

# A Conceptual Approach to Hybridize Pulverized Coal Fired Boiler with Fluidized Bed Boiler for Cleaner Power Generation

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**Abstract-** Power conversion through conventional fossil fired technology produces different pollutants in spite of use of efficient technologies like supercritical, ultra-supercritical, IGCC, FBC etc. Also, technology like, CCS, scrubber, SCR and ESP are used to capture of CO<sub>2</sub>, SO<sub>x</sub>, NO<sub>x</sub> and SPM respectively but at the cost of overall plant efficiency. Co-firing technology is another approach to mitigate pollutants. Despite the use of these methods for arresting the pollutants, complete removal is practically not possible and limited stock of fossil fuel compelled engineers, scientists and technologists to concentrate more on pollution free and sustainable renewable energy sources. But present renewable energy source cannot fulfill our total energy demand due to their low generating capability; high power cost and mostly are intermittent in nature. At this juncture hybridization of fossil fuel technology with renewable sources may be one of the alternatives technologies till complete switchover from conventional power conversion method to renewable power generation, which required further technological advancement and innovation. A new hybrid boiler is conceptualized which capable of burning large varieties of fuel ranging from wood to pulverized coal and also its own mill rejects from pulverize section. CO<sub>2</sub> generation can be reduced upto 50% per unit of power generation compare to solely fossil firing unit. NO<sub>x</sub> generation can be reduced by reducing furnace temperature through flue gas mixing, SO<sub>x</sub> can be captured by feeding CaO in fluidized section and SPM can be arrested by ESP successfully. New hybrid boiler requires techno-economical evaluation to realize in practical use with Palash Wood as main biomass fuel supported by pulverized semi-bituminous coal.

**Keywords-** Pollutants, PC, FBC, hybrid boiler.

## 1. Introduction

Industrialization along with the socio-economic development has also causes ill effect on our environment due to the continuous emission of pollutants from different industries. These pollutants, like greenhouse gases, by products or waste materials when released in our environment affect our ecosystem and causes climatic change. Power sector produce electrical energy is one of these essential sectors of industrialization. The availability of

electrical energy and its consumption per capita is the index of the living standard of people of a place or a country. Presently, 87% of electricity in the world is approximately generated from fossil fuels (coal, petroleum, fuel-oil, natural gas) fired thermal power plants, where 13% of the electricity is compensated from different energy sources [1]. Fossil fuels still meet the major part of our energy demand are getting depleted very fast. Moreover, there are serious pollution hazards like greenhouse effect and global warming which occur due to fossil fuel burning. The use of nuclear

power too has its own problems and nuclear fusion is yet to be realized in practice. Effort has also been made to mitigate the pollution emission by improving energy conversion efficiency, by pre-treatment of fuels, by post-treatment of burnt products before emitting to the environment or storing the pollutant like CO<sub>2</sub> by CCS and or by introducing new concept of energy conversion like IGCC. Emission of SO<sub>x</sub> and NO<sub>x</sub> from fossil fired power plant can be reduced with the aid of different available technologies like scrubber, selective catalytic reduction (SCR) system, Fluidized Bed Combustion (FBC) etc [2]. In spite of the above mentioned methods for arresting the pollutants, complete removal is practically not possible and limited stock of fossil fuel compelled engineers, scientists and technologists to concentrate more on renewable sources of energy like solar, tidal, wind, biomass, geothermal, hydel etc which are pollution free and sustainable or in other words an endeavor to fulfill future energy demand through clean power.

## 2. Pollutants generated in thermal power plant

Conventional fossil power generating unit produce different pollutants as byproducts during energy conversion process. The major pollutants of fossil fuel power generating system are carbon dioxide (CO<sub>2</sub>), SO<sub>x</sub>, NO<sub>x</sub> and suspended particulate matters (SPM). Several attempts have been made to mitigate the emission and as well as formation of these pollutants during coal burning in fossil fired thermal power plants through different technologies. Following are the brief description of the readily available technology to reduce the effect of pollutants from coal fired thermal power station.

