

CERTIFICATION OF APPROVAL

A STUDY OF CO-FIRING BIOMASS WITH COAL AS POTENTIAL FUEL

by

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A project dissertation submitted to the

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

Approved by,

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TRONOH, PERAK

December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD. ZHAFRI BIN MAHDI

ABSTRACT

This project dissertation contains the information of the Final Year Project (FYP). The purpose of this report is to discuss and conclude the data gathering and results from the research.

The first part of the report is the introduction that gives a brief overview (project background and problem statement) of the project. Understanding the nature of the project will give a clear overview about the whole FYP. This section also includes the description about the objectives and scope of study for the project. The second part is the literature review where the theoretical explanation of the project is included. This part consists of the information on coal, biomass, and the co-firing of coal with biomass.

The third part of this report is the methodology. This part actually explains the flow of the work done by the author. This section includes the milestone, and the tools, machines, and software required for the whole project. The fourth part of the report is the results and discussion. The entire data gathering, results and discussion of finding are included in this section.

The last part of the report is the conclusion and recommendation. With the inclusion of all references to facilitate the readers' understanding, it is hoped that the readers will get a clearer picture and idea on the project.

ACKNOWLEDGEMENT

First and foremost, I would to thank to God for all His blessings that made all things possible while doing this project. I also would like to express the warmest and greatest attitude, appreciation to all parties who have contributed towards the success of this project.

I would like to thank to my supervisor, Ms Chin Yee Sing for accepting me in doing my project under her supervision. Not forget along with her precious advices and guidance and for sparing her time to me for consultation and discussion in the tasks undertaken.

I also would like to thanks to my examiners; Mr Kamal Ariff Bin Zainal Abidin and Dr Azuraien Binti Japper @ Jaafar for their supports, comments and guidance that can further improve my project.

Not forget also thank to the coordinator of Final Year Project course, Dr. Saravanan a/l Karuppanan that have done his best to ensure the final year's student can succeed this course.

In addition, I also would like to thanks to all personnel from Tenaga Nasional Berhad Janamanjung for the contribution of coals and Felcra Nasaruddin for the contribution of oil palm residues.

Last but not least, to my family and friends, a deepest thank to all of them for giving the support and providing me with many advice to be successful in life as a whole.

Thank you again for the never-ending support that was supplied to me to complete this project.

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ABBREVIATIONS AND NOMENCLATURES

CO ₂	Carbon Dioxide
GHG	Greenhouse Gas
SO ₂	Sulfur Dioxide
NO _x	Nitrogen Oxide
EFB	Empty Fruit Bunch
CFD	Computational Fluid Dynamics
CAD	Computer-Aided Design
3D	Three Dimensional

CHAPTER 1: INTRODUCTION

1.1 Project Background

Figure 1.1 shows that the world oil production had meet the peak around year 2008. After that, the production continuously decreases. The production of oil product will be insufficient due to the increasing of oil product consumption [1].

