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Analysis of Tar Properties Produced During Co-Gasification of Empty Fruit Bunch Pellet and Oil Palm Shell

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Abstract: In this study, tar produced during co-gasification of empty fruit bunch pellet (EFBP) and oil palm shell (OPS) was analyzed. The aim of the analysis is to characterize tar samples with three different fuel composition of 100% EFBP:0% OPS, 75% EFBP:25% OPS and 50% EFBP:50% OPS. Two types of analysis were carried out, namely the physical and chemical analysis. Physical analysis determines the moisture content, density and calorific value of tar samples while the chemical analysis via Fourier Transform Infrared (FTIR) Spectroscopy determines the functional group in the tar samples. In general, it was found the moisture content, density and calorific value increases with higher amount of OPS in the fuel mixture. The calorific value ranges from 4.722 MJ/kg to 21. 877 MJ/kg whiles the moisture content and the density ranges from 30.90% to 47.20% and 2.74089 g/cm^3 to 2.99075 g/cm^3. From FTIR analysis, it was found the tar contains alcohol, carbonyl, alkene, aromatic, ether and nitro. This corresponds to the characteristic absorptions during FTIR, which were 3200cm^{-1} to 3600cm^{-1} (O-H), 1670cm^{-1} to 1820cm^{-1} (C=O), 1620cm^{-1} to 1680cm^{-1} (C=C), 1400cm^{-1} to1600cm^{-1} (C=C), 1000cm^{-1} to 1300cm^{-1} (C-O) and 1345cm^{-1} to 1385cm^{-1} (N-O).

Keywords: Empty fruit bunch pellet, oil palm shell, physical analysis, FTIR spectroscopy

1. Introduction

Generally, biomass is the waste coming from animal and plant that stores energy from the sun. It is believed to be an alternative to fossil fuels that has good potential for clean energy development [1-3]. The deployment of biomass as a sustainable fuel has become popular, typically involving valorization of forest residues, energy crops and agricultural waste [4]. In Malaysian context, the government through Malaysian Palm Oil Board (MPOB) has provided a variety of initiative to industries and research institutes to utilize of oil palm waste (OPW) for bioenergy production [5, 6]. OPW can be generally divided into two categories, either solid or liquid waste. The solid waste were produced from plantation and mill operation such as palm mesocarp fibre (PMF), oil palm shells (OPS), oil palm fronds (OPF), empty fruit bunches (EFB) and oil palm trunk (OPT) with palm oil mill effluent (POME) as liquid waste [7]. In oil palm production, each fresh fruit bunch (FFB) contains about 14% of fibres, 7% of shell with 20-25% of EFB. By the year 2020, the production of EFB is expected to increase about 8 million tonnes per year due to higher demand on palm oil. As a result, the oil palm waste, particularly EFB will also be available abundantly. Apart from value added products such as paper making pulp, EFB is also widely used as fuel through thermochemical conversion, either by combustion, pyrolysis or gasification.

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Biomass conversion processes produce heat, electricity and fuels. Among the three common routes of thermochemical conversion mentioned above, gasification is the most popular technique used for gaseous fuel production. It is a high-temperature process (873-1273 K) that decomposes complex biomass hydrocarbons into gaseous molecules, primarily hydrogen, carbon monoxide, and carbon dioxide with some tars, char, methane, water, and other constituents [11-13]. The energy efficiency in case of gasification is higher than that of combustion [14]. However, the main concern in biomass gasification is to deal with the tar formed during the process. Tar is a complex mixture of organic hydrocarbon compounds that condense at ambient temperatures. The molecular weight of tar is believed to be larger than benzene [7-9]. It can cause various problems associated with condensation, formation of tar aerosols and polymerization to form more complex structures that can give an issues in the process equipment as well as the engines and turbines used in application of the producer gas [8-10]. Therefore, tar removal has been considered as the biggest technical problem to overcome in gasification before commercialization.

