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Quality Enhancement Process of Hazardous Industrial Waste-Based Solid Fuel

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Global population growth and industrialisation have led to an increase in scheduled waste generation, which poses a threat to the environment and human health. Due to the heterogeneous characteristics of scheduled waste, the quality of the products is affected. Therefore, it is essential to develop a waste-to-raw material conversion process that could enhance the quality of industrial wastes-based solid fuel (IWSF). In this work, the synthesis process of IWSF to remove heavy metal content efficiently was performed, and temperatures were varied around 100 °C, 300 °C and 500 °C to examine the effect of temperature on the quality of the produced IWSF. Based on simulation results, it was found that the reactor temperature did not significantly affect the IWSF, and its heavy metal content was reduced enough to comply with Malaysia Environmental Quality (Schedules Wastes) 2015.

1. Introduction

According to the Department of Statistics Malaysia, the quantity of hazardous waste generated by industries in 2020 was 7,185.2 thousand metric tonnes, an increase of 79.0 % compared to the 4,013.2 thousand metric tonnes reported in 2019, mainly contributed by power plants and water treatment plants (Mahidin, 2021). This increase has resulted in environmental issues such as pollution and greenhouse effects due to harmful waste management and reliance on fossil fuels for energy (Loureiro et al., 2021). As a solution, these wastes can be converted into alternative fuels valuable to industries, specifically the cement industry, the most energy-intensive industry in the world. By converting wastes into energy, landfill disposal can be avoided, and material with no secondary market value can be enhanced in terms of its value (Holzleitner et al., 2020). In order to become a commercially viable fuel, it must meet technical specifications and a standard (Chavando et al., 2022). Environmental and economic considerations are the primary concern in producing industrial wastes-based solid fuel (IWSF). Hazardous wastes can be converted to energy through thermochemical conversion processes such as pyrolysis and gasification (Haydary, 2018). Pyrolysis involves heating fuel without oxygen and is an endothermic reaction, while gasification involves the partial oxidation of fuel to produce combustible gases such as carbon monoxide, hydrogen, and methane as the main products. With waste-to-energy technology, the biodegradable fraction from hazardous waste is removed while enhancing the value of the waste in terms of generating electricity and heat. However, during thermochemical conversion, IWSF may release heavy metals such as zinc, chromium, copper, and lead into the atmosphere, which means that it is crucial to lower the heavy metal content in the IWSF. IWSF are manufactured through several important steps, including crushing, drying, and mixing hazardous wastes. Crushing facilitates the handling process by squashing the combustible wastes into smaller pieces, while drying is essential for reducing moisture content and increasing calorific value. After crushing and drying, a high calorific primary fuel is mixed with a low calorific alternative fuel to achieve specific

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calorific values (Zieri and Ismail, 2019). Numerous researchers have discussed blending hazardous wastes into fuel, which would mitigate environmental damage by converting waste into fuel and reducing fossil-fuel consumption (Karpan et al., 2021), and technology for hazardous waste energy recovery (Chew et al., 2021). However, none focuses on determining the optimal operation of the process to obtain high-quality hazardous waste to industrial wastes-based solid fuel (IWSF) through simulation. In this paper, the Aspen Plus simulator was used to perform a complete mass and energy balance to enhance the quality of IWSF.

2. Model development

2.1 Input data

The data used for proximate and ultimate analyses are shown in Table 1. These data are essential in determining the content of IWSF, such as carbon, moisture and sulphur.

Table 1: Proximate and ultimate analyses data

Test Parameters	M (%)	ASH (%)	VM (%)	FC (%)	S (%)	GCV (kcal/kg)	N (%)	C (%)	H (%)	O (%)
Results	4.4	43.3	50.4	6.3	0.15	2193	0.88	33.60	3.36	62.16

The Particle Size Distribution (PSD) and component composition for solid and liquid components are shown in Tables 2 and 3. Based on Table 2, it can be concluded that the IWSF has an average particle size of 0.85 to 1.7 mm. Various heavy metal and hazardous components were also considered for the simulation model to ensure that the model reflected the actual operation, and the model was verified using plant data.