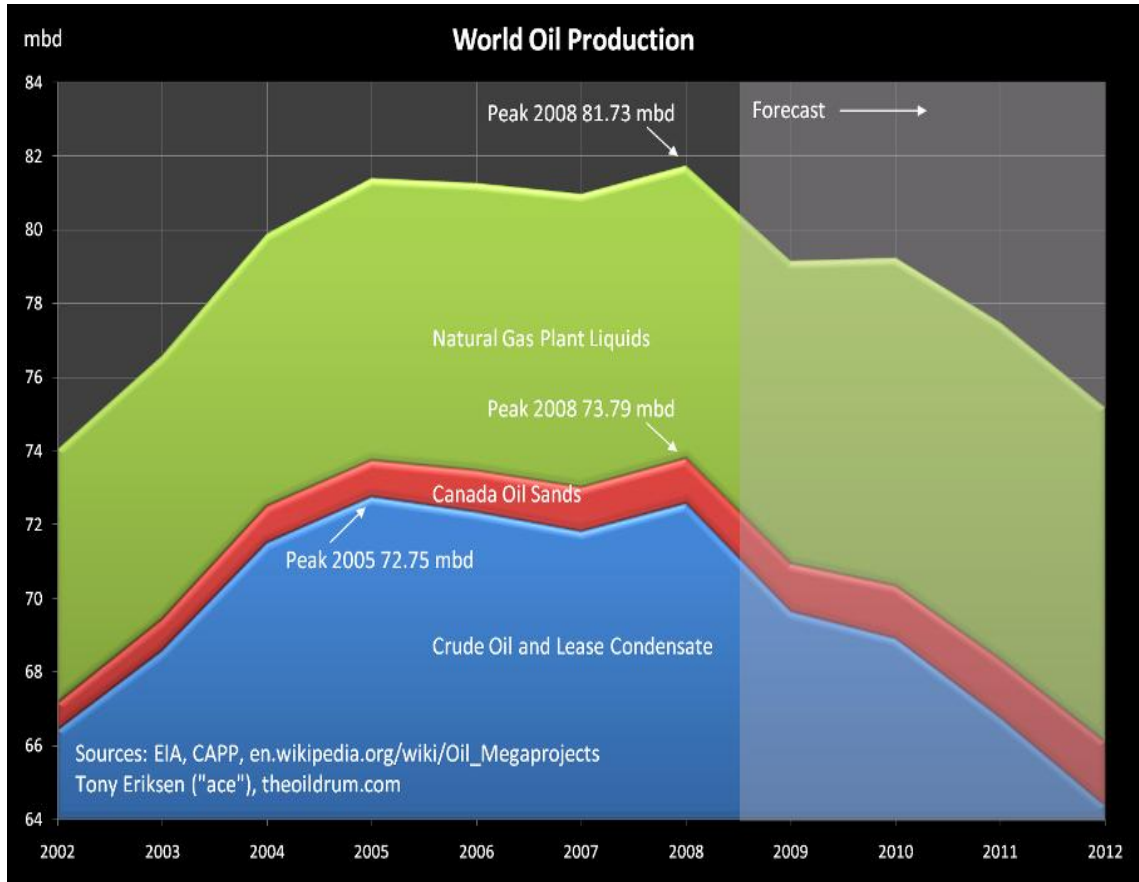


Figure 1.1: World Oil Productions [1]

Being the cheapest and most abundantly available fossil fuel, coal will always have a role in the energy mix of a particular country. Coal, a fossil fuel, is the largest source of energy for the generation of electricity worldwide, as well as one of the largest worldwide anthropogenic sources of carbon dioxide (CO₂) emissions. Gross carbon dioxide emissions from coal usage are slightly more than those from petroleum and about double the amount from natural gas [2].

1.2 Problem Statement

Coal is expected to maintain a major share of the world's future energy use. In recent years, concerns have been growing worldwide regarding the environmental consequences of dependence on fossil fuels. Excessive carbon dioxide (CO₂) emission from fossil fuel burning such as coal burning has been identified as a factor that causes global warming. Utilization of a biomass fuel, a carbon neutral fuel is a possible solution to reduce the excessive carbon dioxide emission.

1.3 Objectives And Scope Of Study

1. To identify the types of biomass available in Malaysia to be co-fired with coal as a potential fuel that will reduce the impacts of global warming.
2. To identify the effects of both coal firing and coal co-firing with biomass in terms of carbon dioxide emission concentration and temperature in the furnace.
3. To simulate the combustion of coal and coal with biomass using Computational Fluid Dynamics (CFD) method.
4. To decide on the suitable range of blending ratio between coal and biomass for optimum power generation.

This project is relevant to the condition of Malaysia which is consuming energy tremendously throughout the recent years. Since Malaysia produces abundant amount of biomass resources and the increasing usage of coal as fuel resources to generate electricity, the study on co-firing both resources are relevant to the country's condition.

CHAPTER 2: LITERATURE REVIEW

2.1 Coal

Coal is a chemically and physically heterogeneous, combustible, sedimentary rock consisting of both organic and inorganic material. Coal consists primarily of carbon, hydrogen and oxygen, with lesser amounts of sulfur and nitrogen [3].

