

Research Article

Converting Biomass and Waste Plastic to Solid Fuel Briquettes

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This work examines the production of briquettes for household use from biomass in combination with plastic materials from different sources. Additionally, the combustion characteristics of the briquettes in a common open fireplace were studied. It is clear that the geometry of the briquettes has no influence on the smoke emissions. When the briquettes have a small amount of polyethylene terephthalate (PET), the behavior in the combustion is steadier because of the increase of oxygen supply. The smoke levels are between the 3rd and 4th grades of the smoke number scale. Measuring the carbon monoxide emission, it was observed that the burning of the plastic in the mixture with biomass increases the carbon monoxide emissions from 10% to 30% as compared to carbon monoxide emission from sawdust biomass emissions which was used as a reference.

1. Introduction

In cities and other industrialized landscapes, the sources of pollution are predominantly transport, industrial, and domestic activities. These activities are the basic cause of the phenomenon which is commonly referred to as climate change [1]. In response to climate change, the use of biomass fuels is increasing as sustainable and carbon (climate) neutral fuels are sought. Additional to climate factors, increasing market prices of traditional fossil fuels have driven consumer preference towards alternative fuels [2]. Furthermore, the price explosion of oil and gas has given a push to the use of renewable energy resources. The recent switch from conventional to renewable energy sources (RES) and their gradually extensive use is a common feature of the energy policy adopted by the developed world. In Greece, in the middle of the economic crisis, the fuel wood consumption in urban regions presents an increasing trend due to the fireplaces used in residences [3].

Additionally the Directive 2000/76/EC for Waste Incineration is in force which sets the limits and the requirements for the waste incineration [4]. In order to enforce this directive the European Commission has issued the mandate M/298 to European Standardization Organizations to elaborate technical means to conforming to Essential Requirements of this

New Approach Directive. Under this mandate, a number of standards for solid biofuels and solid recovered fuels have been issued. Solid biomass and solid recovered fuels as a combustion fuel encompass solid materials (e.g., wood logs or pieces) [5–8], processed materials (wood chip, pellets) [9], waste products (recycled wood, agricultural byproducts) [10, 11], gasified materials (methanization of solid fuels) [12], and liquefied materials (e.g., esterification products) [13]. These fuels can be classified according to their origin and production method (life cycle stage). Primary material is sourced specifically for the purpose of combustion/energy generation, while secondary material has undergone processing to reach its preferred combustion format (e.g., new wood used to make pellets or chips). Finally, tertiary fuels are those derived from materials having already undergone a greater portion of their lifecycle (e.g., recovered building materials). These materials are then recycled, producing pellets, chips, or briquettes for use as combustion fuels [5]. Solid fuels can be burned in a variety of manually and automatically operated burners and boilers. Appliances are classified by their intended use and operational methods (batch fired or automatic). In this study only open fireplaces are addressed. The other household combustion appliances are the focus of undergoing work. Open fireplaces are the simplest class

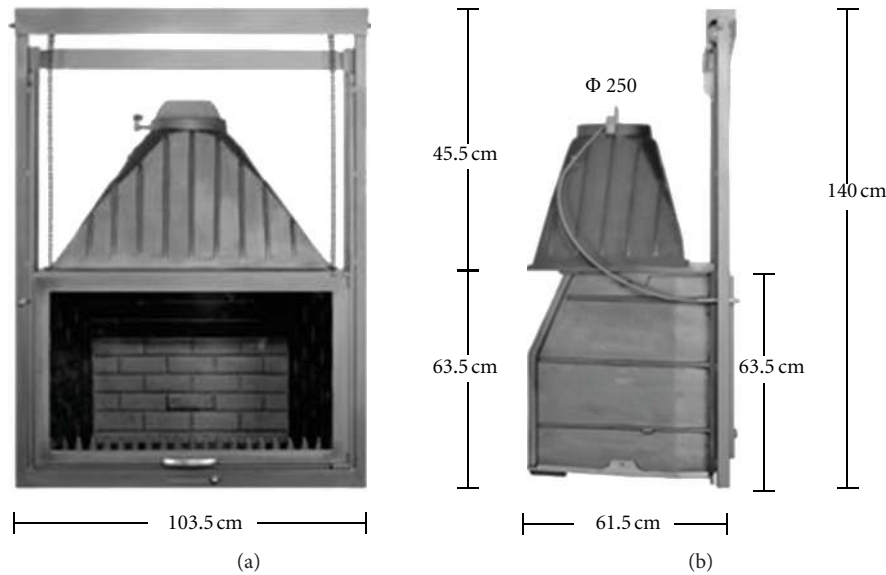


FIGURE 1: View of the open fire place installation.

