Potential of MSW and COVID-19 Medical Waste as Feedstocks for Gasification Process

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***Abstract*— The main problem with the Covid-19 pandemic is the emergence of medical waste which has increased drastically, such as from the use of disposable masks, gloves and personal protective equipment (PPE). The covid-19 pandemic has also caused changes in food consumption, which usually eats more at restaurants, switching to home cooking or ordering food. This has an impact on increasing the amount of solid waste at home from cooking activities and food packaging. One of the efforts to reduce solid waste generation in the community is to destroy solid waste using thermal technology. Gasification is an attractive alternative because it can be developed on a smaller scale to produce syngas as fuel for diesel engines. The purpose of this study was to examine the potential of MSW and covid-19 medical waste, which is dominantly made of plastic, as feedstocks for gasification process. This study will also examine the principal of gasification process and RDF production from MSW using several pre-treatment technology.**

Keywords*— *MSW, covid-19 medical waste, gasification, energy recovery, RDF

I. Introduction

Municipal solid waste (MSW) disposal has now become a serious problem in big cities around the world, including Indonesia. Along with the increasing population, the increasing economic growth of a country, and the increasing people's welfare, it causes an increase in the amount of MSW generation. On the other hand, the availability of land for final disposal sites is very limited, there is no proper waste management and the inappropriate behavior of people in disposing and managing their waste, especially in developing countries like Indonesia, has resulted in the local government getting more and more difficult in handling its waste.

Moreover, the COVID-19 pandemic has been going on for more than two years and is not yet completely over. The main problem with this pandemic is the emergence of medical waste which has increased drastically, such as from the use of disposable masks and personal protective equipment (PPE). Based on the data from the Ministry of Environment and Forestry (MEF), according to reports from 34 provinces until October 2020 there were more than 1600 tons of COVID-19 medical waste that had to be handled [1]. Meanwhile, there are 20% of medical waste and the remaining 80% non-medical waste in hospitals [2]. This of course has an impact on the handling of medical waste which must be better and there needs to be a comprehensive solution so that it does not pollute the environment and is safe for human health.

Furthermore, the COVID-19 pandemic has changed people's lifestyles with more activities at home due to the work and study-from-home (WFH and SFH) policy. The pandemic has also caused changes in food consumption, which usually eat more at restaurants, switching to home cooking or ordering food. This has an impact on increasing the amount of waste at home from cooking activities and food packaging waste. According to the Ministry of Environment and Forestry, Indonesia, it shows that the household waste dominates the waste generation by up to 38% as shown in Figure 1 and of course, it will increase along with changes in people's lifestyles [3]. This condition will have an impact on increasing the amount of municipal solid waste that must be disposed of in the landfills. Meanwhile, the condition of landfill sites in many cities is currently almost full, so they cannot accommodate any more waste.

To date, the problem of MSW has not been fully handled properly, especially with the COVID-19 pandemic garbage. The main problem with this medical waste is that the amount of waste is not so much and the location of the waste is spread all over Indonesia, so that the handling of waste separately requires very expensive operational costs. To find out the potential for handling MSW and COVID-19 medical waste together, a study was conducted to find alternative technologies that can be used simultaneously. Thus, this solution is expected to be an alternative to simultaneously handling MSW and COVID-19 medical waste, thereby reducing the operational costs of processing such waste.

One of the efforts to reduce piles of garbage in the landfill sites is to employ waste destruction technology such as the thermal process. Several thermal technologies can be implemented including combustion/incineration, gasification, and pyrolysis. Incineration technology for electricity production has developed and is widely used in several countries. However, this technology can only be developed on a large scale. Gasification is an attractive alternative technology because it can be developed on a smaller scale to produce syngas as fuel for diesel engines.

