An experimental investigation of concentrated slop combustion characteristics in cyclone furnace

To cite this article: Suphaopich Panpokha et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 113 012198

View the article online for updates and enhancements.

Related content
- Simulation of concentrated slop combustion in cyclone furnace using Computational Fluid Dynamics (CFD)
  Manita Phasomprayoch, Kiatfa Tangchaichit and Tanakorn Wongwuttanasatian
- A novel engine-free dilution-tunnel system for the collection of particulate matter formed during combustion
  C F Cullis, M M Hirschler and M A M Stroud
- Numerical Study of Cofiring Biomass with Coal in Cyclone Combuster
  I I Zulkepli, H Hasini, A M Ikram et al.
An experimental investigation of concentrated slop combustion characteristics in cyclone furnace

Suphaopich Panpokha¹, Tanakorn Wongwuttanasatian¹,²* and Kiatfa Tangchaichit¹

¹Department of Mechanical Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand
²Centre for Alternative Energy Research and Development, Khon Kaen University, Khon Kaen, 40002, Thailand

*Corresponding author Tel. +66.680.317.3170; E-mail: tanwon@kku.ac.th

Abstract. Slop is a by-product in alcoholic industries requiring costly waste management. An idea of using slop as a fuel in a boiler for the industries was proposed. Due to high content of ash, a cyclone furnace was designed to combust the slop. This study aims to examine the concentrated slop combustion in a designed cyclone furnace, consisting of combustion temperature and exhaust gases. The tests were carried out under 4 different air-fuel ratios. Fuels injected into the furnace were 3 g/s of concentrated slop and 1 g/s of diesel. The air-fuel ratios were corresponding to 100, 120, 140 and 160 percent theoretical air. The results demonstrated that combustion of concentrated slop can gave temperature of 800-1000°C and a suitable theoretical air was 100%-120%, because the combustion temperature was higher than that of other cases. In cyclone combustion, excess air is not recommended because it affects a reduction in overall temperature inside the cyclone furnace. It is expected that utilization of the concentrated slop (by-product) will be beneficial in the development of green and zero waste factory.

1. Introduction

Global warming is mainly caused by increased greenhouse gases (GHG). It is reported that human activities have resulted in an emission of greenhouse gases, such as carbon dioxide, and GHG tends to increase continuously and significantly every year. The GHG comes from various sources; including energy sector, industries, transportations, agricultures, and so on. Many researches demonstrated that energy consumption in industries, has resulted in environmental impacts and greenhouse gas emissions.

In 2014, the Center for Alcohol Studies (CAS), Thailand reported that Thai people consumed alcohol 7.01 liters per person per year, ranked number one in ASEAN region, followed by Laos; 6.73 liters per capita per year, and Philippines; 6.45 liters per capita per year [1]. These figures of alcoholic consumption tend to increase and continuously expanded production over the alcohol industries consequently, inevitably leading to the increased waste generated from the production process.

Generally, the liquors production process requires raw materials such as starch and molasses to produce ethyl alcohol and this generates a by-product called concentrated slop. As a result, it costs waste management, including storage and bad odors. The management of wastewater generated by liquor production have put into a discussion by several studies, including the extraction with Cu and Zn solvents, using the scales, and mixing the solution from fermented solution in the laboratory [2], Zn is reinstated to the distillery by precipitation in alcohol [3], the recovery of Th (IV) ions from nitric acid solution by using amino-magnetic glycidyl methacrylate, or granite use with alcohol [4], maintenance
of water quality drained from distillery [5-8], the reduction of alcohol production cost by the reuse of carbon dioxide in the production process [9], etc. Thus, in this study, utilization of concentrated slop (by-product) as fuel in cyclone furnace was proposed. This can be a better waste management leading to zero waste industry.

In present study, ways to use concentrated slop as an alternative fuel by combustion in a designed cyclone furnace are proposed. The combustion in the design furnace was examined using the mix of concentrated slop and diesel fuel. Testing was performed by increasing the air to fuel ratio on the combustion in four different settings. It is expected that utilization of the concentrated slop (by-product) will be beneficial in the development of green and zero waste factory.