### 2.1. Technology to capture pollutants

During combustion process in furnace carbon (C) is combined with oxygen (O<sub>2</sub>) to form carbon dioxide (CO<sub>2</sub>) and release heat energy of 393.8KJ/mole of carbon burning [3,4]. Coal fired thermal power plant is the main source of green house gas, which is the prime causes of global warming. Carbon capture and sequestration (CCS) is used to capture CO<sub>2</sub> but at the cost of overall plant efficiency.

During coal burning process sulphur present in the coal in the form of pyrites or fuel sulphur is converted into SO<sub>x</sub> at around 600°C [4]. Scrubber is used to remove SO<sub>x</sub>. Cost of installation, operation and maintenance of scrubber add to total generation cost and hence decrease the overall plant efficiency. Disposal of the byproducts of scrubber is another problem.

By volume around 78% of atmospheric air is N<sub>2</sub>. Atmospheric air is used for burning of coal in thermal power plant is main source of NO<sub>x</sub>. Atmospheric N<sub>2</sub> at higher temperature above 1300°C it combined with O<sub>2</sub> to form NO<sub>x</sub>. Low-NO<sub>x</sub> burner is designed to reduce NO<sub>x</sub> formation during combustion. Selective catalytic reduction (SCR) system is another method used for removal of NO<sub>x</sub>. SCR system is also raise total power generation cost leads to efficiency reduction.

Sub-bituminous coal produces 45% ash after burning. Coarser size ash particle is collected mostly in bottom ash

hopper. Fine particles of ash collected in ESPs successfully with 99.90% efficiency. Sulphur percentage in Indian coal is very much less and hence SO<sub>x</sub> emission is not big concern for Indian thermal power plant using low sulphur content coal. But SO<sub>x</sub> emission to the atmosphere in USA is main concern during power generation. NO<sub>x</sub> emission during electric power generation is common problem all over the globe and threat to the humanity and big challenge to scientists and engineers [5].

### 2.2. Advanced Firing Technology

Traditionally thermal power plants are broadly divided into three groups, subcritical and supercritical and ultra-supercritical power plant depending upon the operating pressure of the boiler with reference to the critical point, i.e., 22.09 MPa or 220.9 bar.

The typical efficiency of subcritical Rankine-cycle steam power plants is around 30 to 35%, whereas that for supercritical plants could be as high as 40%. Supercritical boilers have been used in several modified Rankine-cycle plants resulting in improved overall efficiency and therefore lower fuel consumption per unit of power generation, hence lower CO<sub>2</sub> emissions. However, the construction of supercritical boilers for PC firing is not as convenient as it is for CFB firing. For this reason, new supercritical boilers with CFB firing are being built [6]

Carbon dioxide (CO<sub>2</sub>) emission with different technologies for power generation of 600 MW coal fired plant is shown in Table-1. It is clear from the table that CO<sub>2</sub> emission decrease with increase in net plant efficiency. Hybridization of Gasifier & PFBC technology is the highest efficient technology and hence emits less CO<sub>2</sub>.

These traditional thermal power plants use either pulverized coal firing or fluidized bed firing process.

#### ➤ Pulverized Coal Fired Boiler

Pulverized coal-fired boilers have been in use for more than 50 years for subcritical or supercritical boiler plants. They can use low NO<sub>x</sub> burners to reduce NO<sub>x</sub> emissions, which again come with their own penalty of combustible loss. The NO<sub>x</sub> emission from PC boilers even with low NO<sub>x</sub> burners is higher than that from fluidized bed boilers. However, PC firing produces significantly lower emissions of the greenhouse gas, nitrous oxide than that by fluidized bed firing. Combustion efficiency of PC firing is slightly higher than that of fluidized bed firing and its combustion air fans consume less power. Presently, the capacity of PC-fired boilers is larger than that for fluidized bed firing.

