A Study of Oil Sludge Combustion in a Bubbling Fluidized Bed Incinerator

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ABSTRACT

At the Combustion Laboratory of the Universiti Technologi Malaysia (UTM), a small pilot plant-scale bubbling fluidized bed incinerator facility was designed, fabricated and constructed to dispose of the refinery oil sludge. For the incinerator, with a refractory-lined combustion chamber of 0.15 m square cross-section and a total height of 1.5 m, the combustor was operated with bed temperature ranging from 700 ℃ to 850 ℃. The combustion efficiency achieved was around 77%. Flue gas emission has CO concentration of 400 ppm to 500 ppm and NO_x *concentration of 98 ppm.*

1. INTRODUCTION

Incineration is gaining wide acceptance as an effective means for disposal of organic waste. The advantages offered by proponents of organic waste incineration include: conversion of toxic components to normal combustion products, substantial reduction in waste volume, the application of incineration to a variety of waste products, effective control of air emissions, and the potential for energy recovery in some instances [1]. Since the application of refinery biotreating sludges is being stringently restricted by EPA regulations, incineration of refinery sludges can reduce volume by 80% to 90%. As a result, various alternatives are being discussed in the following literature.

Corry and Rasmussen [2] have conducted some experiments to incinerate refinery sludges from two different refineries using the fluidized bed incineration facility with a waste heat recuperator to preheat combustion air. They reported, that heat recuperator significantly reduces the incinerator size until 10%. This recuperator also has affected the sludge dewatering process and reduced it 40% by weight. The removal efficiency of 99.99% were obtained at the mild temperature of 691°C without any supplemental fuel required to maintain the incineration temperature. They used positive displacement pump assisted with air to feed sludge injected into the fluidized bed.

The American Oil Company incinerator at Whiting, U.S.A. [3, 4] had a design capacity of over 338 000 kg/day of wet sludge containing 85%-95% water. Waste sludge feed consisted of several streams, including API separator sludge, water-oil emulsions from slop oil recovery, tank cleanings and other waste liquids. In addition to hydrocarbons, these sludges, contained alkali elements such as Ca, Mg, K and Na as well as Fe, Al and phosphates. In this case, the silica sand was replaced by aluminum oxide in the form of pellets. Due to the chemical composition of the fluid bed material produced from this sludge feed mixture, the fluid bed was maintained at a temperature of 687°C to 704°C to avoid softening the bed product.

Legros, et al. [5] tested to burn pitches (tars) in a circulating fluidized bed incineration facility. They reported that two types of pitches were used: CANMET oil and H-oil. The first combustion test used CANMET pitch oil. The experiment was conducted for two different superficial velocities (5.6 m/s and 1.05 m/s), two different secondary and primary air ratios (0.56 and 1.05) and Ca:S molar ratios from 1.5 to 2.3. The outlet oxygen concentration was maintained in the range of 3% to 4%, while the bed temperature was in the range of 850°C to 900°C. The combustion efficiency was between 91% to 99%. The flue gas concentration was reported low enough until moderate level, such as CO 300 ppm to 1000 ppm, SO_2 254 ppm to 404 ppm and NO_x 135 ppm to 165 ppm. The second combustion test used H-pitch oil. Compared to the previous experiment the combustion efficiency has slightly higher value of 99.9%. The sulfur capture efficiency increased with Ca:S ratio. Since the fluctuation in the solids circulation rate was high enough, it effected the fluctuation in SO_2 emission. NO_x emissions were similar to those observed during the CAMNET pitch trials.

The main problem associated with using oil-sludge as a fuel lies with difficulties involved in its preparation, which includes handling, feeding to the combustor, control of the temperature throughout the bed and clinker formation, if the waste is fed into the freeboard, it is possible for the sludge to ignite before reaching the sand bed. This condition makes overheating of the freeboard causing slag buil-up leading to excessive pressure drop and high flue gas temperature. This causes the combustion process to shutdown. As a result of slag formation the bed fluidization performance could be a serious problem for continuation of running process of incinerator [5-7].

Green Bay Packaging Corp. [4] has conducted some combustion tests of waste liquor. To prevent the bed sand from stickiness during fluidization, the chloride content of the waste liquor is adjusted to maintain 3000 ppm to 3500 ppm Cl in the Na_2SO_4 - Na_2CO_3 ash product. Under these controlled conditions the fluid bed is maintained in the 1350°F to 1380°F (730°C to 750°C) range to maintain efficient combustion of the organic matter in the waste liquor with minimum excess air. If the chloride content exceed the above level, bed material become sticky and bed defluidization can occur. This requires the bed temperature to be lowered, in which case waste liquor combustion deteriorates and more excess air is required.