of residential biomass and solid waste combustion appliance with the combustion zone positioned upon a simple grate in a solid form base (i.e., stone or brick). As the name suggests, open fireplaces have at least one exposed side. Exposure of the combustion zone allows for significant heat losses. These losses constrain maximum possible combustion temperatures, limiting combustion rates and leading to high concentrations of particulate and gas-phase emissions [14]. Closed fireplaces are similar in structure to open fireplaces with the addition of side panels closing the gap between the ventilation hood and the base. To facilitate loading and cleaning of the fireplace, a door is fitted to one side of the appliance.

Combustion cycles in residential heating are transient in nature. During transient cycles, there are four clear phases during which emissions vary (ignition, startup, steady state, and burnout.). Of all the phases, the startup phase alone contributes up to 50% of total particulate matter emissions and up to 70% of organic material [5]. Soot (carbonaceous) particles are formed via condensation of volatilised organic materials [5]. Aside from appliance type, fuel composition and combustion conditions are known to influence particulate and gas-phase emissions [15]. Combustion conditions can be characterised according to the combustion air-to-fuel ratio and the concentration of carbon monoxide emissions [5]. Carbon monoxide is an indicator of combustion efficiency and is known to be detrimental to human health [16, 17], while interest in organic carbon and particulate organic matter has increased in recent years as their role in climate and human health impacts is better understood [18–20]. High levels of soot, particulate emissions are formed when the air to fuel ratio is near to 1 and the carbon monoxide is high (mean concentration of above 1000 mg m^{-3}), while high levels of condensable organics are formed when the air to fuel ratio is greater than 4 and the carbon monoxide is similarly high. Under optimal conditions where the air to fuel

ratio is near to 1.5 and the concentration of carbon monoxide is below 100 mg m^{-3} , high mineral to carbon ratio emissions are produced [5].

In this paper a variety of raw materials were used for the manufacturing of briquettes. The raw materials were two different series of used lubricant bottles, bottles from polyethylene terephthalate (PET), high density polyethylene (FIANTHENE 5502), and wax polyethylene, two series of Biomass from kernel, beech sawdust, particle board sawdust, and straw. The manufactured briquettes have been burned in an open fire place where the combustion temperatures have been measured along with the emitted soot in smoke number scale, carbon monoxide, and nitrogen oxide.

The aim of this work is to study the production characteristics of the briquettes for household use. Additionally, the combustion characteristics of the briquettes and their emissions in a common open fireplace were studied.

2. Materials and Methods

For the purpose of this study, used empty bottles from lubricants have been collected from car repairing workshops. After the collection their size was shrunk about 5% with the help of a commercial use shrunk machine manufactured by Carstens GmbH. Additionally, empty bottles from polyethylene have also been collected from a recycling company. Apart from these, two series of biomass from kernel, beech sawdust, particle board sawdust, and straw were ordered. Three patents were applied for the manufacturing of the briquettes, US patent 4561860 [21], US patent 4236897 [22], and the European patent EP0262083 (A1) [23]. With a help of a plastics company's installation using a commercial Adelman BP 650 press briquettes for fireplaces were produced. All the briquettes have a weight of ca. 300 grams. For the simulation of the combustion an open fire place was installed in the National Technical University of Athens, School of Chemical

TABLE 1: Proximate analysis of the raw material on as received basis.

Property	Unit	Raw material									
		Used lubricant bottles series 1	Used lubricant bottles series 2	Bottles from polyethylene terephthalate (PET)	High-density polyethylene (FIANTHENE 5502)	Wax polyethylene	Biomass from kernel (series A)	Biomass from kernel (series B)	Beech sawdust	Particle board sawdust	Straw
Volatile	%w/w	97.9	95.2	91.75	100	100	70.35	67.95	71	72.9	71.65
Moisture	%w/w	0	0	0.46	0	0	7.1	8.6	7	6.9	7.7
Ash	%w/w	2.3	2.4	0.02	0	0	3.6	3.4	2.4	2.5	4.6
Fixed carbon	%w/w	0	2.4	7.77	0	0	18.95	20.05	19.6	17.7	16.05
Nitrogen	%w/w	0	0	0	0	0	1.9	1.5	2.9	2.6	0.3
Carbon	%w/w	85.4	85.3	62.5	85.5	86.1	49	47	44.5	44.8	43.8
Hydrogen	%w/w	12.2	12.3	4.2	14.5	13.9	7.7	7.8	6.9	6.8	6.3
Sulfur	%w/w	0.1	0	0	0	0	0.1	0.1	0.2	0.1	0
Oxygen	%w/w	0	0	33.3	0	0	37.7	40.2	43.1	43.2	45

TABLE 2: Ultimate analysis of the Briquette produced.