2. Methodology

The empty fruit bunch pellets (EFBP) was obtained from Detik Aturan Ptd. Ltd., a company which in Kuala Selangor which processes raw EFB fibers into EFBP for both domestic use and export. As for the oil palm shells (OPS), it was obtained from a nearby oil palm factory to UTHM. Both of these fuels were shown in Figure 1:

(a) (b)

Fig. 1 - (a) empty fruit bunch pellet (EFBP); (b) oil palm shell (OPS)

2.1 PEFB and OPS Properties

The sized EFB pellet generally comes in 0.8 cm diameter and length about 2 to 3 cm while the OPS size ranges from 15 to 20 mm. Both of these fuels were sun dried for 1 day before they were stored at surrounding with approximately 50 - 55% RH. The characterization of fuel was done through proximate and ultimate analysis. Proximate analysis was carried out using 5E-MAC6710 Proximate Analyzer (TGA) to determine its moisture, ash and volatile matter contents and Leco AC350 Bomb Calorimeter to determine the fuels lower heating value. Ultimate analysis was done using Vario EL III Ultimate Analyzer. The analysis was carried for three samples and averaged, and presented in Table 1.

Table 1 - Physical and chemical properties of EFBP and OPS

	Proximate analysis (%)	
Sample Name	EFB Pellet	OPS
Moisture content	8.50	10.58
Ash	10.64	1.49
Volatile matter	28.14	24.16
	Ultimate analysis (%)	
Carbon, C	43.18	50.41
Hydrogen, H	6.59	8.26
Nitrogen, N	0.35	0.35
Sulphur, S	0.19	0.13
Oxygen, O	27.30	27.08

2.2 Blending Ratio of EFBP and OPS

Both of the fuels were blended with three ratios as in Table 2:

Table 2 - Blending ratio of percentage EFB pellet and OPS

	TEST 1	TEST 2	TEST 3
EFB Pellet	100%	75%	50%
OPS	0%	25%	50%

Each of the blends was prepared for about 10 kg each to ensure sufficient fuel supply during gasification of each blend.

2.3 Experimental Procedure

Before the gasification process, the thermocouples were installed at the gasifier wall to measure the temperature of the gasifier. Each thermocouple placed about 15 cm from each other, in the axial direction of the reactor. All thermocouple were connected to data logger (Pico TC-08) and laptop to acquire temperature distribution data during gasification. After that, about 1 kg of fuel was added into the reactor. To facilitate the start of the gasification, the fuel was burned for about 5 minutes using propane torch burner until the fuel becomes ember in colour. Then the fan was switched on to supply controlled amount of air, about 1.29 x 10^{-3} m^3/s. Tap water was supplied to provide cooling of the system to avoid overheating, apart from cooling the synthetic gas produced. During gasification process, the temperature varied around 500˚C to 700˚C. The temperature profile data were recorded automatically using a data logger and computer.

After the synthetic gas which contains CH_4, CO and H_2 was produced, it was ignited to create flare. The system was allowed to operate foe about 15 minutes before it stabilizes before the tar was collected. A small stainless steel pipe connects to the synthetic gas pipe. This pipe has a ball valve which was opened slowly to allow the synthetic gas to flow into condenser, where tar is collected through condensation. The gasification was carried out for at least 4 hours for each fuel blend to ensure sufficient amount of tar was collected. This tar was later analyzed using FTIR spectroscopy to evaluate its physical and chemical contents, as well as testing for its calorific value. The gasification experimental setup was shown in Figure 2, and the experimental flow chart was presented in Figure 3. Collection of moisture and tar is performed in a series of 4 impinger bottles or in specially designed equipment referred to as ‘‘Petersen column’’ [9]. The displayed Figure 4 is schematic of the tar sampling train shown its many component parts.