2. EXPERIMENTAL PROCEDURE

2.1 Pilot Scale BFBC Facility

There are two aspects which are of main interest in this present work: firstly, to determine the burnout characteristics and secondly, to examine the emission characteristics of the flue gas. For this work, a small pilot scale incinerator was designed and fabricated at the Mechanical Engineering Department-Combustion Laboratory, Universiti Teknologi Malaysia. This combustion system has a capacity of about 32 kW of heat and a refractory-lined combustion chamber of 0.15 m square cross section with preheat plenum chamber for starting up. Figure 1(a) shows the simplified schematic diagram of bubbling fluidized bed combustion facility.

The physical properties of oil sludge waste, as received from Techno Indah Sdn. Bhd., are given in Table 1. It deals with the disposal of oil sludge from tanker by incineration and generated power for its own uses. The boiler is of corner tube type with a separate fluidized bed combustor unit and designed to burn the oil sludge. The system is capable of producing a maximum continuous rating of

Table 1. Ultimate analysis of the oil sludge as received and in a mixture with 18% diesel fuel.

Element of	%wt.	
	As received	Mixing
C	28.9	46.98
H	4.8	5.69
N	0.17	0.15
O	25.34	20.49
S	6.48	6.61
Ash	41.6	22.9
Moisture	13.2	2.6
Oil content	29.36	47.76
Kin. viscosity (cSt)	7.476	9.66
GCV (MJ/kg)	13.885	33.4