Property	Unit	Briquettes						
		10% PET + 25% PE + 65% beech sawdust	60% HDPE + 40% beech sawdust	25% used lubricant bottles 1 + 25% used lubricant bottles 2 + 50% beech sawdust	50% HDPE + 50% straw	48% HDPE + 50% beech sawdust + 2% Wax PE	20% used lubricant bottles 1 + 20% used lubricant bottles 2 + 25% biomass from kernel A + 25% biomass from kernel B	Commercial product
Volatile	%w/w	86.9	89.3	84.5	85.7	89.25	82.7	90.25
Moisture	%w/w	3.2	2.6	2.8	2.8	2.35	3.2	4.7
Ash	%w/w	0.7	0.6	0.7	0.2	1.3	0.9	0.6
Fixed carbon	%w/w	9.2	7.5	12	11.3	7.1	13.2	4.45
Nitrogen	%w/w	1.7	1.1	1.3	0.2	1.3	0.9	1.6
Carbon	%w/w	56.8	69.2	65.2	64.7	65.3	62.3	60.2
Hydrogen	%w/w	8.2	11.4	10.7	10.4	10.5	9.6	9.8
Sulfur	%w/w	0	0	0	0	0	0	0.1
Oxygen	%w/w	32.7	17.3	21.6	22.5	21.6	24.1	27.7

TABLE 3: Geometrical characteristics of the manufactured briquettes.

Briquette	Geometrical characteristics	
	Diameter ($d = \text{mm}$)	Height ($h = \text{mm}$)
Sawdust	50	190
Oak wood	50	190
Beech sawdust	50	190
60% HDPE + 40% beech sawdust	50	190
70% PE + 30% beech sawdust	50	190
50% PE + 50% beech sawdust	50	190
40% PE + 60% sawdust	50	160
30% PE + 70% sawdust ($h/d = 3,4$)	With a perforated internal diameter of 10 mm	170
30% PE + 70% sawdust ($h/d = 3.94$)	47	185
35% PE + 65% sawdust	50	175
Commercial product 1	50	185
Commercial product 2	55	180
10% PET + 25% PE + 65% sawdust	50	180
30% PET + 25% PE + 65% sawdust	50	180
15% PET + 30% PE + 55% sawdust	50	180
7.5% PET + 27.5% PE + 65% sawdust	50	180