2. Method

2.1. Cyclone furnace design

A cyclone furnace system was designed for concentrated slop combustion as shown in Figure 1. Basically, 3 g/s on concentrated slop and 1 g/s on diesel were injected into the furnace at a burner with some primary air. Most of the air was entered into the chamber tangentially, forming a cyclone motion, so the air and fuels were well mixed [10] as compared with a typical furnace. In addition, the combustion temperature in the cyclone furnace is expected to be higher than that of other type of furnace. The combustion temperature could reach up to 1,650 °C, depending on the type of fuel used. Since a very high combustion temperature, the ash swirled onto the marginal wall of the chamber would be melt into a liquid slag (about 50-70%). [11]

![Figure 1. Concept of cyclone furnace combustion system](image)

The cyclone furnace was designed to provide a high speed secondary air tangentially entered the chamber generating a cyclone motion. The chamber was a cylinder with an inner diameter of 30 cm and 100 cm long. The thickness of concrete wall was 20 cm, covered by 6 mm thick steel. Finally, the chamber was insulated by 5 cm thick insulator as shown in Figure 3. The chamber was tiltedly mounted with 23.8 angle to the horizontal line as seen in Figure 4.
2.2 Concentrated slop analysis and combustion

A sample of concentrated slop was analyzed to find its compositions. The ultimate analysis of the concentrated slop was shown in Table 1 having heating value of 8,373 kJ/kg. It was found that the concentrated consisted of a relatively high content of ash leading to ash management problem. Therefore, cyclone furnace would be a better way of concentrated slop combustion.

| Table 1. Concentrated Slop Ultimate Analysis |
|---------------------------------------------|
| Fuel            | C  | H₂  | O₂  | N₂  | S   | H₂O | Ash    | Viscosity (cPs) |
|-----------------|----|-----|-----|-----|-----|-----|--------|-----------------|
| concentrated    |    |     |     |     |     |     |        |                 |
| slop            | % wt| 15.874 | 3.925 | 19.380 | 0.7927 | 1.566 | 35.550 | 22.912         | 27               |
| diesel          | % wt| 86  | 13.1 | 0    | 0    | 0.9 | 0      | -               | 2.4              |

When 3 g/s of concentrated slop and 1 g/s of diesel were burnt simultaneously in a chamber, the stoichiometric combustion equation can be written as follows.

\[
(0.11135C + 0.12438H_2 + 0.01817O_2 + 0.00085N_2 + 0.00175S + 0.05925H_2O + \text{Ash}) + 0.15710(O_2 + 3.76N_2) \\
\rightarrow 0.11135CO_2 + 0.18363H_2O + 0.96740N_2 + 0.00175SO_2 + \text{Ash}
\]  

(1)
According to the combustion equation, stoichiometric air-fuel ratio can be determined to be 5.4 \((g_{\text{air}}/g_{\text{fuel}})\). Then an amount of primary and secondary air flow rates were calculated and set for 4 different cases, i.e. 100%, 120%, 140% and 160% theoretical air combustions as illustrated in Table 2.

**Table 2. Primary and Secondary air flow rate.**

| Theoretical Air Requirement (g/s) | Primary Air Flow (g/s) | Secondary Air Flow (g/s) | Velocity Of Secondary Air (m/s) |
|----------------------------------|------------------------|--------------------------|-------------------------------|
| 100%                             | 21.6                   | 2.32                     | 19.28                         | 8.2                          |
| 120%                             | 25.9                   | 2.32                     | 23.6                          | 10.1                         |
| 140%                             | 30.2                   | 2.32                     | 27.9                          | 11.9                         |
| 160%                             | 34.6                   | 2.32                     | 32.2                          | 13.8                         |

A round spray nozzle with a diameter of 1.5 mm is recommended for concentrated slop fuels [12] [13]. The concentrated slop was preheated by a heater up to 90 °C to reduce the viscosity of the concentrated slop. Afterward, a diaphragm pump was used to pump the concentrated slop through a pulsation dampener to stabilize the flow rate. Finally, concentrated slop was sprayed at the nozzle with some primary air.

**2.3. Combustion tests**

Combustion tests were set to burn 3 g/s of concentrated slop with 1 g/s of diesel at 4 different air-fuel ratios corresponding to 100%, 120%, 140% and 160% theoretical air. Each test were repeated five times. Combustion temperature inside the furnace were monitored by B-Type thermocouple probes at 6 different positions. Six different points of type B thermocouples inside the chamber were located on the top and side 15 cm deep into the centre as seen in Figure 5. Exhaust gases for each case were also measured using a gas analyzer TESTO 350. Each case was repeated for five times and the average result for its case was determined as a representative.

