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A computational and analytical study of the effect of different coal kinds on combustion characteristics in coal-fired boilers

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ABSTRACT

There is a negative correlation between the quality of coal and the efficiency of coal-fired power plants. One environmental hazard created by low-quality coal is its poor combustion properties, which leads to ash accumulation. The paper detailed the findings from a computational fluid dynamics (CFD) investigation of a huge furnace's combustion and flow operations. Three different sub-bituminous coals, A, B, and C, were tested. To predict the efficiency of the coals' combustion, we monitor the temperature, species concentration, and flow rate of the furnace. In order to optimise the mesh, the operator supplied the exact boiler furnace geometry, which was then transformed into a computational fluid dynamics (CFD) model. Coal B had the highest combustion temperature, at around 1400°C, according to the analysis. For particular furnace zones, coal C is expected to have the biggest velocity peak and the shortest flame duration, therefore more flow is required to achieve the same penetration as other coals. The trace of the furnace's oxygen concentration demonstrates optimal combustion. Coal A feeds the back pass, which has almost little oxygen left.

Introduction

One of the fundamental requirements of our species is a steady supply of clean energy that is also reasonably priced. In order to reduce emissions of greenhouse gases—which include water, carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and aerosols—our energy supply system is now experiencing a long-term shift from its traditional form to a more sustainable and low-carbon one. The average global temperature and atmospheric CO_2 concentration have both risen sharply since the beginning of the industrial revolution, and there is strong evidence to imply that these two variables are highly connected. Anxieties about global warming has prompted a surge in research and development into methods to lessen the impact of human-caused carbon dioxide emissions. A combination of increased use of nuclear power and renewable energy sources including hydropower, solar power, wind power, and geothermal power, as well as carbon capture and sequestration (CCS), might be the technological answer to this issue.

Due to its plentiful reserves and relatively cheap pricing, coal has been and will be one of the key energy resources in the long run, particularly for base-load power production. Example: in 2009, coal accounted for 29.4 percent of global energy consumption, but oil and natural gas each contributed 34.8 and 23.8 percent, respectively. Coal is still the most used fuel for power production; in 2009, it produced over 45% of the nation's energy and nearly 80% in China. One way to lessen the carbon dioxide (CO2) emissions caused by coal-fired power plants is to use post-combustion capture, another is pre-combustion capture, and a third is oxy-fuel combustion capture:

In pre-combustion capture, the fuel is transformed into syngas—a combination of hydrogen and carbon monoxide—by gasification or reforming. Then, it is shifted using steam reforming. Following this, the syngas is refined by removing CO2 via a steam-switched carbon monoxide reaction, which produces pure hydrogen (the water gas shift process). One kind of system that captures gas before combustion occurs is the Integrated Gasification Combined Cycles (IGCC) used for coal.

Without modifying the combustion process, post-combustion capture uses chemical solvents, sorbents (such calcium oxide or carbon fibres), and membranes to remove CO2 from flue gases. The solvent regeneration process requires a significant amount of low-pressure steam, which may be altered by including a post-combustion capture unit into the steam cycle.

• Oxy-fuel combustion: This method drastically alters the combustion process by substituting pure oxygen (O2) or a combination of O2 and recycled flue gas for air as the oxidiser, resulting in product gas with a high concentration of CO2. As an additional oxy-fuel combustion method, Chemical-Looping Combustion (CLC) uses metal oxides to provide combustion with pure oxygen instead of air, hence eliminating the need to combine CO2 and N2.

For more information about CLC, the reader is directed to the source, since this technology is not the main subject of this study.

Generally speaking, the aforementioned technologies can be used to produce energy from coal and natural gas, with the exception of certain low-rank coals that pose unsolved technical challenges. However, this study mainly focusses on pulverised coal combustion because of its significant role in base load electricity generation and its contribution to CO2 emissions. Other fuels are also mentioned.

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Table1-1.Representativeperformanceandeconomics dataforthethreemaincapturetechnologies,

Performance	Supercritical PC[a]		SC[b] PC-Oxyfuel	IGCC[c]	
	w/o capture	w/ capture	w/ capture	w/o capture	w/ capture
Generating efficiency	38.5%	29.3%	30.6%	38.4%	31.2%
Efficiency penalty	CO_2 recovery (heat): -5%		Boiler/FGD: 3%	Water/Gas shift: -4.2%	
	CO_2 compression: -3.5%		ASU: -6.4%	CO_2 compression: -2.1%	
	CO_2 recovery (power): -0.7%		CO_2 compression: -3.5%	CO_2 recovery: -0.9%	
			Other: -1%		
Capital Cost ($/kWe)[e]	1330	2140 (1314)[d]	1900 (867)[d]	1430	1890
COE (c/kWh)[e]	4.78	7.69	6.98	5.13	6.52
Cost of CO_2 ($/t)[e]	40.4		30.3	24.0	

PC: pulverized coal; b SC: supercritical; c IGCC: A mixed cycle that integrates gasification; d The anticipated capital expenditure for upgrades is shown by the figures in brackets; e Using the Consumer Price Index (CPI) inflation rate for 2005$, this is based on design studies conducted between 2000 and 2004, a time of stable costs. Efficiency in power production, capital expenses, and costs of electricity (COE) have all been included in analyses of these three main carbon capture methods for coal-fired power stations. Table 1-1 compares the economic performance and energy efficiency of several technological solutions. In both the rebuilt and retrofitted scenarios, these estimations are predicated on a CO_2 collection rate of 90%. The price of carbon dioxide (CO2) is the price paid to collect one metric tonne of carbon dioxide, excluding the price of transportation and storage. There may be some differences in the exact percentages between the research, but the general tendencies are consistent. While post-combustion capture has the lowest COE and highest CO2 costs, oxy-fuel capture and pre-capture/IGCC have the lowest costs and the highest CO2 emissions. However, all three capture systems have an efficiency penalty. Comparing IGCC technology to oxy-fuel combustion technology, the former produces more efficient generation at a somewhat cheaper cost. But, there is a lot of room for improvement as all of these technologies are still in their early stages of development. For the purpose of retrofitting current coal-fired power plants—which now possess the greatest potential for CCS—oxy-fuel combustion has emerged as the most competitive technological solution, according to these research. Despite a fall in the number of coal power generating units constructed during the 1990s, a boom in the construction of new coal power plants has been seen in the last few years. In addition, the majority of the current coal-fired power capacity—98.7 GW or 29%—was constructed after 1980. In emerging nations like India and China, where coal power generating capacity has been increasing rapidly over the last 20 years, this problem is much more pronounced. It is reasonable to expect that retrofits would significantly decrease CO2 emissions from current facilities. Reusing much of the plant's equipment is a natural benefit of oxy-fuel combustion systems when upgrading existing PC power plants. You can see the benefits of oxy-fuel combustion as a retrofit technique in Table 1-1 as well. Compared to post-combustion retrofits ($1314/kWe) and newly-built IGCC plants ($1890/kWe), the capital cost of oxy-fuel supercritical PC retrofits is $867/kWe. Atmospheric oxy-fuel combustion systems are a cost-effective option for carbon capture due to its cheap retrofit capital investment and minor efficiency penalty. In the United States Department of Energy's FutureGen 2.0 initiative, it has lately replaced the original IGCC design. Prior research has examined its features and basics, as well as current advances in demonstration plants at the pilot and commercial scales. Despite its success, the technology isn't without its flaws. Some of them include air leaking into the flue gas system, poor energy efficiency, inefficient air separation, and a lack of facilities for flue gas clean-up and plant integration. Specifically, the combustion process is anticipated to provide considerable obstacles, such as stability and emissions, burner design and scalability, and identifying optimum operating conditions. The Use of Oxy-Fuel in CCS Creation of Oxy-Fuel Technology for Carbon Capture and Storage It wasn't until 1982 that the concept of using oxy-fuel operations in conjunction with flue gas recycling in coal-fired power stations was first suggested as a way to reduce CO2 emissions and/or generate concentrated CO2 for EOR. In response to these suggestions, ANL was an early adopter of studying this process in the 1980s, when they zeroed down on the system and how it burned. A renaissance in interest in this technique occurred in the 1990s as more and more scientists came to the conclusion that this system works in tandem with the two other main methods for capturing carbon dioxide.Several institutions

