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Drying of biomass for utilising in co-firing with coal and its impact on environment – A review

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ABSTRACT

Coal is the most widely used primary fuel for energy generation but it emits toxic gasses after combustion. Whereas, biomass is a renewable energy source and it is used for environment friendly energy production. Biomass does not add carbon dioxide to the atmosphere because it absorbs the same amount of carbon in growing as it releases when consumed as fuel. Generally, biomass used for co-firing with coal includes wood and woody wastes, municipal solid waste, animal wastes, agricultural crops and their waste by-products, waste from food processing, aquatic plants and algae. The inherent moisture content in biomass decreases its heating value and it needs to be dried before using it for co-firing. The drying of biomass could be performed in various types of dryers and all of them have their own merits and demerits. This paper provides a detail review on the need of drying of biomass before co-firing, different technologies used for biomass drying, biomass co-firing to the existing coal fired power plants and the environmental benefits of biomass co-firing.

1. Introduction

Energy is one of the most fundamental parts for any country and it is known as a strategic commodity. Any uncertainty about its supply can threaten the functioning of the economy, particularly in developing economies. India is a fast growing country where the different sources of energy are used and their present contributions to the total energy production are as follows; 68% from thermal energy, 17% from Hydro energy, 2.08% from Nuclear energy and 12% from Renewable energy. In India, till date, the main source of power is the coal based thermal power plants, which produce 58.75% of the total energy [1]. These thermal power plants use about 70% of total coal in India. After combustion, the coal based thermal power plants emit CO_2, NO_x, SO_x and air-borne inorganic particles such as fly ash, carbonaceous material (soot), suspended particulate matter and other gases. Emission of pollutants cause a variety of adverse impacts such as premature mortality, morbidity, crop losses, risks to biodiversity and acidification of soil and surface water [2]. Currently in India, 32% of primary energy is contributed by biomass and it is expected to increase in the coming decades [3]. Biomass fuels are considered to be environmentally friendly for several reasons. There is no net increase in CO_2 as a result of burning a biomass fuel because biomass consumes the same amount of CO_2 from the atmosphere during growth as is released during combustion. Therefore, blending of biomass with coal can reduce fossil-based CO_2 emissions [4].

Generally, the initial moisture content of most of the biomass is high. Therefore, it needs to be dried before co-firing in order to increase the energy efficiency, improve the energy quality and reduce the emissions. It is observed that the energy efficiency of a boiler can be increased by 5–10% if dried biomass is used instead of wet biomass [5]. This is because of increased combustion temperature due to use of dried biomass. The two main techniques are used for drying of biomass materials such as Mechanical drying and Thermal drying. If the feed moisture content is more than (50 w/w) %, then the mechanical drying technique is used. It requires equipment such as filter beds, pressers and centrifuges [6]. Thermal drying is often used after the mechanical drying to further reduce the moisture continent to a lower level. Drying serves as the first stage of any biomass pyrolysis and combustion process [7,8]. For drying of biomass, various dryers are used. These dryers have their own merits and demerits which are discussed later in details. However, fluidized bed dryer has more advantageous features than others [9]. The solid material in granular as well as in powder form can be dried in fluidized bed dryer. It is extensively used in industry because of the cost-effective drying [10]. Uniformly dried product can be obtained using fluidized bed dryer even in large scale operation, whereas, it is very difficult to obtain a product of uniform moisture content in other dryers [11].

Biomass co-firing is regarded as one of the attractive options for

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biomass utilization in the power generation industry. It is defined as the simultaneous blending and combustion of biomass with other fuels such as coal and/or natural gas in a boiler in order to generate electricity. The amount of biomass fuel that is co-fired is called the co-firing level or the rate of co-firing. Co-firing of biomass in existing coal fired boilers is a practical approach for increasing the use of biomass as fuel. This is because it draws upon widely-available, existing infrastructure and presents immediate opportunity for the production of electricity form biomass in an efficient and cleaner way [12,13]. Co-firing of biomass with coal also offers several environmental benefits. It reduces emissions of carbon dioxide, a greenhouse gas that can contribute to the global warming effect. Biomass also contains significantly less sulphur than most coal. Therefore, co-firing of biomass will reduce emissions of sulphur dioxide.

Agbor et al. [14] reviewed different aspects of biomass co-firing which includes available co-firing levels and technologies, various technological and environmental issues associated with biomass co-firing, etc. However, their study focused on the biomass resources available and used in coal-fired boilers in North America only. Dzikuć and Piwowar [15] studied the ecological and economic aspects of electricity production using the biomass co-firing method in Poland. They presented the current environmental impact of energy production and potential ways of limiting it by extended use of biomass co-firing method using the Life Cycle Assessment (LCA) method.

However, the present paper gives a comprehensive review on the different technologies used for drying of biomass and its benefits on co-firing, different co-firing technologies, advantages and disadvantages of biomass co-firing to the existing coal fired power plants and its environmental impact.