Table 2: Particle size distribution of IWSF

Feed particle size (mm)	Mass retained (g)	Mass fraction (%)
1.7-2.8	44.97	4.91
0.85-1.7	814.07	76.22
0.6-0.85	68.3	6.4
0.6-0.5	47.74	4.47
<0.5	85.47	8
Total	1,060.55	100

Table 3: List of solid and liquid components in IWSF

Compound	Quantity (mg/L)	Compound	Quantity (mg/L)
Arsenic	<0.05	Methoxychlor	<0.005
Barium	0.7	Nitrobenzene	<0.005
Cadmium	0.20	Pentachlorophenol	<0.050
Chlordane - cis & trans	<0.005	Pyridine	<0.050
Chromium	0.08	Selenium	<0.1
o-Cresol	<0.005	Silver	<0.01
m-Cresol	<0.005	Toxaphene	<0.050
p-Cresol	<0.005	2,4,5-Trichlorophenol	<0.005
Cresol	<0.005	2,4,6-Trichlorophenol	<0.005
2,4-D (dichlorophenoxy acetic acid)	<0.010	2,4,5-TP (Silvex)	<0.010
1,4-Dichlorobenzene	<0.005	Benzene	<0.005
2,4-Dinitrotoluene	<0.005	Carbon Tetrachloride	<0.005
Endrin	<0.005	Chlorobenzene	<0.005
Heptachlor and heptachlor epoxide	<0.005	Chloroform	<0.020
Hexachlorobenzene (HCB)	<0.005	1,2-Dichloroethane	<0.005
Hexachlorobutadiene	<0.005	1,1-Dichloroethylene	<0.005
Hexachloroethane	<0.005	Methyl Ethyl Ketone	<0.050
Lead	0.30	Tetrachloroethylene	<0.005
Lindane	<0.005	Trichloroethylene	<0.005
Mercury	0.002	Vinyl Chloride	<0.050

2.2 Process Flow Diagram (PFD)

Figure 1 shows the PFD of the process of enhancing the quality of IWSF. The PFD can be divided into several main parts, as shown in Table 4.

Table 4: Main parts of the process flow diagram

Main part	Stream
Thermal energy supply system for nitrogen gas	2, 3, 4, 5, 6
Batch reactor	BRR01
Waste heat recovery system	9, 10, 11, 12, 13, 14
Gas post-treatment system	15, 16, 17, 18, 19
Enhanced IWSF production line	7, 23, 24, 25
Waste liquid	8, 20, 21, 22