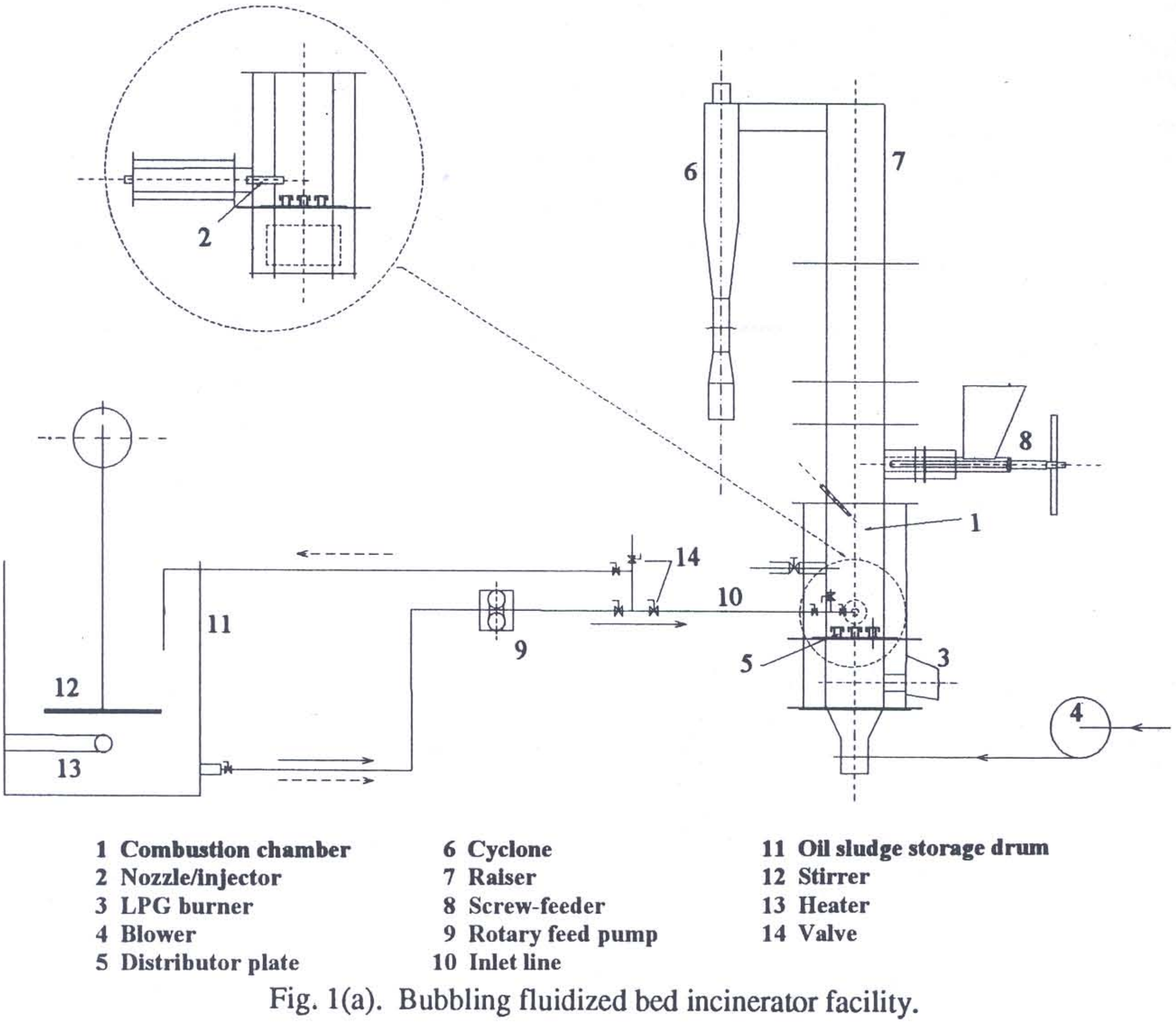

Fig. 1(a). Bubbling fluidized bed incinerator facility.

10 500 kg per hour of superheated steam at 29.5 bar (abs) and 340°C with feed water temperature of 95°C. The facility could generate power of about 1.5 MW net.

Figures 1(a), 1(b) and 1(c) show the incinerator facility. This incinerator has the static bed height of 0.11 m and expanded until 0.17 m during fluidization. The bed sand used was silica sand with size of 400 μm - 600 μm. Air superficial velocity during combustion process was 0.11 m/s to 0.18 m/s. A blower is used for fluidization as well as for air mixing during LPG combustion. The air distributor plate has nine nozzles, which is bubble cap type. These nozzles give the fraction of open area 1.14% on the distributor plate. Entrained solids from the gas leaving the riser are separated in a cyclone inside diameter 0.085 m.

The combustor was operated over a temperature range from 700°C to 850°C. Excess air levels was 86% to 97%. Two feed system were used in the experiment. The first was a controlled-speed rotary feed pump used for liquid-like oil sludge with a valve used to maintain the desired feed- rate of the liquid waste. Water is used as cooling medium to prevent early combustion at the end of the sludge-injector. The sludge fuel is stored in a container fitted with a motor-driven stirrer to maintain uniformity of slurry composition. This feed point is located at 0.065 m above distributor plate. The second type of feed system is a screw-feeder especially used for mud-like oil sludge. The feed point was located above fluidizing bed height.

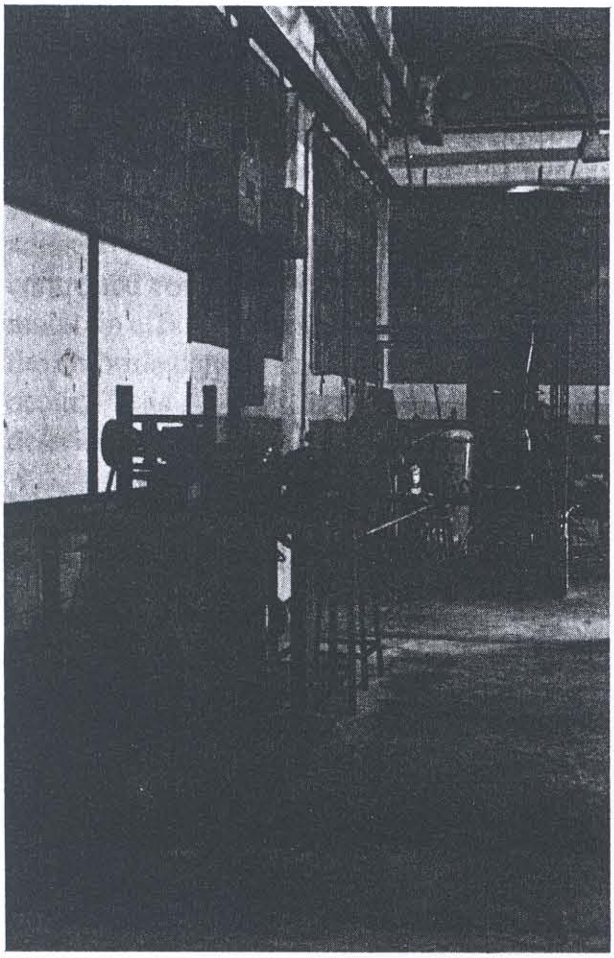

Fig. 1(b). Overview of the bubbling fluidized bed incinerator facility with oil sludge Storage-Drum system (SD).