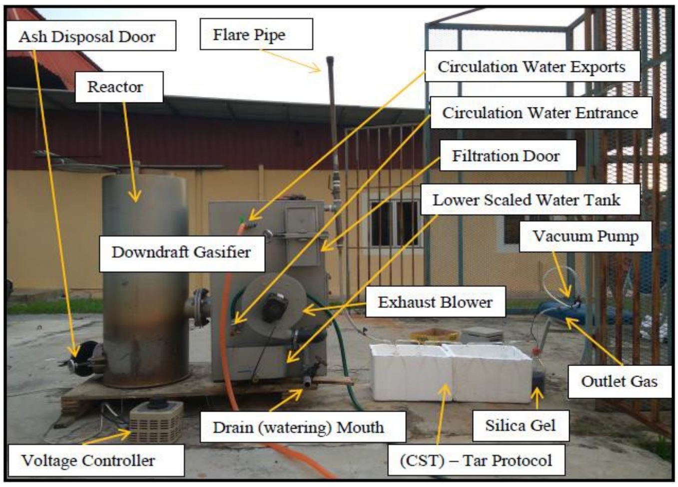


Fig. 2 - Experimental set-up of downdraft gasifier

The gas sampling train consisted of a short and small volume sampling line (1) to avoid blockage due to condensation, a number of impinge bottles (3) filled with proper solvent for tar trapping and a vacuum pump (6). The first two impinge bottles filled with 50 ml of with acetone as the solvent were placed inside the first reservoir containing water at room temperature. In the first impinge tube (2) moisture was condensed by absorption in acetone, in which the heat released by cooling and condensation was removed by the water bath at 20°C surrounding the impinger bottles. After the first moisture collector bottle the gas was passed through three more liquid tar collecting impingers (3), the last two of them immersed in a cooling liquid (ice, water, and salt mixture) at −10°C. For support sampler impinge bottle trap moisture is to place silica gel (5) because the silica gel will ensure the moisture present on the sample will be absorbed before the vacuum pump helps to release the synthetic gas. Vacuum pump (6) of capacity power 100 watts, 20 L/H output induced the flow of tar through the sampling train and to produce syngas.

After completion of the tar collection, all sample impinger bottles were collected in a container containing 220 ml. The content of the sample was mixed with acetone and tar solvent which needs to be evaporated to ensure that the sample is not mixed with other materials. For evaporated sessions it is important to know the boiling point for acetone because in order to avoid the tar it also evaporates if the heat is over. The boiling point of acetone is 56˚C and when evaporated it is necessary to use a rotary vacuum evaporator instrument to isolate tar and acetone. The best suitable for evaporated must be higher standard acetone then use 60˚C for about 35 minutes until acetone solvent was evaporated. Only after this, FTIR spectroscopy and calorific value analyses was conducted.

