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Analysis Of The Effect Of Co-Firing On Boiler Loading Limitations Using Computational Fluid Dynamic (CFD) Methods

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Abstract

The increasing depletion of high-calorific coal resources has driven coal-fired power plants (PLTU) to switch to low-calorific coal with calorific values ranging from 4,200 to 4,800 kcal/kg. Simultaneously, the Indonesian government aims to achieve a renewable energy mix of 23% by 2025 and 31.2% by 2050, promoting the co-firing of biomass with coal at rates of 5% to 12%. However, this transition presents operational challenges, such as altered combustion characteristics, overheating in superheater zones, and increased slagging and fouling potential. This study aims to analyze the impact of co-firing biomass with coal on boiler performance at a 600 MW PLTU using Computational Fluid Dynamics (CFD) simulations. Data inputs include coal specifications and biomass mixing ratios of 3%, 5%, 8%, and 12%. Simulations were conducted using Ansys Fluent software to assess variations in temperature, pressure, and flow distribution. The results indicate that increasing biomass percentages reduces combustion temperatures and alters the distribution of key combustion byproducts, such as H_2O and SO_2. A higher biomass ratio mitigates the risk of overheating but requires careful operational adjustments to maintain efficiency. The findings support the optimization of co-firing operations, contributing to reduced carbon emissions and compliance with Indonesia's renewable energy targets. This study provides actionable insights for improving PLTU performance while aligning with sustainable energy goals.

Keywords: Coal, Co-firing, Computational Fluid Dynamic

Introduction

In connection with the Government of Indonesia signing the Paris Agreement to the United Nations Framework Convention on Climate Change on April 22 2016 in New York, United States and then the Government of Indonesia rati-fied it with Law Number 16 of 2016 con-cerning the Ratification of the Paris Agreement To The United The Paris Agreement to the United Nations Framework Convention on Climate Change United Nations Work on Cli-mate Change), and to follow up on activ-ities to mitigate the risk of greenhouse gas (GHG) emissions, the Government of Indonesia made Presidential Regula-tion of the Republic of Indonesia Num-ber 22 of 2017 (Presidential Decree of the Republic of Indonesia No. 22/2017) about the National Energy General Plan (Taler et al., 2018).

Technically, co-firing is the combus-tion of the main fuel accompanied by other fuels (MANURUNG, 2020; SAPUTRI, 2017). For the implementation of co-firing in coal-fired power plants, the goal is to reduce carbon emissions in a sustainable manner by substituting some coal with biomass that is generally sourced from wood. Both waste wood (including husks, rice, etc.) and wood produced by energy forests (land plant-ed with trees as raw materials for bio-mass) (Adnan, 2020; Herindrasti et al., 2024). The idea of co-firing has been built for a long time. However, it was only in 2020 that the co-firing roadmap began to be implemented at PLTU as part of PLN's Transformation. The implementa-tion of co-firing continues to improve and develop (Herindrasti et al., 2024). The development of bio-mass co-firing involves the collaboration of many parties, including local govern-ments, community groups, campus ele-ments, and research institutions. With more co-firing being operated, the reduc-tion of national carbon emissions will be faster (Herindrasti et al., 2024).

Previous research from Heri Purnomo, 2019 on numerical simulation of influence coal particles (finness) on com-bustion characteristics in sub-critical pulverized coal capacity of 600 MW, where the larger the size of the coal par-ticles that enter the boiler, combustion is increasingly shifting upwards (back-wards). In combustion, the average par-ticle size of 128 um was highest at 28.69 m with a temperature of 1706.22 oC. For particle size an average of 160 um at an elevation of 38.63 m with a temperature of 1705.83 oC. For partake size 193 um at an elevation of 47.43 m with a tem-perature of 1705.49 oC. The larger the size of the coal particles, the longer the coal stays in the boiler. old. At a particle size of 128 um burned out in the sec-ondary super heater area, 160 um at primary super heater, and 193 um on the reheater (Sung et al., 2016).

Meanwhile, in the previous research from Giri Nugroho, 2014 on CFD Simulation To find out the effect of adding medium coal on low-rank boilers coal at the power plant of PLTU Suralaya Unit 8, the use of LRC coal is 100% at risk of occurring overheating at the location of the super heater platen, Addition of MRC which has a combustion time longer than LRC, can reduce the area of overheating with the maximum temperature occurring in a more even area, the addition of MRC can also even out the maximum temperature distribu-tion Because it reduces the intensity of flow turbulence (Wu et al., 2019; Yi et al., 2014).

This study provides a new approach to understanding the impact of biomass co-firing with coal using the Computational Fluid Dynamic (CFD) method (Kirichkov et al., 2020; Madejski, 2018). Unlike previous studies that only focused on changes in the combustion characteristics of single coal, this study deeply analyzes the effects of biomass mixture variations on boiler performance parameters such as temperature, pressure, and mass flow distribution in a 600 MW steam power plant (PLTU). The use of biomass variations up to 12% creates a new perspective for combustion process optimization, which supports sustainable energy policies in Indonesia.

The purpose of this study is to analyze the impact of biomass and coal co-firing combustion on the distribution of temperature, pressure, and mass flow in a 600 MW boiler using CFD simulation. Identifying optimal parameters to reduce the risk of overheating in the super heater zone that occurs due to changes in combustion characteristics. Supporting the implementation of renewable energy policies by providing scientific data on the efficiency of biomass and coal mixture combustion in meeting national energy mix targets.