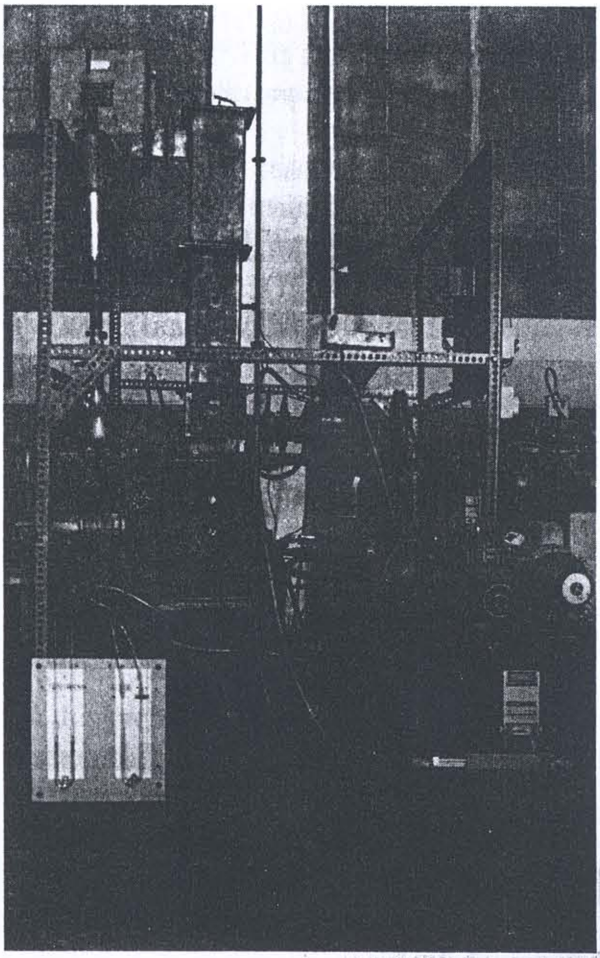

Fig. 1(c). Overview of the bubbling fluidized bed incinerator facility with Screw-Feeder system (SF).

2.2 Operating Procedure

Due to high viscosity of oil sludge and difficulty in handling, it is decided that the oil sludge was fed by screw-feeder. The as-received oil sludge was mixed with 18% diesel fuel. At this percentage of diesel fuel, the oil sludge were found to be not too sticky, to be fed into the screw-feeder. The mixture of oil sludge with 18% diesel fuel will be called oil sludge throughout this paper.

Start-up process was commenced by heating-up the bed with LPG torch inserted at the plenum chamber. With the help of palm shell, the heating took about 30 minutes for the bed to raise its temperature until 775°C. Then feeding commenced through the hopper, slowly with the oil sludge. The amount of oil sludge increased while the percentage of palm shell decreased until about 10% of the total feed ratio. The 10% of palm shell was enough to prevent the hot sand from solidifying process.

Based on experience, by burning only oil sludge, solidified formation occurs in the short time which caused stickiness of the sand particles leading to solidification of the bed. The solidification caused not only to degradation of bed temperature but made combustion or chemical kinetics process errate properly. To reduce this effect, solidification palm-shell as co-combustion process was used in experiment. With the use of 100% palm shell the bed temperature reached around 850°C to 890°C. After mixing with oil sludge (10% palm shell) the average bed temperature was about 750°C to 775°C.

Data collection was taken at a steady-state condition. The thermocouple was inserted into combustion chamber and at the raiser. Flue gases composition were tapped at the outlet- pipe of the cyclone and it was analyzed.

3. RESULTS

3.1 Bed Temperature with Oil Sludge Feed-Rate

Figure 2 shows a plot of bed temperature against fuel feed-rate. It shows that the increasing fuel feed-rate has the tendency to increase the bed temperature initially to 860°C.

