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A review of Drying Technologies for Refuse Derived Fuel (RDF) and Possible Implementation for Cement Industry

Windi Zamrudy, Sandra Santosa, Arief Budiono, Eko Naryono

Department of Chemical Engineering, State Polytechnic of Malang, Indonesia

Abstract: Refused-Derived Fuel (RDF) in global energy demand plants has risen over the past decades as a sustainable secondary supply of energy resources. Food waste as a significant fraction of municipal solid waste (MSW) has a great potential for energy production especially in developing country such as Indonesia. To date, many industries focus on drying technologies development for utilization of food waste for energy conversion. Lowering moisture content of food waste is essential to improve RDF heating value (LHV) and further to avoid more steam generation in the combustor. Vaporization of the moisture in fuel consumes a portion of the available energy. The review highlights a number of drying technology application for RDF including direct and indirect steam drying. Furthermore, the review highlights the considerable opportunity for further development of dryer application for Indonesia's cement industry. **Keywords :** Cement industry, Drying technologies, Food waste, Municipal Solid Waste (MSW), Refuse-Derived Fuel (RDF)

Introduction

High demand of sustainable energy resources in the recent decades has risen to substitute the use of conventional fossil fuels in energy intensive industries such as cement production and power generation plants. The increasing fossil fuels costs promote the cement industry to consider the use of alternative fuels for clinker production. In addition, the energy resources such as coal, oil and other fuels are also affecting to the environment such as greenhouse gasses emission. Its concentration in the atmosphere is rapidly increasing upon combustion of fossil fuel-oil, coal and gas [1].

Environmental regulations and energy costs are the key reasons to replace fossil fuel with renewable energy. In Indonesia, most of cement industry is still generating energy from coal. The problem with power generation from this fuel is their limited availability and the climate damage caused by the emission of fossilderived CO_2 . As described in [2], the production of 1 ton of cement commonly results in the release of 0.65– 0.95 tons of CO_2 depending on the efficiency of the process, the fuels used and the specific type of cement product. In this regard, production and utilization of Refuse-Derived Fuels (RDFs) can be an alternative fuels resources.

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RDFs are types of derived materials from Municipal Solid Wastes (MSW) through various processes such as separation at source, sorting, shredding, screening, blending, drying and pelletizing [3]. Screening process is to separate ferrous compounds and glass which are recyclable; as well as bio wastes (e.g. food) which are highly wet. Pelletizing process can be also ignored depending on the location of RDF production systems and combustion facilities [4]. RDF composition highly depends on its origin; as a result, it may vary considerably [4].

Food waste and organic waste are the major composition of municipal solid waste (MSW) found in most household and commercial waste in Indonesia. Furthermore, several properties of RDF such as calorific value, moisture content, and the amount of chlorine, sulfur and alkali compounds and ash content are important when it used in cement production plants. Compared to coal, RDF has lower calorific value and sulfur content and higher chlorine amount [5]. The lower amount of sulfur is favorable to reduce sulfur dioxide emission to meet environmental regulations.

Among the mentioned specifications above, the main problem face by industries these days is to lower the water content of the solid fuel to enhance the heating value (LHV). As many studies reported [6, 7, 8, 9] that organic waste for example, a large content of food waste, kitchen waste and leftovers from residences, restaurants, cafeterias, factory lunch-rooms, and markets have high moisture and high biodegradability. Consequently, the proper drying technology and method have to be analyzed and studied prior applying in practical industrial use, especially in cement production plants. In this paper, a review of the development in drying technologies and techniques for RDF is presented. Moreover, possible drying technologies for cement industry is also analyzed. Apart from them, the level of drying and operating cost are also needed to be considered in selecting the most appropriate method.

Experimental

Drying Technologies for RDF

Drying is the removal of water or other solvent from solids, or a mixture of liquid and solids [10]. Studies on RDF drying technologies especially for organic solid wastes such food wastes have developed increasingly and new techniques together with the conventional types of drying have been recently brought more into discussions. However, drying of organic solid wastes is still challenging because of process complexities and some variations in solid heterogeneity and physical, chemical and biological properties.

There are different dryer classifications to help selecting a proper drying method. This diversity could stem from various solid waste types, their origins and challenges in working with heterogeneous systems. Some categories based on heat transfer methods and some based on solid characteristics [3]. The three main categories of dryers are direct dryers, indirect dryers and Infrared radiant heat dryers.