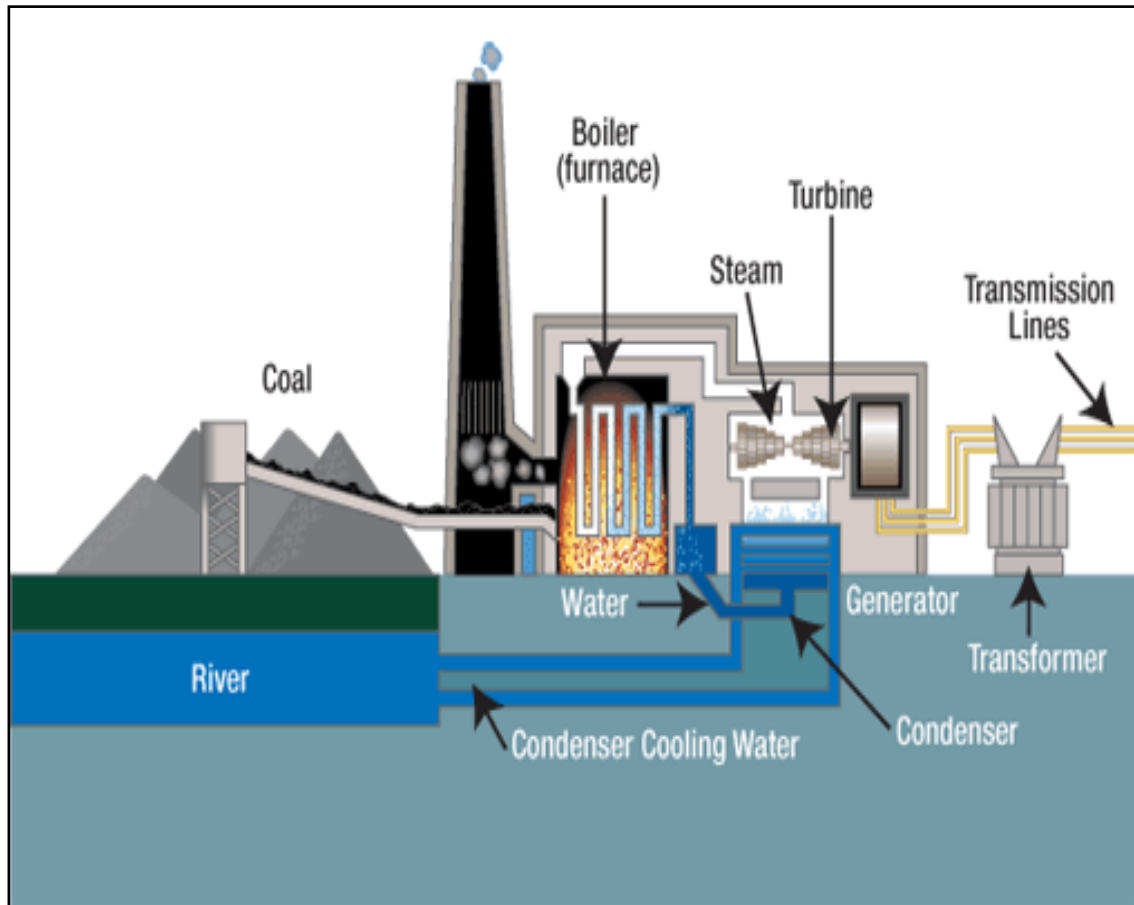


Figure 2.1: Schematic Diagram of Coal-fired Power Plant [4]

Figure 2.1 shows the schematic diagram of coal-fired power plant. Coal-fired units produce electricity by burning coal in a boiler to heat water to produce steam. The steam, at tremendous pressure, flows into a turbine, which spins a generator to produce electricity. The steam is cooled, condensed back into water, and returned to the boiler to start the process over and over again.

Despite environmental issues, coal is expected to maintain a major share of the world's future energy use. In recent years, concerns have been growing worldwide regarding the environmental consequences of dependence on coal since it contributes to the greenhouse problem. The main greenhouse gas (GHG) emissions from coal combustion are carbon dioxide (CO₂), sulfur dioxide (SO₂), and nitrogen oxide (NO_x).

TABLE 2.1

LIST OF COAL FIRED POWER PLANTS IN MALAYSIA, YEAR 2009 [5]

Plant	Location	Capacity (MW)
Jimah Power Station	Lukut, Negeri Sembilan	1400
Jana Manjung Power Station	Manjung, Perak	2295
PPLS Power Generation Plant	Kuching, Sarawak	110
Sejringkat Power Corporation Plant	Kuching, Sarawak	100
Sultan Salahuddin Abdul Aziz Shah Power Station	Kapar, Selangor	2420
Tanjung Bin Power Station	Pontian, Johor	2100

2.2 Biomass

People have used biomass for fuel since human being learned to burn wood. Biomass is a sustainable organic matter feedstock, derived in recent times, directly or indirectly, from plants as a result of photosynthesis. Biomass includes wood and other plant or animal that can be burned directly or can be converted into fuels. Availability is one advantage biomass has relative to other forms of renewable energy [6].