Research Methods

Research Type

This research is included in the type of experimental quantitative research using simulation based on Computational Fluid Dynamic (CFD) software (Aspriliansyah & Adiwibowo, 2020; OBBIE, 2024). This approach aims to analyze the impact of variations in biomass co-firing in a 600 MW PLTU boiler on the distribution of combustion parameters, such as temperature, pressure, and mass flow.

Data Collection Techniques

The data used in this study were collected through several stages:

1. **Primary data**

   Computational Fluid Dynamic (CFD) simulation results using Ansys Fluent software. Simulation data includes variations in biomass input of 3%, 5%, 8%, and 12% combined with low-calorie coal.
2. **Secondary data**

   Steam-fired power plant boiler technical information and fuel characteristics are taken from boiler design documents, operating manuals, and related literature, including journals and previous technical reports.

Data Analysis

Data were analyzed quantitatively with the following steps:

1. **Numerical simulation**

   Using CFD software to generate temperature, pressure, and mass flow distributions in various biomass mixture scenarios.
2. **Data validation**

   Comparing simulation results with historical data or previous research results to ensure the accuracy of the model used.
3. **Result interpretation**

   Analyzing temperature and pressure distribution patterns in the boiler to identify the impact of biomass co-firing on combustion efficiency and overheating risk

Flowchart

Technically, co-firing is the combus-tion of the main fuel accompanied by other fuels (Nugraha, 2016; RODION, 2023). For the implementation of co-firing in coal-fired power plants, the goal is to reduce carbon emissions in a sustainable manner by substituting some coal with biomass that is generally sourced from wood. Both waste wood (including husks, rice, etc.) and wood produced by energy forests (land plant-ed with trees as raw materials for bio-mass). The idea of co-firing has been built for a long time. However, it is only in 2020 that the co-firing roadmap has begun to be implemented at PLTU as part of PLN's Transformation

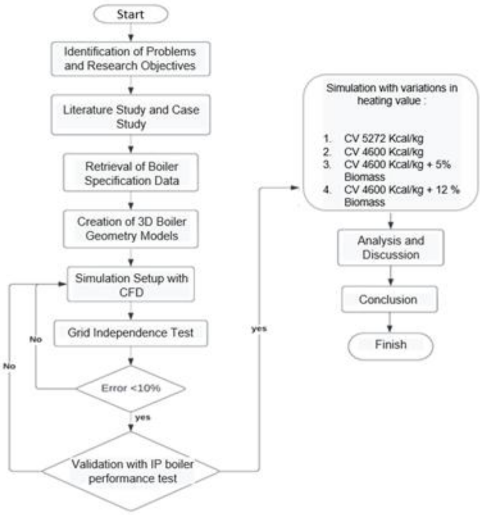
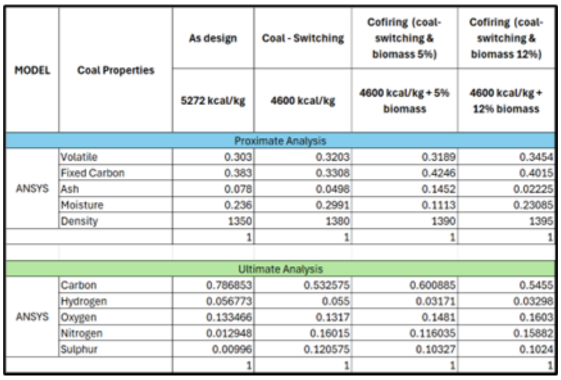


Figure 1. Flowchart of Research

Table 1. Proximate & Ultimate Coal



MODEL	Coal Properties	As design	Coal - Switching	Cofiring (coal-switching & biomass 5%)	Cofiring (coal-switching & biomass 12%)
		5272 kcal/kg	4600 kcal/kg	4600 kcal/kg + 5% biomass	4600 kcal/kg + 12% biomass
Proximate Analysis					
ANSYS	Volatile	0.303	0.3203	0.3189	0.3454
	Fixed Carbon	0.383	0.3308	0.4246	0.4015
	Ash	0.078	0.0498	0.1452	0.02225
	Moisture	0.236	0.2991	0.1113	0.23085
	Density	1350	1380	1390	1395
		1	1	1	1
Ultimate Analysis					
ANSYS	Carbon	0.786853	0.532575	0.600885	0.5455
	Hydrogen	0.056773	0.055	0.03171	0.03298
	Oxygen	0.133466	0.1317	0.1481	0.1603
	Nitrogen	0.012948	0.16015	0.116035	0.15882
	Sulphur	0.00996	0.120575	0.10327	0.1024
		1	1	1	1