In direct drying, heat is transferred through a direct contact between moist solid and the hot drying gas. The hot gas acts as a drying medium and the moisture carrier. Whilst, in indirect drying, there is a wall between drying gas and the wet material. Therefore, heat transfer is through the wall or via a hot surface. As a result, drying gas does not play the role of moisture carrying anymore [3].

In Infrared or radiant heat dryers, heat transfer is via radiation. The source of radiant heat could vary. It can be from electricity by infrared lamps or from electric resistance elements and other sources. This method is not as applicable as direct and indirect methods in chemical processing industry. Furthermore, Dryers are also divided into batch and continuous mode of processing [3].

Among different classifications of dryer, in this paper review more emphasis on the most commercially dryers for RDF treatment. The fluidized bed, TORBED, screw conveyor is one of the drying technologies and methods that can be used for solids drying [10]. In addition, in the report of [3] describe that rotary dryers', fluid bed dryers' and belt dryer's' functionalities are mostly used for RDF drying. Table 1 shows review summary of drying technologies application for RDF.

Technology	Type of dryer	Ref.
1. Conveyor belt dyer	Direct dryer	[3,11,12]
2. Direct rotary drum dryer	Direct dryer	[3,11,14,15]
3. Indirect rotary dryer	Indirect dryer	[11,16]
4. Fluid-bed dryer	Direct dryer	[10,14,17,18]
5. Screw conveyor	Indirect dryer	[19,20]
6. TORBED reactor	Direct dryer	[10,21]

Table 1. Summary of drying technologies for RDF



Figure 1. Belt dryer configuration for RDF drying [11]

Conveyor belt dryer

Belt conveyors and screen-type conveyors are of the types of dryers used in a completely continuous process [3]. Screen-type belt dryers are type oy dryer in the group of continuous through circulation dryers [11]. Belt dryers consist of some sections with circulating fans and heating coils. They are all placed inside a housing or a tunnel in which a conveyor belt is running through. Solid bed which is 2-15cm deep, is conveyed on the belt and transported in the tunnel while being in contact with the drying medium [11].

STELA Laxhuber GmbH [12] developed and configured belt dryer for RDF drying (Fig. 1). The input material with a moisture content of approx. 35 % and more is fed directly into the dryer via conveying systems (label 1). The solid bed on the conveyor belt can be well-spread via a distributing screw (label 3). A stream of hot air flows (label 13) through the layer of wet material and continuously dries it to a residual moisture

content of approx. 10%. Then, the dried solid is finally discharged by a discharged screw (label 4). If the fresh air is going to be used as the hot gas, it should be heated up to a certain level by passing through the heat-exchangers installed in the dryer chamber. As described in [13] the layer of solid bed and a web belt play the role of filtration in the dryer to reduce the exhaust air dust emission to the atmosphere

Direct rotary drum dryer

A rotary dryer is a proper choice for heterogeneous solid materials for a continuous process [3]. Rotary dryers have a cylindrical drum with a bearing to rotate upon. These dryers are mostly inclined to some degree to ease the movement of the moist solids forward. Moist materials enter the cylinder from one side and move ahead as a result of head impact, rotational movement and cylinder slope to exit from the other side. Drying gas flow in the cylinder could be either co-current or counter-current with the solid flow which may enhance the solid flow or slow it down, respectively.

Countercurrent flow improves the heat transfer rate while co-current flow may be more applicable for heat sensitive materials because the hot gas temperature decreases significantly as a result of surface moisture initial evaporation [11]. Rotary dryers do not have simple operations and the process is controlled by different mechanisms such as momentum, heat and mass transfer. Many independent parameters like solid flow rate, solid type, moisture content, hot gas flow rate, hot gas temperature, drum diameter and length, angle of slope, rotation speed and residence time play key roles while working with rotary dryers [14].

Direct rotary dryer is a simple cylindrical drum with or without flights. Direct rotary dryer is simpler and more cost-effective to manufacture than the indirect counterpart. However, it is only applicable when there is no restriction of direct contact between solid and drying gas. In direct rotary dryers, a large amount of drying gas volume and gas velocities are needed. The drying gas velocity is mostly higher than 0.5m/s for an effective design. When the solid material has the tendency to produce dust, solid particle entrainment to the gas stream is inevitable. As a result, a filter or a cyclone maybe needed to catch the dust from the exhaust gas [11].