The bed temperature reached the maximum 860°C with air flow-rate of 130 lit/min. At higher fuel feed-rate and higher air flow-rate the temperature was decreasing. It could be due to the design factor of the incinerator combustion chamber. At a fuel rate of about 10 rpm or 114 g/min, the maximum heat capacity of the combustion chamber was achieved. Increasing the rate of oil sludge feed-rate or air flow-rate tended to decrease the bed temperature and resulting in low combustion reaction. This shows insufficient turbulence in the bed, which was due to too much oil sludge, resulting in an inadequate mixing and consequently the presence of fuel rich zones within the sand bed. Under such conditions, inadequate air/fuel ratio gives low temperature processes.

At higher fluidizing air velocity of 1.4 m/s at all fuel feed-rate the bed temperature has a lower bed temperature. At fuel feed-rate from 103 g/min to 114 g/min the bed temperature increased from 775°C to 795°C, but at fuel feed-rate of more than 114 g/min the bed temperature reduced from 780.6°C to 720°C. As mentioned before, bed temperature is the function of air-fuel ratio, hence, at higher air fluidization with same rate of fuel feeding, the air-fuel ratio has a condition called lean mixture. Therefore the kinetic rate of combustion process was also slower and as a consequence the bed temperature was decreasing.

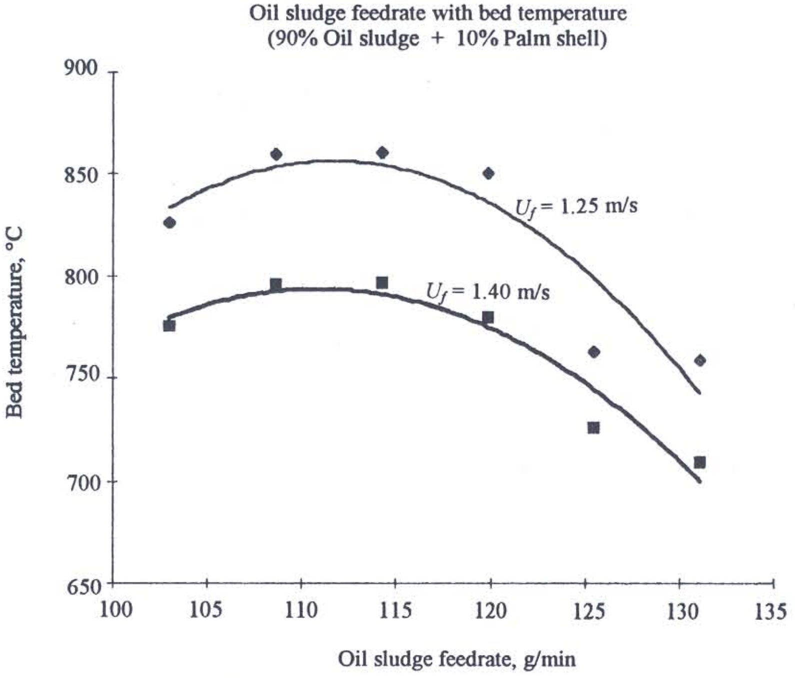

Fig. 2. The influence of air flow-rate on bed temperature.

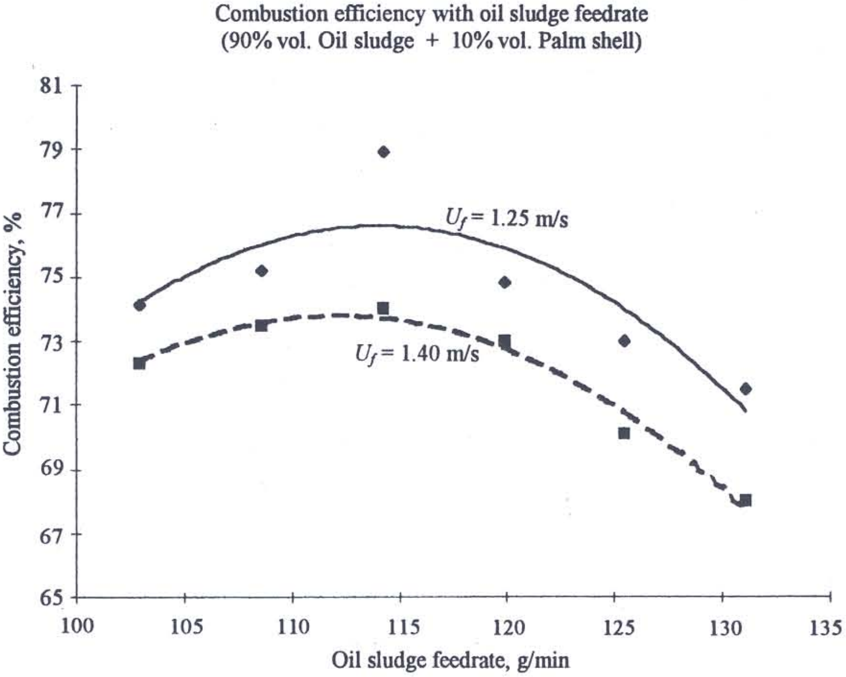

Fig. 3. The variation of combustion efficiency on the feed-rate.