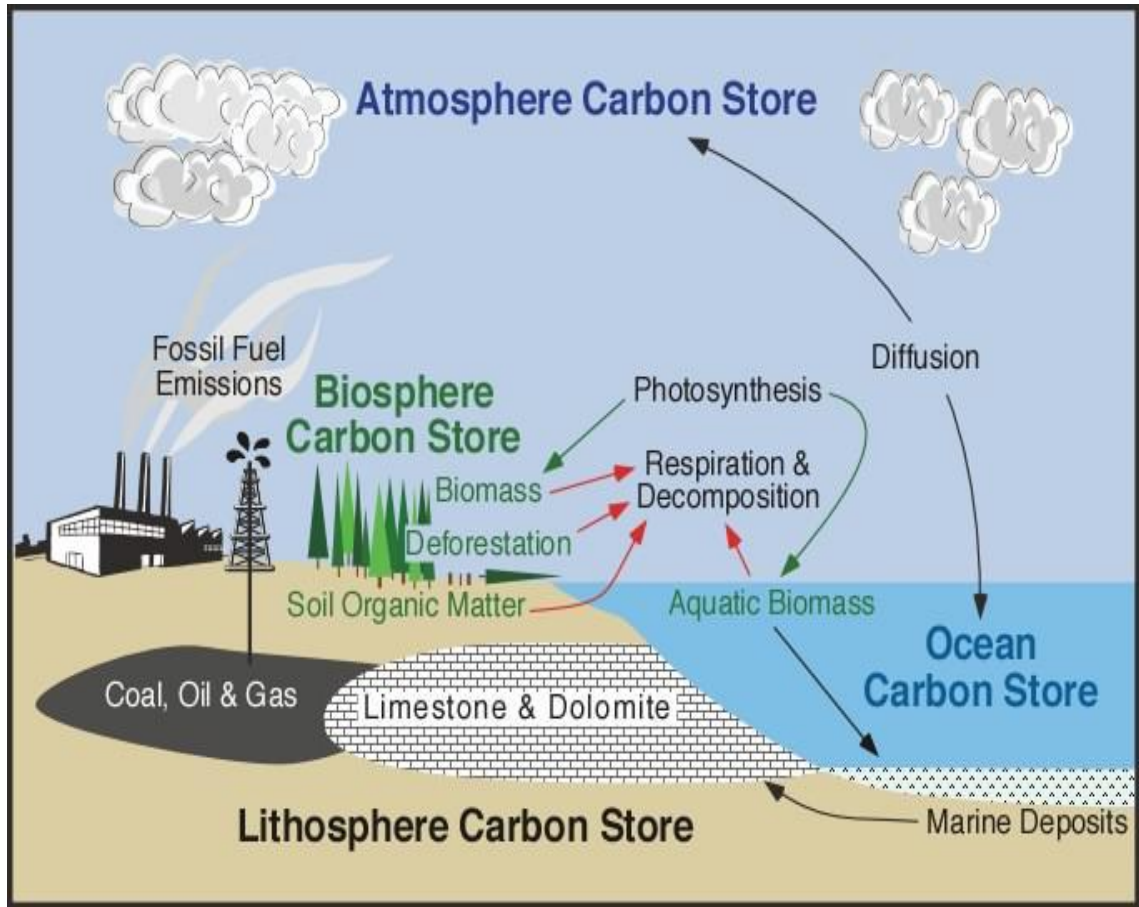


Figure 2.2: Carbon Cycle [7]

Figure 2.2 shows cycle of carbon dioxide in the environment. The life cycle of biomass is considered to be neutral regarding carbon dioxide emissions, closing the carbon cycle, even when fossil fuels are used in harvesting and transporting the biomass.

2.2.1 Oil Palm

Main sources of biomass in Malaysia are domestic wastes, agricultural residues, animal wastes, effluent sludge/wastewater, and wood chips. Agricultural residues are the most abundant in Malaysia (70 million tonnes annually) due to the production throughout the year with the present of high sunlight intensity/time and high rainfall [8].

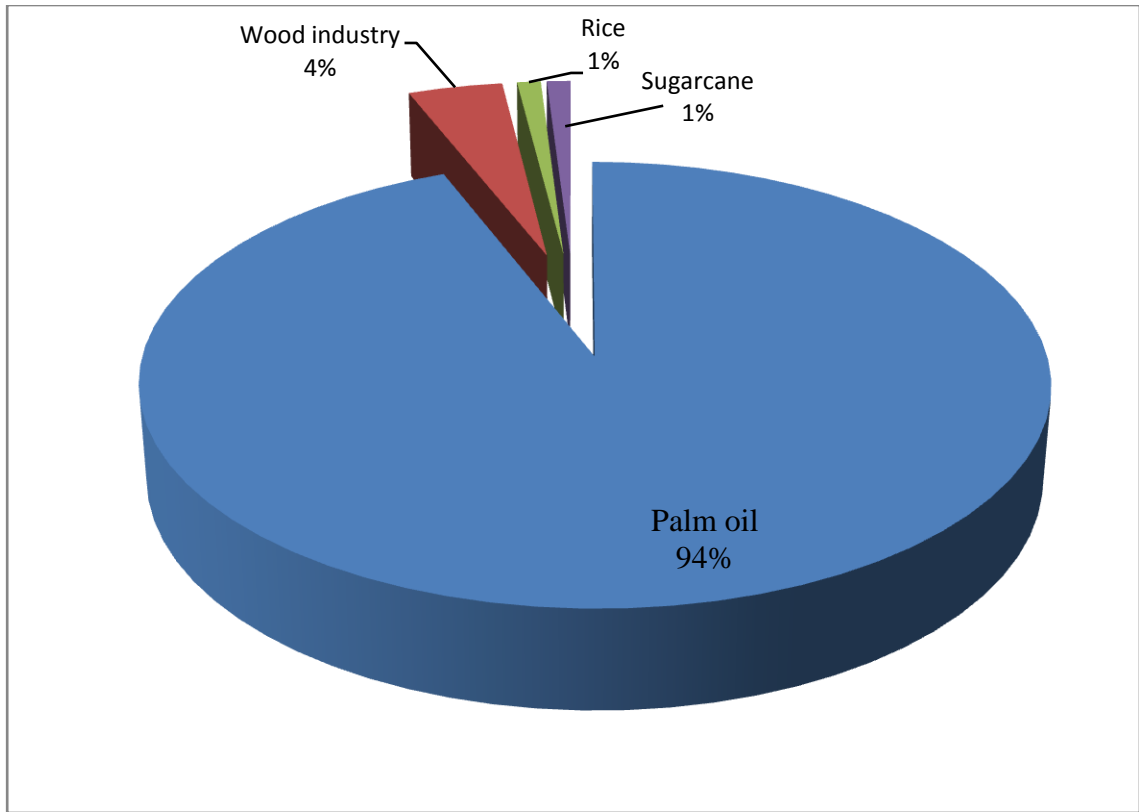


Figure 2.3: Agricultural residues in Malaysia [8]

From figure 2.3, the main contributor of agricultural residues is palm oil industry that takes about 94% throughout Malaysia. Examples of palm oil residues are empty fruit bunches (EFB), palm oil mill effluent (POME), mesocarp fiber, kernel shells, and kernel cake (residue) [8].

