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Alternative Fuel Sources to Reduce Air Pollution in Industrial Boilers

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Abstract: The boiler is one of the most energy-consuming applications in industries. In Sri Lanka, several biomass sources can be used as alternative renewable fuels for the boiler. Various industries use biomass boilers. Biomass boilers also emit some air pollutants, which should be minimized. Also, deforestation to meet the biomass demand is another problem. Using suitable combustion technologies, non-conventional biomass-based fuels such as briquettes, biomass can be consumed sustainably with controlling air pollution. Air pollutant emissions, usage of industrial biomass in Sri Lanka, Available alternative biomass fuels, their impact, and different combustion technologies have been discussed to identify suitable alternative fuels and the potential for air pollution reduction.

Index Terms: Air pollution, Alternative fuel, Boiler, Biomass, Briquette

1. INTRODUCTION

Currently, fossil fuel sources are the prime energy resources in the world. However, extreme fossil fuel consumption has created many environmental problems and damages, including air pollution, global warming, and acid rain. Thus, reducing fossil fuel consumption and shifting to more renewable sources is necessary. Biomass is one alternative to fossil fuel sources such as coal [2]. Biomass contributes about 10% to 15% of world energy demand. In industrialized countries, 9 % to 14 % of the energy supply depends on biomass-based sources, while in developing countries, biomass contributes 20 % to 33.33 % [1].

Industrial boilers are one of the crucial fuel-consuming applications of most industries. A boiler is an enclosed vessel that generates heat by fluid (usually water) in a heat transfer mechanism. According to the circulation method, working pressure, fuel source, fabrication method, boiler can be categorized. In Sri Lanka, boiler operations happen mainly around three sources: coal, diesel, and biomass. In Sri Lanka, biomass dominates the source of primary energy.

Since ancient times, people have used biomass as an energy source because of its special characteristics. The possibility of using fossil fuels like oil, coal, and natural gas as energy sources, with their primary characteristics of high calorific values, simplicity of transportation, and ease of storage. However, the consequent demand for fossil fuel resources has resulted in their depletion, which scientists say will happen very quickly over the next 40–50 years. As a result, their market price is

rising every year. The potential to replace fossil fuels with renewable energy sources like biomass is now being explored. In fact, switching from fossil fuels to biomass for energy production may significantly decrease non-neutral carbon dioxide (CO_2) emissions.

Forest firewood provides a significant portion of the rural population's energy needs, increasing the leading industrial sector in Sri Lanka that uses biomass. Most of the boilers are processed under the biomass source since its cost is lower than coal and diesel, and the most available renewable energy source in Sri Lanka.

Biomass is a renewable energy source that may be used to generate electricity and heat for various purposes. There are two sectors: modern bioenergy and traditional bioenergy.

Burning biomass, such as wood and charcoal, is a traditional method of producing bioenergy. Modern technologies like wood pellets and liquid biofuels are made from bagasse and other plants.

Although the major rice mills use rice husk and rice straw as fuel sources. Because it is freely available alternative fuel generated in the rice production process. As well as palm fruit bunch, coconut shells, and bagasse used in the palm, coconut, and sugar industries in order. Mainly rubberwood is used in textile industries, food industries such as Ceylon Biscuit Limited, Brandix, and other major industries in Sri Lanka. Even though using biomass fuel generates solid, liquid, and gas which release into the atmosphere. For example, the gaseous emissions of the Sri Lankan coconut industry due to the combustion of fuel oil (in modernized factories) and firewood (in conventional factories) have been estimated as, carbon dioxide (CO_2) 72,500 tons per year, CO 7000 tons per year, SO_2 250 tons per year, and the total CO_2 emission of the industry accounts for about 1 percent of the national figures [2].

When biomass is burning, biomass carbon reacts with atmospheric oxygen to form gaseous carbon dioxide. The amount of combusted carbon dioxide is equal to amount which had taken from the atmosphere during particular plant growing stage. Therefore, burning renewable biomass is expected to be Green House Gas (GHG)-neutral, in contrast to burning fossil fuels [3]. This is known as zero carbon emission by biomass cobustion. It is illustrated in Fig. 1.