Drawing and Data Input

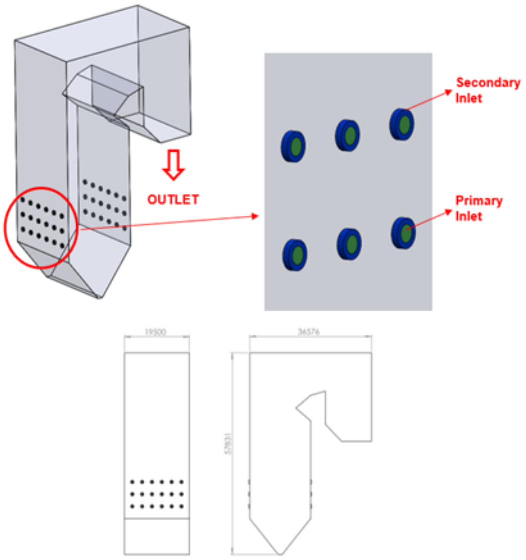


Figure 2. 600 MW Power Plant Boiler Drawing

Setting Parameter Data

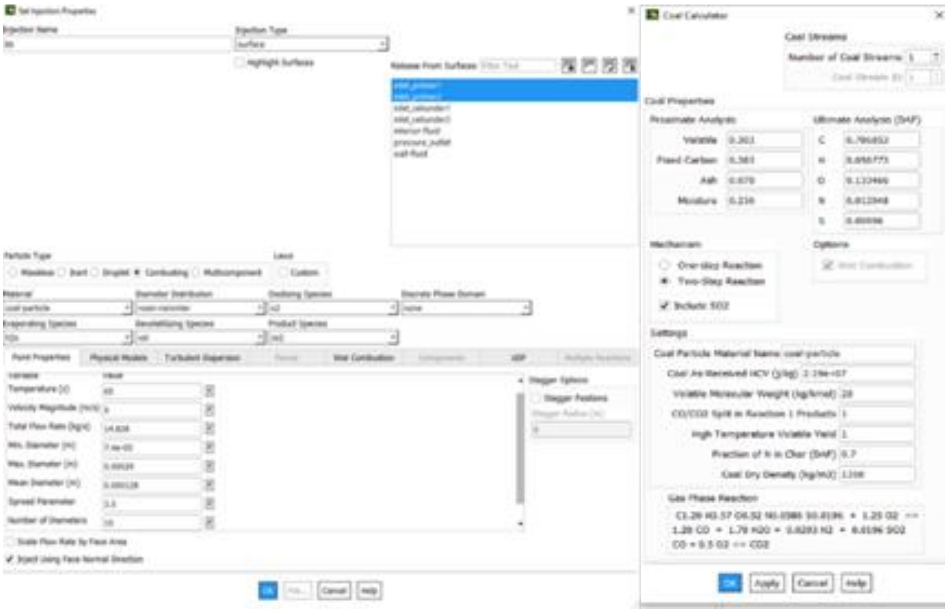


Figure. 3. Setting Data Input as Design

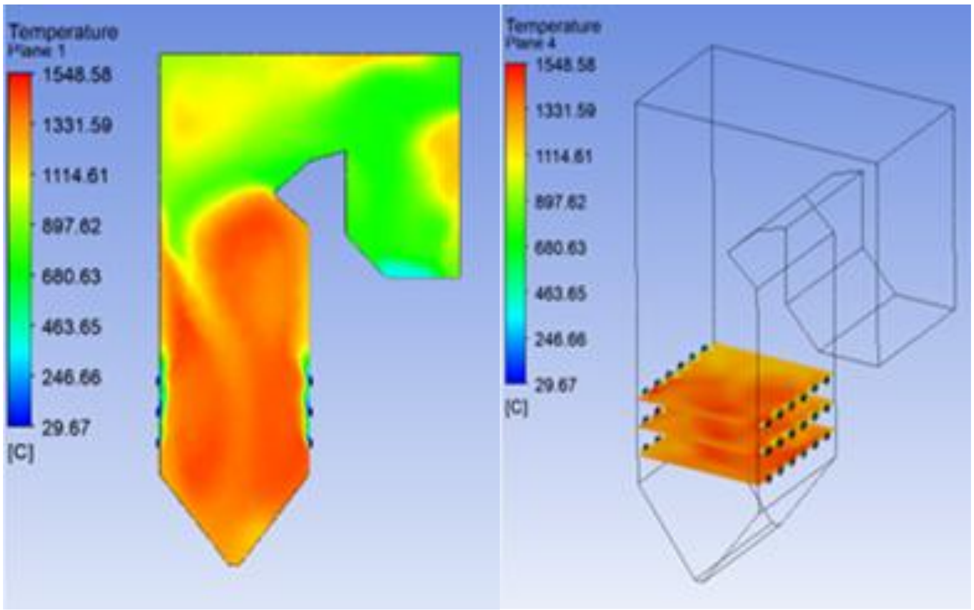


Figure 4. Distribution Temperature Design

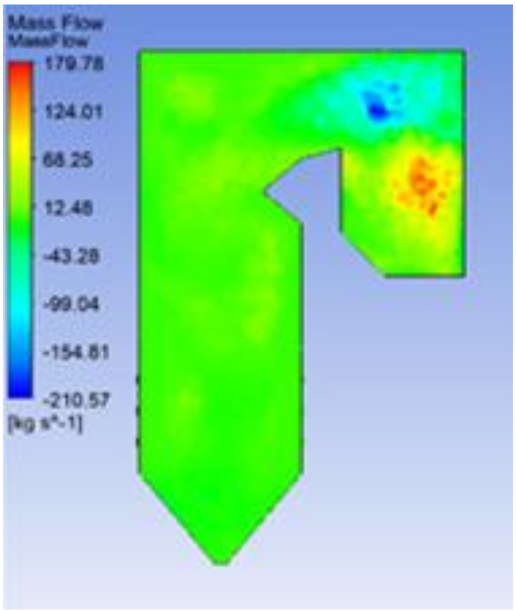
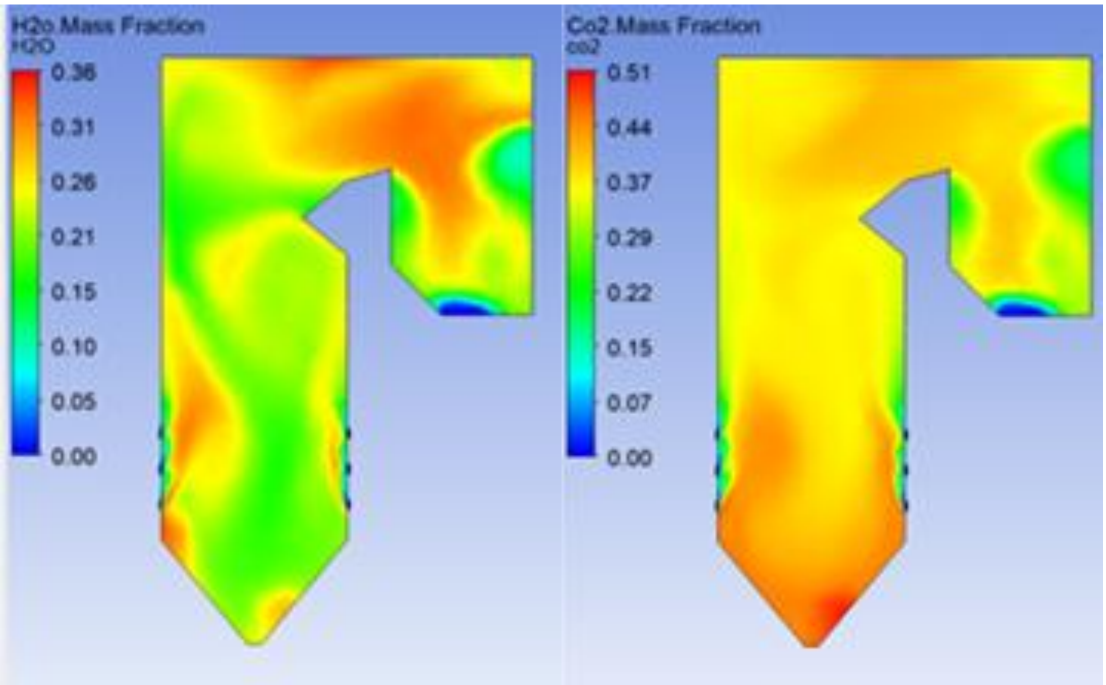


Figure.5 Distribution Mass Flow



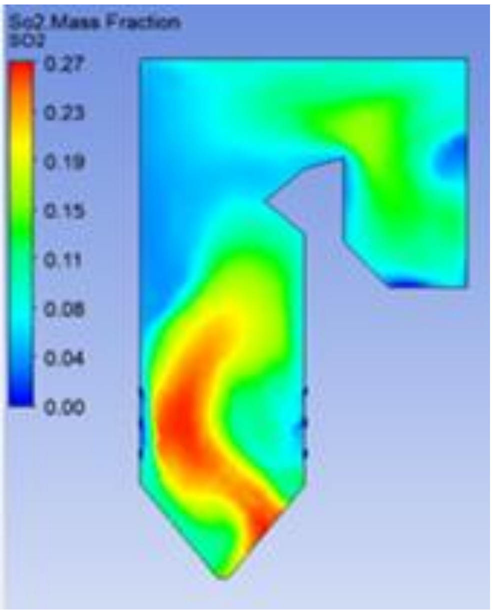


Figure. 6 Distribution Mass Friction

Value of mass fraction for H2O minimum 0 and maximum 0.36, Value of mass fraction for CO2 minimum 0 and maximum 0.51, Value of mass fraction for SO2 minimum 0 and maximum 0.27. Design of Boiler Minimum Temperature 29.67oC and Maximum 1548.58oC, Value of Mass flow minimum in -210.57 kg/s^-1 and maximum 179.78 kg/s^-1

Results and Discussion

Simulation of Coal 4600 kcal/kg

Table 3. Simulation Boundary

Boundary Condition	Variable	*Input*	Temperature °C	Species (O_2)	DPM Model
Coal Feed	Mass Flow Inlet	58.84 ton/h	65	-	-
Air inlet Primary	Velocity	15.47 m/s	65	0.22	escape
Air Inlet Secondary	Velocity	30.43 m/s	30	-	Reflect
Outlet	Pressure Outlet	-870 Pa	380	-	Escape