TSH Bio-Energy Sdn. Bhd. is the subsidiary company of TSH Group of Companies, is the first company to be grid connected biomass power plant in Malaysia. The plant has the total capacity of 14 MWe and 33 tons per hour extracted low-pressure steam supply to the neighboring palm oil mill. The project is located in Tawau, Sabah. The project development stage has been started in 2002 and received the commercial operation date (COD) on September 2004. The total capital cost of the project was RM47 million. The capital cost incurred is to the all equipment cost, services and interconnection to the Sabah Electricity Sdn. Bhd. (SESB) grid. The biomass resources used are residues from palm oil; empty fruit bunch (EFB), fiber and shell [9].

2.3 Coal Co-Firing With Biomass

Co-firing is a process of combusting two different materials simultaneously in a combustor. Usually biomass (secondary fuel) is fed together with coal (primary fuel) into the boiler. Co-firing of biomass with coal allows energy production to be switched entirely or partly over to coal if there are seasonal or temporary shortfalls in the supply of plant materials. Thus the energy output continues without interruption. Co-firing also creates less air pollution than power generation using fossil-based fuels alone. There are three methods of co-firing, which are direct co-firing, indirect co-firing and parallel co-firing. For direct co-firing method, biomass (secondary fuel) is fed together with coal (primary fuel) into the same boiler. For indirect co-firing method, biomass is gasified first before the resulting synthetic gas (syngas) is fed together with coal into the boiler. Parallel co-firing involves separate combustor or boiler for biomass and coal. The resulting steam is fed into the main steam circuit [10].

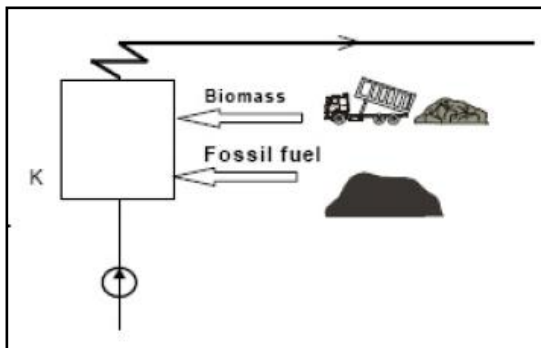


Figure 2.4: Direct Co-firing Method [10]

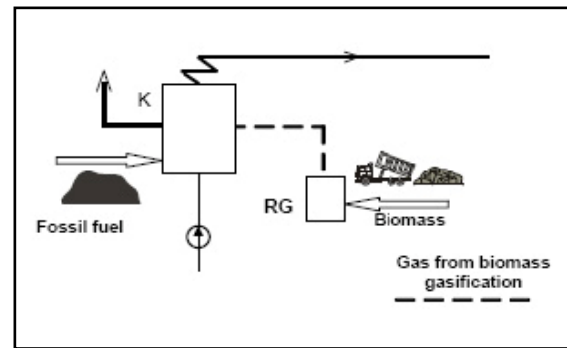


Figure 2.5: Indirect Co-firing Method [10]

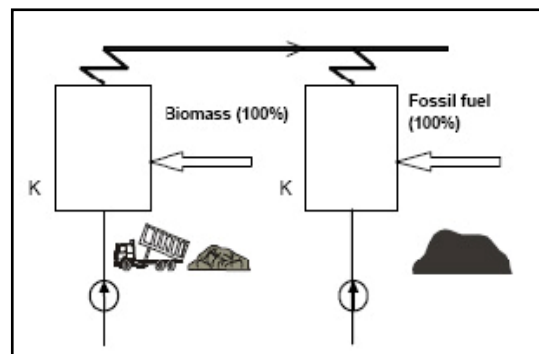


Figure 2.6: Parallel Co-firing Method [10]

TABLE 2.2

ADVANTAGES AND DISADVANTAGES OF CO-FIRING METHODS [10]

Types	Direct Co-Firing	Indirect Co-Firing	Parallel Co-Firing
Advantages	Lowest cost	High efficiency and low ash contain	Highest efficiency and lowest ash contain
Disadvantages	Highest contain of ash and has the lowest efficiency	Relatively expensive	Very expensive

Table 2.2 shows the advantages and disadvantages of three types of co-firing method. The best method will be the parallel co-firing though it is very expensive to be applied. So, cost is one of the considerations to choose the co-firing method. In the current situation, the most suitable method is direct co-firing method because there is no need for modification to the existing power plants.