#### ➤ Fluidized Bed Firing Boiler

Fluidized bed combustion though newer technology than PC firing, has proved itself on a practical use. FB boilers can burn a wide variety of fuels without a major penalty in performance. Table-2 shows the wide varieties of coal burnt in fluidized bed boiler. Higher or lower ash content coal than designed coal could cause a serious problem in PC boiler, but fluidized bed boiler can burn any coal with different ash contents. The inherent characteristics of this process allow it

to mitigate the emission of both NO<sub>x</sub> and SO<sub>2</sub> within the standard limit. Also, it does not require any pretreatment of the fuel. No additional arrangement like catalytic converters or Low-NO<sub>x</sub> burners is required to limit NO<sub>x</sub> emissions.

However, limestone is required for absorption of SO<sub>2</sub>. Hence, it produces a larger quantity of dry solid wastes and carbon dioxide. This dry solid waste can be disposed easily and inexpensively.

**Table 1.** CO<sub>2</sub> emission with different technologies [4, 7]

	Technology		Overall Plant Efficiency (%)	CO <sub>2</sub> Emission Factor (gC/kWh) for Coal
			LHV	
Conventional system	Pulverized coal	Subcritical steam	39	253
		Supercritical steam	42	216
		Ultra-supercritical	45	202
		Advance ultra-supercritical	50%	180
	AFBC	Subcritical steam	39	233
Combined cycle	IGCC	Subcritical steam	38–43	211–239
	PFBC	Subcritical steam	44	206
	Gasifier & PFBC	Supercritical steam	52	174

**Table 2.** Fuels used in Fluidized Bed Boiler [4]

Coal	Coal Residue	Petroleum Product	Gas	Wood	Agricultural Waste	Sludge	Municipal Waste
Anthracite	Washery waste	Oil	Natural	Wood	Straw	Paper mill	Garbage
Bituminous	Mill rejects	Delayed coke	Methane from cow dung	Wood chips	Husk	De-inking	Refuse derived fuel
Sub-bituminous	Anthracite Culm	Fluid coke	Off gas	Saw dust	Olive waste	Municipal	Waste paper
Lignite	Coal slurry	Oil shale	Other gases	Forest residue	Dry leaves	Gasifier fines	Shredded tires

Wide range of fuel with reduced air pollution, fluidized bed combustion is the better choice of energy conversion method. Fluidized combustion is generally of two types, circulating fluidized bed (CFB) and bubbling fluidized bed (BFB). CFB is the better choice over BFB where medium to large capacity required, better sulfur capture, NO<sub>x</sub> formation control, fuel flexibility, short start up and high availability required.

The pulverized coal (PC) fired boiler, which first appeared in 1911, was the main energy conversion system for large power generation until fluidized bed boilers appeared in the early sixties. The main difference between PC and BFB boilers lies in their furnaces design. The convective zone of the boiler, which accommodates the economizer and superheater coils, is very similar in these boilers.

NO<sub>x</sub> formation in pulverized coal power plant cannot be avoided completely even after air staging and LOW NO<sub>x</sub> burner designing. SO<sub>x</sub> can be removed with the help of scrubber which increase the installation cost of the plant. FBC combustion boiler has several advantages: wide range of fuel can burnt, higher combustion efficiency, efficient SO<sub>x</sub> removal, reduction in NO<sub>x</sub> formation till today it cannot be used for higher capacity power generation. Its combustion

mechanism is not totally clear due to the complexity and unavailable literature. Ash removal is another challenging job to the engineers working with FBC boiler. Fuel preparation particularly for biomass fuel is difficult. Availability and their collection of huge quantity of fuel required for higher generation is another problem.