The solid materials fed in the rotary dryer depends on solid characteristics and location as well as upstream equipment. However, in order to seal the feeding system and dryer properly and if the gravity feed is not practical (gravity feed needs a chute through which solid is fed to the dryer) a screw conveyor is applied [11].

The carrier gas flow is usually countercurrent with respect to the solid flow and it drives off the produced vapor at the feed end of the dryer [11]. Based on the study done by Pinacho, et al. drying of heterogeneous solids is more efficient using a continuous rotary dryer than the tray ones [11]. So that it can be expected to have an effective RDF drying as it is heterogeneous.

According to the analysis done by Zabanitou, different design parameters like angle of slope, rotation speed and hot gas condition could have profound impacts on forestry woody materials drying. For instance, it was observed that air temperature reduction led to increased constant dying rate period and reduced falling drying rate period. Other outcome of their analysis was the effect of residence time in a way that short residence time may result in less drying efficiency [11]. Fig. 2 shows a flowsheet of a drying system using direct rotary system. As can be seen, the dryer has a cyclone or a bag filter is inevitable.



Figure 2. Rotary drum dryer system overview (image courtesy of ANDRITZ Separation) [15]

Indirect rotary dryer

Steam tube rotary dryer is one of the most applicable indirect rotary dryers as shown in Fig. 3. In this type of dryer, steam tubes are installed radially along the drum length in one or several rows. Drying occurs when solids are in contact with the heated tubes through conduction and radiation heat transfer. Drying is controlled by steam temperature or pressure in the tubes and also by the solids residence time. In case of dealing with sticky solids, one tube row is suitable. Steam tubes can be normal pipes having condensate drainage or they can be bayonet-types. Flight installation inside the cylindrical drum assists material mixing and enhances turbulence in the system [11].

In this dryer type, solid materials are fed into the dryer via a screw conveyer or a chute and leave the dryer through openings on the shell at the other end. These openings are also used for a carrier gas intake to remove the moisture vapor. Vacuum pressure in the dryer could also drive the moisture off the system [11].



Figure 3. Steam-tube rotary dryer component [16]

Fluid-bed dryer

Fluid-bed dryers or fluidized-bed dryers are quite well-known in the industry because of their vast applications and broad operating conditions. The fluidized bed is a drying technology that allows controlled, gentle and uniform drying of wet solids [10]. A system of a fluidized bed consists of cylindrical body as the fluidized bed column filled with a bed of solid particles which provides a proper contact with the gas phase coming into the cylinder [14].

In case of using air as the drying gas, its temperature may be in the range of 100°C to 450°C which

depends on the solid to be dried; however, drying at inlet low temperature can reduce fire risk in the dryer [17]. This type of dryer also includes a gas blower to assist the gas flow, a heater and a gas cleaning system to separate some fine particles that entrained to gas phase [14, 18]. Fig. 4 is a simple set up of a fluidized bed drying system. In this type of dryer, a bed of moist solids requires a greater minimum fluidization velocity than the bed of same dried materials. So that, only the upper levels of the bed can become fluidized and the lower levels may not move during the first stages of drying [18].

This type of dryer offers a great solid mixing, considerable heat and mass transfer, uniformity of the dried solids and easy solid transport [14]. The behavior of the solid bed in the fluidized bed column is partly shown in the upper right side of the Fig. 4. As seen, two zones are generated, named as dense phase zone and freeboard zone. The former is at the bottom and the latter is located on top. In freeboard zone, solid hold-up and density are inversely proportional to the bed height. Fine solids that have terminal velocities smaller than the gas velocity can be carried by fluidizing gas flow in the freeboard region.

Solid hold-up is reduced with the increase of freeboard height to a level above which solid hold-up does not change. This level is called Transport Disengagement Height (TDH). The gas discharge point in the column should be above the TDH level to avoid solid entrainment to the gas stream [18]. Despite of the advantages coming with this dryer type, some restrictions such as high pressure drop, increased power consumption, inability to proper fluidization behavior of some solids, non-uniformity of solids in some dryer types, pipe and vessel erosion, particle entrainment and etc. also exist [18].

According to the research done by Moreno et al. elevated temperature as high as 187°C resulted in some advantageous in forestry wastes drying by a fluidized bed. This conclusion was based on some experiments, showed that higher gas temperature led to a more energy-efficient drying system as a result of higher rate of drying [14].