CHAPTER 3: METHODOLOGY

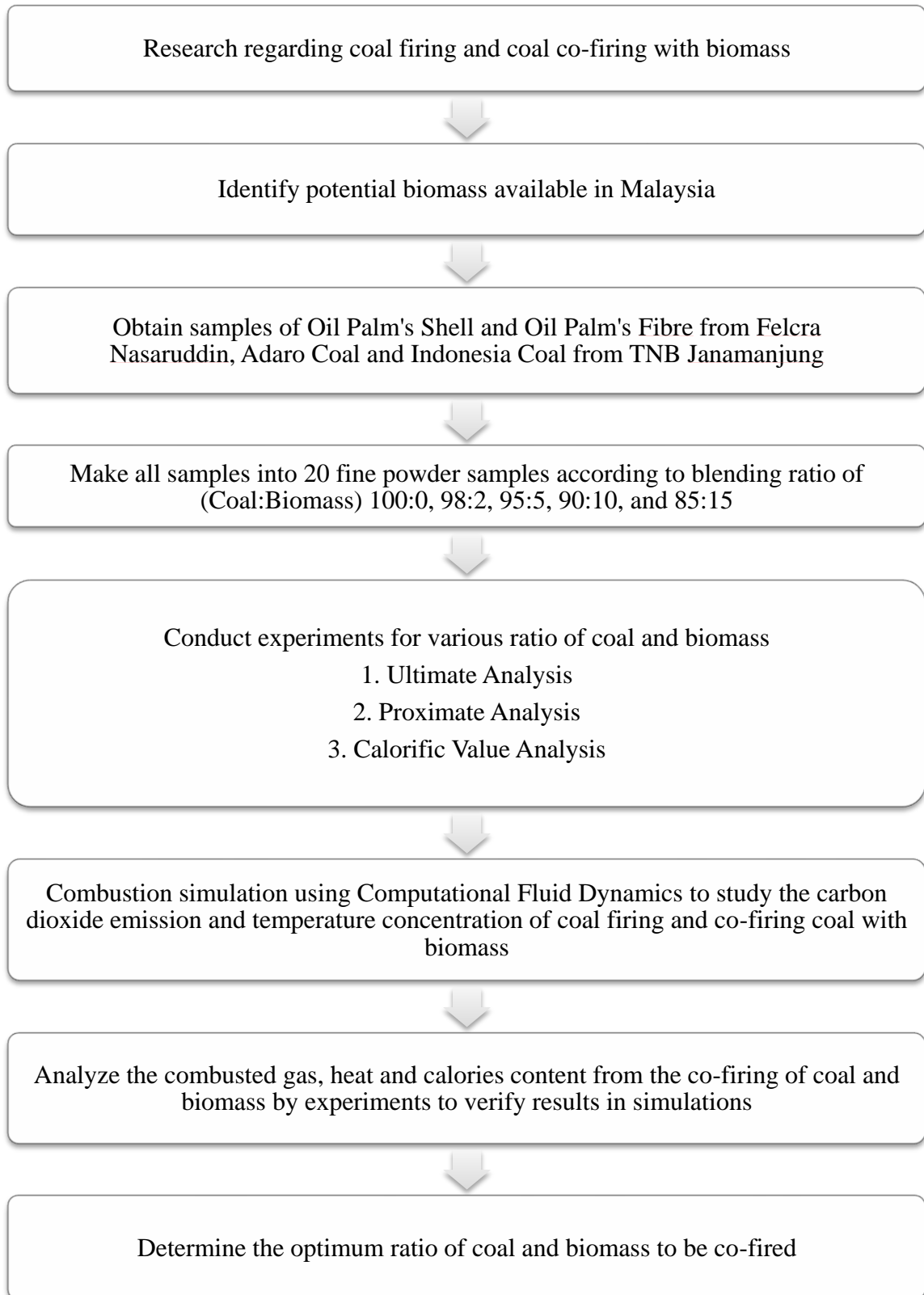
3.1 Project Milestones for FYP 1

Details	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Selection of Project Topic															
Preliminary Research Work -Research on Coal -Research on Biomass -Research on Coal Co-Firing with Biomass															
Submission of Preliminary Report															
Research Work -Research on Available Resources in Malaysia -Research on the Coal and Biomass Candidates															
Submission of Progress Report															
Seminar															
Project Work Continues -Getting Coal and Biomass Samples from Available Resources -Making the Required Samples for Further Analysis															
Submission of Interim Report Final Draft															
Oral Presentation															

3.2 Project Milestones for FYP 2

Details	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Work Continues -Obtain samples of Oil Palm ' Shell and Oil Palms' Fibrec from Felcra Nasaruddin -Obtain samples of Coals from TNB Janamanjung -Make all sample into a fine powder samples -Blend samples according to ratio	X	X	X											
Submission of Progress Report 1				X										
Project Work Continues -Do the Ultimate Analysis -Do the Proximate Analysis -Analyze the combusted gas, heat and calories content from the co-firing				X	X	X								
Submission of Progress Report 2								X						
Seminar								X						
Project Work Continues -Do the simulation using CFD							X	X	X	X	X	X	X	X
Poster Exhibition											X			
Submission of Dissertation Final Draft														X
Oral Presentation	During Study Week													
Submission of Dissertation (Hard Bound)	7 Days After Oral Presentation													

3.3 Work Flow



3.4 Tools, Machine, and Software Required

3.4.1 Bomb Calorimeter



Figure 3.1: Bomb Calorimeter

- To measure the heat of combustion in a particular reaction.
- To calculate the High Heating Value (HHV) content of the fuel.