*2.3. Biomass co-firing*

Biomass co-firing with lignite represents an attractive solution for operating lignite-fired thermal power plants (TPP) with the dual advantage of using local renewable resources and simultaneously reducing emissions [8]. Biomass can be fired into a coal fired unit in two ways, directly or indirectly. Direct co-firing can be achieved either by feeding the biomass with the coal when biomass percentage is less than 3% through same coal crusher or in a separate feed system when it is more than 3%. Direct co-firing systems can have detrimental effects upon boiler performance affecting thermal efficiency, slagging and fouling, plant maintenance requirements, and emissions. Indirect co-firing involves either gasify the biomass to produce syngas in a separate plant and then burning the syngas in the adjacent coal plant or firing the biomass in a separate combustor like FBC and routing the produced steam

to the adjacent coal fired plant. Direct co-feeding has the lowest co-firing capital cost and indirect co-firing the highest. Each approach has different attributes [9]. Biomass has immense potential to be fuels in future, because it is relatively abundant, clean and carbon dioxide neutral. Externally fired biomass combined cycle and combined cycle with co-firing of biomass and natural gas can be used to generate cleaner power [10]. It can be fired as supplementary fuel with natural gas fired combined cycle (NGCC) and with integrated coal gasification combined cycle (IGCC) [11]. In lignite/biomass co-firing concept pelletized biomass is pulverized with lignite or shredded biomass is pulverized in dedicated mills. Dedicated biomass milling system with dedicated biomass burners is economical despite its higher investment cost, due to the lower fuel cost of raw biomass [12]. Biomass/coal co-firing system has been proposed as a near term solution for CO<sub>2</sub> mitigation because it can be retrofitted to coal plants without major modifications [13]. In China biomass such as corn stalks, twigs, and straws are crushed and then briquetted to make suitable for milling and fed into boiler by primary air [14]. In Brazil co-firing coal with woody biomass in 600MW thermal power plants with 30% biomass can be used [15]. Carbon price and renewable energy certificates have the potential to make co-firing a cost effective option for reducing CO<sub>2</sub> emissions in Australia [16]. Co-firing system offers a near-term alternative to reduce CO<sub>2</sub> emissions from traditional fossil fuel power generating system. An incremental gain in CO<sub>2</sub> reduction can be achieved by immediate implementation of biomass co-firing system in nearly all coal-fired power plants with minor modifications and moderate investment, making co-firing a near-term solution for the greenhouse gas emission problem. If most of the coal-fired power plants operating around the globe implement co-firing systems, the total reduction in CO<sub>2</sub> emissions to atmosphere would be significant [17].

Power generation through fossil fuel firing technology cannot avoid emission of pollutants like CO<sub>2</sub>, SO<sub>x</sub>, NO<sub>x</sub>, SPM etc; FBC, IGCC technology can mitigate emission of SO<sub>x</sub>, NO<sub>x</sub>, CO<sub>x</sub> but cannot fulfill total demand due their lower generating capacity. Renewable sources of energy like solar, biomass, tidal, wind, geothermal, hydel etc which are pollution free and sustainable. But power from renewable sources alone cannot fulfill our present energy demand due to their low generating capacity, higher power generation cost and mostly are intermittent in nature. Hence it is required to search for some other alternatives for continuous power generation with low pollutant emission. Hybrid energy system, i.e., two energy system installed in one location could be the solution to ensure continuous supply with low emission. Hybrid energy system like, PV-diesel, wind-diesel, biomass-diesel, wind-PV, micro hydel-PV, biogas-solar thermal, solar-biomass etc are already operative. These hybrid systems also cannot fulfill total demand due to their low capacity.

### 3. Hybridization of pulverized coal fired boiler and FBC boiler

Though renewable power generation are sustainable and not produce any pollutants, it cannot fulfill our present energy demand due to their low generating capability, high power cost and mostly are intermittent in nature. At this juncture depleting fossil fuel consumption for power generation should be reduced and maximum utilization of renewable energy is required. Hybridization of fossil fuel technology with renewable sources may be the alternatives technology till complete changeover of conventional power conversion method by burning fossil fuel to renewable power generation.