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II. Waste Characteristics and Generation

A. COVID-19 Medical Waste

Medical waste is one of the biggest challenges that must be faced by the local governments, especially during the COVID-19 pandemic where there is a very significant increase in this type of waste. Several types of COVID-19 medical waste generated include face masks, gloves, and personal protective equipment (PPE). Indonesia with a population of more than 250 million has produced more than 159 million face mask waste and more than 420 tons of medical waste every day [4]. Of the amount of medical waste, one third is made of plastic material [5], even for face mask waste, the composition of the material is dominated by polypropylene (PP), polyethylene (PE) and nylon up to 95% by weight [6].

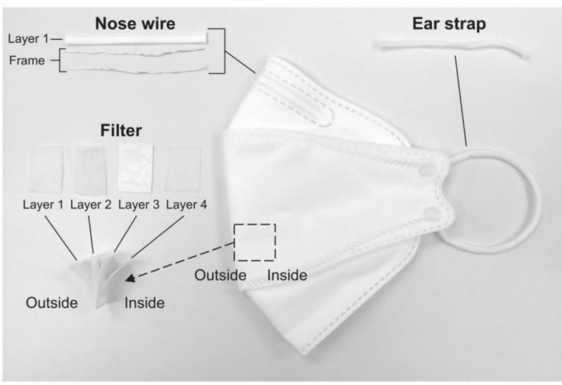

Fig. 1. A snapshot of face mask and its components [6].

As shown in Table 1, plastic has the highest energy content of the various types of waste-contributing materials. As we know that plastics was made of oils which means that plastics and fuels are form the same origin, therefore the heating value of plastics was similar to those of fuels such as kerosene, gasoline and diesel fuel. As a result, the addition of COVID-19 medical waste is expected to increase the calorific value of MSW and ultimately improve the quality of syngas produced from the gasification process. Plastics in co-gasification have influenced gas composition and thus indirectly affect the calorific content of the producer gas.

TABLE I. Heating Value of Some Waste Materials [7]

Waste Materials	Heating Value (MJ/kg)
Papers	13.88
Plastics	24.88
Textile	12.56
Food waste	10.16
Yard waste	19.64
Rubber	23.20

The results of research conducted by Fazil et al. [8] showed that the addition of plastic can increase the temperature in the gasifier and increase the calorific value of syngas from 3.5 MJ/Nm^3 to 4.7 MJ/Nm^3 and also increasing the cold gas efficiency from 43.8% to 61.8% [8]. The majority of the CO released by the Boudouard reaction contributes significantly to this increase. There is also an increase in hydrogen and methane concentrations. Furthermore, the presence of alkali metals such as Ca, Na, and K in the samples can enhance heterogeneous gasification reactions.

B. Municipal Solid Waste

In Indonesia, municipal solid waste generation is assessed using data on sources, generation rate, and composition. One of the most important factors in determining waste characteristics is the source of waste. According the data from Ministry of Environment and Forestry, MSW was generated from household, office, traditional market, commercial facilities, public facilities, etc as shown in Fig. 2. The household waste dominated the total of MSW generated. This is the most common source of municipal solid waste in Indonesia. DKI Jakarta and Surabaya, in general, have a lower contribution from the household sector. This could be related to the characteristics of human activities performed in those two metropolitan cities with different facilities [9].

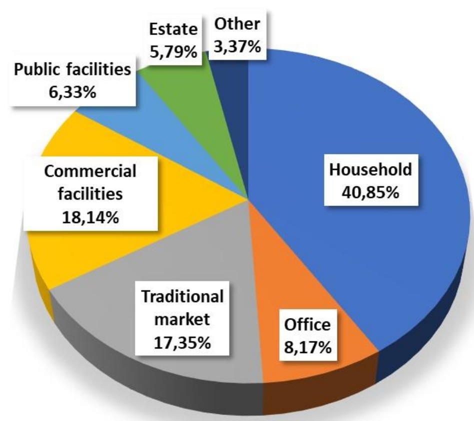

Fig. 2. Solid waste composition in Indonesia based on the generation sources [10].