![Figure 5. Temperature measured points inside the chamber](image)

**3. Results and Discussions**

**3.1. Combustion test**

Temperatures inside the cyclone chamber were monitored at 6 different points as mentioned earlier. The results are summarized in Table 3. It was found that the highest temperature was at TC3 where it was at the top far end from the burner. Since the high velocity airflow but low temperature entering into the chamber disturbed the temperatures at point TC1, TC2 and TC4 then the average combustion temperature was selectively determined by using temperatures at points TC3, TC5 and TC6.
Table 3. Average combustion temperature

| Cases               | Adiabatic Flame Temperature | Average temperature for all points (TC1-TC6) | Average peak temperature (TC3) | Average temperature of chambers (TC3, TC5, TC6) |
|---------------------|-----------------------------|---------------------------------------------|-------------------------------|-----------------------------------------------|
|                     | (°C)                        | (°C)                                        | (°C)                          | (°C)                                          |
| 100% theoretical air| 2,214                       | 988.64                                      | 1,031.92                      | 1,022.99                                      |
| 120% theoretical air| 2,142                       | 920.23                                      | 1,015.05                      | 971.03                                        |
| 140% theoretical air| 2,039                       | 885.93                                      | 968.50                        | 910.51                                        |
| 160% theoretical air| 1,894                       | 811.38                                      | 863.04                        | 840.68                                        |

As illustrated in Table 3, the maximum temperature was at 100% theoretical air whereas the lowest temperature was at 160% theoretical air. The temperature tends to drop with the increase of air which agrees with the theory. This suggested that minimum air provided as necessary could result a higher combustion temperature. In addition, according to the principle of cyclone furnace, air and fuel would be well mixed and thus there is no need of high excessive air. On the other hand, if an excessive air is added to the combustion chamber, the overall temperature inside the combustion chamber decreases even where the cyclone is formed. Because the entering air temperature is much lower than inside temperature and the nitrogen (N2) in the air induces an endothermic reaction, causing lower heat release from the combustion reaction [14]. This agreed with the works of Warzecha and Boguslawski [15], Alattab and Zainal simulation [16].

However, the actual combustion temperatures from the tests shown in Table 3, were much lower than the adiabatic flame temperatures due to the heat loss from the chamber wall and partially incomplete combustion of some slops. Experimental results showed that a peak temperature was 1,031.92 °C for 100% theoretical air and trended to decline with increase of air. The average combustion temperature were plotted against theoretical air in Figure 6 and a linear semi-correlation was generated expressed in equation (2) with R² = 0.9525.

\[ Y = -3.0373x + 1331.1 \]  
(2)
Likewise, Luo et al. (2009) [17] reported that an excess of oxygen in a combustion chamber can significantly reduce the combustion chamber. However, an appropriate content of oxygen would increase the temperature in a combustion chamber.

3.2 Flue gases analysis for concentrated slop combustion

The exhaust gases were measured at the flue gases duct by using a gas analyzer Testo-350. The measured gases included O₂, CO, NOₓ, NO, NO₂, CO₂, SO₂ and HC. The measurement of each test was carried out when combustion was steady every 1 minute for 30 minutes. Each test was repeated for five times and the average value was determined and shown in Table 4.

| Case Theoretical Air | O₂ (%) | CO (ppm) | NOₓ (ppm) | NO (ppm) | NO₂ (ppm) | CO₂ (ppm) | SO₂ (ppm) | HC (ppm) |
|----------------------|--------|----------|-----------|----------|-----------|-----------|-----------|---------|
| 100%                 | 5.51   | 2274.14  | 253.82    | 254.17   | 0.47      | 11.24     | 146.63    | 116.33  |
| 120%                 | 6.49   | 1893.92  | 188.97    | 188.67   | 0.29      | 9.53      | 89.02     | 89.31   |
| 140%                 | 7.47   | 1710.56  | 172.13    | 170.58   | 0.19      | 8.44      | 68.88     | 74.44   |
| 160%                 | 8.38   | 1521.28  | 155.18    | 155.07   | 0.12      | 7.49      | 54.74     | 64.74   |

As shown in Table 4, it is the fact that increasing of supplied air resulted in an increase of O₂, but a decreases in CO₂. This was due to excessive of air would dilute the concentration of CO₂ in the exhaust gas. For CO and HC, they are produced because of incomplete combustion. It was shown that CO and HC were decreased when more air was supplied at a high speed causing higher cyclone motion inside the combustion chamber and thus more complete combustion was achieved. Similarly, SO₂ concentration was minimized with excessive air supplied. Obviously, oxides of Nitrogen tended to decrease with increasing air since the combustion temperature was diminished so that forming of Nitrogen and oxygen atoms could be decreased.