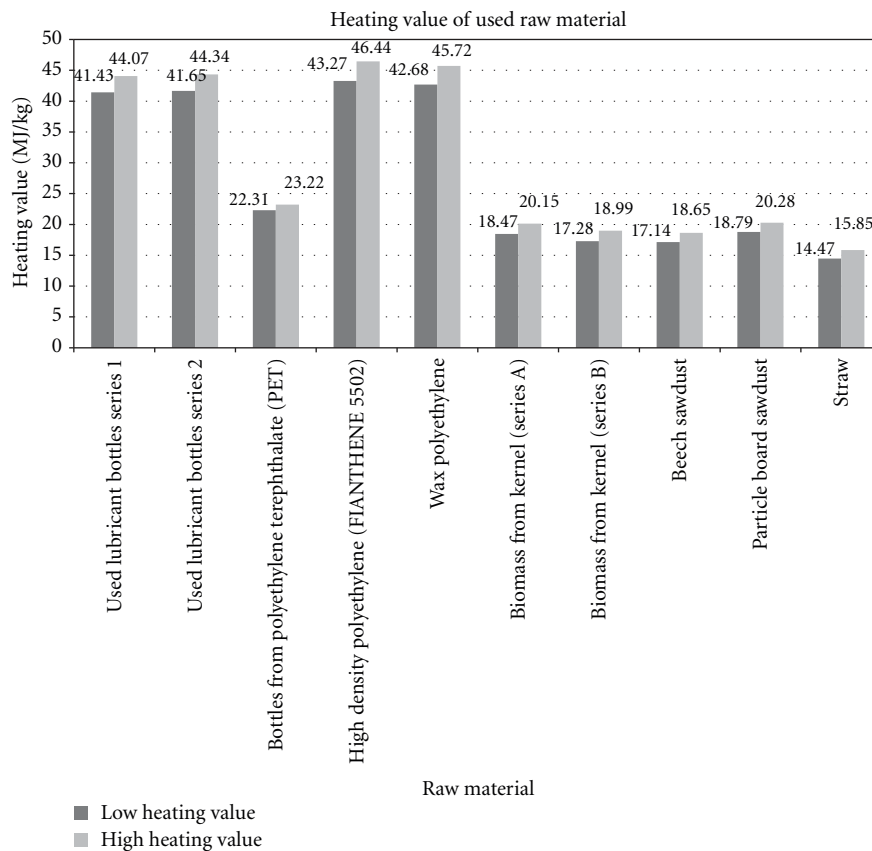


FIGURE 2: High and low heating value of the selected raw material.

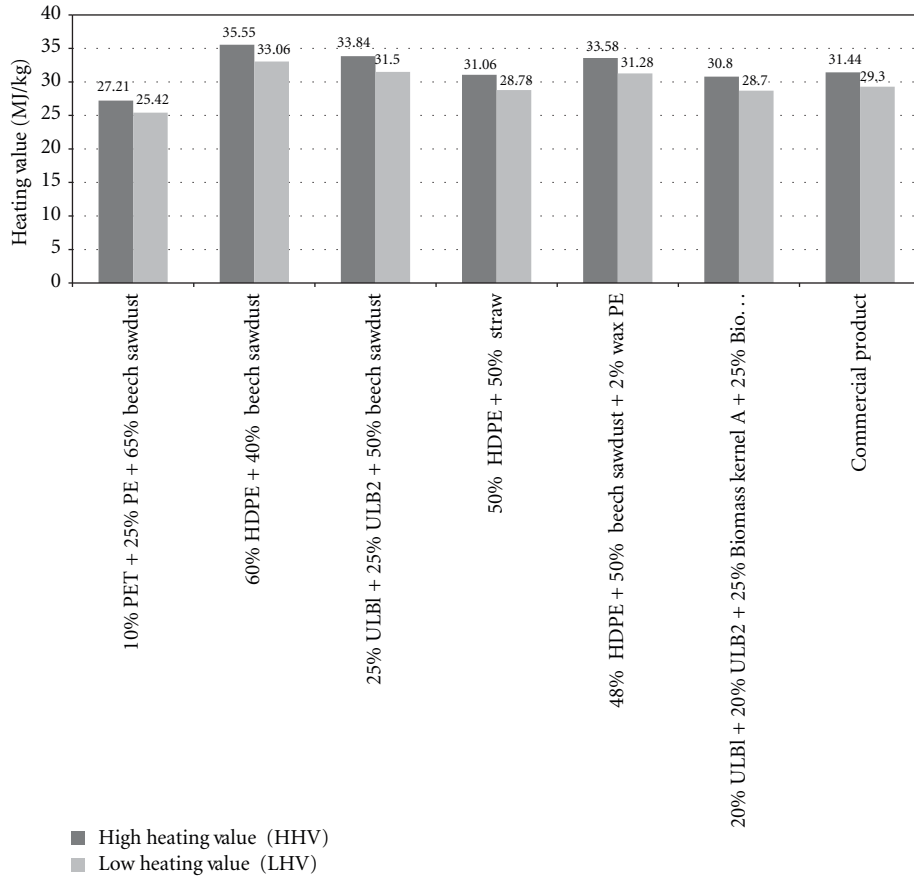


FIGURE 3: High and low heating value of the briquettes which were manufactured from the selected raw material compared with a commercial product.

