Investigation on Mechanism of Potassium Removal from EFB by Hydrothermal Treatment: Characterization and Regression Model

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Introduction

Palm tree

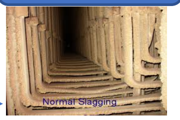
From a whole palm tree, only 10%mass is used for oil production
90%mass remain as agricultural waste (such as EFB)

Solid biofuel

Empty Fruit Bunches (EFB)

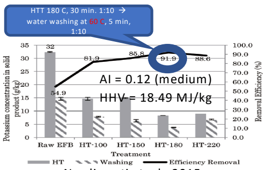
high potassium content → Low HHV

Cause slagging and fouling!



Inside boiler

Various past studies utilize **Hydrothermal Treatment (HTT)** to **lower potassium content and increase HHV** of EFB



Nurdiawati et. al., 2015

However, the **mechanism of potassium removal**, **effect of process parameters** and **feedstock properties** on potassium removal using HTT are still unknown

Research Objectives

- ❑ To **characterize potassium existence form** in raw EFB
- ❑ To **investigate the effect of** Hydrothermal Treatment **process parameters and feedstock characteristics on potassium removal in EFB** by using statistical model using data from published studies

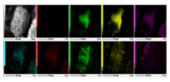
Materials and Methods

Characterization Study

- ❑ Evaluation of raw EFB as solid biofuel:
  - **Proximate and Ultimate analysis,**
  - **Ash composition (XRF)**,
  - **Potassium Concentration Measurement (ICP-OES)**
- ❑ Speciation of Potassium in raw EFB:
  - **XRD (Crystalline Structure),**
  - **SEM-EDX line profile analysis**

  to **check potassium existence correlation with other elements and predict its existence form**.
  Elemental mapping of the surface was firstly conducted (shown in Picture 1). Particles with high potassium content were selected and divided to 4-5 sections (Picture 2). Elemental intensity were plotted to each other.

Materials:
EFB used for characterization in this study were taken from palm oil mill in **Malaysia**



Picture 1. Elemental Mapping

Picture 2. Particle division for Line Profile Analysis

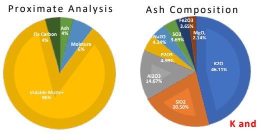
Statistical Model

- ❑ Data Collection
  Google Scholar and Web of Science were used to collect papers treating EFB using HTT for biofuel production purpose. **Kconcentration in hydrochar (%), Kconcentration in feedstock (%), ash in feedstock (%), feedstock size (mm), HTT Temperature (°C), HTT holding time (min), solid load (%), reactor volume (mL), involving washing or not (1 or 0)** data were collected
- ❑ Model Construction
  Best Subset Selection method (using `regsubsets` function of `leaps` package in R) were used to select **Multiple Linear Regression Model** on **Kcont in hydrochar (%)**
- ❑ Validation
  Model robustness was validated using **10-folds cross validation method** in R
- ❑ Weighting Parameter
  Each parameter's importance was determined using `calc.relimp` function of `relaimpo` package in R

Results and Discussions

Characterization Study

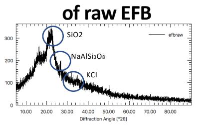
Raw EFB Characteristics



HHV = **17.86 MJ/kg**
K concentration = **15,060.8 mg/kg**
Alkali Index (AI) = **1.1475 kg Alkali / GJ** (**high**)
AI >= 0.34, fouling is certain to occur

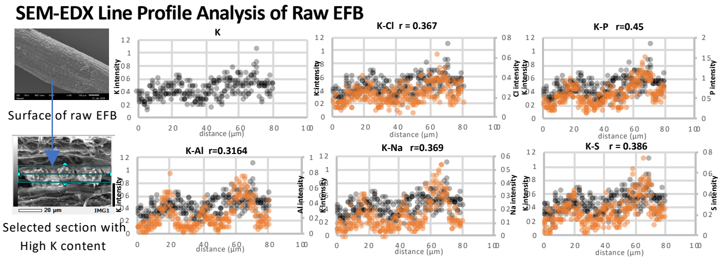
K and Si are major elements in raw EFB ash

XRD Crystalline Analysis of raw EFB



K is detected only as sylvite (KCl)

SEM-EDX Line Profile Analysis of Raw EFB



K shows **positive existence correlation** with P, S, Na, Cl and Al, distributed on EFB surface with no clear localization.
We also found strong existence correlation between (Na-Al-Si-O) which proves the existence of $NaAlSi_3O$
It is predicted that K mostly exists in EFB surface **as readily soluble K+ ion** or **organically bonded in between EFB matrix**.

Statistical Model

Overview of Data Collected

25 papers using HTT on EFB for biofuel production were collected. However, only **32% papers** provides all variables data needed. Resulted in **65 data points** to construct multiple linear regression model.

Table 1. Range and mean of collected parameters

Parameters	Kcont. in hydrochar (g/kg)	Kcont. in feedstock (g/kg)	Ash in feedstock (%)	HTT Temp. (°C)	Hold time. (min)	Solid load (%)	Reactor vol (L)	Wash or not
Range (mean)	0.17 – 21.3 (5.7)	5.4 – 32.4 (21.3)	1.00 – 4.90 (4.282)	28 – 220 (127.3)	25 – 120 (58.23)	1 – 40 (9.64)	0.5 – 2.5 (1.215)	0 or 1 (0.123)

Multiple Regression Linear Model on Percentage of Potassium Remained in Hydrochar (%)

K in hydrochar (g/kg) = 2.755 Ash int – 0.0085 Temp + 0.19 HT + 0.213 SL – 4.86 vol -7.09 washornot + 0.156 K init – 4.7692

Explain data **quite well** with Adj R squared **= 0.7324** **low** RMSE cv = 2.8263
Statistically significant (p<0.05) variables : vol >> ash in feedstock >> wash or not >> solid load > K in feedstock
T and holdtime are statistically insignificant (p>0.05) but included in the model due to effects reported in several studies

Process Parameters and Feedstock Properties Influences

Table 2. Independent parameters relative weight (%) in linear model

Reactor volume (L)	= 35
Ash in feedstock (%)	= 30
involve washing or not (0 or 1)	= 9
K in feedstock (g/kg)	= 8
Temperature (°C)	= 8
Holding time (min)	= 5
Solid load (%)	=4

Relative weights (%) were calculated to assess each variable's importance in the model.
It turned out that **reactor volume, initial ash concentration in feedstock, involving washing or not** are statistically three **most determining variables on K concentration remain in hydrochar.**
Process using larger reactor volume, selection on lower ash feedstock and **involvment of washing** will be beneficial **to produce low-potassium EFB biochar by HTT**

Conclusions & Future Works

- ❑ Potassium is predicted to exist on EFB surface as **readily soluble K+ ion** or **organically bonded** in between EFB matrix
  → Cross-sectional SEM-EDX line profile analysis in future study may provide more information on potassium form inside EFB.
- ❑ **Multiple linear regression model constructed has explained the data quite well.**
  → However, current model doesn't assume any synergetic relation between variables.
  Future study using more advance statistical learning methods (such as regression tree and random forest) may help understanding synergetic effects between variable on K cont. in hydrochar and allow non-linear relation to response variable
- ❑ **Reactor volume, initial EFB ash content, HTT involving washing or not;** are statistically three most important parameters in determining potassium concentration left in hydrochar. **Larger reactor volume, selection on lower ash feedstock and involvement of washing** will be beneficial to produce low-potassium EFB hydrochar by HTT

References

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