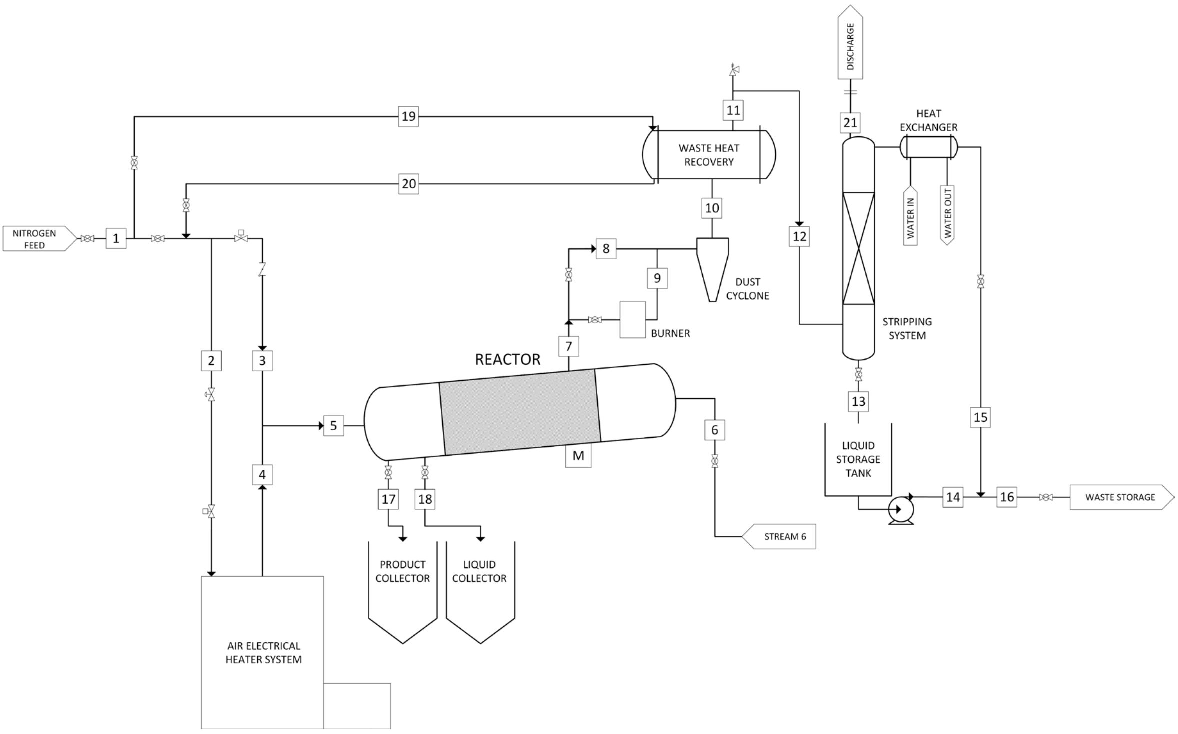

Figure 1: Process flow diagram

The Aspen Plus simulator and data in Section 2.1 were used to develop a model representing the PFD in Figure 1. The process consists of 2 main feeds: nitrogen gas (Stream 1) and IWSF (Stream 6) produced from the existing system. The overall PFD obtained using Aspen Plus is shown in Figure 2. The purpose of the nitrogen was to be the medium to supply heat to the batch reactor (Stream 5). The process used an electric heater as a source of heat energy to heat the nitrogen supplied to the batch reactor, and the temperature of the nitrogen gas fed to the reactor would keep the temperature of the batch reactor at 300 °C. The gas product produced in the reactor (Stream 7) was sent to the cyclone separator to remove any solids that might escape through the vapour stream. The vapour (Stream 7) was then transferred to a burner to burn heavy metal that escaped through the stream. The flue gas produced from the combustion process was sent to the heat recovery system to recover the heat from the stream before it was exported to the waste gas treatment system (if necessary). The heat recovered was used to pre-heat the nitrogen before entering the reactor, reducing the energy consumption of the electrical heater. The solid product (IWSF) was obtained from Stream 17, and a liquid collector was prepared to collect any liquid produced from the batch reactor. A total of 3 hours was required for the batch reactor operation.

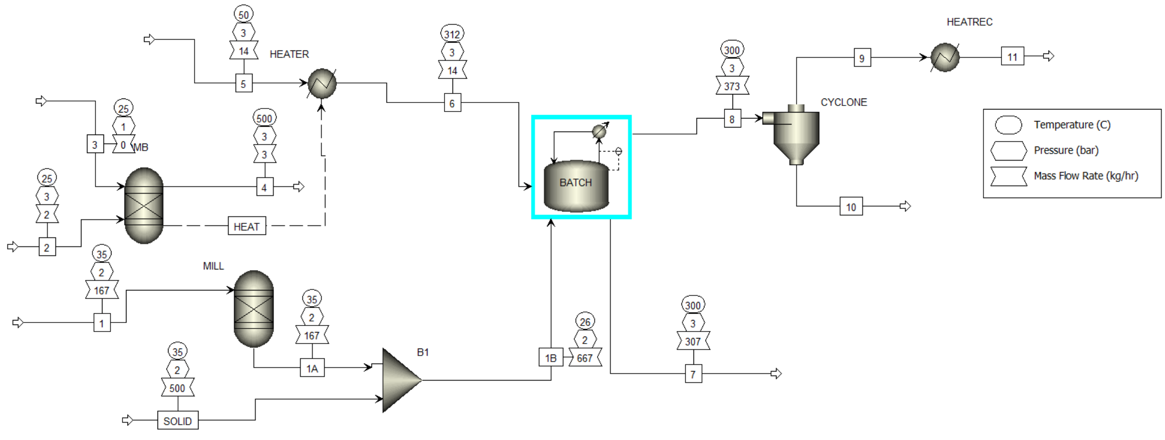

Figure 2: Process flow diagram developed using Aspen Plus

3. Model analysis

3.1 Effect of temperature on the batch reactor

This section presents the analysis of the batch reactor under three different temperatures: 1) 100 °C, 2) 300 °C, and 3) 500 °C. Figure 3 shows the mass flow rate of the components present in the inlet stream of the reactor based on two metric tons of IWSF per batch. As shown in the figure, metals such as barium and selenium had the highest composition, followed by lead, arsenic, oxygen, and carbon. It is also worth noticing that some other heavy metals (refer to the red box) were also present in the inlet stream. Figures 3 to 6 present the results obtained for the outlet streams of the batch reactor under the specified temperatures.