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and industrial parties have made significant contributions to our knowledge of this process via their research, including the International Flame Research Foundation (IFRF), CANMET, and IHI. Development of air-like oxy-coal technology is accompanied by the construction of pilot and large-scale demonstration facilities globally.In their compilation of the historical evolution of this technology, Wall et al. evaluated research on oxy-fuel technology from pilot-scale testing to industry-scale tests and full-scale demonstrations.The world's first 30-megawatt demonstration plant was commissioned in Germany in 2008, marking a significant milestone in the energy sector.According to Tables 1-2, which are based on the research of Wall et al. and Herzog, more large-scale trials using coal-fired boilers are either planned or already ongoing.More widespread commercial deployment is anticipated as a result of successful completion of these demonstrations. There has been a lot of recent effort to enhance the economics, environmental performance, and energy efficiency of this technology by expanding the range of operating conditions of oxy-coal combustion. For example, oxy-syngas combustion in conjunction with solid fuel gasification technology and oxy-coal combustion using recycled flue gases are both suggested to be executed in pressurised systems.In the sections that follow, these methods are explained in greater depth.

Combustion Systems for Atmospheric Oxy-Coal Using FlueGasRecycle

As a temporary fix to modify existing coal-fired power plants to accommodate the possibility of CCS, the atmosphericoxy-coal combustion system (Figure 1-1) was first proposed.Researchers in mostoxy-coal system studies use recycled flue gases with different recycle ratios to regulate the combustor flame temperature; this produces flue gas mainly composed of steam, which is subsequently condensed, and purified carbon dioxide, which is then compressed and sequestered.When compared with air-fired systems, the extra equipment needed is outlined below:

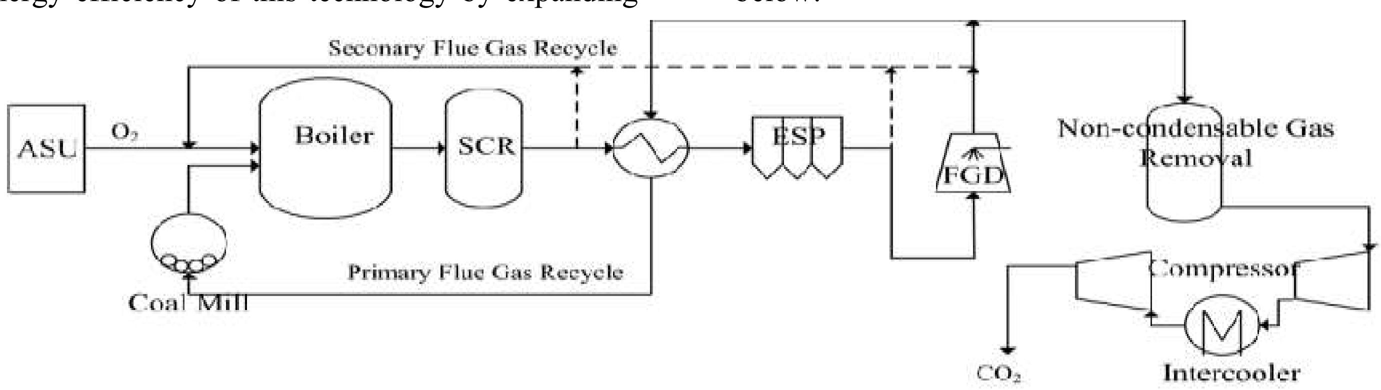

Figure 1-1. Atmospheric oxy-coal combustion system with flue gas recycle proposed for carbon capture in coalpower plants.

With the exception of an air separation unit (ASU) that produces an oxygen rich stream for combustion, the system mostly employs existing equipment for retrofitting existing PC power plants.At now, cryogenic distillation is the only ASU technology capable of satisfying the volume and purity requirements of a large-scale coal-fired utility boiler. In order to split air into two streams, one rich in oxygen and the other in nitrogen, the air is compressed, cooled, and cleaned before being put into the distillation column.With a 95% oxygen purity, cryogenic air separation uses around 0.24 kWh/kgO2.Cryogenic separation operations may use over 15% of the gross power production, even though the oxygen purity requirement for oxy-coal combustion is lower (85~98%) than in the process industry (99.5~99.6%) [39].

In order to prepare flue gas for sequestration, the Carbon Dioxide Purification Unit (CPU) uses gas clean-up equipment to extract water, particulate matter, and other polluting gases. The methods of removing NOx, PM, and SOx from the fluegas usually include selective catalytic reduction (SCR), electrostatic precipitator (ESP), and fluegas desulphurization (FGD) because oxy-combustion is compatible with retrofits.Post-combustion capture plants may also benefit from this technology when used in combination with amine-type absorbents.

Everyone knows that non-condensable pollutants, such ozone, may cause pipeline corrosion while being transported, which makes people wonder whether the storage locations are safe. Hence, it is necessary to use a non-condensable gas purification unit to remove non-condensable gases such as Ar, N2, and O2 once acid gases like SOx and NOx have been removed.The inert gases are removed by means of interstage cooling in the multi-stage compression units that make up this unit. The necessary purity of CO2 for storage and sequestration remains an open question at the time of this assessment. To be sure, there is a trade-off between the operational expenses and efficiency losses that occur during purification and the safety standards of transit and storage that determine the permissible degree of purity of the store-ready CO2.

The FGR System for Reusing Flue Gas:To control the combustion temperature, recycled flue gas is needed.There are many areas downstream of the economiser where wastewater may be recycled, either wet or dry, depending on the system efficiency and operating standards. Research on oxy-coal systems began with lax standards for CO2 purity and a lack of urgency to implement desulfurization and de-NOx measures. Consequently, the plan was to collect all of the flue gas, whether it was dry or wet, from a single spot downstream of theESP. Afterwards, in an effort to improve energy efficiency, Dillon et al. suggested separating flue gas recycling into two streams: primary and secondary. Primary stream recycling requires drying and reheating to 250–300 oC in order to remove moisture from coal feed, while secondary stream recycling can be done at higher temperatures without drying.

temperature changes that occur during chilling and reheating should be eliminated.

Flue gas recycling systems now include pollution control equipment due to more stringent requirements for CO2 purity during pipeline transmission and storage.For medium and high sulphur coal, the primary recycle must be at least partly desulphurized to prevent corrosion in the coal mill and fluegas pipes, as SO2 concentration in the flue gas may build up owing to the flue gas recycling, leading to a concentration that is two or three times greater than in traditional air-firing systems.