Although the environmental advantages of using biomass and biomass wastes are well known, this source of energy is still primarily restricted to small-scale heat and power generation. The problems associated with biomass and biomass waste applications in large capacity power plants are due to the fact that this energy source as a low quality feedstock mainly characterized by high moisture content, low energy density and impurities as well as low calorific value and lack of uniformity can trigger many handling and operating difficulties. However, when these concerns are successfully addressed, biomass co-firing can become a means of reducing coal consumption and improving environmental performance. Feasibility of direct co-firing and parallel co-firing technology has already been proved for dual advantages of using local renewable resources and simultaneously reducing emission of mainly SO<sub>x</sub> and CO<sub>2</sub>. SO<sub>x</sub> can be removed by feeding lime stone (CaO) into the fluidized section. It captures SO<sub>x</sub> and is removed. Hence costly scrubber is not required. At present ESP is a successful technology to remove fine particles with 99.90% efficiency. CO<sub>2</sub> generation during biomass combustion is equal to CO<sub>2</sub> consume during photosynthesis of its life cycle from environment.

#### 3.1. Hybrid Boiler

This boiler is unique and versatile in fuel firing, capable of burning biomass, oil, mill rejects, lignite as well as pulverized coal.. Any of these single fuels can be used separately or in different combination of fuels can be fired. Boiler firing zone or furnace is divided into two parts i) fluidized and ii) pulverize firing section. Schematic of the hybrid boiler is shown in figure-1.

##### ➤ Fluidized firing section

In this section fluidized air entered into fluidize bed on which biomass fuel and or mill rejects are fed to burn. A solid fuel particle in the fluidized section passes through different stages during combustion like: heating and drying, de-volatilization and volatile combustion, swelling and primary fragmentation, combustion of char with secondary fragmentation and attrition as depicted in figure-3. Fine particles and smaller particle are burnt in the furnace zone and rest relatively higher sized fuels are burnt in the cyclone separator and where ash is also collected and come back to the main furnace through heat exchanger or directly. Heat

flux along the path of combustion products, i.e., along the height of a fluidized boiler is shown in the figure-2 in maroon color. Heat flux in this section is much more uniform along the path of combustion products than that of a

pulverized firing boiler. Maximum furnace temperature in this section is observed around 1200°C.