4. Conclusion

Slop is a by-product in alcoholic industries requiring costly waste management. An idea of using slop as a fuel in a boiler for the industries was proposed. Due to high content of ash, a cyclone furnace was designed to combust the slop. Thus, in this study, combustion of concentrated slop in the designed chamber at four different setting i.e. 100, 120, 140 and 160 theoretical air were investigated. 3 g/s of slop and 1 g/s of diesel were injected into the chamber with varied air supplied. It was found that the highest average combustion temperature was 1,031.92 °C for the case of 100% theoretical air and the temperature decreased with increasing air supplied. In addition, based on flue gases analysis, it indicated that more complete combustion was accomplished due to cyclone combustion. However, high combustion temperature and NOₓ forming are reversely and have to be traded off when setting a combustion. Finally, the present work suggests that a proper minimum diameter of a cyclone furnace should be investigated in a future work in order to obtain a good combustion. Too small diameter of the chamber could result in bad cyclone motion inside the chamber.

Acknowledgments

The authors gratefully thank you Thai Beverage Energy Co., Ltd. for an assistance of factory information and financial supports. Appreciation is also given to the Centre for Alternative Energy Research and Development, Khon Kaen University for technical supports and suggestions.

Reference

[1] Thaipbs 2014 Alcohol consumption in Thailand
   http://englishnews.thaipbs.or.th/infographic/alcohol-consumption-thailand/
[2] Sinha M K, Sahu S K, Pramanik S, Prasad L B and Pandey B D 2015 Hydrom 165 9
[3] Pathak A, Roy A and Manna M 2016 Hydrom 163 6
[4] El-Magieda M O Abd, Tolbaa A A, El-Gendya H S, Zakia S A and Atia A A 2017 *Hydrom* **169** 10
[5] Simate S G, Cluett J, Lyuke S E, Musapatika E T, Ndlovu S, Walubita L F and Alvarez A E 2011 *Desalination* **273** 13
[6] Braeken L, Bruggen B V D and Vandecasteele C 2004 *Water Res* **38** 8
[7] Filladeau L, Blanpain-Avet P and Daufin G 2006 *J Clean Prod* **14** 9
[8] Olajire A A 2012 *J Clean Prod* 21
[9] Titu A M and Simonffy A 2014 *Procedia Econ Financ* **16** 8
[10] Shaha A K 1974 *Combustion Engineering and Fuel Technology Optimum Utilization of Fuels* (New Delhi: Oxford & IBH)
[11] Keating E L 2007 *Applied Combustion* 2 ed (New York: CRC Press)
[12] Faculty of Mechanics and Energetics Wroclaw University of Technology 2017 *Combustion And Fules Atomization Of Liquid Fuels* http://fluid.wme.pwr.wroc.pl/~spalanie/dydaktyka/combustion_MiBM/BCS/LIQUID_FLUIDS_ATOMIZATION.PDF
[13] Chong C T and Hall H 2011 *Combustion Characteristics of Alternative Liquid Fuels* https://www.repository.cam.ac.uk/bitstream/handle/1810/244379/Chong_PHD_thesis.pdf?_sequence=1&isAllowed=y
[14] Cleaverbrooks 2017 *Excess Air and Boiler Efficiency* http://www.cleaverbrooks.com/products-and-solutions/boilers/firetube/cbex-elite/excess-air-and-boiler-efficiency.aspx
[15] Warzecha P and Boguslawski A 2014 *Energy* **66** 12
[16] Al-attab K A and Zainal Z A 2011 *Appl Energy* **88** 12
[17] Luo S Y, Xiao B, Hu Z Q, Liu S M and Guan Y W 2009 *Energy* **34** 5