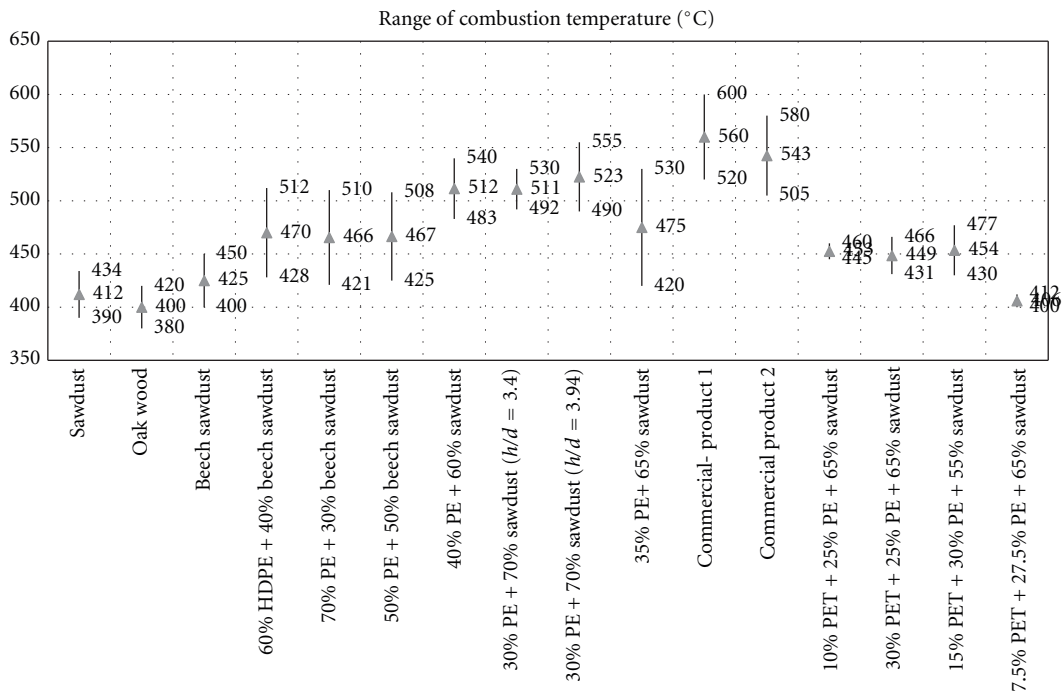


FIGURE 4: Range of combustion temperature in the open fireplace.

Engineering, Fuels and Lubricants Technology Laboratory. The installation has been traced in Figure 1.

The raw material and the manufactured briquettes have been analyzed and the key properties (volatile matter, moisture, ash, and fixed carbon) have been examined. A Carlo Erba 1108 CHNS-O elemental analyzer was used to determine the content of carbon (%wt.), hydrogen (%wt.), nitrogen (%wt.), and sulfur (%wt.) in the raw material and in the produced briquettes. The results are presenting in Tables 1 and 2, respectively. These have been examined according to ASTM standard test methods [24–27].

The produced briquettes have all a weight of 300 gr/piece and a cylindrical shape. The geometrical characteristics are presenting in Table 3. All the products were burned in an open fireplace and the temperature of the combustion of each one was measured with the help of KIMO TK 102 (K thermocouple) instrument. The smoke was measured with a typical smoke number scale probe according to ASTM D2156 method [28]. The emissions of carbon monoxide and nitrogen oxides were measured with the help of a Horiba instrument (type MEXA 574-GE, that gauges, CO exhaust emissions near dispersive infrared analyzer) and a NO_x analyzer (42C NO–NO₂–NO_x high level analyzer, Thermo Environmental Instruments Inc.), respectively. In order to evaluate them, results are expressed in comparison with the emission from burning 300 gr of pure straw. The fireplace was cleaned after the combustion of each type of briquettes and the residues were removed. Each measurement was taken after one hour of combustion in a cold fireplace.

3. Results and Discussion

For this experimental work raw materials of biomass and used bottle for lubricants were collected from various car repair and petrol stations across Athens area. Additionally, plastic bottles of polyethylene terephthalate were collected too.

The high and low heating value of the raw material as received are presented in Figure 2. It can be easily observed that the heating values of used lubricant oil bottles and the polyethylene are higher than the other products. Thus, it was tried to produce briquettes with a standard average weight of ca. 300 gr, high heating value of 31,40 MJ/kg and low heating value of 29,31 MJ/kg.

The heating values of the produced briquettes have been depicted in Figure 3. The rest of the characteristics for these products are presented in Table 2. The higher heating value is observed for the briquette which contains 60% high density polyethylene and 40% beech sawdust, whilst the lower heating value is observed for the briquette which contains 10% polyethylene terephthalate, 25% polyethylene, and 65% beech sawdust. All of these products have been burned in an open fireplace.