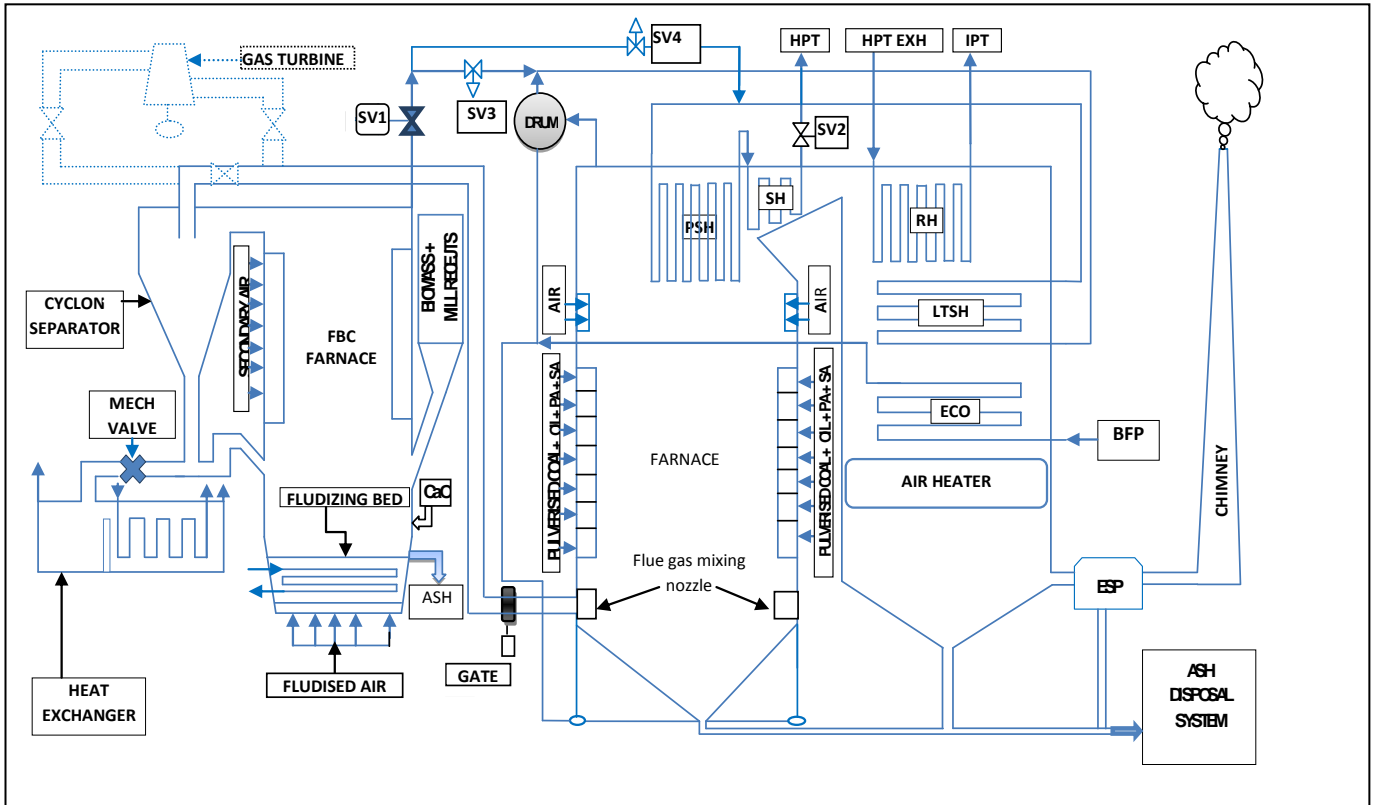


Fig. 1. Schematic of Hybrid Boiler

➤ Pulverized firing section

This section is same as corner fired pulverized boiler. Pulverized coal from pulveriser is fired in this section tangentially to form a cylindrical fireball in the centre as shown in figure 4. Secondary and tertiary air is supplied through a set controlling damper for complete combustion of the pulverized coal. Heat flux in the solely pulverized firing boiler along the path of combustion products is not uniform as depicted in figure-2 in blue color. Time required for burning of pulverized coal around two seconds [4]. Combustion products moved around 20m above the firing initiation area, (i.e. burner tip) in two seconds. Hence maximum heat observed at 20m above the coal burner position in the pulverized section.

Flue gas comes out of fluidized section and entered into the pulverized section through typically designed mixing nozzle to mix with flue gas. The flue gas in the pulverized section gets diluted and combined heat flux pattern got changed. Maximum heat flux at height around 20m reduced. Flue gas from fluidized section the hybrid boiler at around 300-350°C is introduced in the PC section at the bottom from all four side of the boiler. Maximum temperature in the furnace of the PC firing section is in the order of 1400-1600°C. After mixing with flue gas of temperature around 300-350°C from FB firing section furnace temperature expected to be decreased to 800°C. Nitrogen (N<sub>2</sub>) present in

combustion air oxidizes only at a temperature above 1400°C to form NO<sub>x</sub>. Hence chance of NO<sub>x</sub> formation in this pulverize section could be drastically reduced.