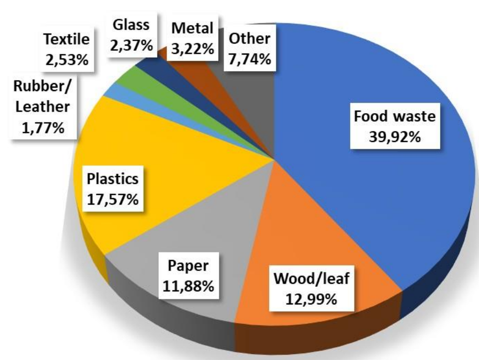

Fig. 3. Solid waste composition in Indonesia based on the type of waste [10].

MSW has also classified based on the type of waste as shown in Fig 3. Food waste was the largest amount of waste generated which is composed of organic waste. Two key parties work together to manage the solid waste sector in Indonesia: the State Ministry of Environment and Forestry for control and oversight and the Ministry of Public Works and Public Housing for infrastructure. Data on waste generation provided by cities to national stakeholders can be obtained through field surveys, sampling, or estimation.

III. Gasification Technology for Waste to Energy

A. Gasification

Waste and biomass can be converted into energy in the form of solid, liquid and gas. One of the technologies for converting waste into gas that is widely developed and has future prospects is gasification. Gasification is a method for converting solid waste into gaseous fuel through a thermal (thermochemical) process with a limited air supply in a reactor called a gasifier [11]. The advantage of gasification compared to conventional combustion is the high efficiency for small-scale energy generation (< 1 MW). There are several types of gasifiers that are commonly used, namely up-draft, downdraft and fluidized bed types as shown in Fig. 4.

In the updraft type gasifer, air enters through the grate at the bottom. The fuel flow entering the gasifer from the top is flowing in the same direction as this air flow. While the ash is collected at the bottom of the gasifer, producer gas or syngas produced exits from the top. The simplest and most straightforward gasifier is the updraft kind. However, the main drawback of this kind is its high tar concentration, which prevents it from being used in generator engines because it will shorten engine life by causing deposits in the combustion chamber. The updraft gasifier is often utilized for heating and frying purposes.

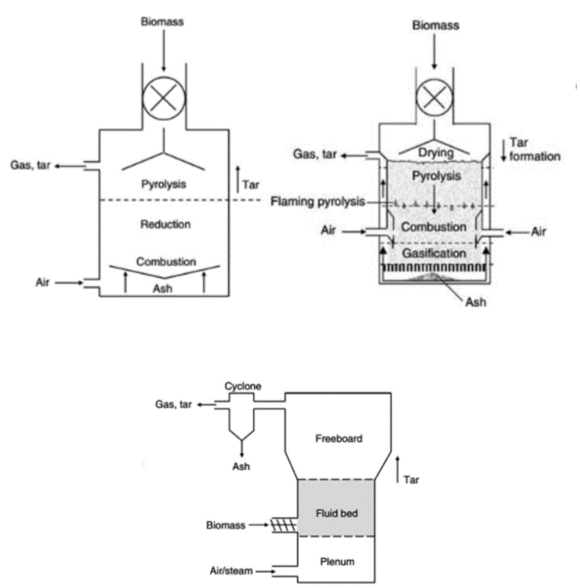

Fig. 4. Several types of gasifier reactor [12].

The downdraft type gasifier is one type that has advantages in small-scale use with simple construction, low tar content in syngas and can be connected to a diesel engine or gas engine to generate electricity [13]. In the downdraft type gasifier, the air flow moves to the gasification zone at the bottom which causes the pyrolysis gas produced to pass through the hot gasification zone. This allows the tar contained in the gas to burn, so that the gas produced by this reactor is cleaner. The advantage of this type of reactor is that it can be used for continuous gasification operations by adding fuel through the top of the reactor. However, for continuous operation, a good ash extraction system is needed, so that fuel can be continuously fed to the reactor.