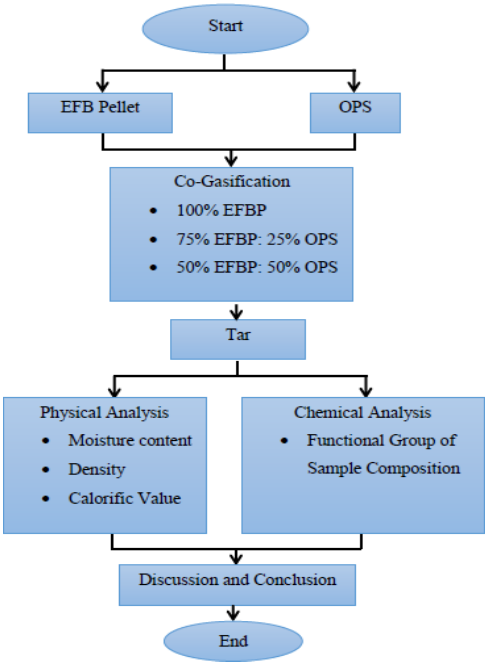


Fig. 3 - Experimental flow chart

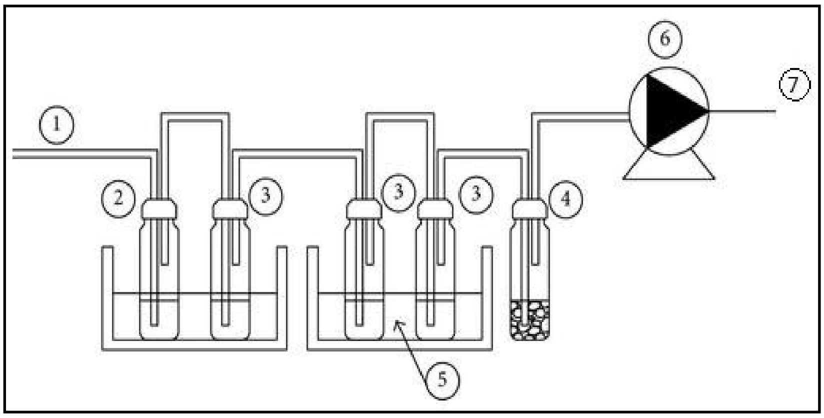


Fig. 4 - Schematics of tar sampling train : (1) Gas from sampling line, (2) Moisture collector, (3) Series of impinge bottles, (4) Silica gel, (5) Ice bath at -11˚C, (6) Vacuum pump, (7) Syngas outlet [3]

3. Results and Discussion

The tar content for each fuel blend was characterized physically and chemically as following:

3.1 Physical Characterization

Based on Figure 5, the tar moisture content was found to be the highest for 100% EFBP at about 47.2% moisture, and becomes lower with increasing amount of OPS in the fuel blend. For 75% EPBP: 25% OPS fuel blend, the moisture content was found to be of 36.4% and finally for EFBP 50%: OPS 50%, the moisture content was only about 30.9%. The density of tar was found to be decreasing with increasing amount of EFBP in the fuel blends, as presented in Figure 6.

The highest density of tar is for 50% EFBP: 50% OPS fuel blend, about 2.99075g/cm^3, followed by 75% EFBP: 25% OPS fuel blend with 2.82128g/cm^3 and finally for 100% EFBP, the density is about 2.74089g/cm^3. Apart from this, the tar was also seen to be more viscous with higher amount of OPS content in the fuel. Figure 5 above shows the calorific values of tar for each fuel blends. The calorific value was highest for 50% EFBP: 50% OPS 50% a1t 21.877MJ/kg, and this value reduced by one-third when the OPS ratio was reduced to only 25%. For 75% EFBP: 25% OPS furl blend, the calorific vale was 14.601MJ/kg. Finally, for 100% EFBP, the calorific value of tar was only 4.722MJ/kg. This shows that tar with OPS has potentials to be used as liquid fuel.The colour of tar collected was presented in Figure 8, whereby higher amount of OPS in the fuel blends result-in darker coloured tar. The tar colour is one of the important physical properties commonly studied in gasification. It is a quick method to assess the quality where darker tar colour implies heavier compounds were present or it may also attributed to lower conversion efficiency during gasification. From Figure 8, it was found that OPS content in the fuel blend result in darker tar.