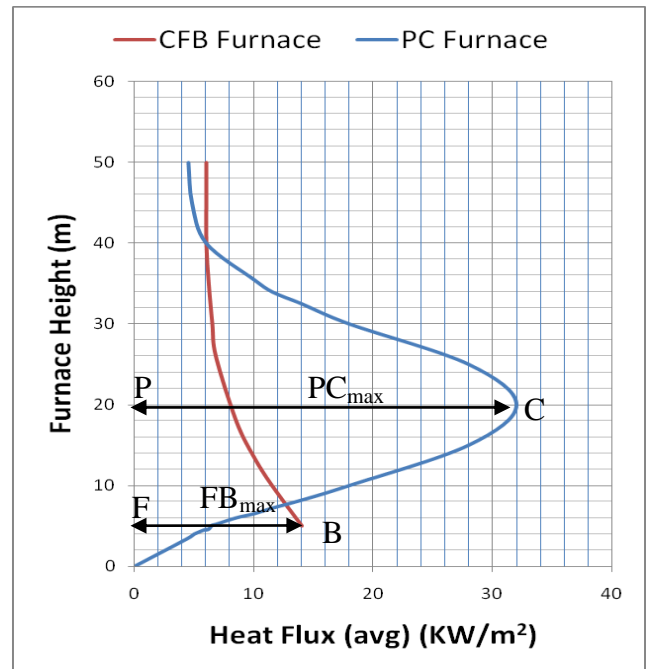
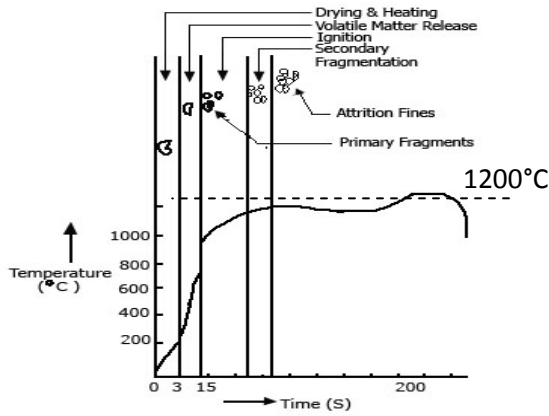


Fig. 2. Heat Flux in a PC and CFB boiler [4]