Source: Data processed

Variation of Co-Firing 3%, 5%, 8%, and 12%

Figure. 7 Data Input Variable Variation of Co-Firing

Result Variation of Co-Firing 3%, 5%, 8%, and 12%

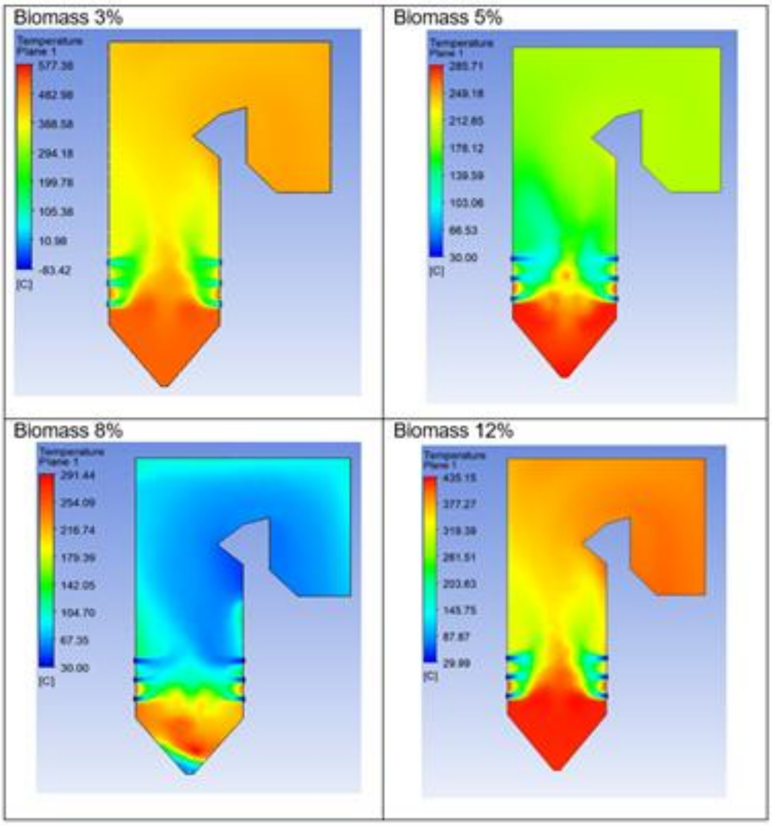


Figure. 8 Distribution of Temperature Plane

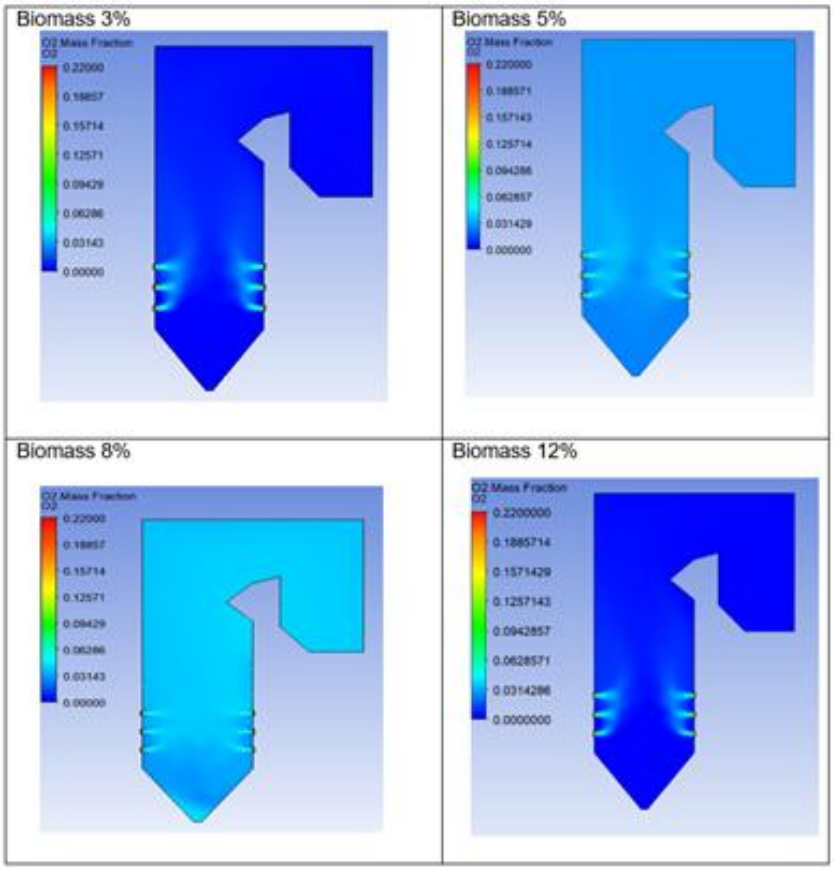


Figure. 9 Distribution of O₂

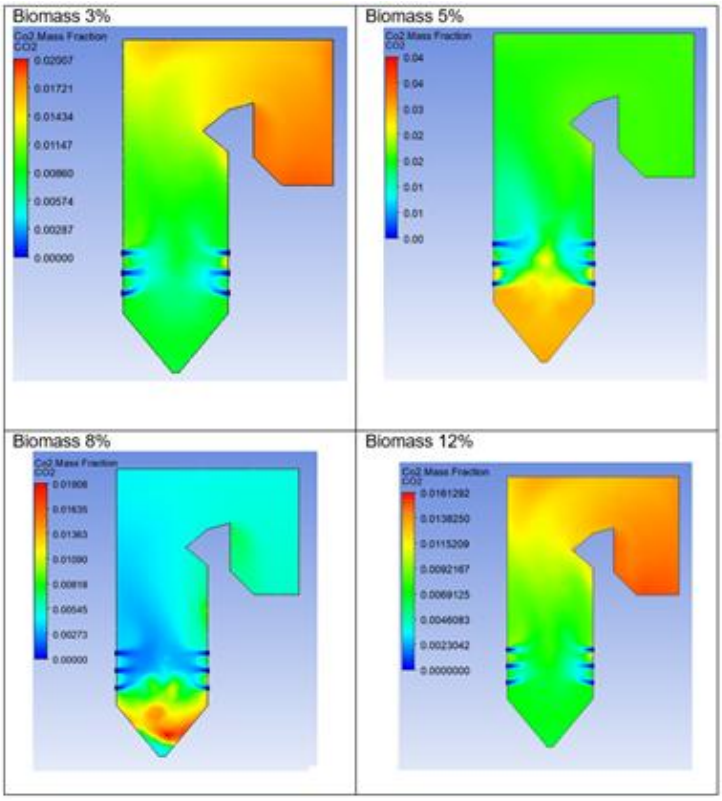


Figure. 10 Distribution of CO2