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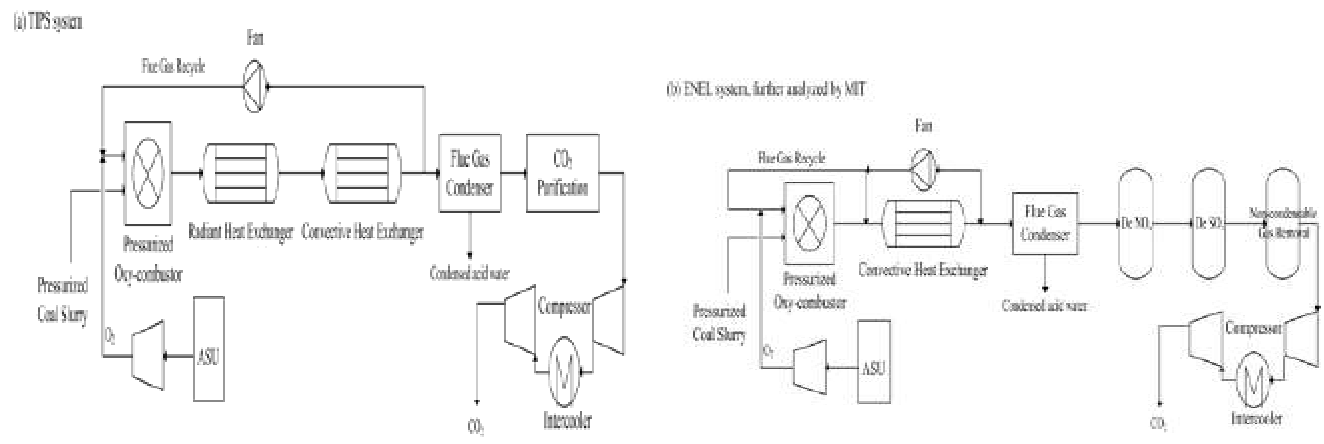

Pressurizedoxy-coalcombustionsystemsproposedforcarboncaptureincoalpowerplants,

a)SchematicoftheThermoEnergyIntegratedPowerSystem(TIPS),(b)SystemproposedbyENELbasedona combustionprocesspatentedbyITEA,

Pressurized Oxy-Coal Combustion Systems Pressurizedoxy-fuelcombustionsystemshavebeenproposedrecently,withtheobjectiveofimprovingtheenergyefficiencybyrecoveringthelatentheatofsteaminthefluegas.Thefluegasvolumeisreducedunderelevatedpressure,whichresultsinsmallercomponentsandpossiblereductionsincapitalcostforthesamepoweroutput.Severalstudieshavereportedonthetechnicalandeconomicfeasibilityofthisprocess,allconcludingthattheoverallprocessefficiencyimproveswithincreasingoperatingpressure.Thisismainlybecauselatentheatrecoveryfromthefluegasesbecomes possible at higher temperatures. Other potentialadvantagesofpressurizedoxy-fuelsystemsarethereductionoftheauxiliarypowerconsumptionsuchastherecyclefanwork,andtheeliminationofairingressintothesystem.However,therearechallengesassociated with combustion and heat transfercharacteristicsatelevatedpressures,andhencetheburners, steam/gas FURNACEs and condensingFURNACEsmustbe redesigned.

Figureillustratestwodifferentpressurizedoxy-coalcombustionsystemsproposedintheliterature.Oneofthe first designs is the Thermo Energy Integrated PowerSystem (TIPS) proposed and studied by CANMET andBabcockpower.Thissystem(Figure1-2a)usesapressurized combustion unit and FURNACEs, as well asa flue gas condenser (FGC). Downstream of the radiatedboilerandconvectiveFURNACEs,steam inthefluegases is condensed in the FGC, where most of the latentheat in the flue gas is recovered by the feed water in thesteam cycle. The rest of the flue gas, which is essentiallyCO2, is purified and compressed to the sequestrationspecifications. In contrast, the hot flue gases from thepressurized combustor is quenched to about 800 ºC bythe recycled cold flue gas, eliminating the need for aradiant FURNACE and thus incurring a lower capitalcost. It should be noted that in these pressurized oxy-coal systems coal is fed in the form of coal- water slurry(CWS). Since the pressurized system takes advantage ofthelatentheatrecoveryfromthesteaminthefluegas,

using a coal-water slurry does not significantly decreasetheoverallenergyefficiency. Forthepressurizedoxy-fuelpowerplantswithCO2enrichedfluegasstreams,desulphurizationandNOxremoval solutions have been proposed with potentiallylowercostandhigherenergyefficiency,usingleadchamber chemistry and nitric acid chemistry at elevatedpressures. For instance, Air Products utilizing two highpressurecountercurrentreactiveabsorptioncolumns(see Figure 1-2 (b)) combines them into a single highpressure column to remove SOx as H2SO4 and NOx asHNO3.BothsolutionsclaimtohavesignificantlyreducedthecostofCO2purificationwiththelatterhavinganadvantageintermsofreducedpowerconsumptionand capitalcost.

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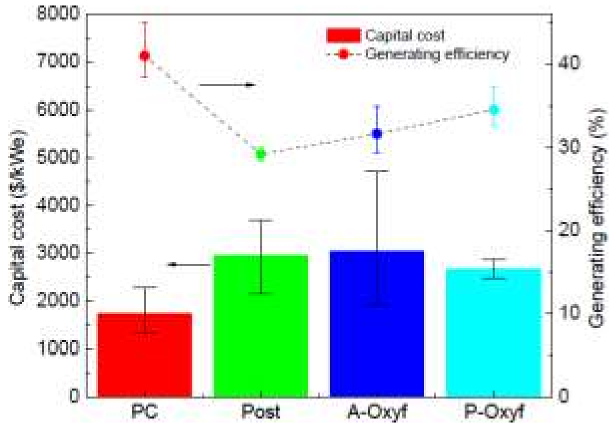

EnergyEfficiencyPerformanceoftheOxy-CoalCombustionSystems

An important question to address at this juncture is thecomparativeperformanceoftheatmosphericandpressurizedoxy-fuelcombustionsystemsdescribedabove. Figure 1-3 shows the capital expenditure ($/kWe)and efficiency (HHV%) of these systems for newly-builtpowerplants,comparedtotheperformanceofsupercriticalpulverizedcoalsystemswithoutcaptureand with post-combustioncapture.. Forinstance, fueltype,sizeandconfigurationofthepowerplants,percentageofCO2captured,andparametersofthesteam turbine, etc. Allowing for differences in modellingassumptions, the results from these studies are averagedin Figure 1-3, with the minimum and maximum valuesshown as error bars; and they should only be comparedqualitatively.

System efficiency estimates showed a loss of about 10-15% percentage points when post-combustion capture isadded to the base case PC power plant. On the otherhand,theatmosphericoxy-fuel combustionshowsanadvantage of 1-5 percentage points when compared withpost-combustion capture; while the pressurized systemgains a further 3 percentage points efficiency. The mainadvantage of pressurized oxy-fuel system is the highersaturationtemperatureofwater at elevatedpressures,which enables more thermal energy recovery and therecuperationoflatententhalpy,asstatedpreviously.AlthoughthepowerconsumptionoftheASUishigherin the pressurized combustion system, the power savingsin the CO2 compression unit and in the recycled flue gascompressorisevenhigher,culminatinginabetteroverallefficiency.