Figure 4 presents the range of the combustion temperature for each briquette examined. The temperature was recorded when the flame was in full length. The temperature measurement referred to the intermittent flame region which is above the continuous flame region. In this region the flame temperature of the open fireplaces drops as a function

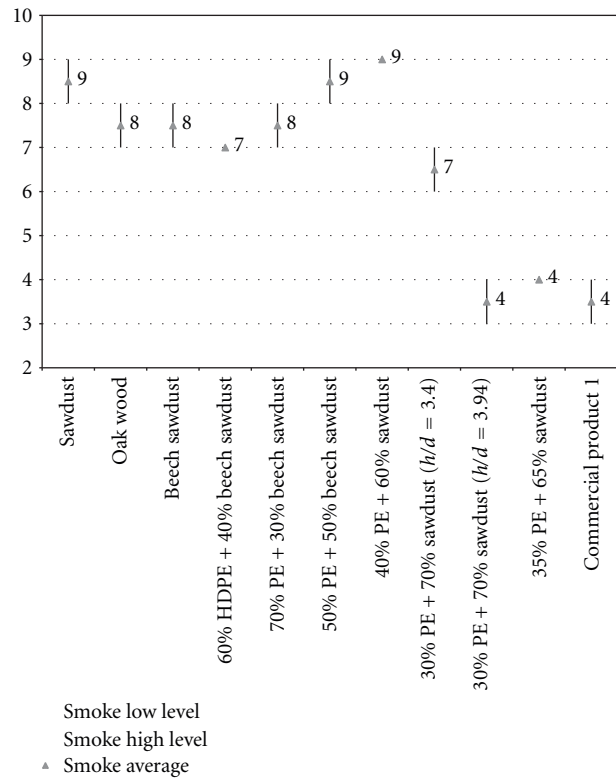


FIGURE 5: Smoke number level for each briquette.

of distance up the plume. Additionally the thermocouple was unshielded. As it can be easily seen the shorter range appeared when the briquette contained biomass in a percentage of around 65%, polyethylene and polyethylene terephthalate. This is expected because the increased amount of oxygen which these briquettes contain gives more steady behavior during the combustion. The combustion of the above-mentioned briquette appeared to be similar to wood combustion and the briquette retains its original shape.

Figure 5 depicts the smoke number scale for the combustion of the briquettes. If the level of polyethylene is above 40% then the smoke exceeds the grade nine (9+) in the scale. When the biomass is around 70% with a percentage of polyethylene of around 30% the smoke is between seven (7) and eight (8) of the Bacharach scale. It is also observed that when the percentages between biomass and polyethylene shift a bit there was no change in the above-mentioned scale. Additionally, the commercial available product has a smoke scale of nine (9). The comparisons of emissions of carbon monoxide and nitrogen oxides are presented in Figure 6. It is obvious that when the briquette contains plastic and biomass, the amount of carbon monoxide is increased from 10% to 30% as compared to pure straw biomass briquette. When the biomass is around 70% with a percentage of polyethylene of around 30% the carbon monoxide emissions increased 10%. Furthermore, no change was observed when the percentages between biomass and polyethylene shift a bit. On the contrary with the carbon monoxide emissions the nitrogen oxide emissions are decreased between 20% and 35%.