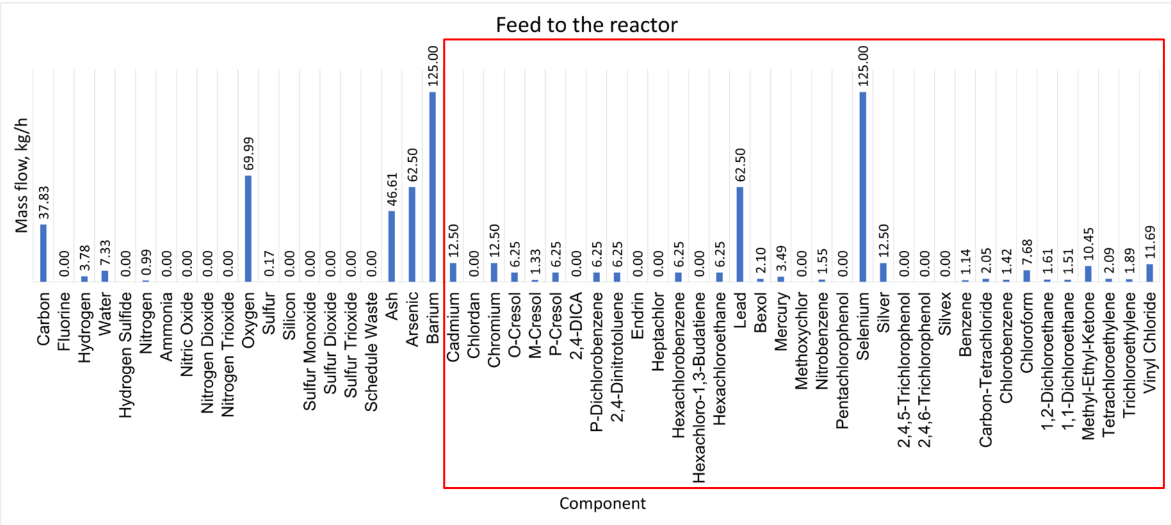

Figure 3: Inlet stream of the batch reactor

Figures 4 to 6 show that parts of the heavy metals from the IWSF were removed through the vapour stream, thus reducing the content of heavy metals in the IWSF (solid stream) produced from this process. In addition, some heavy metal content was significantly reduced and converted to other components. This analysis proves that the quality of the IWSF was enhanced through the process. However, operation under different reactor temperatures only gave minimum impact on the products. The trend for components in the outlet streams for both solid and vapour was almost the same, where only a reduction in moisture content (refer to the red box) at elevated temperature can be noticed in the figure. Hence, a lower temperature is preferable as the process would require less energy.