3.4.2 Thermal Gravimetric Analyzer (TGA) and CHNS-932

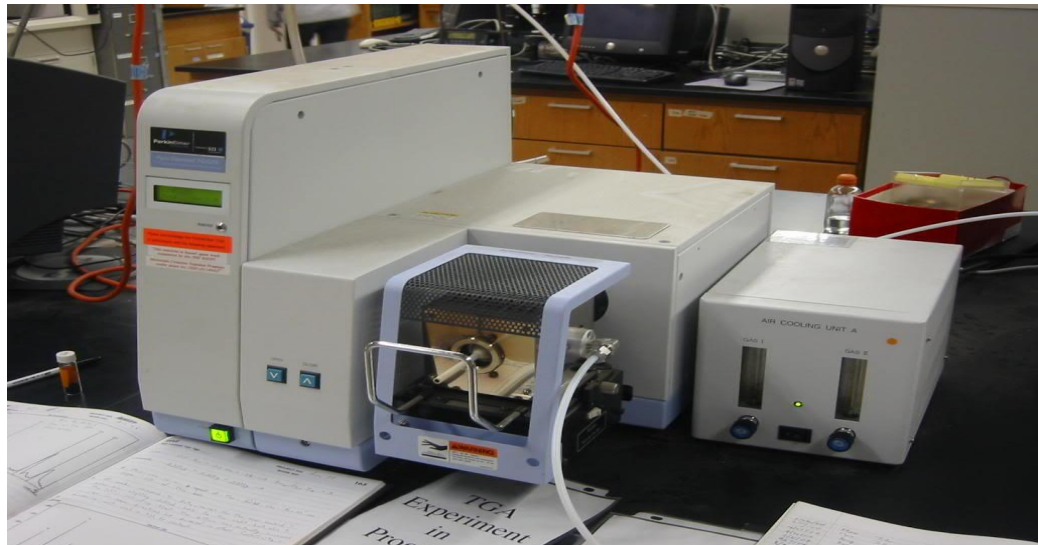


Figure 3.2: Thermal Gravimetric Analyzer (TGA)



Figure 3.3: CHNS-932

- To analyze biomass and coal using Proximate (TGA) and Ultimate Analysis (CHNS-932).
- Proximate Analysis gives the weight percentage of moisture, volatile matter, fixed carbon and ash.
- Ultimate Analysis gives the composition of the solid fuel in weight percentage of Carbon, Hydrogen, Nitrogen, and Sulfur.

3.4.3 Gas Analyzer



Figure 3.4: Gas Analyzer

- To determine the content the emitted gases (CO_2 , O_2 , NO_x) in fuel during combustion

3.4.4 Computational Fluid Dynamics (CFD)

- CFD is a computational technology that enables the study of dynamics of things that flow
- Preprocessing is the first step in building and analyzing a flow model. It includes building the model within a computer-aided design (CAD) package, creating and applying a suitable computational mesh, and entering the flow boundary conditions and fluid materials properties.
- Solving is the second step in CFD. The CFD solver does calculation based on the mesh and produces the results required in the analysis.
- Post-processing is the final step in CFD analysis, and it involves the organization and interpretation of the results.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Ultimate Analysis

4.1.1 Results

The results were analyzed using bar charts in Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4 according to the types of composition. Tabulated form of the results is incorporated in Appendix A.