3.2 Combustion Efficiency with Oil Sludge Feed-Rate

Figure 3 indicated the transient process of combustion efficiency while increasing the oil sludge feed-rate. At low fuel feed-rate of 103 g/min for fluidizing air of 1.25 m/s the combustion efficiency was around 74%. Beyond this fuel feed-rate the combustion efficiency increased until its maximum value of around 77%, which is obtained at the feed-rate of 114 g/min. Beyond this point, the combustion efficiency decreases from 77% to 70% as feed-rate increases to 131 g/min. This condition could be explained as follows:

1. *Increasing phase of combustion efficiency*: The combustion efficiency increases with increasing temperature (Fig. 2 and Fig. 3) and fuel feed-rate. This indicates more fuel oxidized by oxygen from exact stoichiometric air-fuel ratio causing the kinetics rate of combustion process to reach the optimum which is 1.14.
2. *Decreasing phase of combustion efficiency*: The decreasing phase of combustion efficiency results from heat loss combustion reactions taking place very slowly, as a result of rich mixture of air-fuel ratio. This condition results in black smoke emission with the increase of CO emission level.

At higher fluidizing air (1.4 m/s), the combustion efficiency is lower than that of fluidizing air 1.25 m/s (Fig. 4 and Fig. 5). Low fuel feed-rate has a tendency to increase the combustion efficiency from 72.3% to 74% (fluidizing air 1.4 m/s), but if it were compared to fluidizing air of 1.25 m/s, it reduced to 70.6%.

Air-fuel ratio is 1.26 at feed-rate of 114 g/min and at fluidizing air of 1.4 m/s. This condition has higher than optimum air-fuel ratio of 1.14. At higher fluidizing air, (1.4 m/s) combustion efficiency should be higher, because of more air or oxygen that can burn the fuel completely. But on this work the result has different value. It has the possibility of higher air velocity causing the high elutriation rate of fuel, therefore more fuel were unburned completely, increasing the heat loss or ash in the flue gases.

3.3 Gas Emission with Oil Sludge Feed-Rate

Figure 6 shows the effect of increasing the fuel feed-rate on the emission of CO and NO_x concentration level.

Analyzing CO Emission

Figure 6 shows the emission of CO at different fluidizing air velocity. Almost all CO emission in this experiment is lower than 400 ppm, which is nearly half of the EPA Regulation (maximum value 700 ppm). The scattered data-results at fluidizing air of 1.25 m/s is caused by inconsistency of air mixing with the fuel or variation of excess air from run to run. CO concentration at constant fluidizing air, while increasing oil sludge feed-rate, has a tendency of increasing its emission level. It could be due to oxygen diffusion to fuel which is less than the desired concentration, so that the reaction product is more to CO rather than CO_2.

For higher fluidizing air velocity of 1.4 m/s the CO concentration has lower emission level than for fluidizing air velocity of 1.25 m/s. This indicates that at air velocity of 1.25 m/s, the fuel either did not react enough with oxygen or the oxygen diffusion rate was not high enough. Therefore, CO emission in this air velocity is higher than emission from fluidizing air of 1.4 m/s. It also shows that the combustion efficiency is not much influenced by CO emission level, but more influenced by heat loss of particle carbon in ash.