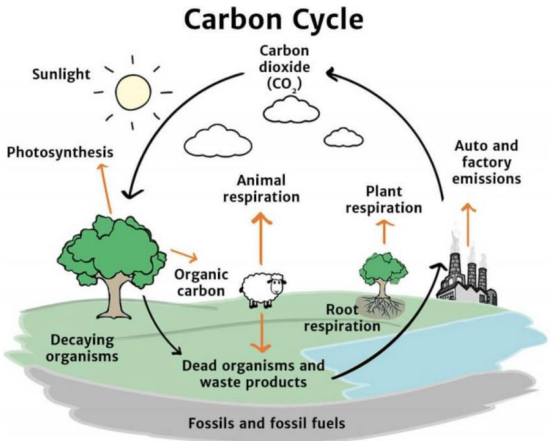

Fig. 1. Carbon Cycle [4]

2. BIOMASS BOILERS IN SRI LANKA

Using industrial biomass boilers in Sri Lanka is vital to fulfilling the energy requirement in production processes. A large number of biomass boilers is leading to several environmental problems today. The fuel source for those boilers is well-grown trees, especially rubber. The main idea behind this study was to evaluate the total amount of biomass required for the biomass boilers and propose environmentally friendly fuel replacements to protect the environment while keeping the industrial processes. Around 400 biomass boilers are operating around Sri Lanka, using approximately 3200 metric tons of biomass to produce the daily demand for steam. Therefore, most industries use rubber wood as a biomass fuel source.

Sri Lanka is a developing nation that should continue its industrial processes. There are several industries use steam for the manufacturing process. Most industries produced steam from biomass boilers and furnace oil boilers. Other than steam, some industries are using hot water which is also generated by hot water generators [5]. Those industries can be categorized as,

- Plantation (Tea, Rubber, Coconut, Palm oil).
- Food and Beverages (Rice, confectionery, soft drinks, alcohol, meat, desiccated coconut, sugar, milk powder)
- Rubber and Plastic (Tire, leather products, plastic household manufacturing, carpets, Styrofoam, water tanks,
- PVC Products, nylon ropes
- Pulp and Paper (Paper, corrugated, printing)
- Cement and Concrete (cement, cement products, tiles)
- Wood and Timber
- Textile (garment, elastic, yarn, buttons and zippers, yarn and fabric dyeing)
- Hotels and Hospitals
- Metal and steel
- Health care and cosmetics
- Medicine and Ayurveda drugs

There are around 36 MW of boilers under operational conditions, 20 MW from Dendro, and 12 MW from agricultural waste, and the balance still needs to be commissioned by the Sustainable Energy Authority of Sri Lanka. Biomass boilers operating in Sri Lanka provide the daily steam requirement, which uses about 8000 metric tons (36 MW x 8000 MT = 288,000 MT) of biomass for each MW. Currently, most enterprises use rubber wood as their primary source of biomass [6].

The following pie chart in Fig. 2 shows percentages of industries with installed biomass boilers in Sri Lanka.

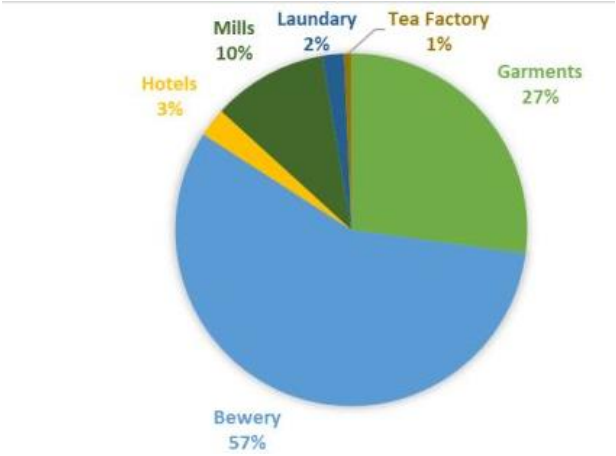

Fig. 2. Installed biomass boilers percentages in Sri Lanka [4]

The main issues with industrial biomass boilers are deforestation to meet the biomass demand, depletion of water resources, an increase in air temperature, CO2 emissions, high volume, and larger size of the ash produced, which will need time and labor hours to shred and reduce it. Biomass-based thermal energy has been taken part in the Sri Lankan industries due to the contribution of fuel cost towards high manufacturing cost and the contribution of biofuel on climate change mitigation. This trend remained steady as a result of government policy changes, technical upkeep and maintenance, and the biomass supply chain. Industrial boilers are used in major industries such as tea, hotels, yoghurt, hospitals, and dried food production. The major production for agriculture-based foreign exchange earners, Sri Lanka Tea has a well-known brand name. The largest producers of organic tea (manufacturing on average 3000 kilograms of green tea leaf daily) are medium-sized estates 2-160 Tons/hour burnt by biomass dryers in suburban regions of the southern province. To support the strong, sustainable mindset of "going green" and the "zero carbon emission." concept, tea manufacturers have installed a biomass-fired dryer.