CFD Modeling of Pulverized Coal CombustionandtheChallengesunderOxy-FuelConditions

Overview

CFD techniques have become the third dimension in fluid dynamics and combustion studies alongside analytical modeling and experimental diagnostics. CFD provides a relatively inexpensive (when sub models are used in connection with Reynolds-averaged Navier- Stokes (RANS) or when using coarse grain large-eddy simulation (LES) models) and indispensable tool to perform comprehensive studies on the fluid flow, heat transfer and chemical reactions in combustion. Currently, CFD modeling of oxy-coal combustion utilize approaches and sub-models that are similar to those developed under air-fired conditions. With the accumulated knowledge on the fundamental differences between air-fuel and oxy-fuel combustion, some effort has gone into developing and validating sub-models for the new combustion environment. A selection of the CFD simulation studies on oxy- fuel combustion is summarized in Table 2-1, which includes the sub-models used for turbulence, radiation heat transfer, char combustion and homogenousreactions. Since the existing sub-models were developedfor conventional air-coal combustion, their assumptionsand approximations may not be valid in the CO2-richenvironment. In the following sections, the developmentof CFD sub-model for an accurate prediction in oxy-coalcombustion is reviewed, and the findings of these recentnumericalstudiesaresummarized.

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Table2-1.SummaryofCFDsimulationsandtheirsub-modelsforoxy-fuelcombustion.

Author	Simulated object		Modeling approaches					
	Facility	Fuel	Code	Turbulence	Radiation	Char Combustion	Homogeneous Reaction Mechanism	Chemistry-Turbulence
Wang et al. [28]	BCL Subscale combustor	Wage coal	1-DICOG (1-D)	N/A	Zone Method [128], transparent gas	$C+O_2$ $C+CO_2$ $C+H_2O$	Vilatiles combustion	Chemical Equilibrium
Khare et al. [129]	IHI 1.2 MWth vertical pilot scale test facility	Coal A	Fluent	$k-\varepsilon$	P-1 WSGG	$C+O_2$	Volatiles combustion	Chemical Equilibrium
Nozaki et al. [77]	IHI 1.2 MWth horizontal combustion test facility	Coal A/B	VEGA-3	$k-\varepsilon$	Multi-flux Radiation model [130] Three-gray-gas model	$C+O_2$ $C+CO_2$ $C+H_2O$ [131]	Volatiles combustion	EBU
Chui et al. [132]	CANMET 0.3 MWth VCRF	Western Canadian sub-bituminous coal	CFX-TASCflow	Standard $k-\varepsilon$	N/A	$C+O_2$	Volatiles combustion	EBU
Rehfeldt et al. [78]	E.ON 1 MWth horizontal firing facility and IVD 500 kWth down firing facility	Tselentis coal and Lausitz lignite coal	Fluent	Standard $k-\varepsilon$	DO	$C+O_2$ $C+CO_2$	N/A	N/A
Toporov et al. [133]	RWTH Aachen U test facility	Rhenish lignite	Fluent	$k-\varepsilon$	DO WSGG	$C+O_2$ $C+CO_2$ $C+H_2O$	Volatile breakup CO and H_2 burning [134]	Finite Rate/Eddy Dissipation
Chen et al. [62]	ISOTHERM PWR® 5 MWth pressurized test facility	Bituminous coal	Fluent	Realizable $k-\varepsilon$ $k-\omega$	DO WSGG	$C+O_2$ $C+CO_2$ $C+H_2O$	Modified JL	Finite Rate/Eddy Dissipation
Andersen et al. [135]	100 kW down-fired furnace [68]	Propane	Fluent	Realizable $k-\varepsilon$	P-1	N/A	WD [136] and Modified WD [135], JL [137] and Modified JL [135]	EDC
Vascellari et al. [138]	IFRF 2.4 MW furnace	Gottelborn hvBp coal	Fluent	Standard $k-\varepsilon$	P-1	$C+O_2$ $C+CO_2$ $C+H_2O$	Volatile decomposition, tar partially oxidation, Modified JL [139]	EDC
Muller et al. [140]	IFK 0.5 MWth test facility	Lausitz lignite	AIOLOS	Standard $k-\varepsilon$	DO Leckner's model [141]	$C+O_2$ $C+CO_2$ $C+H_2O$	JL [137]	EDC
Nikolopoulos et al. [142]	330 MWe PC boiler in Meliti power plant, Greece	Lignite from Achlada mine	Fluent	Standard $k-\varepsilon$	DO EWBM	$C+O_2$ $C+CO_2$	Volatile combustion and CO burning	Finite Rate/Eddy Dissipation
Edge et al. [143]	0.5 MWth Air- and oxy-fired combustion test facility with Doosan Babcock triple-staged low-NOx burner and IFRF Aerodynamically air-staged burner	Coal A and B	Fluent	RNG $k-\varepsilon$ and LES	DO WSGG/FSK	NA	Volatile combustion and CO burning	EDM

In 1999, Eaton et al. introduced a new version of combustion models.The models typically rest on the basic conservation equations of mass, energy, chemical species, and momentum, and the closure problem is addressed by turbulence models like the k−ε, combustion models like Arrhenius, radiative transfer models based on the Radiative Transfer Equation (RTE), and models for devolatilization and combustion of solid and liquid fuels.

In a large-scale laboratory furnace, Abbas et al. (1993) detail an experimental and projected evaluation of the impact of coal particle size on NOx generation in a swirl-stabilized burner.Under the same operating circumstances, three particle size distributions of high volatile coal were fired: 25, 46, and 121 µm average size.Along with the supplementary anticipated investigations, the results reported here include precise in-flame measurements of gas temperature, gas species concentrations of CO, CH4, O2, NOx, HCL, NH3, particle burnout, and "on-line" N2O. The experimental data agrees well with the projected outcomes. Predicted values for each percentage are greater, indicating a constraint in the NOx reduction processes utilised in the model, even if the NOx emission patterns with particle size are identical.The NOx generation was calculated using three mechanisms: heat, fuel, and quick. The coal combustion process in a 350 MW front-wall pulverised coal fired utility boiler with 24 swirl burners mounted at the boiler front wall was analysed by Xuetal. (2000) using the CFD code.Five distinct scenarios were modelled, each with a boiler full load of 100%, 95%, 85%, 70%, and 50%.The models and method used in the calculation were validated by the comparisons, which showed high agreement between anticipated and measured outcomes in the boiler for all but one example.

In order to simulate three-dimensional turbulent reactive flows and coal burning, Lietal.(2003) numerically examined the combustion process utilising a two-fluid model (rather than the Eulerian gas - Lagrangian particle models). An improved two-phase turbulence model and a second-order moment (SOM) reactive rate model were suggested to enhance the flow field and NOx generation simulations. By simulating NOx generation during methane-air combustion using the suggested models, we were able to compare our prediction findings to those obtained using simply the presumed-PDF (Probability Density Function)-finitereaction-rate model or experimental data. A double-air-register swirl-pulverized-coal burner's NOx production and coal combustion were both predicted using the suggested models. A pulverised coal concentrator, when placed in the burner's main air tube, significantly alters coal combustion and NOx generation, according to the findings.

