performed in the experiment for it may cause danger. When the ratio of oil against water is mixed the height of the burning flame will reach the extreme level. It was expected that if,

$$\frac{d_o}{d_w} > 20$$

the ratio is dangerous for flame at extreme height

Water contains hydrogen which has a wide flammable range and a high adiabatic combustion temperature [19]. It has a larger flammability zone and a lower minimum ignition energy; thus, the probability of a fire or explosion is higher [20]. For burned oil, large heat flux could be generated by the plume directly above the fire, which could lead to fire spread to surrounding [21]. It is therefore necessary to put up a limitation in the ratio of mixing oil and water as furnace fuel.

G. Melting of the Materials

The materials that were observed are made of plastic, lead, aluminium and bronze. These materials are selected for they have low melting point. The scenarios are based from melting the materials using used lubricating oil and used lubricating oil incorporated with water drops.

Table 4. Melting of materials with oil and water drops

Materials	Weight (g)	Fuel	
		Used lubricating oil	**Used lubricating oil with water drops.**
		Melting time (min.)	**Melting time (min.)**
Plastic	25	5:45	6:58
Lead	65	5:34	Not melted
Aluminium	65	Not melted	Not melted
Bronze	65	Not melted	Not melted

The table revealed that the plastic with weight 25 grams was melted with duration of five minutes and forty-five seconds using used oil while it was melted with six minutes and fifty-eight seconds duration if incorporated with water droplets. This shows that plastic materials melt faster if burned with used oil than if droplets of water were incorporated. On this process, the oil acts as a fuel source when burning plastic materials with used oil which provides additional heat energy to the combustion process. This increases the temperature of the fire since the extra heat accelerates the melting of the plastic. On the other hand, the temperature of the fire was reduced when water droplets are incorporated, acting as a cooling agent. that slowed down the melting process making the fire isn't as hot. On this case, the presence of used oil speeds up the burning and melting process, while water slows it down. In liquid fuel technology, it is desirable for the droplets to evaporate as quickly as possible since it is not the liquid that burns but its vapour [22]. The minimum temperature for burning plastic bags and aluminium plastic is 180 C while mica plastic requires a minimum temperature of 220 C [23]. The melting temperature for pure lead is 327C and 232C for pure tin [24]. Incorporation of water into the melted plastic may alter its properties and affect the quality of the final product, potentially leading to defects or inconsistencies. It is thus important to carefully control the melting process and minimize the introduction of water to ensure the desired outcome. Aluminium and bronze did not melt from the conducted investigation. Using used lubricant oil as fuel for melting aluminium and copper isn't common because of several reasons: Used lubricant oil typically doesn't burn at a high enough temperature to melt aluminium and copper. The aluminium melting temperature is 740 ℃ which was obtained by making a simple piping system for mixing used lubricating oil mixed with kerosene supplied with air from the blower [25]. A new copper-based material alloyed with Al and Be was obtained through the classical induction furnace which melting continued until the temperature of the metal bath reaches 1150-1200°C [26]. To effectively melt lead, it's preferable to use a heating source that can reach temperatures above the melting point of lead, such as a furnace fuelled by natural gas, propane, or electricity. These sources can provide the necessary heat energy for melting lead safely and efficiently. To effectively melt plastic materials, it's essential to use heating sources capable of reaching temperatures high enough for plastic melting, such as industrial furnaces or specialized equipment designed for plastic melting. These heating sources provide controlled and efficient heat transfer, ensuring safe and effective plastic melting processes. The combustion of used lubricant oil with air from a fan may not produce consistent or sufficiently high temperatures for melting plastic. Without proper control of fuel-air mixture ratios and combustion chamber design, the process may lack the required heat intensity. Used lubricant oil, when burned with air from a fan, may not reach temperatures high enough to effectively melt most types of plastic. Plastic generally requires relatively high temperatures to melt, and achieving these temperatures solely with a fan and used lubricant oil may be difficult. Even if the combustion process could generate temperatures close to the melting point of the plastic, the heat transfer efficiency from the combustion gases to the plastic material would likely be insufficient. Air from a fan has relatively low thermal conductivity, making it less effective at transferring heat compared to other heating methods.

H. Weight and the time of melting of the materials using different of kind fuel as the source of energy.

The relationship between weight and time of melting the objects were observed. The result is shown in Table 5.

Table 5. Weight and time of melting the materials

Materials	Fuel Used	
	Used oil	**Used oil with water**
Plastic	72.46 mg/s	60.81 mg/s
Lead	194.61 mg/s	Not melted

The result shows that using used lubricant oil as fuel is faster to melt plastic than when fuel was incorporated with water droplets. The plastic material melted at 72.46 mg/s while when the fuel was incorporated with water droplet was melted at 59.81 mg/s. Using used lubricant oil typically has a higher heat capacity and thermal conductivity than when incorporated with water droplets which means that it can transfer heat more efficiently to the plastic, leading to faster melting. Its combustion releases a significant amount of heat energy, which accelerates the melting process. This allows sustained heating of the plastic, resulting in faster melting. When incorporated into the melting process, water droplets can sometimes have a cooling effect on the plastic due to the latent heat of vaporization as they evaporate that can counteract the heating from the fuel, slowing down the melting process.