In Sri Lanka, the hospitality sector is vital to the country's economy. At one of the international hotel chains in Sri Lanka, Jet Wing Hotels, the use of biomass energy dates back to 2008. Since then, using biomass whenever possible has become standard practice at their hotels. Jet Wing Blue successfully installed the first biomass boiler (Fig. 3) from a technical and financial standpoint. The boilers were used to produce steam for the laundry and hot water for the guest rooms.

Fig. 3. Biomass (firewood) boiler in Jetwing hotels, Sri Lanka [5]

Sri Lankan processed food producers prepare meals and beverages using food processing techniques and traditionally sourced, incredibly nutritious ingredients. Furthermore, producing hot water for patients in the healthcare sector and yoghurt production (for the heating process) boilers are required [5]. Ediriweera et al.

completed case studies to find out biomass boiler usage and its impacts on greenhouse gas (GHG) emissions. The summary has illustrated as follows in Table 1.

Table 1. Biomass boiler usage [6]

Types of Industry	Main application	Capacity	Annual GHG reduction
Tea	Drying tea leaves	1000 kW	273 t CO_2
Hospitality	Hot water for guest rooms	150 liters/hour of water at 100^0C	8 t CO_2
Home-based dried food production	Drying fruits & vegetables	240kg/day	29 t CO_2
Small Hotels	Hot water for guest rooms	150 liters/hour of water at 100^0C	8 t CO_2
Healthcare	Hot water	12 kW	2.57 t CO_2
Yogurt	Yogurt production	150 liters/hour of water at 100^0C	17 t CO_2

3. BIOMASS TO ENERGY GENERATION

Biomass can be converted to fuel using several ways. It depends on the type of available biomass feedstock, environmental standards, economic conditions, and some other factors.

3.1 Direct combustion of raw biomass

Although raw biomass such as wood, sawdust, and rice husk can be burned directly, it causes substantial air pollution compared to other methods. It depends on the combustion air supply rate, size and type of biomass, etc. [7]. The lignin content of the lignocellulosic fuels such as wood pieces, sawdust, coconut husk, and rice husk is correlated with the calorific value. If fuel has a lower calorific value, it takes more heat energy to evaporate its moisture content before combustion. It leads to lower the entire efficiency of the combustion process. Carbon and Hydrogen in the fuel tend to increase the calorific value, and oxygen reduces it. [1]. The following Table 2 shows the energy contents of different types of biomasses.

Table 2. Energy contents of biomass [1]

Type of biomass	Energy Content (MJ/Kg)
Rice Straw	18.7
Softwood	19.8
Hardwood	19.0
Corncob	17.3
Tea waste	17.2
Coconut shell	20.00
Rice husk	13.324
Fuelwood	16.10
Sawdust	18.14

Eucalyptus (Grandis)	19.35
Cotton refuse	18.83

3.2 Briquettes production from biomass

Most industries are using biomass-based fuels in their industrial boilers for steam generation. Nevertheless, biomass regrowth needs to be promoted to continue as a sustainable energy source. However, extreme usage of firewood biomass sources leads to deforestation. It has become alarming around the world by destroying natural resources. Deforestation directly effects on carbon cycle (figure 1) in a negative way. It leads to an increase in global warming and other environmental problems. Instead of using fuel wood biomass taken directly by destroying plants, alternative biomass sources can be used, such as industrial and agricultural waste [8]. The following table 3 provides some examples of alternative fuels which can use for briquettes production.

Table 3. Raw material for briquettes [8]

Origin	Examples
Agricultural waste	Coconut frods, corn stalk, Coconut Fiber (coir), Casava stalk/leaves, Rice straw, sugar cane leaves, palm oil frond
Industrial residue from agriculture	Coconut shells, Oil palm husk, Sugar cane bagasse, Paddy husk, corn cobs, Coffee husk, peanut shells
Other industrial waste	Water treatment sludge, Cotton flocks, Sewage, Sawdust, Paper waste
Other materials	Coal ash or fly ash

Even though the above alternative fuels can be used as fuels for industrial boilers, handling those in industries is not attractive. They occupy larger ground space than fossil fuels and wood biomass. Moreover, agricultural waste, sewage, or sludge handled is not an environmentally friendly process. One of a most suitable ways to handle these kinds of alternative biomass fuels is by converting them into briquettes, which take less space. Briquettes are easier to store and easier to generate thermal energy in boilers. Furthermore, it converts low-density biomass into high-density biomass briquette, providing higher calorific value [8].