Kurose et al. (2004) conducted a numerical study that detailed the combustion processes in a furnace using a low-NOx burner, CI-α, by applying a three-dimensional simulation to the powdered coal combustion field. We also looked at the validity of existing NOx generation and reduction models. The findings demonstrate the formation of a circulation flow in the high-gas-temperature area close to the CI-α burner outlet,

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which increases the residence time of coal particles in this region, facilitates the evolution of volatile matter and the char reaction process, and creates an extremely low-O2 region for effective decrease of NO.
Using an algebraic unified second-order moment (AUSM) turbulence-chemistry model to analyse the influence of particle temperature variation on charcoal combustion, Zhangetal.(2005) provided a numerical inquiry on the coal combustion process.The EBU-Arrhenius volatile and CO combustion model, the six-flux radiation model, the $k - \varepsilon - k$ p two-phase turbulence model, and the gas-particle fluxes in coal combustion were all simulated using the AUSM model.Since the latter completely removes the impact of particle temperature variation on combustion rate, the simulation results show that the AUSM char combustion model performed well.
Developing a CFD model for the combustion of flow-grade lignite and characterising the combustion process in the test furnace were the goals of the study by Bosoaga et al. (2006). The researchers ran a number of computations to predict the effects of coal particle size, lignite moisture content, combustion temperature, and the operation of the support methane flame on the furnace's performance and emissions.The implications of decreased fuel usage and CO2 emissions were investigated by modelling the action of lignite predrying. Findings show that NOx tend to decrease with increasing moisture and significantly rise with methane support flame.
A further study by Backreedy et al. (2006) used experimental and theoretical analysis of the coal combustion process to forecast how pulverised coal would burn in a 1 MW test furnace.A low-NOx swirlburner with three stages is housed in the boiler. In order to determine NOx and the amount of unburned carbon-in-ash, numerous simulations were conducted using different kinds of coal. The latter served as a sensitive test for the char combustion model's accuracy.Fuel-NO, thermal, and quick mechanism halt prediction of NO generation on combustion processes are all part of the NOx modelling.
In a 210 M Weboiler that was burned tangentially, Kumar and Sahur (2007) used the commercial code FLUENT to study the influence of the burner tilt angle.Consequently, they demonstrated how the tilt angle affected the temperature profiles along the boiler and the residence times of the coal particles.
Additionally, Asotani et al. (2008) investigated the igniting behaviour of powdered coal by means of the code FLUENT.a 40 MW commercial tangentially fuelled boiler using alclouds.The validity of the findings for unburned carbon in ash and output temperature were confirmed by the operational data and the design parameter, respectively.Using footage from a high-temperature-resistant video camera system, we conducted an aqualitative assessment of the temperature and ignition behaviour outcomes in the area around the burners.
Choi and Kim (2009) used the code Fluent to explore the features of flow, combustion, and NOx emissions in a 500 MW tangentially burned pulverised coal boiler numerically.
Demonstrating that the Methodology

Boiler Description

A 700 MW boiler with a tangential firing design is the boiler system under investigation. We have 28 coal burners in our fire apparatus. Pulverisers provide uniformly sized coal powder to the boiler as part of the burner system. Combustion of the fine coal in the boiler furnace takes place in the burners, which are carried by the main airflow.A fireball is created in the centre of the rectangular furnace by use of four burners that are fired from each corner.
A computer program was used to simulate the boiler combustion process.The estimated distributions of the ANSYS-FLUENT model clearly illustrate a relationship between temperature, O2 mass fraction, and CO2 mass fraction; the anticipated findings reveal that NOx generation in the boiler is strongly dependent on the combustion process, temperature, and species concentration. Investigating the intricate physical and chemical processes taking place within boilers of thermal power plants is of paramount interest due to the energy's strategic role and the present worry about greenhouse effects.Several processes are involved in combustion, including chemical reactions, particle movement, turbulence, and heat transmission (both radiative and convective).It is a challenging issue to study these coupled phenomena.Numerical investigations of combustion processes are encouraged by the state-of-the-art in computational fluid dynamics and the availability of commercial packages. The current research aimed to simulate the operating circumstances and find inefficiency issues in a 160 MWe thermal power plant located in the centre of the Brazilian coal deposits area by using a commercial CFD code, CFX©AnsysEurope Ltd. The process of pulverised coal combustion was examined. CFD program for 2021 R1 with the assumptions of steady, turbulent, and compressible flow.The investigation starts with gathering data and configuration information about boiler designs.The design was used to build the CFD models, which were then verified using operational data from the boiler.Several coal combustion parameters were subsequently predicted using the model. These included flame temperature, the composition of O2 and CO species, and furnace exhaust gas temperature (FEGT) when the boiler settings were mass flow of coal and air and burner tilting angle were kept constant.

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The properties of coals

Coal properties	Coal A	Coal B	Coal C
Calorific Value, kJ/kg	5732.57	6122.24	6495.45
Moisture, %	13.30	5.89	6.55
Volatile matter, %	43.80	41.03	40.98
Fixed carbon, %	41.25	43.69	45.32
Ash, %	1.65	9.40	7.16
C, %	61.80	70.80	73.45
H, %	5.63	5.76	5.76
O, %	31.21	21.90	18.81
N, %	1.09	1.34	1.46
S, %	0.27	0.50	0.53

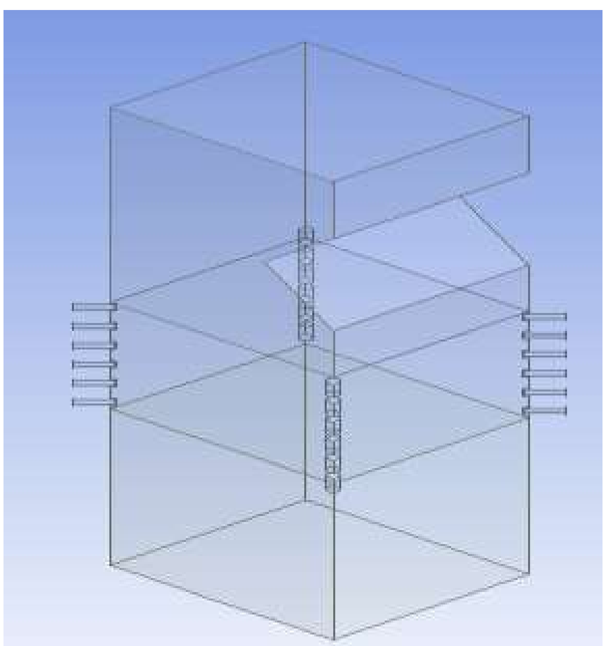
GEOMETRY

ForimportingtheModelofHeatExchanger,

Startworkbench2021R1→selectthefluidflow(fluent)
→ Edit Geometry → import External Geometry →Choose the image file which is in IGES format
→Generateasshown inthe Fig 5.2

Geometry:
Geometrywascreatedin3Dmodellingsoftwarecreoandwasimportedin toAnsysenvironment
Geometryspecifications

length	28.6 m
Breadth	24.9 m
Height	64.5 m
BurnerDiameter	900mm
Numberofburners	24



Geometry

MeshGeneration

Thegeometryandmeshgeneratedfortheboilermodelis shown in Figure 3.1. The overall framework of themeshing scheme used in this study is quadrilateral mesh.Fine mesh was constructed in critical regions, such as intheareaclosedtoburners,primaryandsecondarynozzlesa ndwithinthewinebox.Themodelwasdevelopedbasedonth eactualoperatingboilerinthepowerplant.Fromthedrawing obtained,fewsupplicationsweremadetoavoidextremeske wnesslevelthatmightaffectthestabilityofthecalculation.T hesimplicationsmadehowever,doesnot affect thefinal outcome as the main aim is to observe the flow andcombustiontemperatureoftheoverallfurnaceflowdom ain.Thenumberofmeshconstructedisapproximately 2.3 million cells. Prior grid dependencystudyhasbeenundertakenanditisshownthatth ecurrent mesh is sufficient enough to resolve the flowfield,especiallyincomplexregionswhereflowpropert iesarecritical.Comparisonofthesimulationresults with different mesh density is shown in Figure 2.Themeshquantitywasreducedby20%andincreasedby 20%. It is shown that the differences of the predictedtemperaturebetweenthesevaryingmeshwerene gligible.