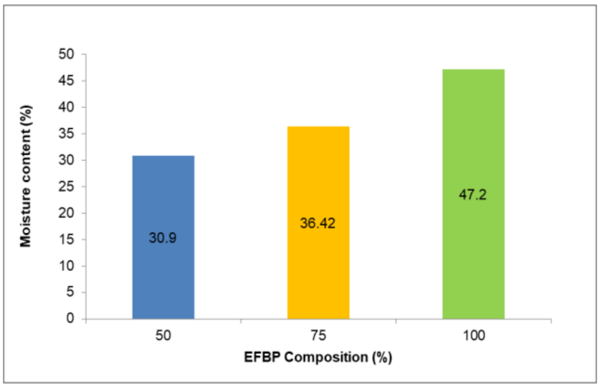


Fig. 5 - Moisture content for each EFBP:OPS blends

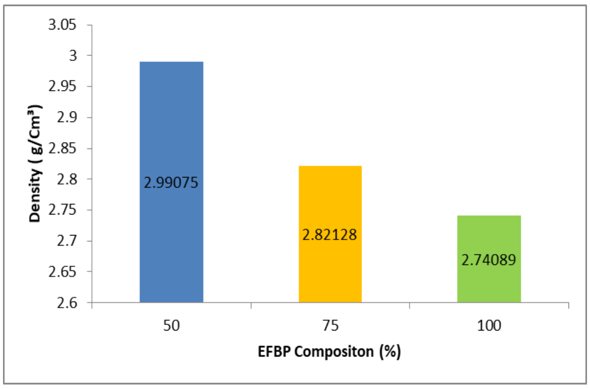


Fig. 6 - Density for each EFBP:OPS blends

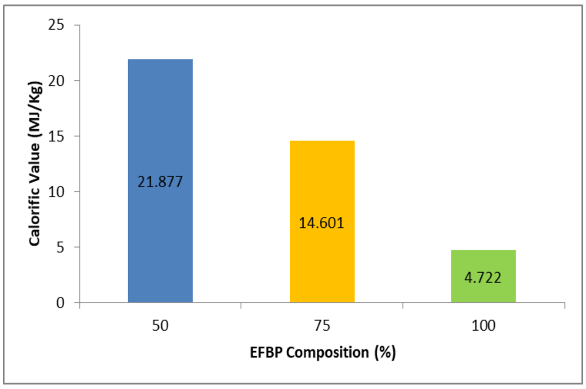
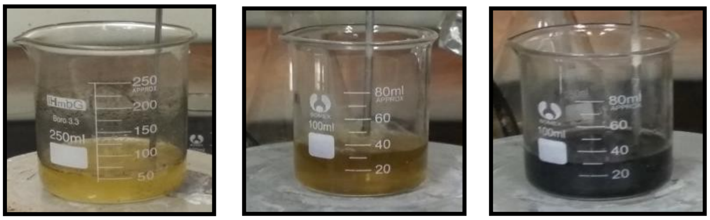


Fig. 7 - Calorific values for each EFBP:OPS blends



(a) (b) (c)

Fig. 8 - Tar sample for: (a) 100% EFBP; (b) 75% EFBP: 25% OPS; (c) 50% EFBP: 50% OPS

3.2 Chemical Characterization

The FTIR spectroscopy was carried out to observe the functional groups available in the tar. The functional groups of the tar was referred based on Table 3 which was common for FTIR analysis.

Table 3 - Characteristic IR absorption frequencies of organic functional groups

Functional Group	Characteristic Absorptions (cm^{-1})	Absorption Intensity
Alcohol (O-H)	3200-3600	Strong, broad
Carbonyl (C=O)	1670-1820	Strong
Alkene (C=C)	1620-1680	variable
Aromatic (C=C)	1400-1600	Medium-weak, multiple
Ether (C-O)	1000-1300	Strong
Nitro (N-O)	1345-1385	Strong, two bands