The emission of gases after combustion depends on the feedstock. For example, the raw material means the feedstock's sulfur content is directly related to sulfur dioxide emission. Thus, it is important to select raw materials which have lower sulfur and nitrogen contents to reduce sulfur dioxide, and nitrogen oxide gas emissions at the combustion process.

4. COMBUSTION TECHNOLOGIES FOR BIOMASS

There are various types of combustion technologies can be used for biomass boilers, such as fluidized bed combustion, circulating fluidized bed combustion, and pulverized bed combustion. Optimum combustion technology should be selected depending on the calorific value and type of fuel. The type of combustion technology affects the efficiency of the combustion process. Hence it affects flue gas emissions [1].

4.1 Fluidized bed combustion

This method has advantages over conventional firing systems. It provides a compact design for biomass boilers, fuel flexibility, higher combustion efficiency, and reduction of noxious gas emissions such as NOx and Sox. The following Fig. 4 shows the components of the fluidized bed combustion system [9].

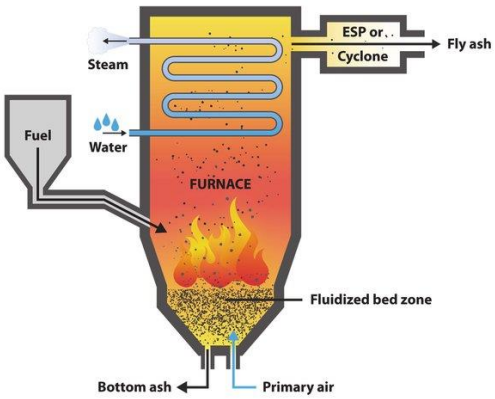

Fig. 4. Schematic of circulation fluidized bed combustion unit

4.2 Circulating fluidized bed combustion

This technology utilizes the fluidized bed principle in which crushed fuel and limestone need to be injected into the furnace of the boiler. It has a recirculating loop for increasing combustion efficiency. It has been found that this method can absorb around 95% of pollutants before being emitted into the atmosphere. It can keep a reasonably constant temperature in the furnace throughout the combustion process, which is about 870 ^{0}C due to the high circulation of solids and high turbulence. As a result, the lower NOx gas formation can be expected. If sulfur is present in the fuel, it retains the form of calcium sulfate and can be removed in solid form. Using limestone or dolomite sorbents with fuel allows a higher sulfur retention rate. Hence, SOx emissions also can be reduced with this technology. The following figure shows the main components of the circulating fluidized bed combustion process [10].

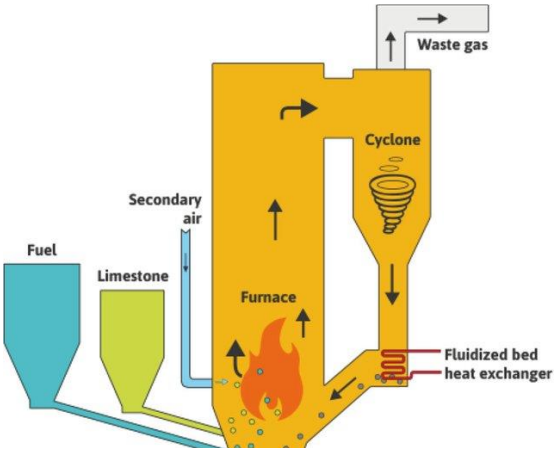

Fig. 5.Schematic of circulation fluidized bed combustion unit

4.3 Co-firing of biomass with coal

Co-firing biomass and coal can be beneficial for replacing fossil fuels, lowering fuel costs and NOx and CO2 emissions, minimizing waste, decreasing soil and water pollution, improving boiler efficiency, and

reducing water pollution. There are various types of biomass co-firing technologies used all around the world.

4.3.1 Direct co-firing

It entails feeding the boiler with a mixture made by mixing the biomass and coal in the fuel handling system.

4.3.2 Parallel co-firing

In this method, the biomass is prepared separately from the coal and injected into the boiler without affecting the traditional coal delivery method.

4.3.3 Indirect co-firing

Biomass should be gasified and burned in the boiler with coal.