Gasification products are gaseous fuels whose main components consist of H_2, CO, CH_4, and CO2. This product can be used directly for combustion, connected to a dual fuel engine for electricity production [14,15] or integrated into a fuel cell by utilizing its hydrogen [16]. Improvements in gasification performance to increase the heating value of producer gas continue to be carried out by optimizing several parameters.

In this gasification process, waste is burned with limited air, so that the gas produced contains mostly carbon monoxide, hydrogen, and methane. The principle of the global gasification reaction is as follows [17]:

$$CH_{1,4}O_{0,6} + 0{,}2O_2 \rightarrow CO + 0{,}7H_2 \quad (1)$$

However, there is more energy contained in CO and H_2 compared to waste (endo-thermic reaction), so that external energy is needed and causes the process to be more complex. In practice, more oxygen has to be added for this process, so it will produce CO_2 and H_2O based on the reaction:

$$CH_{1,4}O_{0,6} + 0{,}4O_2 \rightarrow 0{,}7CO + 0{,}3CO_2 + 0{,}6H_2 + 0{,}1\,H_2O \quad (2)$$

The global reaction is a combination of several elementary reactions. The principle of the elementary gasification reaction is as follows:

Water gas:

$$C + H_2O \rightarrow CO + H_2 \quad (3)$$

Water Shift Reaction:

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (4)$$

Boudouard Reaction:

$$C + CO_2 \rightarrow 2\,CO \quad (5)$$

Methane Reaction:

$$C + 2\,H_2 \rightarrow CH_4 \quad (6)$$

Several parameters will affect the waste gasification process including:

- Energy content.
- Water content.
- Dimensions and shape of the waste.
- Dimensional distribution of waste.
- Reaction temperature

Each type of gasifier has its own characteristics. The initial development of gasification was carried out on the updraft type because it was the simplest and suitable for thermal applications, however, the tar content was still high. To improve it, a downdraft type with low tar content was developed. With low tar content, it is possible to be connected to power generating machines such as diesel generators as illustrated in Fig. 4. In the downdraft type it requires fuel with low moisture content (<20%), produces lower tar, and can be designed on a small scale. The integration of gasification for thermal and electrical purposes is very prospective in the future for a small scale application where the waste can be handled at every level.

B. Downdraft Gasifier

Downdraft type gasification is very suitable for small scale applications [18]. In general, the capacity of the downdraft type gasifier ranges from 10 kW – 1 MW [19]. Several applications of this type of gasifier are for generating electricity from waste, wood, agricultural waste and others [20]. This type of gasifier has several advantages including easy to fabricate and operate, low tar content. However, this type also has several disadvantages, namely the occurrence of blockages and is only suitable for waste with low water content. To overcome these weaknesses, several modifications have been made starting from the fuel supply, air supply system, gas recirculation system, and others [21].

There are two main models of this downdraft type gasifier, namely gasifier models with a throat (imbert/throated) and models without a throat (stratified/throatless/open core). Both of these gasifier models have been widely used for biomass and waste gasification (RDF) with gasification agent media in the form of air, oxygen and steam [22].

The Imbert model gasifier is particularly suitable for feedstocks with an ash content and a moisture content of less than 5% and 20%, respectively. The presence of a throat results in maximum gas mixing at high temperature conditions so that it can reduce the tar content because it has been cracked in the zone. However, this model of gasifier has a lower efficiency because some heat is removed through the syngas at high temperatures.

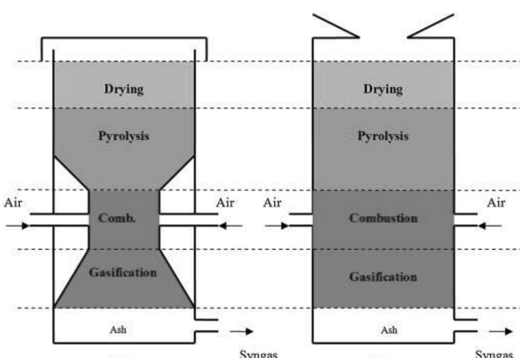

Fig. 5. A schematic model of (a) Imbert downdraft gasifier dan (b) Stratified downdraft gasifier [23].