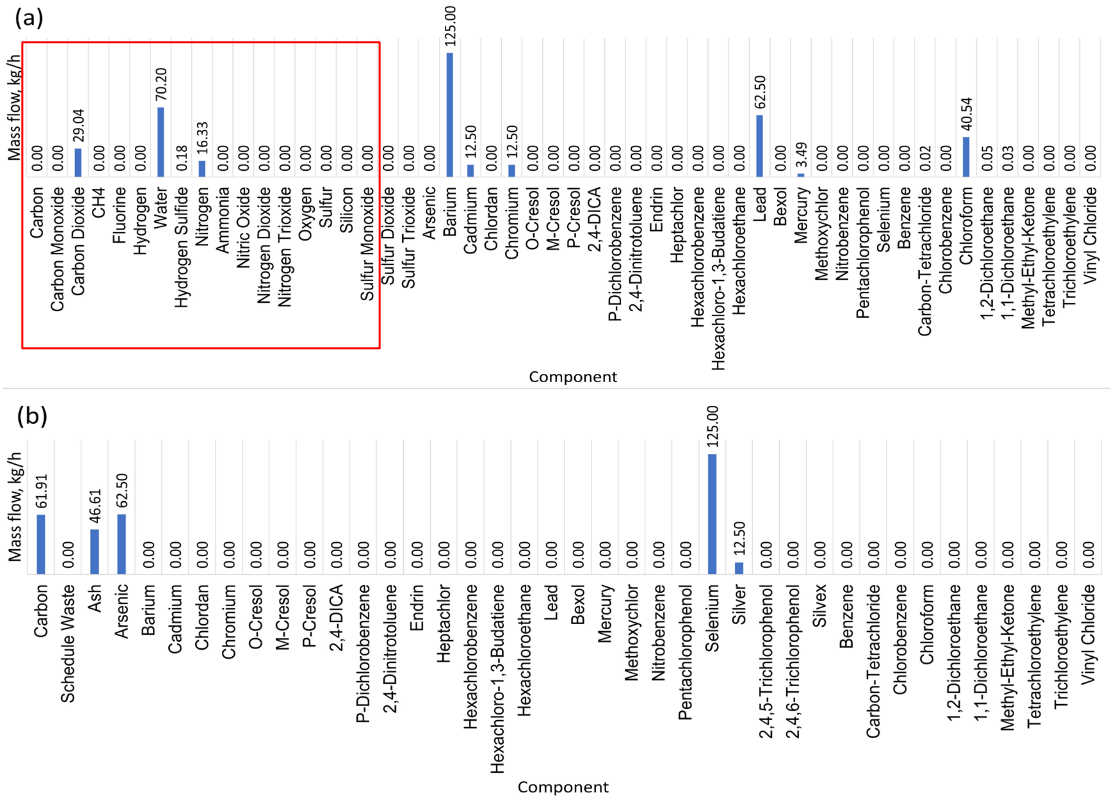

Figure 4: Outlet streams of the batch reactor at 100 °C (a) vapor stream (b) solid stream