2. Classification of biomass and coal

2.1. Biomass

Biomass is classified as woody biomass (tree, bamboo, plants etc.), non-woody biomass (grass, stem and roots, cotton etc.), process waste (bagasses, saw mill waste etc.) and processed fuel (charcoal, biogas, producer gas etc.) [16]. Changes in structure and composition of vegetation are often accompanied by changes in biomass [17]. Biomass obtained from different sources may vary in initial moisture content, size and shape, property etc. The three main polymeric constituent of biomass are hemi-cellulose, cellulose and lignin. For a typical lingo cellulosic biomass, the hemi-cellulose content is 20–40% (w/w), the cellulose content is 40–60% (w/w) and lignin content is 10–25% (w/w) approximately. Cellulose is a linear polymer and its degradation starts anywhere from 240 to 350 °C because of high resistance of its crystalline structure to thermal depolymerisation owns to its strength. Hemi-cellulose is a complex carbohydrate polymer with a lower molecular weight than cellulose. Thermal degradation of hemi-cellulose occurs between the temperatures of 130–260 °C, with the majority of weight loss occurring above 180 °C. Lignin is an unstructured and highly branched polymer that fills the spaces in the cell wall between cellulose, hemi-cellulose and pectin components. It is relatively hydro-phobic and aromatic in nature and decomposed between 280 °C and 500 °C when subjected to a thermal treatment. Lignin is difficult to dehydrate and thus converted to more char than cellulose or hemicelluloses [18].

2.2. Coal

Coal is primary source of energy which is characterized on the basis of the percentage of carbon contain. The minerals percentage in it plays a significant role in the ash content of the coal which will in turn affect the quality of coal as fuel [19]. Carbon and hydrogen are the principal combustible elements in coal. On the weight basis, carbon is the predominant one and it constitutes about 60–95% of the total weight. For most of the coals carbon content is 90% or less, hydrogen content is generally in the range of 5%, it drops to about 2% for coals having 95% carbon. The nitrogen content of coal is generally in the range of 1–2% and the oxygen content is inversely related to carbon content. For example, coals of 65% carbon may contain 30% oxygen, while coals of 95% carbon may contain only 2–3% oxygen. But, the oxygen content in coal is important because the coal which contains more oxygen it is easier to achieve its ignition. The process of conversion of vegetable matter to coal involves loss of oxygen, hydrogen and concentration of carbon. The chief stages of coal formation are Peat, Lignite, Bituminous and Anthracite coal. Peat is not a coal though it is fuel. In coals, carbon occurs in two forms either as fixed carbon or as volatile matter. The ratio of these two determines the rank of the coal [10].

3. Drying of biomass before co-firing

Drying is a complex transient operation of simultaneous heat and mass transfer along with several rate processes. In drying, liquid from wet material is evaporated with the supply of heat. In drying (except microwave and radio frequency), heat is transported by convection form surroundings to the boundary of the drying object first and then diffused into the material by conduction. Moisture is transported in the opposite direction to that of the heat. Moisture migrates from interior to the material surface of the drying object before it is taken away by the drying medium [20]. The rate of drying is determined by the moisture content and the temperature of the material to be dried, the (relative) humidity and the velocity of the air in contact with the material. Materials behave differently on drying according to their moisture content. The typical drying rate curve of a hygroscopic material is shown in Fig. 1. It is observed that drying occurs in three stages. In the first stage the drying rate is constant. The constant rate period is governed fully by the rates of external heat and mass transfer since a film of free water is always available at the evaporating surface. This drying period is nearly independent of the material being dried. Towards the end of constant rate period, moisture is transported from the inside of solid to the surface by capillary forces and the drying rate may still remain constant. In the second stage of drying the surface film of liquid is entirely evaporated. This drying period is known as unsaturated period or unsaturated surface drying. In the third stage of drying, moisture may move though the solid as a result of concentration gradients between the inner parts and solid surface [21].

For the co-firing of coal and biomass blend, it is required that the moisture content of the biomass should be in a certain range so that the boiler performance and the plant efficiency increase. Moisture in biomass can exist in three forms: water vapour, capillary water in the pores and bound water in the solid matrix [22]. Drying of biomass occurs at about 100–200 °C when the moisture from it is driven out and converted into vapour. Biomass at this temperature does not

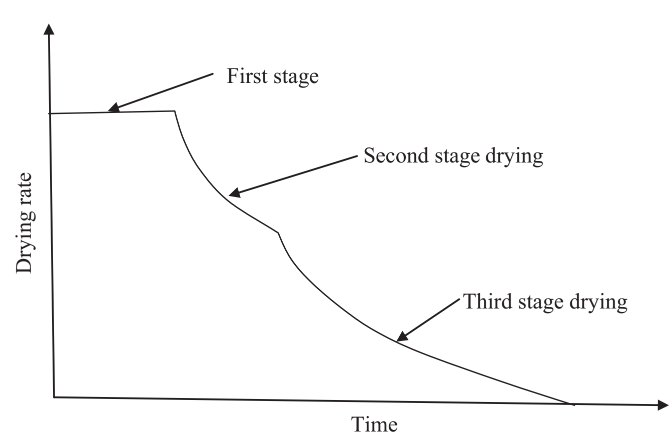

Fig. 1. Typical rate of drying curve at constant drying condition.