The stratified downdraft gasifier is designed to eliminate bridging and channeling problems in the throat of the Imbert model gasifier. The gasifier consists of a cylindrical reactor tube straight down without any narrowing where the core of the gasification reaction is at the bottom. In the operational process, waste and air move downward through 4 zones in the reactor. This stratified downdraft gasifier is suitable for feedstocks with an ash content of up to 20%. This model is also easy in terms of manufacture and can be enlarged according to needs. However, with this throatless model, the tar content is higher because the reaction at high temperature cannot be achieved as is the case with the Imbert model.

IV. RDF FOR GASIFIER FEEDSTOCK

Refused Derived Fuel (RDF) is a fuel derived from Municipal Solid Waste (MSW) that can be burned in a combustion chamber or gasification reactor. To make RDF, waste must first be shredded and then carefully sorted to remove all non-combustible materials such as glass, metal, and plastics (which can then be reused or recycled). While shredding and separating require a series of energy-intensive mechanical processes, RDF still has advantages over mixed MSW as a fuel due to the quality and uniformity of its physical and chemical properties, as well as the fact that converting MSW to RDF results in a higher Lower Heating Value (LHV). These properties result in a more homogeneous physical and chemical composition, lower pollutant emissions, lower excess air requirements during combustion, and easier storage, handling, and transportation [24].

Preparation of raw MSW to suit the needs of the gasifier is a very important part of gasification plant. Based on the facts, it is not possible to directly put fresh waste into the gasifier because the moisture content is still very high, the size of the waste particles is very diverse and the content of inert materials must be separated from the waste. For this reason, the pre-treatment process is necessary to prepare the waste to fulfill the standards for gasifier feedstock. There are several pre-treatment processes for MSW that can be used to produce RDF including thermal drying, hydrothermal treatment, torrefaction, solar greenhouse drying, and biological drying.

A. Thermal Drying

The thermal drying method combines drying with outside heating. The heating source can come from anywhere, either from outside the plant or from waste heat generated within the plant. Thermal drying is the most common type of dryer and is simple to use. In general, waste is dried by using external heaters to evaporate the water contained in the waste. The rotary dryer is the most commonly used type of thermal drying, and a schematic of the thermal drying process with a rotary dryer is shown in Fig. 6.

Because this rotary dryer is widely used in a variety of industries, it is technologically advanced. The drying process takes place in a long cylindrical drum that is tilted slightly downward to allow the material to flow downward. The flow of gas in the drum is highly dependent on the type of material to be dried; it can flow in the same direction as the flow of waste material or in the opposite direction. Flow in the opposite direction is usually more efficient than flow in the same direction.

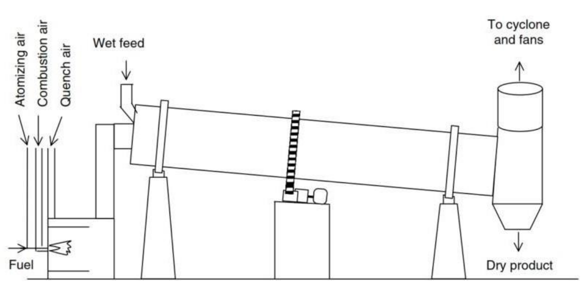

Fig. 6. A Schematic diagram of the process in a direct heating rotary dryer (Krokida et al., 2006)

B. Hydrothermal Treatment

Hydrothermal treatment or hydrothermal carbonization (HTC) or wet torrefaction is a thermochemical process for reforming biomass/waste in pressurized hot water. Under conditions of high temperature and pressure, especially when exceeding the critical points (373.3°C and 22.1 MPa), the density, dielectric constant and ion dissociation constant drop drastically, which can speed up the reaction rate. Hydrothermal treatment itself has been used extensively for the recovery of fuel and chemical products from biomass/waste that has a high water content.