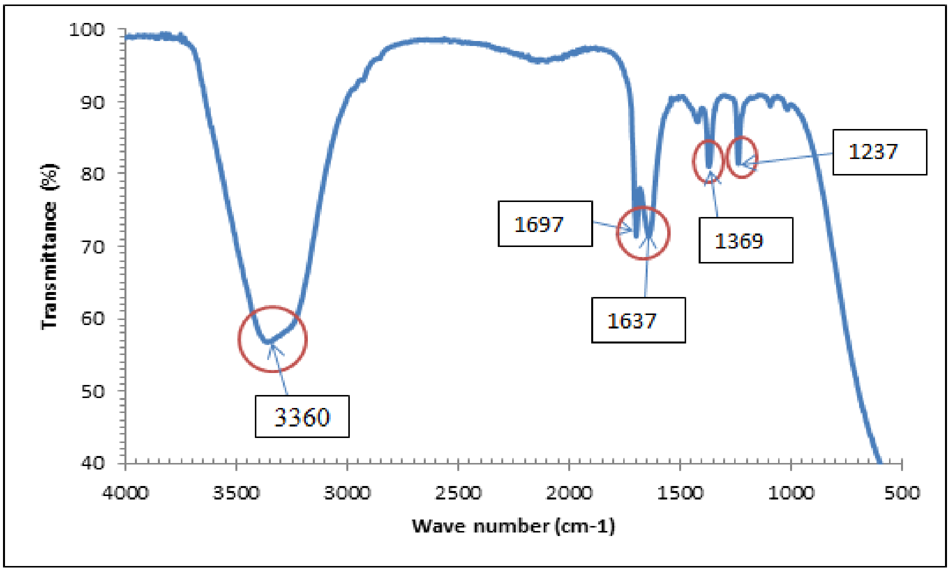


Fig. 9 - Wave number and transmittance for 100% EFBP

According to the characteristic absorptions in Figure 9, different products can be recognized. For 100% EFBP O-H functional group from 3200cm^{-1} to 3600cm^{-1} at the beginning stage. This value is at peak of 3360cm^{-1}. This means the tar has a relatively high alcohol element. After that, the second highest value is 1697cm^{-1} at group C=O 1670cm^{-1} to 1820cm^{-1} at the second stage. Group for second stage is carbonyl. Then for next value is 1637cm^{-1} from group alkene C=C from 1620cm^{-1} to 1680cm^{-1}. Next is nitro an N-O from 1345cm^{-1} to 1385cm^{-1} at value 1369cm^{-1}. For the last stage functional group is ether from 1000cm^{-1} to 1300cm^{-1} at value 1237cm^{-1}.

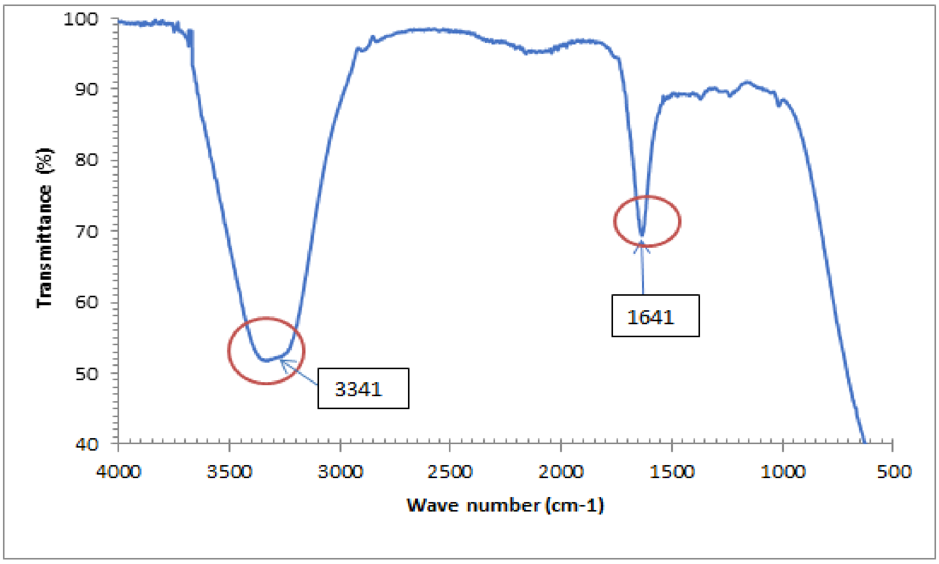


Fig. 10 - Wave number and transmittance for 75% EFBP: 25% OPS

According to the characteristic absorptions in Figure 10the functional groups that prominently there are only two. The first is O-H functional group from 3200cm^{-1} to 3600cm^{-1} at value 3341cm^{-1}, this means the tar has alcohol. The second is the alkene group at the value of 1641cm^{-1} in functional group C=C 1620cm^{-1} to 1680cm^{-1}. Based on the above graphs it is clear that the fuel scenario between EFBP and OPS has the characteristic impact on tar where only two functional groups are alcohol and alkene. This is to compare with fuel 100% EFBP that has many functional groups.