Figure 4. Typical fluidized bed drying set-up [18]

Screw conveyor

Recently, drying has been investigated using screw conveyors. Recently, drying has been investigated using screw conveyors. Osman et al. [19] used a steam-jacketed screw conveyor/mixer to dry low rank coal particles such as lignite and sub-bituminous coal (Fig. 5a). Although this study has yet to be completed, preliminary results have shown that the dryer technology was cost- and energy efficient compared to competing technologies. The authors also conducted discrete element modelling (Fig. 5b), which indicated an excellent particle mixing in the dryer (in this case, at 7.5 rpm screw rotation and 300 m3/h material throughput).

Kaplan and Celik [20] carried out wood chip drying by using a similar technology and managed to reduce the moisture content from 60 to 27 wt.% under optimum conditions: 30 m³/h drying air flow rate, 200 °C drying air temperature and co-current air/feed configuration.



Figure 5. (a) A steam-jacketed screw-conveyor dryer for drying of low rank coal, (b) particle mixing

simulation in the dryer (time constant) – different colours correspond to different particle types [19]

TORBED reactor

The TORBED reactor has also found uses in drying of slurries, sludges and biomass solids [10]. As an example, a paper mill in Holland installed in 2004 a TORBED for drying paper sludge (55 wt.% moisture content) at a rate of 2 tons/h. By combining recycled low-grade waste heat (60 °C) elsewhere in the mill and primary hot air at 120 °C, the TORBED was able to reduce the moisture content down to 5 wt.%. Compared to other technologies, it enabled a more convenient processing – it coped with the sticky nature of the sludge through rapid 'skinning' of the particles [21].



Figure 6. TORBED[™] Compact Bed reactor [21]

Results and Discussion

Possible Drying Technologies Development for Cement Industry

As reported in [22] that municipal solid waste remained an issues for most city in Indonesia while cement industries needed a sustainable alternative fuel resources. Bio-drying is a common drying technology selected by these cement industries since waste has approximately 50% organic waste [22].

Even though bio-drying method is quite effective to increase calorific value of MSW, however, this

technology seems time consuming for RDF production and batch system processes. Since drying of RDF is quite vital to increase its calorific value before being used as a fuel, it is required to develop drying technology that can solve the drawbacks of bio-drying method.

Based on the available excess heat in cement production plants [3, 23] such as heat waste from raw mill, clinker, kiln and pre-heater cyclones, authors highlight three different theoretical possibilities to use excess energy in the plant to provide RDF drying energy as following:

- 1) Direct steam drying: producing super-heated steam from available hot air in the plant and its utilization as drying medium in a dryer with direct mode
- 2) Indirect steam drying: producing steam using available hot air energy in the plant and applying that indirectly in the dryer
- 3) Hot air drying: taking available hot air in the plant as drying medium and applying that directly into the dryer

In order to select the most appropriate drying method from all three suggested systems, different factors should be taken into account, such as, energy consumption of the system, existence of auxiliary equipment, operability and controllability of the process and cost of the drying system [3].

Based upon the survey conducted by the authors, item 1 (direct steam drying) is the most recommended process for this purpose. The reasons to choose direct drying with hot air are firstly, it will reduce total equipment cost to some extent. Secondly, from the energy point of view, it does not need to have an intermediate heating medium. From this case, some heat loss will be avoided. In addition, the dryer will have no steam equipment, results in lower capital and operating cost, lowering maintenance requirement and simpler control system.

Furthermore, as a result of review of various drying technologies as given in TABLE 1 that direct rotary drum dryer and fluid-bed dryer seems to be promising and suitable to utilize food waste for RDF production to be implemented in cement industry by using direct drying system.

Conclusion

In this state-of-the-art review, technologies and techniques related to drying technologies for RDF have been described. Type of drying technologies and methods have been selected and classified into direct and indirect dryer for RDF application.

An overview of the reviewed technologies and methods as given in TABLE 1 highlights direct rotary drum dryer and fluid-bed dryer to be perhaps the most common drying technologies application to have been investigated for RDF production. The desirable features of RDF drying technology in cement industry relate mostly to improved product properties (e.g lower moisture content, high LHV, high calorific value) but also demonstrate other processing advantages such as improved energy efficiency and reduced in environmental effects.

To summarize, authors recommend for future prospect of RDF drying technologies development to be applied in cement industry are direct rotary drum dryer and fluid-bed dryer by utilize direct heat waste drying.

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