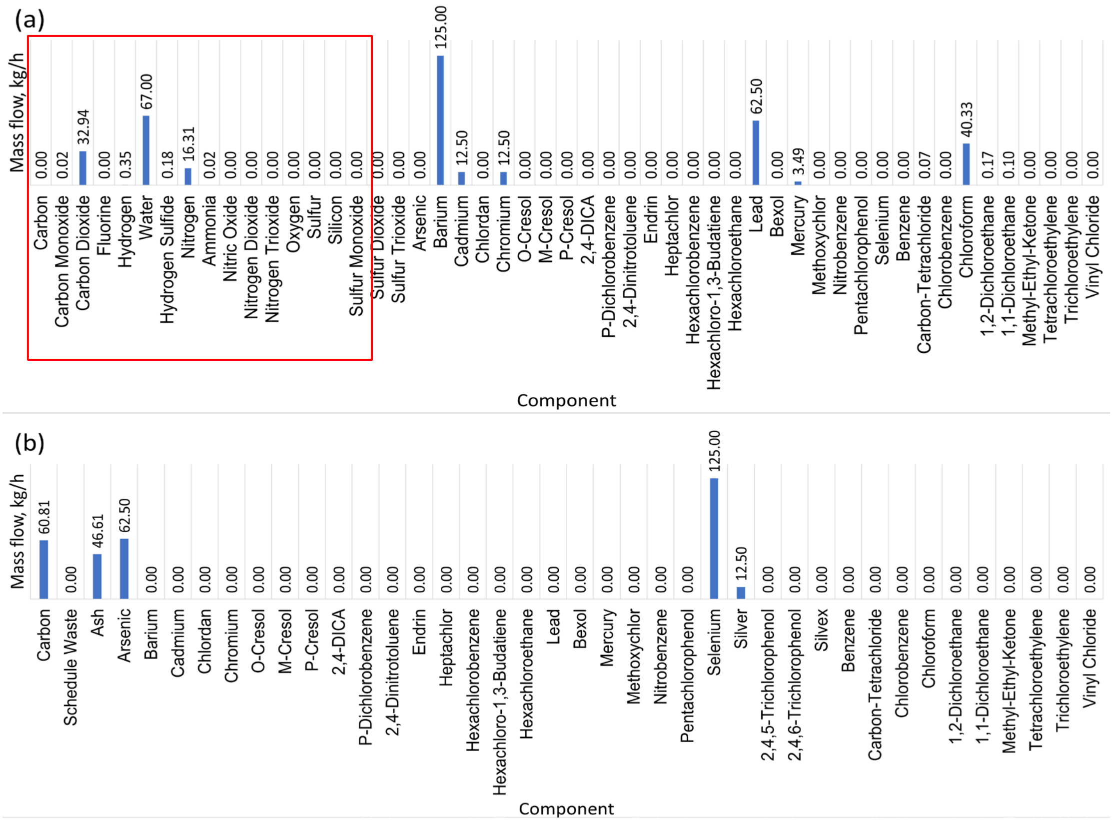

Figure 5: Outlet streams of the batch reactor at 300 °C (a) vapor stream (b) solid stream

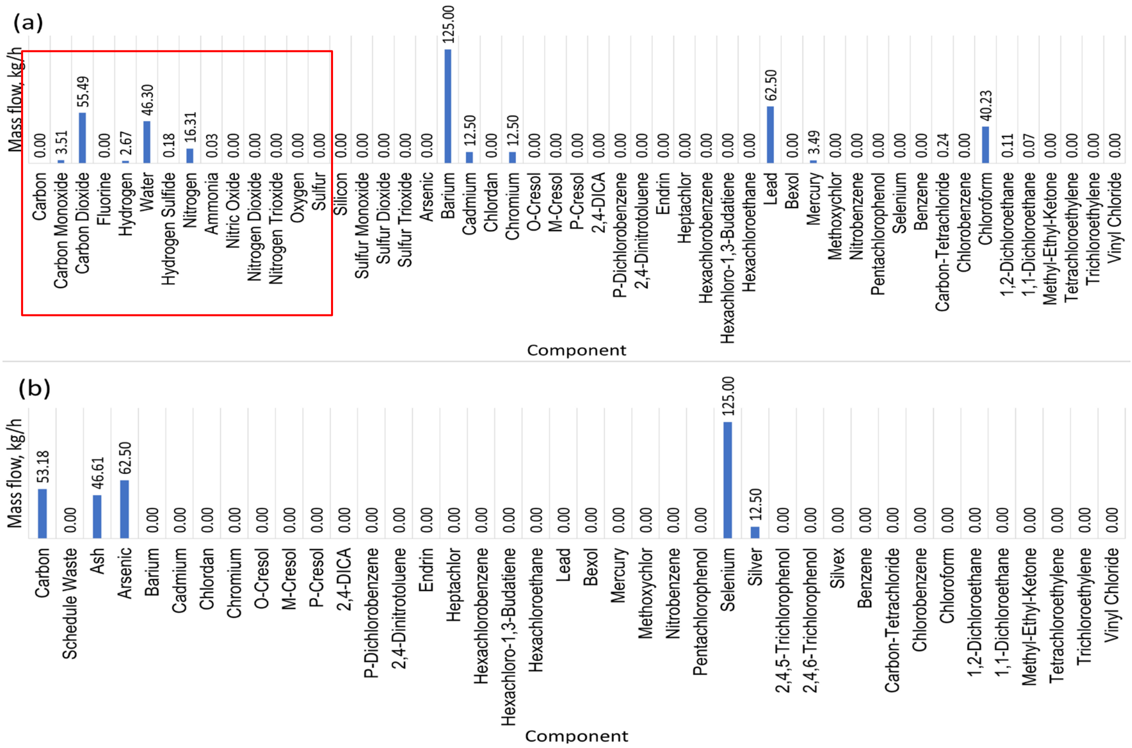

Figure 6: Outlet streams of the batch reactor at 500 °C (a) vapor stream (b) solid stream

4. Conclusion

The analyses have demonstrated that the simulated process successfully improved the quality of the IWSF, as the heavy metal content in the solid and liquid streams was reduced. It is also notable that varying the reactor temperature would not affect the IWSF significantly; hence it is recommended that such processes are carried out using a relatively lower temperature to ensure energy efficiency.

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