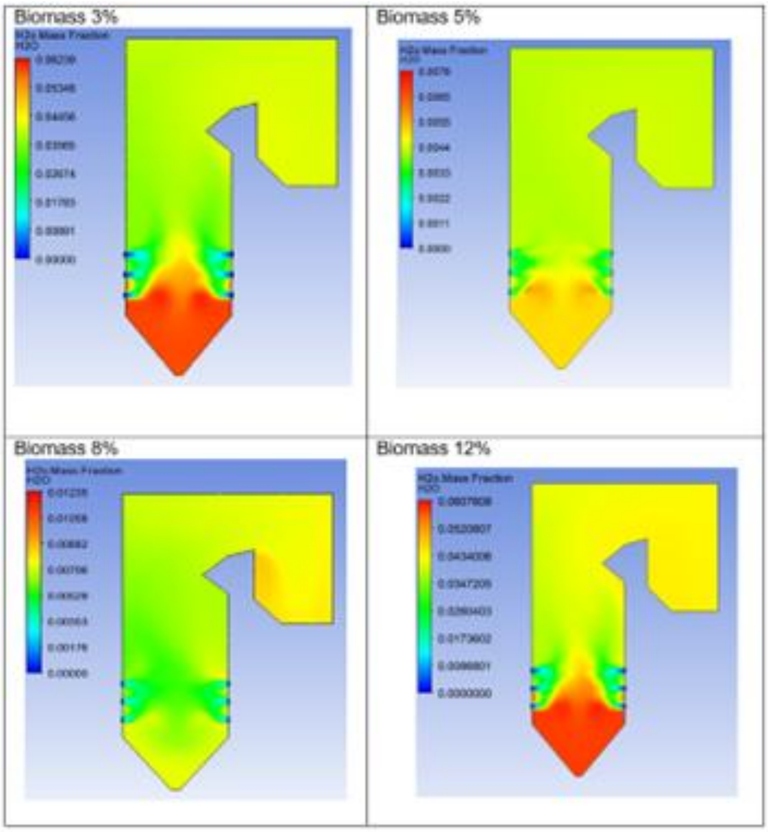


Figure. 11 Distribution of H2O

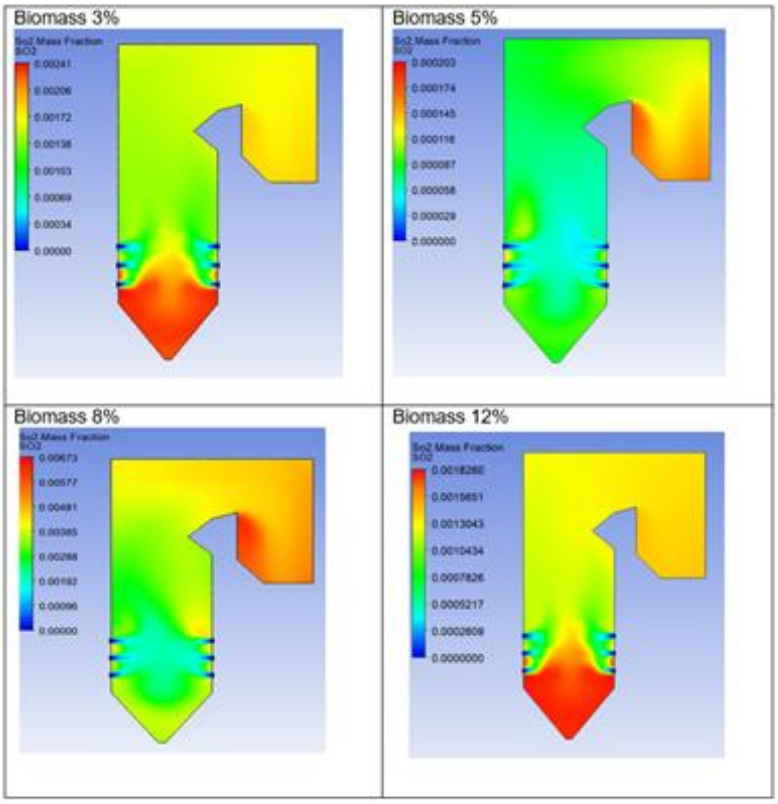


Figure. 12 Distribution of SO2

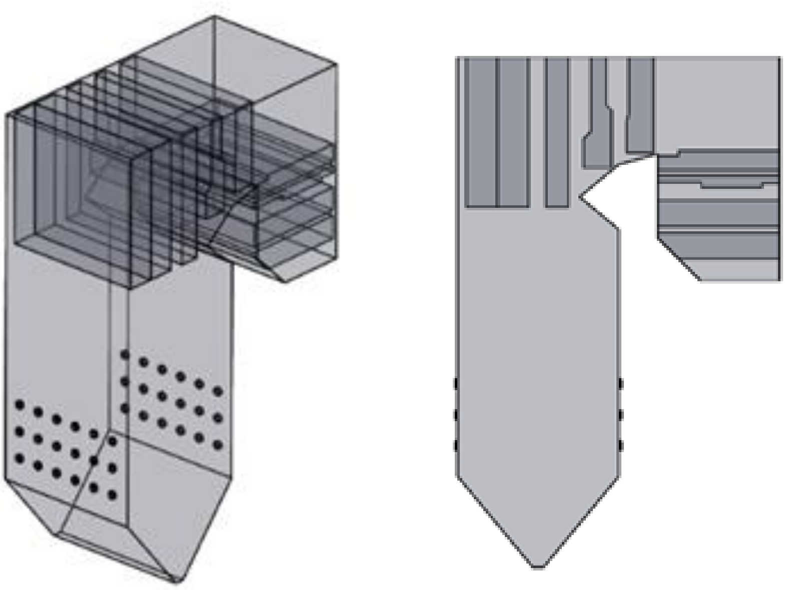


Figure. 13 Design Porous Media Boiler 600 MW

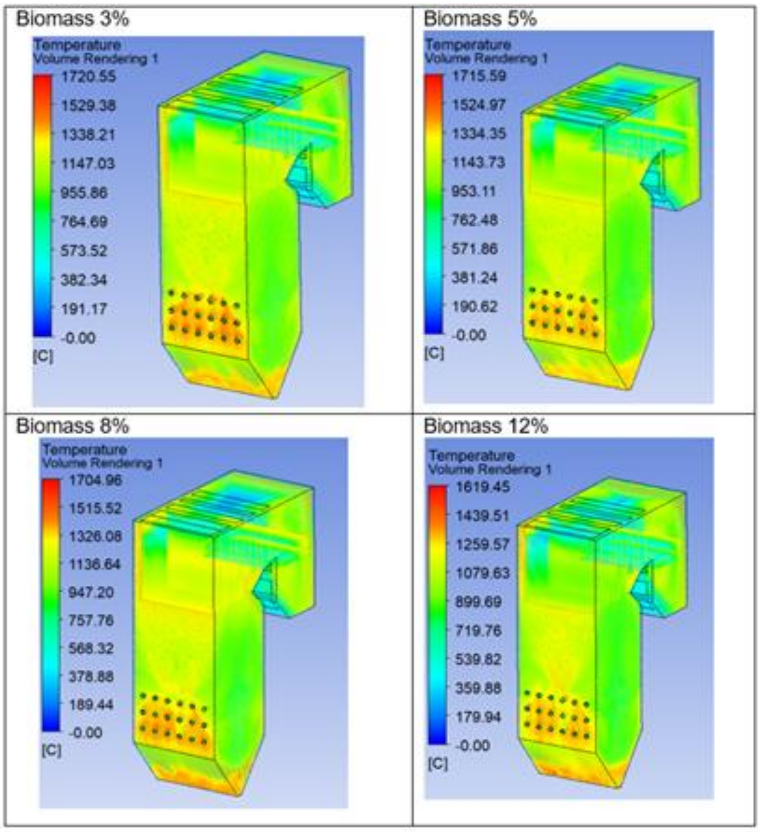


Figure. 14 Isometric Temperature Distribution with Variation of Biomass

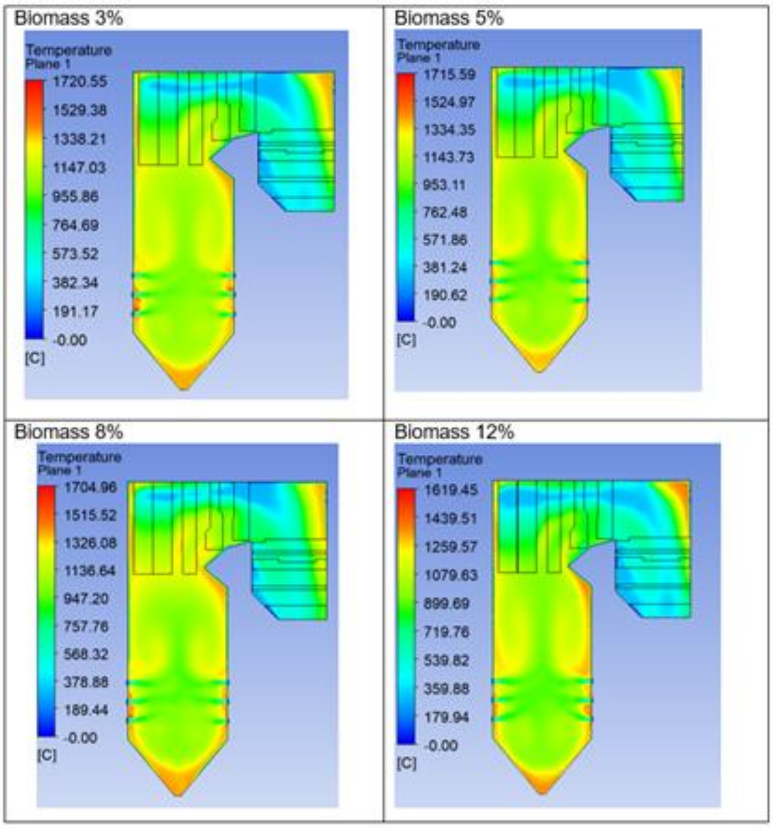