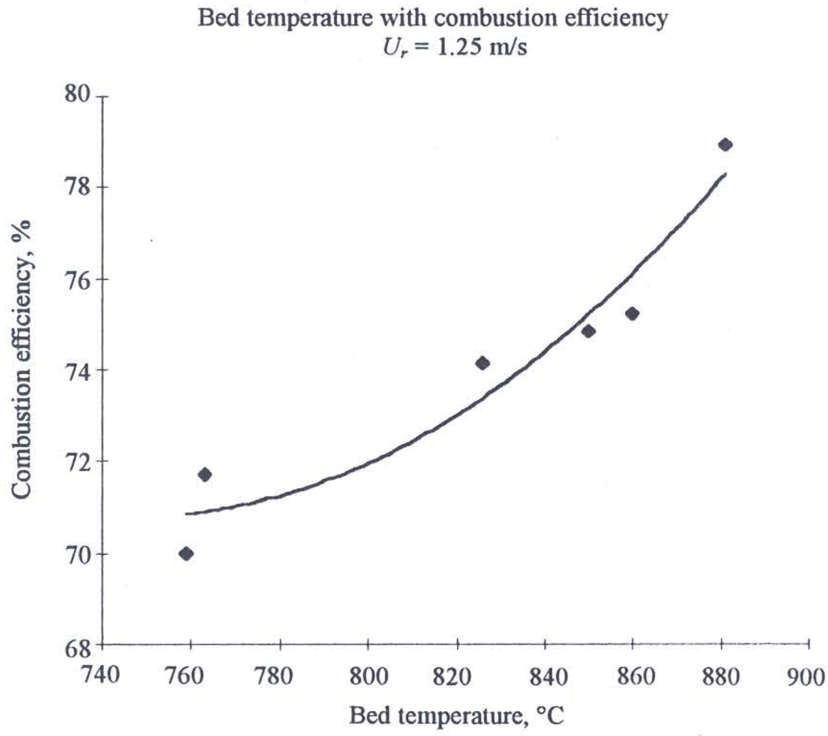

Fig. 4. Combustion efficiency versus bed temperature (U_f = 1.25 m/s).

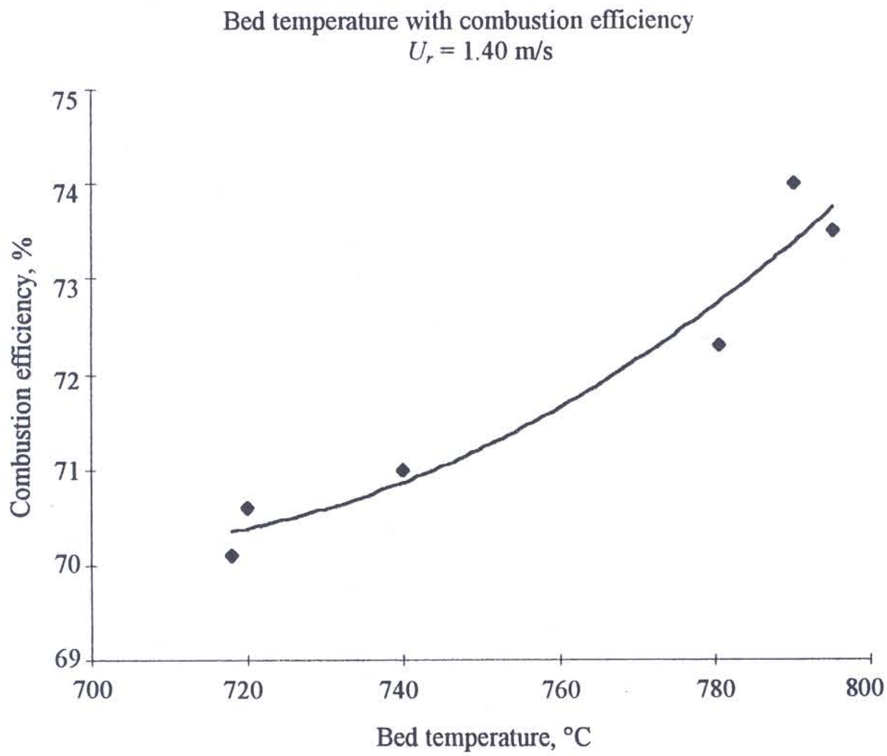

Fig. 5. Combustion efficiency versus bed temperature (U_f = 1.40 m/s).