Since direct co-firing allows for co-firing percentages up to approximately 3% on an energy basis without substantial investment expenses, it is the least expensive, most straightforward, and widely used co-firing approach.

A high degree of fuel adaptability may be provided by indirect co-firing, and the fuel gas may be cleaned before combustion to reduce the effect of the fuel gas's combustion byproducts on the efficiency and structural integrity of the boiler. The following figure 6 shows each technology briefly [11].

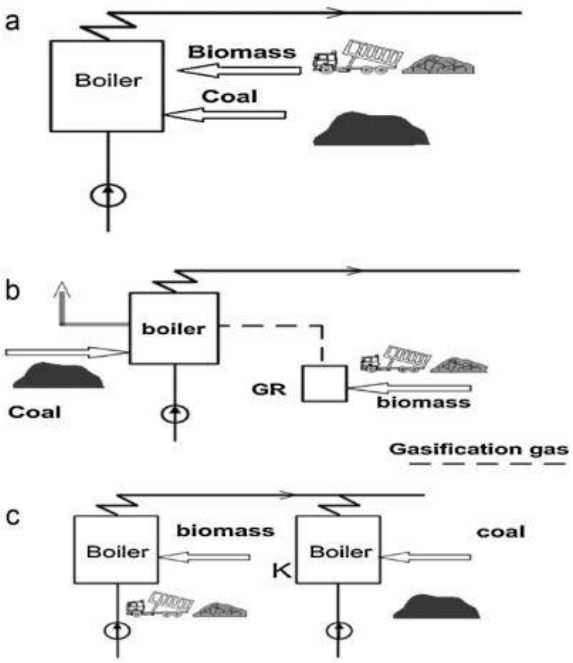

Figure 6: Biomass co-firing technologies. (a) Direct co-firing. (b) Indirect co-firing (c) parallel co-firing

Biomass co-firing technologies help to mitigate greenhouse gas emissions by decreasing CH_4 to 21 times more potent than release from the landfill biomass because CH_4 has 21 times higher potential than carbon dioxide for global warming. Moreover, co-firing decrease NOx emission by as much as 15 % [12].

5. CONCLUSION

The excessive consumption of fossil fuels has led to environmental issues, and there is a need to shift to renewable energy sources like biomass. Biomass contributes about 10-15% of world energy demand and is the primary energy source for industrial boilers in Sri Lanka. Biomass is used to generate electricity and heat, and there are traditional and modern methods of producing bioenergy. Various biomasses, including forest firewood, rice husk, palm fruit bunch, coconut shells, and bagasse, are used as fuel sources. While burning biomass can result in emissions, it is GHG-neutral compared to fossil fuels. Using renewable energy sources like biomass can significantly reduce carbon dioxide emissions and help combat climate change. Using industrial biomass boilers in Sri Lanka is crucial for meeting the energy demands of various industries. However, it is causing environmental problems such as deforestation, depletion of water resources, and CO_2 emissions.

Most industries use rubber wood as the primary source of biomass fuel, and around 400 biomass boilers operate in Sri Lanka. The biomass boilers industries include tea, food and beverages, rubber and plastic, pulp and paper, cement and concrete, wood and timber, textile, hotels and hospitals, metal and steel, and medicine and Ayurveda drugs. The biomass supply chain and government policies have contributed to the steady trend of using biomass-based thermal energy. The hospitality sector and food producers also use biomass energy in their operations. Case studies have been conducted to assess the impact of biomass boiler usage on greenhouse gas emissions. Biomass can be converted into fuel through various methods depending on factors such as the type of biomass, environmental standards, and economic conditions. Direct combustion of raw biomass can cause air pollution, and alternative sources such as industrial and agricultural waste can be used to prevent deforestation. Briquettes can be produced from these alternative sources to provide a more environmentally friendly and space-efficient way to handle them. The emission of gases after combustion depends on the feedstock used. Selecting raw materials with lower sulfur and nitrogen content can reduce sulfur dioxide and nitrogen oxide gas emissions. The combustion technology used in biomass boilers affects the efficiency and emissions of the combustion process. Three types of combustion technologies are available: circulating fluidized bed combustion, fixed bed combustion, and pulverized bed combustion. Fluidized bed combustion technology provides higher efficiency and reduces emissions of noxious gases such as NOx and Sox. Co-firing biomass and coal can replace fossil fuels, lower fuel costs and NOx and CO_2 emissions, minimize waste, improve boiler efficiency, and reduce water pollution. Three types of co-firing technologies are available: direct, parallel, and indirect.

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