Figure. 15 Plane Temperature Distribution with Variation of Biomass

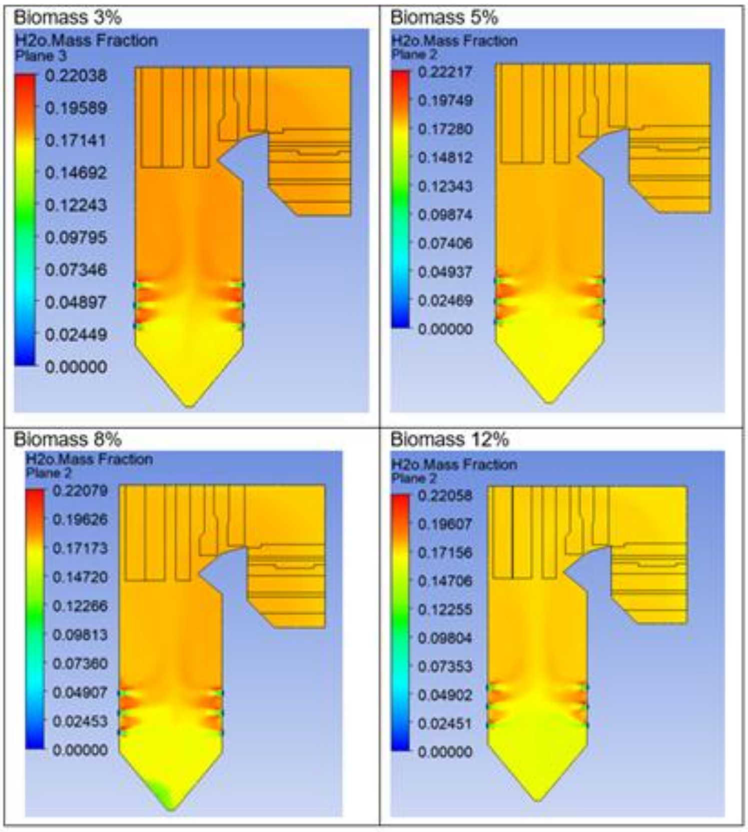


Figure. 16 Plane H2O Distribution with Variation of Biomass

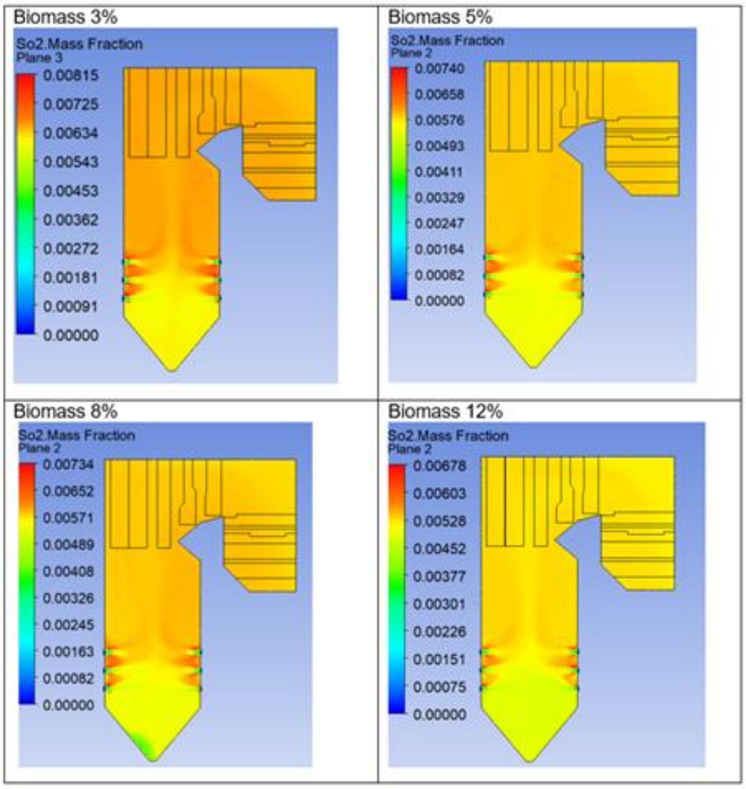


Figure. 17 Plane SO2 Distribution with Variation of Biomass

Conclusion

The purpose of the analysis is to understand the distribution of air, temperature and pres-sure in the furnace. In the following simula-tion, 2 material inputs are used, namely air and coal particles that have been mixed with biomass or called the co-firing process. The simulation uses variations in existing calorie values, namely 5700 kcal/kg and biomass mixing innovations with 4600 kcal/kg calories. The greater the value of the biomass %, the lower the temperature value will be. Likewise, with the values of H2O and SO2.

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