HTC is a thermochemical process at a relatively low temperature to increase the solid phase. This process can convert various types of biomass and waste into lignite-like coal and even sub-bituminous with a residual mass of around 35-60% [26]. The carbon loss is very high in this process because the organic compounds are dissolved in the liquid phase and only a small amount of gas is produced. This process is strongly influenced by the type of waste and operating conditions which include residence time and temperature [27].

Some biomass and waste material has been studied employing hydrothermal treatment such as herb residue [28], nyamplung/calophyllum inophyllum [29], soybean dregs [30], empty fruit bunch [31], and MSW [32]. Prawisudha et al. reported that the reaction temperature and holding period were critical operating parameters in obtaining a usable solid fuel. Higher reaction temperatures and longer holding times result in a more uniform and dense product. Furthermore, higher reaction temperatures and longer holding times result in products with lower organic chlorine content. The heating values of the hydrothermally treated products were not significantly changed. The highest heating value measured was 24 MJ/kg, with an overall average of 20 MJ/kg, which is nearly equal to low-grade sub-bituminous coal. The products also performed well in terms of drying.

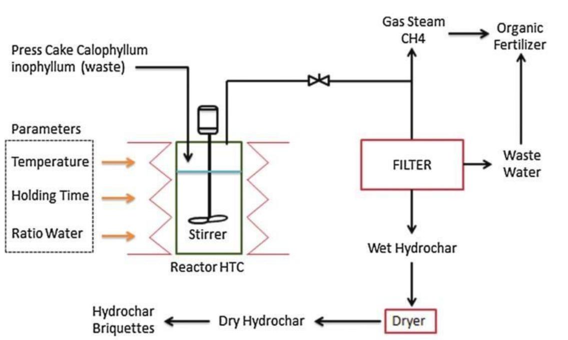

Fig. 7. Hydrothermal treatment process for nyamplung/calophyllum inophyllum [29].

C. Torrefaction

Torrefaction is a heat treatment process on biomass/waste at temperatures between 200-300°C and atmospheric pressure without the presence of oxygen. Torrefaction is used as the preconditioning step for biomass/waste conversion methods such as gasification and co-firing. Torrefaction not only changes the fiber structure, but also the ductility of the waste. During the torrefaction process, the waste will experience devolatization causing a decrease in weight, but the initial energy content of the torrefied waste is maintained in the solid product so that the energy density of the wastes becomes higher than the initial waste.

Several factors influence the torrefaction process, including: time, temperature and type of biomass/waste. The longer heating time and increasing temperature have an effect on the torrefaction results, as well as the type of biomass affecting the quality of torrefaction biomass. During the torrefaction process, the water content will be released and a limited devolatilization process will occur. With this process the mass will change to 70% of the initial mass, the energy content will be 90%, and the water content will be 1-2%. As a result, the heating value per unit mass will rise overall [33].

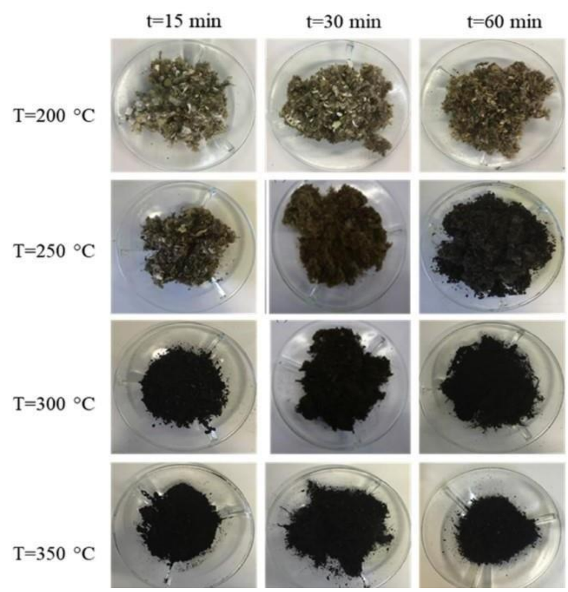

Fig. 8. Example of RDF chars produced by torrefaction [34].