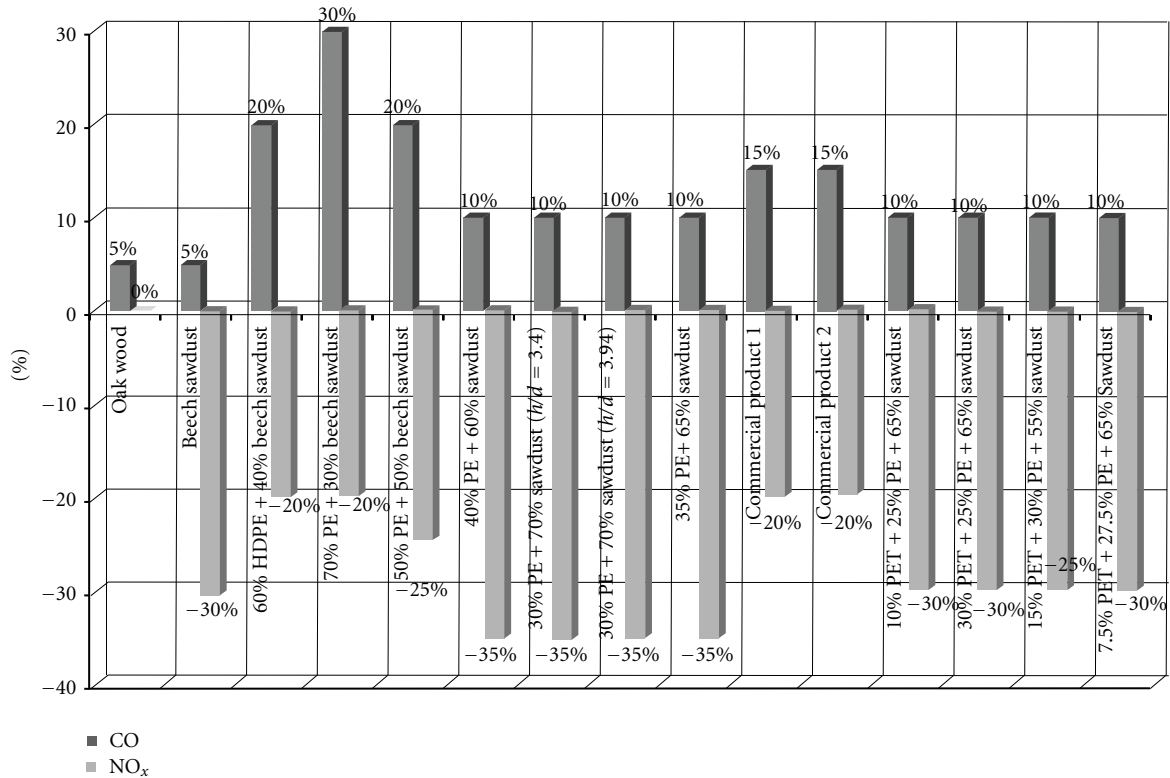


FIGURE 6: CO and NO_x emissions variation in comparison with the straw emission.

This is expected since for briquettes that contain polyethylene, which has no nitrogen, the amount of nitrogen present in the briquette is significantly lower leading to lower production of nitrogen oxides from the combustion. Similar results are observed when the briquette contains polyethylene terephthalate. At all circumstances the amount of carbon monoxide and nitrogen oxide emissions are better than the emissions from the combustion of the commercial available briquette.

4. Conclusions

All briquettes examined have no problem in the combustion procedure. The used plastic material has polyethylene content from 30% to 70%. The basic observation is that the briquettes with content in polyethylene greater than 40% burned intensely and lose their basic shape rapidly because of the combustion's high temperature.

On the other hand, when the polyethylene content is higher than 40% the smoke exceeds the smoke number scale level of 9+. When the briquettes samples have concentration 70% biomass and 30% polyethylene the smoke is between 7 and 8 of smoke number scale. It is also observed that the smoke has no measured alterations when the concentration changes slightly. Additionally, the geometry of the briquettes has no influence to the smoke emissions. Measuring the carbon monoxide emission, it was found that the burning of the plastic in the mixture with biomass increases the carbon monoxide emissions from 10% to 30% as compared to carbon

monoxide emission from sawdust biomass emissions. When the proportion of biomass to plastic is 70 to 30 the carbon monoxide emissions increased 10% in relation to the sawdust biomass emissions.

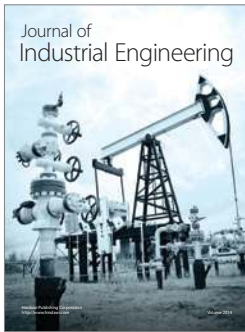
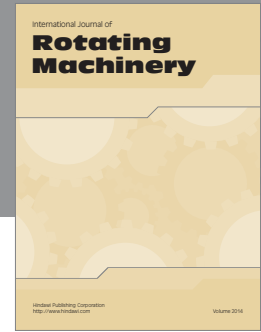
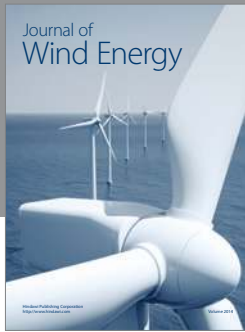
In reverse with the carbon monoxide emissions the nitrogen oxide emissions decreased from 20% to 35%.

When the briquettes have a small amount of Polyethylene terephthalate (PET) the behavior in the combustion is steadier because of the increased concentration in oxygen. Additionally the smoke levels are between the 3rd and 4th grades of the smoke number scale. These levels are similar to the rest of the biomass samples which were burned into the open fireplace.

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