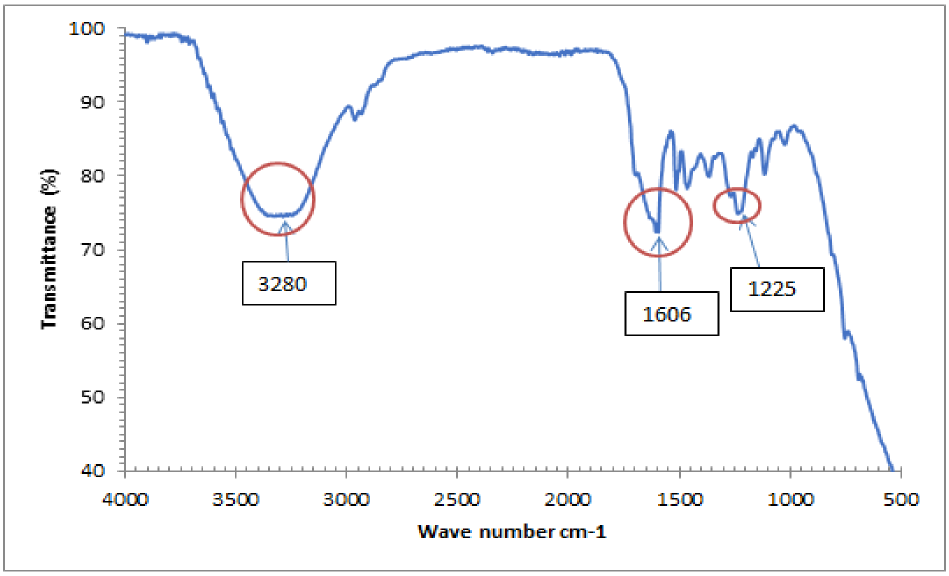


Fig. 11 - Wave number and transmittance for 50% EFBP: 50% OPS

In Figure 11, the first is O-H functional group from 3200cm^{-1} to 3600cm^{-1} at value 3280cm^{-1}, which means the tar has alcohol but is relatively low in content compared to other fuel graphs. Additionally, it is clear that if reduced EFBP fuel the value of alcohol contained in the tar also affects. The second is aromatic group at 1606cm^{-1} in functional group C=C 1620cm^{-1} to 1680cm^{-1}. For the last stage is C-O functional group 1000cm^{-1} to 1300cm^{-1}, this group is ether at 1225cm^{-1}. Overall, if the EFBP and OPS fuels amount were same then alcohol will decrease. Additionally, new functional groups for the functional group aromatic in the tar for this type of fuel composition and possibly if compared to other fuel ratios, various things can be analyzed.

4. Conclusion

Tar produced during co-gasification of EFBP and OPS with three different percentages was analyzed in terms of physical and chemical properties. For physical analysis, moisture content, density and calorific value was analyzed while for chemical analysis, Fourier Transform Infrared (FTIR) Spectroscopy was used to identify the functional groups in the tar sample. In general, it was found the moisture content, density and calorific value increases with higher amount of OPS in the fuel mixture. The calorific value ranges from 4.722MJ/kg to 21. 877MJ/kg whiles the moisture content and the density ranges from 30.90% to 47.20% and 2.74089g/cm^3 to 2.99075g/cm^3. It was found that the calorific value in the tar is relatively high about 21.877MJ/kg and suitable for use as fuel. From FTIR analysis, it was found the tar contain alcohol, carbonyl, alkene, aromatic, ether and nitro. Value functional group for characteristic absorptions is 3200cm^{-1} to 3600cm^{-1} (O-H), 1670cm^{-1} to 1820cm^{-1} (C=O), 1620cm^{-1} to 1680cm^{-1} (C=C), 1400cm^{-1} to 1600cm^{-1} (C=C), 1000cm^{-1} to 1300cm^{-1} (C-O) and 1345cm^{-1} to 1385cm^{-1} (N-O).

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