D. Biological Drying

Biodrying is a biologically treated drying technique. The application in waste processing is for the drying process in bioconversion reactors which is integrated with mechanical processes, for example the process of crushing and classifying using screens. This process is usually known as a mechanical-biological treatment (MBT) system. The operating principle of biodrying is to reduce the moisture content of the material by means of evaporation using exothermic heat resulting from waste decomposition so that dry products are produced according to the desired characteristics.

The waste biodrying process can produce a stable RDF with a high heating value. The water content of the product from this process is <20% with a processing time of 7-15 days. During the process there is a decrease in CO_2 and H_2O by 25-30%. This process produces volatile organic compounds (VOC), which are volatile materials formed during biological decomposition processes such as dimethyl disulfide, dimethyl sulfide, benzene, 2-butanone, limonene, and methylene chloride. MSW that has been dried by the biodrying process is more environmentally friendly when burned than wet waste [35].

The biodrying process is based on aerobic technology, which involves removing water primarily as steam as a result of composting temperature and adequate ventilation. Adani, et al. [36] and Sugni, et al. [37] reported that proper aeration and temperature settings can increase drying efficiency by 66.7% from the initial moisture content. When the water-to-biodegradable-organic-matter ratio is too high, the heat generated by the biodegradation process is insufficient to evaporate the water.

The development of biodrying reactors has been carried out by many researchers and companies, one of which uses the rotary biodrying model for the waste drying process as shown in Fig. 9. The advantage of this system is the continuous flow of waste, which allows it to maximize production. This system also includes leachate disposal, which is typically produced from waste. A blower mounted on the device provides air supply to the reactor.

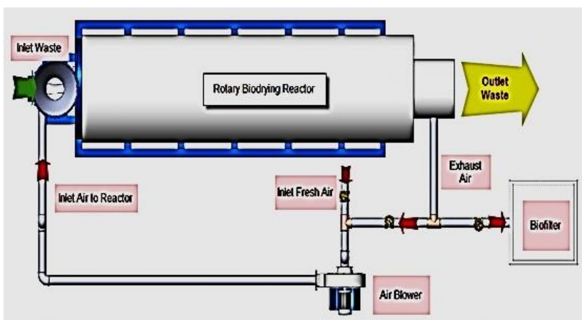

Fig. 9. A schematic design of rotary biodrying reactor [38].

V. CONCLUSION

The potential of MSW and covid-19 medical waste has been examined as feedstocks for gasification process. MSW disposal has now become a serious problem in big cities around the world, including Indonesia. Moreover, the COVID-19 pandemic has been going on for more than two years and is not yet completely over. The main problem with this pandemic is the emergence of medical waste which has increased drastically, such as from the use of disposable masks and personal protective equipment (PPE). Of the amount of medical waste, one third is made of plastic material, even for face mask waste, the composition of the material is dominated by polypropylene (PP), polyethylene (PE) and nylon up to 95% by weight. Plastic has the highest energy content of the various types of waste-contributing materials. As a result, the addition of COVID-19 medical waste increase the calorific value of MSW and ultimately improve the quality of syngas produced from the gasification process. Plastics in co-gasification have influenced gas composition and thus indirectly affect the calorific content of the producer gas.

The downdraft type gasifier is one type that has advantages in small-scale use with simple construction, low tar content in syngas and can be connected to a diesel engine or gas engine to generate electricity. Preparation of raw MSW to suit the needs of the gasifier is a very important part of gasification plant. For this reason, the pre-treatment process is necessary to prepare the waste to fulfill the standards for gasifier feedstock. There are several pre-treatment processes for MSW that can be used to produce RDF including thermal drying, hydrothermal treatment, torrefaction, solar greenhouse drying, and biological drying.

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