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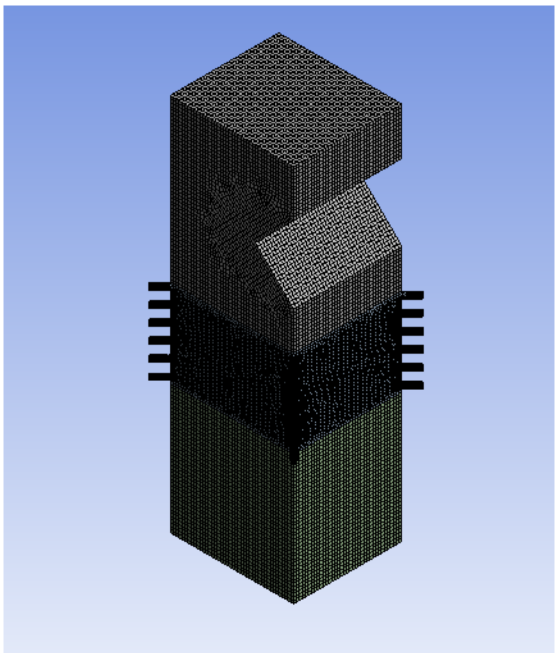


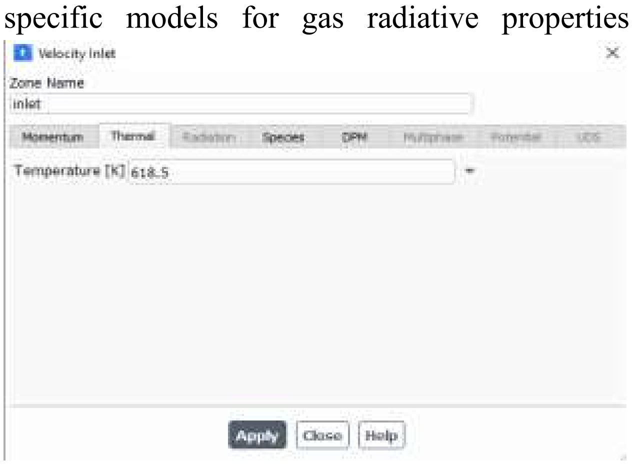
Meshingof3Dmodeloffurnace

CFDMODELLING

Coalcombustion:

AcommercialCFDprogram,ANSYSFluentversion2021 R1, was used to simulate the oxycoal combustionprocessinthereactionzoneoftheEFR.Thecomputationswereperformedinathree-dimensionalstructuredgridconsistingof~75,000cells,whosedetails

have been reported previously. The CFD code solved theappropriate transport equations for the continuous phase,and a Lagrangian approach was used to calculate particletrajectoriesthroughthecalculatedgasfield. TheRealizable k-ε turbulence model was employed to modelthe dynamic of the flow. Heat transfer by radiation wasaccountedforbytheDiscreteOrdinateModelbecauseof the higher accuracy and smaller optical length of theEFR,togetherwiththecellbasedWeighted-Sum-ofGray-GasesModel(WSGGM)fortheradiativeproperties ofthegases.Otherresearchershavedeveloped specific models for gas radiative properties



InletBoundaryConditions

inoxy-fuelenvironmentsimplementedanewgaseousradiativepropertiesmodelinCFDsimulationsinalaboratory-scale0.8MWfurnaceandfoundlittledifference in the radiation source in comparison with theWSGGM model. They concluded that the two modelsmadenegligibledifferenceinthesimulation resultswhenappliedtosmall-scaleoxy-fuelcombustionmodelling,buttheirimplantationis necessaryinmodellinglarge-scaleoxy-fuelfurnaces.

BoundaryConditions:

The boundary conditions were obtained from the dailyoperational data at 100% Boiler Maximum ContinuousRate (BMCR). The inlet conditions are the air and coalflows entering the domain from the burner nozzles. Coalflowrateandcombustionstoichiometricratioweresetas30m/sand1.2respectively.Temperaturesofcombustion air are set as 345 °C. Pulverized coal sizewas modelled by a Rosin-Rammler distribution between300µm. The outlet conditions is the flue gas passage atboilerrearpass.

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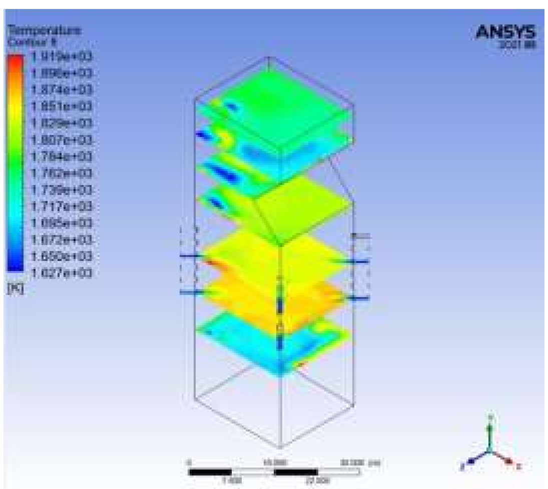
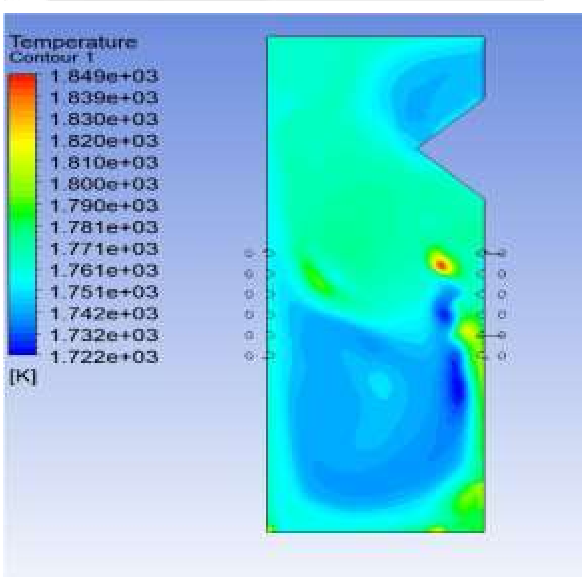
After initializing the cfd model, run thr calculation. Setthe umber of iterations 2000 and run the solution

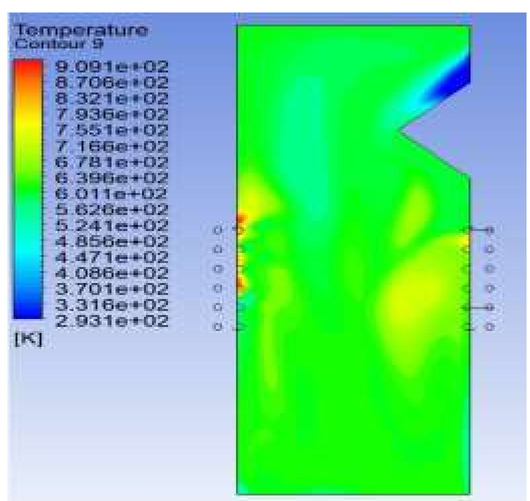
untiltheproblemisconverged.