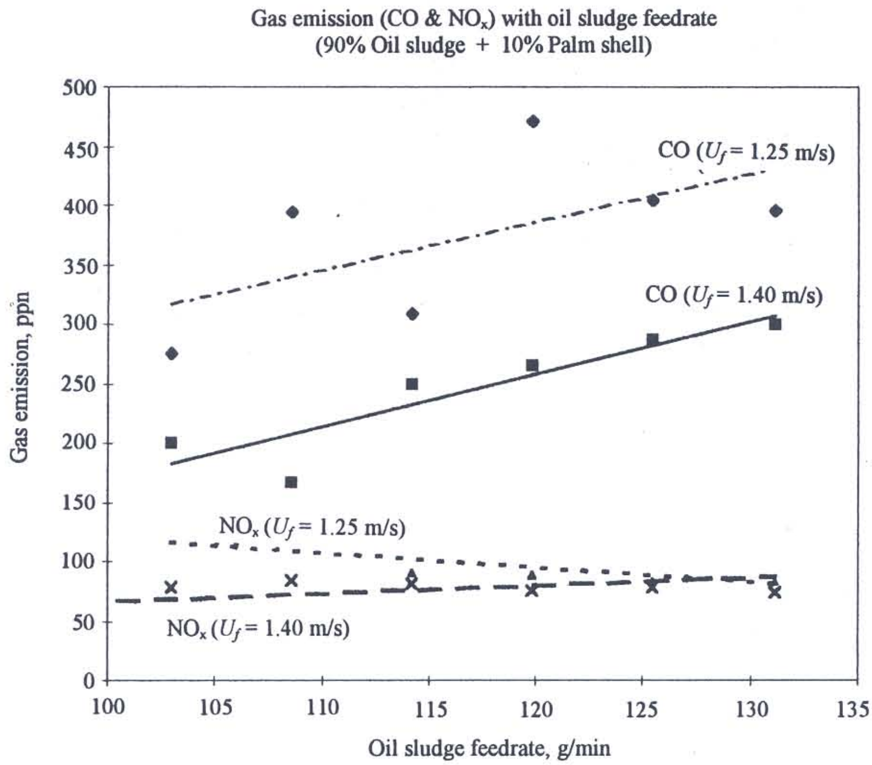

Fig. 6. Effect of fuel feed on gas emission (at 8.9% O_2).

Analyzing NO_x Emission

Figure 6 also shows that if the relative measurements of NO_x that are held at a constant value while increasing the feed-rate at air velocity of 1.4 m/s, but at air velocity of 1.25 m/s, then NO_x emission decreases slightly. Thus, this experiment shows two possibility, i.e., the NO_x concentration does not depend too much on the air flow-rate, but depends on nitrogen composition in the fuel. The other possibility is, the decrease of NO_x due to the decrease of O_2 while increasing the feed-rate at constant air flow-rate. This could be seen from the increase of CO concentration. The excess air in this experiment is in the range 87%-98% and the maximum of NO_x concentration has an average value of 98 ppm. Based on the current regulations for gaseous emission of hazardous constituent, the best available control technology (BACT) in Illinois [4], specifies NO_x concentration must not exceed more than 100 ppm. When compared with EPA, where maximum of NO_x concentration is limited to 250 ppm, the emission of the current experiment does not exceed the limiting value. So this experiment has shown a positive result.

4. CONCLUSIONS

The measurement of bed temperature and the flue gas emission have been carried out during the combustion of oil sludge and 10% palm shell waste in the bubbling fluidized bed incinerator. The conclusions derived from the results of these experiments are as follows:

1. The fluidized bed incinerator has the capacity of about 26.40 kW of burning oil sludge at the fuel feed-rate of 114 g/min. The fluidized bed incineration works with excess air at about 88% to 92%, and the combustion efficiency maximum is around 78.9%. Its capacity is lower than the design capacity of the incinerator based on the palm shell heat release calculation.
2. The maximum operating temperature achieved was 881.2°C when the feeding rate was 114 g/min or 10 rpm and fluidizing air velocity was 1.25 m/s.
3. Co-combustion of around 10% by volume of palm shell in the oil sludge is necessary to remove the clinker formation.
4. The oil sludge burnt well and fluidization was good.
6. Measurements have shown that this experiment produced a low NO_x emission level, but a slightly higher of CO emission level. Nevertheless, it has demonstrated that both those emission levels are lower than the standard emission regulation, e.g., BACT and EPA.

5. ACKNOWLEDGMENT

The authors are grateful to Mr. Shaari Zakaria from Techno Indah Sdn. Bhd. Malaysia Shipyard & Engineering for supplying the fuel waste to this research, and for supplying out other information, so that the experiment could be conducted. Furthermore, the authors wish to thank the Ministry of Science, Technology and Environment under the IRPA Research Program for the research grant awarded and Combustion Laboratory Universiti Teknologi Malaysia for the support of the measurement equipment during carry out the research work. The services rendered by Petronas Research and Scientific Services Sdn. Bhd. Kuala Lumpur in carrying out to specify the structure of the sludge is highly acknowledge.

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