The table also shows that the lead melted at the rate of 194.61 mg/s while it does not melt when incorporated with water droplets. Used lubricant oil as fuel can achieve higher combustion temperatures than when incorporated with water droplets. Lead has a relatively low melting point so that if the temperature achieved with used lubricant oil is higher than this melting point, lead would melt faster. However, when water droplets are incorporated, the lead may not reach its melting point and therefore not melt.

Used lubricant oil maintains its stability and provide more direct and consistent heat transfer to the lead at high temperatures, providing continuous heat for melting lead. Oppositely, water droplets may evaporate quickly at high temperatures, leading to fluctuations in heat transfer and potentially hindering the melting process. The differences in temperature, heat transfer, combustion efficiency, and environmental factors between used lubricant oil and water droplets can result in variations in the rate of lead melting.

Several studies on lead were carried out to a pressure of 1 megabar and temperatures near 400 Kelvin [27] while high pressure and high temperature phase diagram up to 80 GPa and 3700 K was used by means of a laser-heated diamond cell [28]. Melting on the release of lead by carrying out two shock compression measurements at 51 GPa was investigated using pyrometric and VISAR measurement techniques [29].

I. Melting time of the materials using water as the source of fuel

The droplets of oil which is twenty times faster than the droplets of water the plastic material which is also supplied with airflow from a small fan was melted at 60.81 mg/s. Although there was evidence that the plastic materials melted using used lubricant oil and water drops, the difference was very small compared to using used lubricant oil only. There are presented studies showing that a higher combustion temperature of 900 °C can be produced during combustion [30] but some challenges associated with this process include the need for precise control of fuel and air supply [31]. Water droplets blown with air from a fan may not significantly contribute to raise the combustion temperature to the levels required. Water has a high heat capacity and absorbs a significant amount of heat energy during vaporization that this can cool down the surrounding environment. it may not efficiently transfer heat will be efficient to the plastic material, hindering the melting process. Heat output may be reduced since water vapor can dilute the concentration of combustible gases in the air-fuel mixture.

Formation of stream maybe introduced through water droplets that can displace oxygen and reduce the combustion efficiency. While it is possible to attempt to melt plastic materials using used lubricant oil and water droplets blown with air from a fan, it is impractical and ineffective due to the limitations in achieving the high temperatures required for plastic melting and the potential disruption of the combustion process by introducing water droplets.

Melting lead materials solely using used lubricant oil with air from a fan as fuel would be challenging. Lead has a relatively low melting point of around 327.5°C (621.5°F), which is achievable with the right heating source. However, using air from a fan as the primary oxidizer for combustion may not produce sufficient heat to melt lead. The air from a fan provide oxygen necessary for combustion that may not reach temperatures high enough to melt lead. Even if the air from the fan were heated, it may not transfer heat efficiently to the lead material due to the relatively low thermal conductivity of air compared to other heating methods like flames or electrical resistance heating. Lead is not easily oxidized at typical combustion temperatures achieved with air from a fan or if it is oxidized will requires much higher temperatures and prolonged exposure to oxygen.

V. CONCLUSION

This study was able to establish a setup of a furnace by which the combination of oil, water and air was used for sustainable burning. Using oil with water and no air fan was found to attain the highest burning flame while it has also the shortest period of duration. Looking at the ratio d_o/d_w can establish the sustainable operation between water and oil to be burned as fuel. The functionality of the flame burning inside the furnace will not function well if the ratio between the speed of the droplet of oil against the speed of the droplet of water (d_o/d_w) is equal or lesser to 2. It may function if with sustainability if d_o/d_w varies from more than 2 to 20. However, with do/dw at above 20 is already dangerous for the furnace to continue the burning operation since the height of the burning flame could reach the extreme level. In contrast with bronze and aluminum plastic materials and lead melted using used lubricant oil as fuel. The reason could be attributed that plastic and lead materials have lower melting temperature compared to aluminum and bronze. When used lubricant oil was incorporated with water droplets, only the plastic materials were melted. The plastic materials generally have lower melting points compared to metals like lead, bronze, and aluminum. When the heat from the oil was combined with any generated friction, The melting point of the plastic is sufficient to be reached and surpassed causing it to melt. Oppositely, the thermal conductivity of metals like lead, bronze, and aluminum are higher compared to plastics which means they can dissipate heat more efficiently helping them to resist melting when exposed to heat sources like used lubricant oil. Plastic materials are susceptible to melting under certain conditions due to its chemical composition so that when the materials are exposed to heat, the polymer can break down leading to softening and eventually melting. It was established that the plastic material melts faster in used lubricant oil compared to when it was incorporated with water droplets.

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