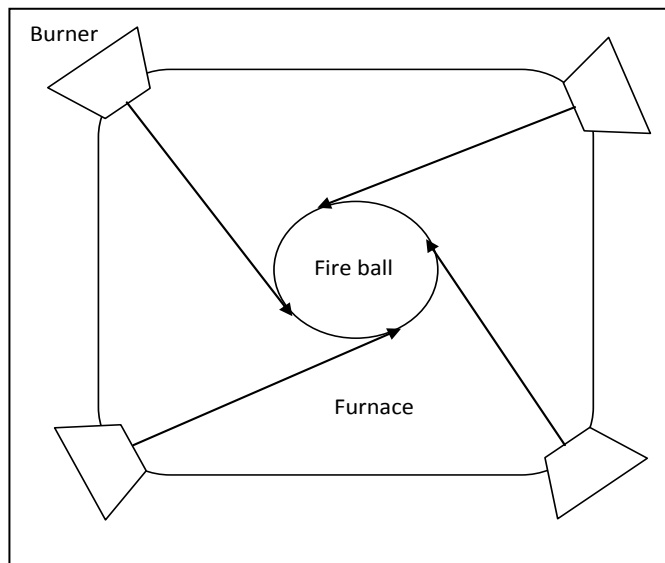


**Fig. 3.** Different stages during combustion of a coal particle [4] in FBC boiler

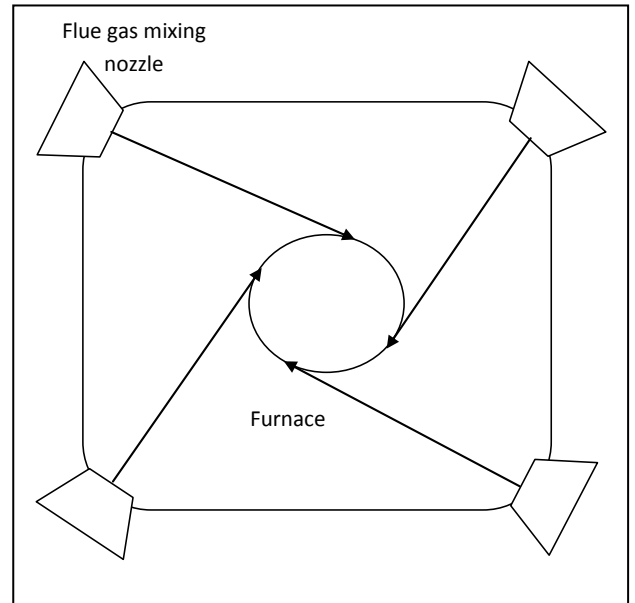
➤ Flue gas mixing nozzle

Flue gas comes out of fluidized section through typically designed flue gas mixing nozzle entered into the pulverized section to mix with flue gas of pulverized section. Burner tips are arranged at angle called firing angle to form an imaginary cylindrical fire ball rotating anti-clock wise direction as shown in the figure-4. Flue gas from fluidized section passes through flue gas mixing nozzle increase the velocity and form a rotating ball of lesser diameter than that of above fireball in clockwise direction for generation turbulence in the above firing zone as shown in figure-5.

In the radiant zone pendent super heater is installed and heat is absorbed by radiation only. Final super heater is placed in goose neck area where heat is absorbed through radiation as well as convection. Economizer and low temperature super heater final super heater are placed in the second pass. Reheater is placed in between final and economizer where heat transfer takes place through radiation as well as conduction. Heating surface area should be placed such that heat transfer by convection and radiation balance theirs opposite effects during unit load changing.



**Fig. 4.** PC coal burner arrangement



**Fig. 5.** Flue gas mixing nozzle

➤ Mixing of Steam

Steam from fluidized section will be introduced in pulverized section into saturated steam after drum before low temperature superheater, between low temperature super heater and platen superheater or between the platen superheater and final superheater depending upon the steam conditions, i.e., pressure and temperature of both sides. It is always required higher pressure steam to be generated in fluidized section than the steam of pulverized section of boiler, which ensures flow of steam from fluidized section to pulverize section. This difference in steam temperature causes generation of entropy i.e., destruction of exergy or loss of available work.

3.2. Palash Wood as Biomass Fuel

New hybrid boiler is required to be techno-economically evaluated to realize in practical use with Palash Wood as a main biomass fuel supported by pulverized semi-bituminous coal and it will be the promising power generation technology in the plateau of West Bengal, Jharkhand and Odisha in India or any region where biomass farming is possible. In this region in India around 80% people considered wood mainly Palash wood as primary fuel for household use like cooking meals, rice preparation from paddy etc. In this process only 8-10% of the heat is utilized. This wood can be used in this boiler with 85% efficiency or total plant efficiency of around 40% saving 30% of lost energy.

4. Conclusion

Though renewable power generation are sustainable and does not produce any pollutants, it cannot fulfill our present energy demand due to their low generating capability, high power cost and mostly are intermittent in nature. At this juncture depleting fuel's consumption should be reduced and maximum utilization of renewable energy is required. Hybridization of fossil fuel technology with renewable

sources may be the alternatives technology till complete changeover of conventional power conversion method by burning fossil fuel to renewable power generation.

A new hybrid boiler is conceptualized which is capable of burning wide varieties of fuel ranging from wood to pulverized coal and also its own mill rejects. SO<sub>x</sub> can be captured by feeding CaO in fluidized section. NO<sub>x</sub> formation can be minimized by lowering furnace temperature through flue gas mixing. In biomass fuel burning CO<sub>2</sub> generated is equals to CO<sub>2</sub> consumed during photosynthesis of its life cycle. This hybrid boiler expected to be share maximum 50% of total fuel, hence, effective CO<sub>2</sub> emission per unit of power generation is reduced up to 50%. ESP is used to capture fine suspended particulate matter. The new hybrid boiler is required to be techno-economically evaluated to realize in practical use with Palash Wood as main biomass fuel supported by pulverized semi-bituminous coal, will be the promising power generation technology in the plateau area of West Bengal, Jharkhand and Odisha or any region where biomass farming is possible.

Further scope of work: This boiler can be used to produce combustible gas which can be expanded in the gas turbine for producing electricity with higher plant efficiency. Feed water heater by extraction steam from different stage of turbine can be replaced by solar thermal panel, which requires techno-economical evaluation and in-depth research and analysis before realizing it in practical application.

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