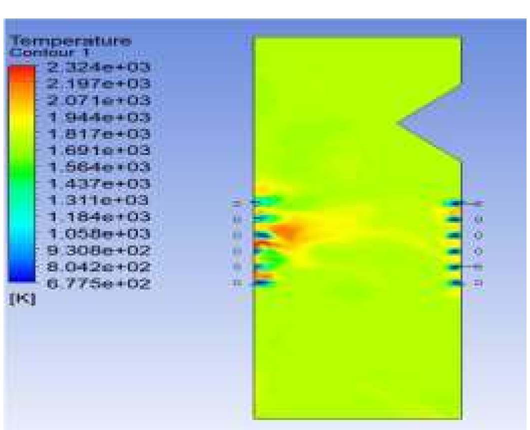
RESULTSANDDISCUSSION

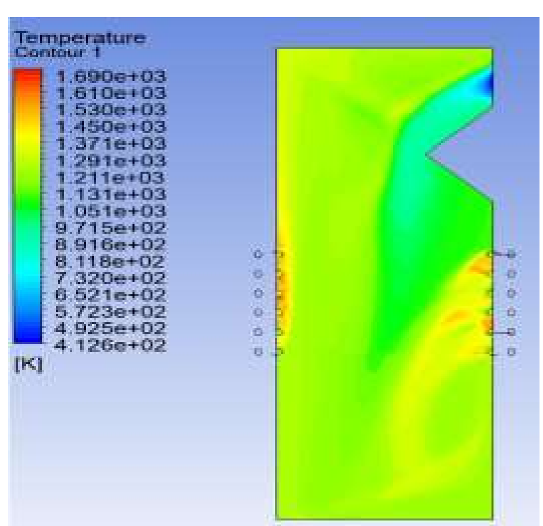
Temperature Distribution:Coalc:











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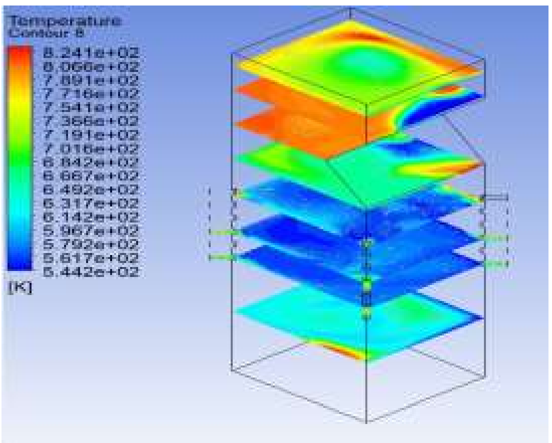
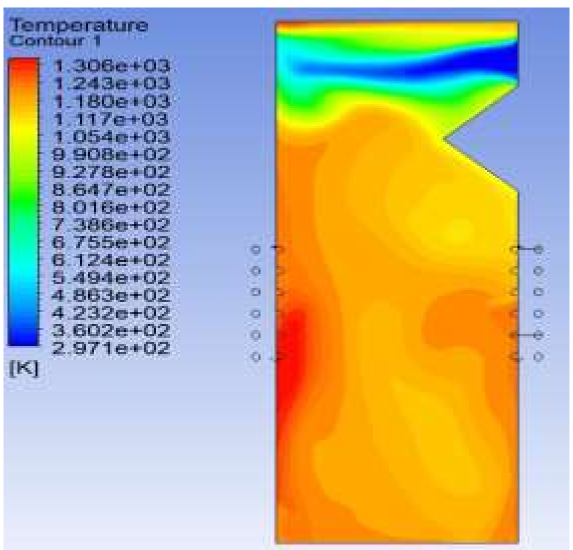
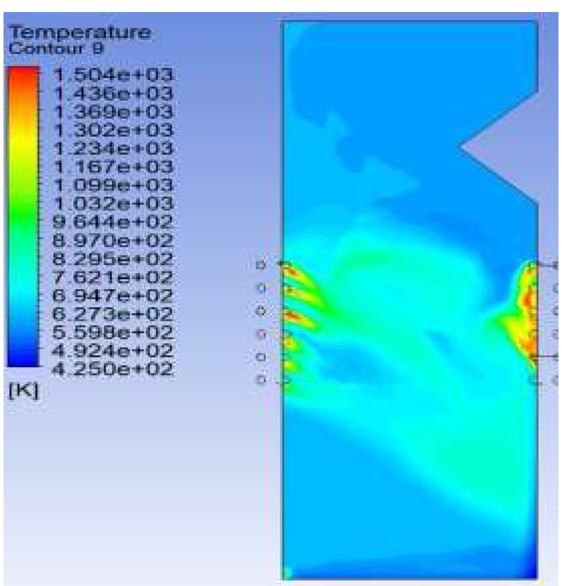
CoalB:





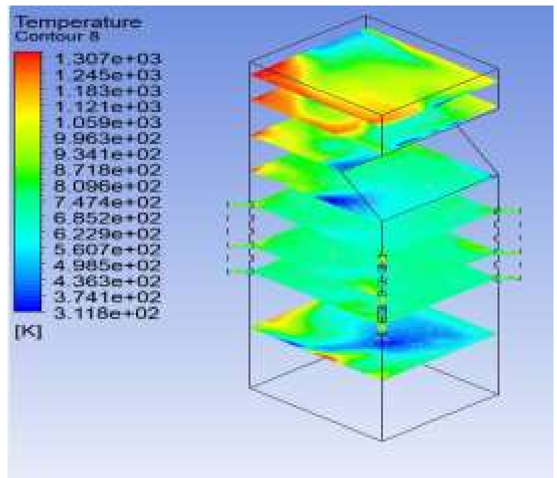


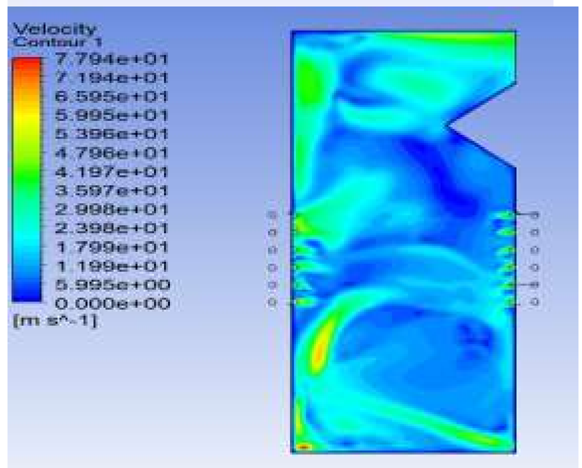
VelocityContours:

CoalC:

CoalB:

CoalA:





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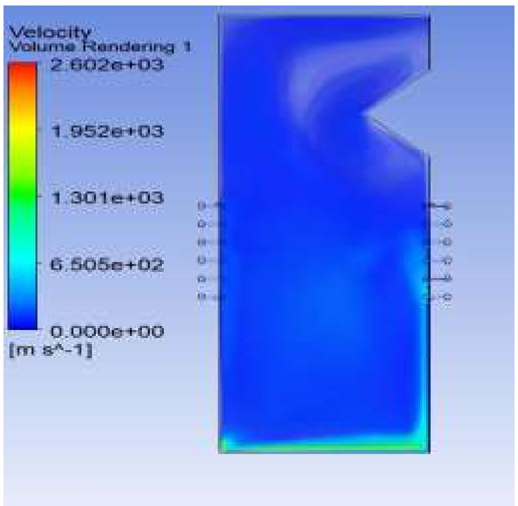
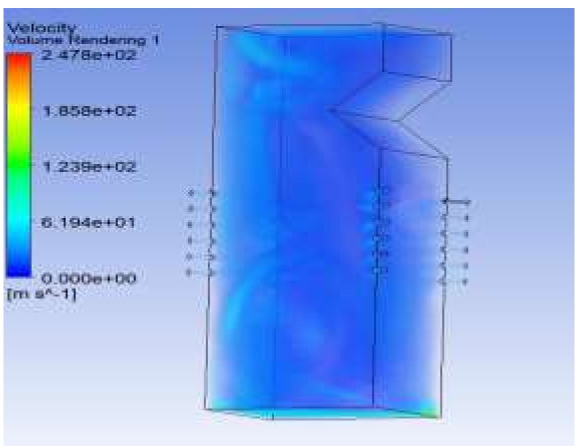
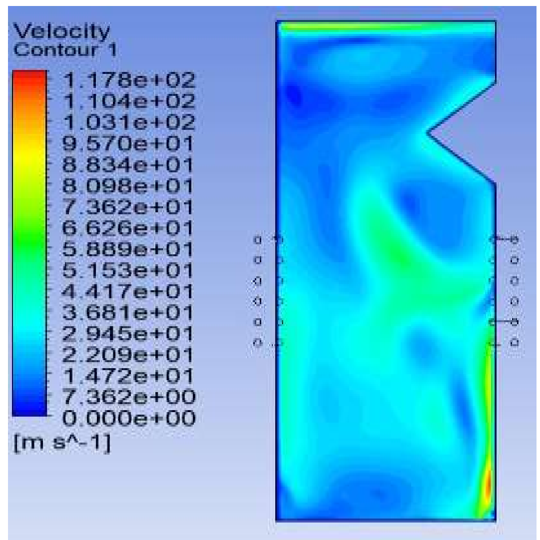


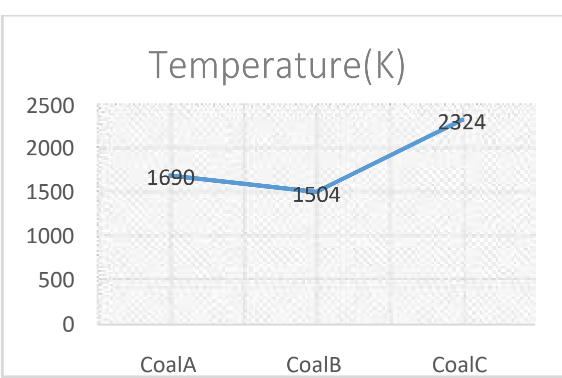
CoalA



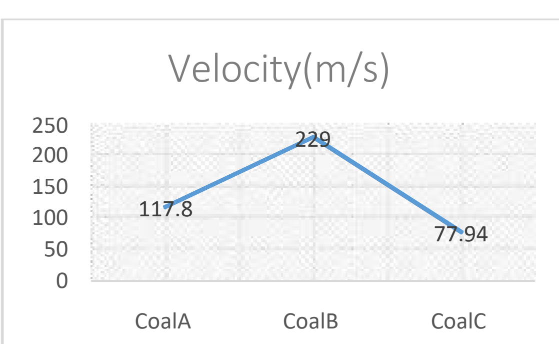


	Temperature (K)	Velocity (m/s)
Coal A	1690	117.8
Coal B	1504	229
Coal C	2324	77.94

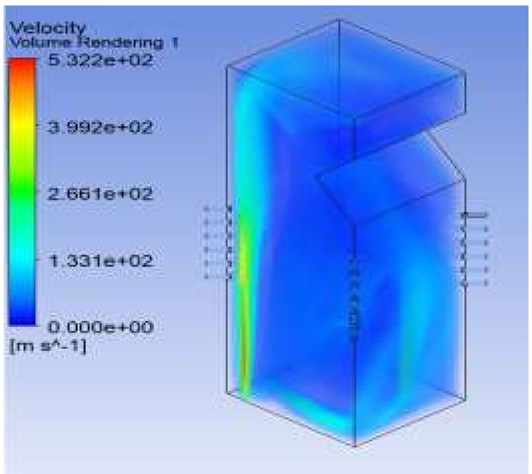
Table



CoalsamplevsTemperature



CoalsamplevsVelocity



Fromtheabovecontourplots,

Conclusion:

The combustion and flow processes of a full-scale power plant furnace were modelled using computational fluid dynamics (CFD) software in order to get a better understanding of how different sub-bituminous coals burn inside the boiler. The link between the kinds of coal and the distributions of temperature, velocity, O2, and CO species was shown by the predicted results; three suitable coals were burned in the boiler. Furnace temperatures are high because more energy is released during combustion when burning coal with a high calorific value. The fuel ratio is another critical component that could influence the distribution of temperatures. Boiler combustion behaviour influences flue gas compositions and, by extension, CO and O2 distributions. Results demonstrate that the velocity and temperature profiles conform to the anticipated behaviour of a tangential-fired boiler, and this was accomplished by validating the model using data collected from the boiler's performance, which included the temperature, oxygen, and carbon monoxide percentage of the boiler's exit gas.

The complex physical and chemical interactions occurring inside boilers may be better understood if this endeavour continues to simulate with a wider range of sub-bituminous coal grades. Additional investigation on the effects of varying operating circumstances on combustion results is necessary. Improving the boiler's efficiency is as simple as changing its design to work with different types of coal.

• Fuel The highest temperature achieved by sample C is 2324 K, whereas samples A and B reach 1690 K and 1504 K, respectively. This is because samples A through C have a larger concentration of coal, which is a fuel.

In comparison to the oxygen content in the mixture, the coal concentration in Coal A is lower. Utilisation of coal sample A leads to the loss of oxygen. • Coal B can be effectively combined with the appropriate amounts of oxygen. Coal sample B produces no trash or oxygen when used in this way.

• Coal C has a greater coal concentration than the oxygen in the combination. Coal sample A is used up and then discarded. Because of incomplete combustion, more pollutants will be a consequence.

From an operational perspective, the efficiency of the boiler might be negatively impacted if scales develop in the tubes due to the rising temperature of the boiler.

But of the three samples of coal, sample B yields the highest quality findings. Nevertheless, if the boiler's capacity is substantial, we may use Coal sample A.

Future Scope:

Coal combustion efficiency is affected by a number of variables, including intake temperature, mixture oxygen and coal content, flow rate, mixture pressure, furnace height and coal calorific value. Therefore, the boiler's design conditions dictate how the aforementioned parameters may be adjusted to vary the furnace's efficiency.

The combustion efficiency may therefore be enhanced indefinitely. Here are a few examples of them:

1. Combustion efficiency might be enhanced by making more oxygen available for complete combustion. Which can be done in two ways.

• Increasing the oxygen concentration in the oxy-coal mixture. • Using a secondary route to ensure that the burner has an adequate supply of oxygen.

2. Adjusting the entering oxy-coal mixture's speed may improve efficiency.

Changing the temperature of the incoming oxy-coal mixture is one way to increase efficiency.

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