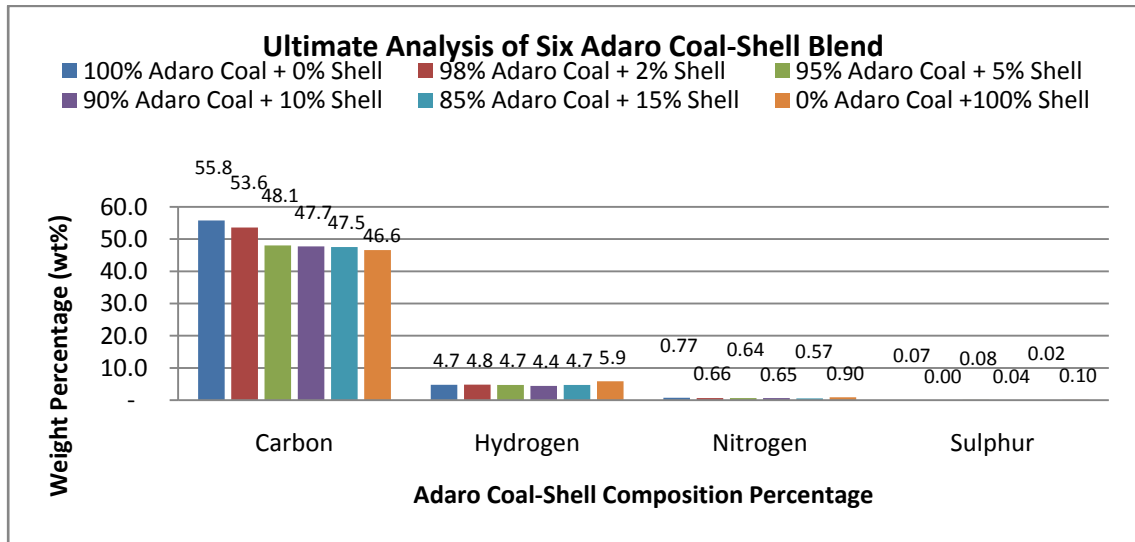


Figure 4.1: Ultimate Analysis of Six Adaro Coal-Shell Blend

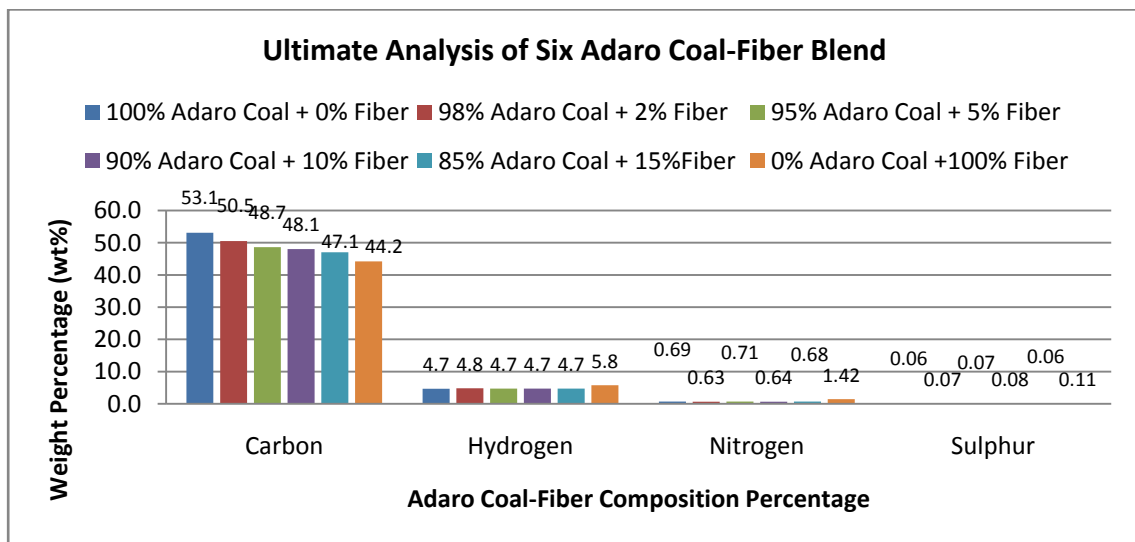


Figure 4.2: Ultimate Analysis of Six Adaro Coal-Fiber Blend

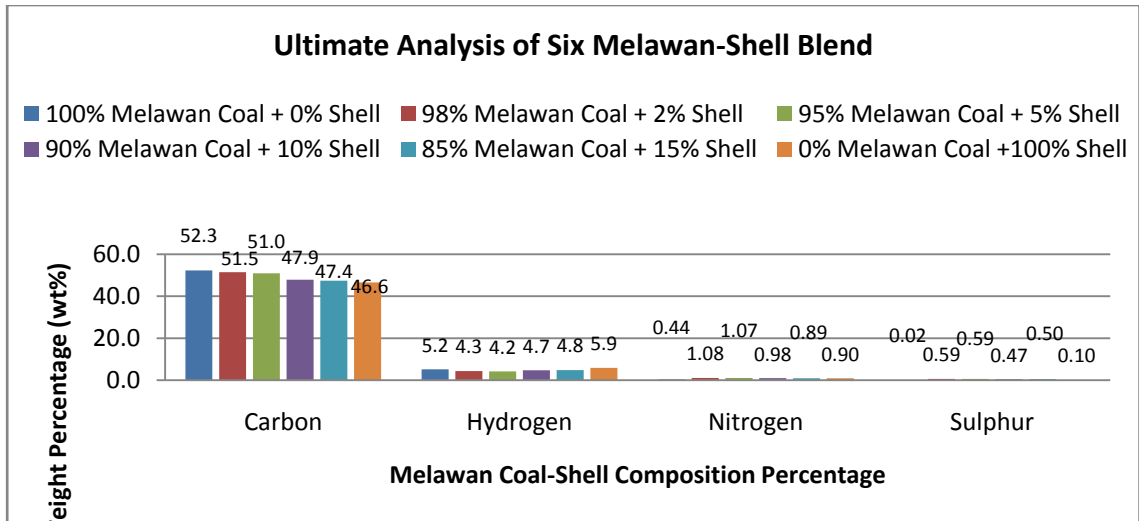


Figure 4.3: Ultimate Analysis of Six Melawan-Shell Blend

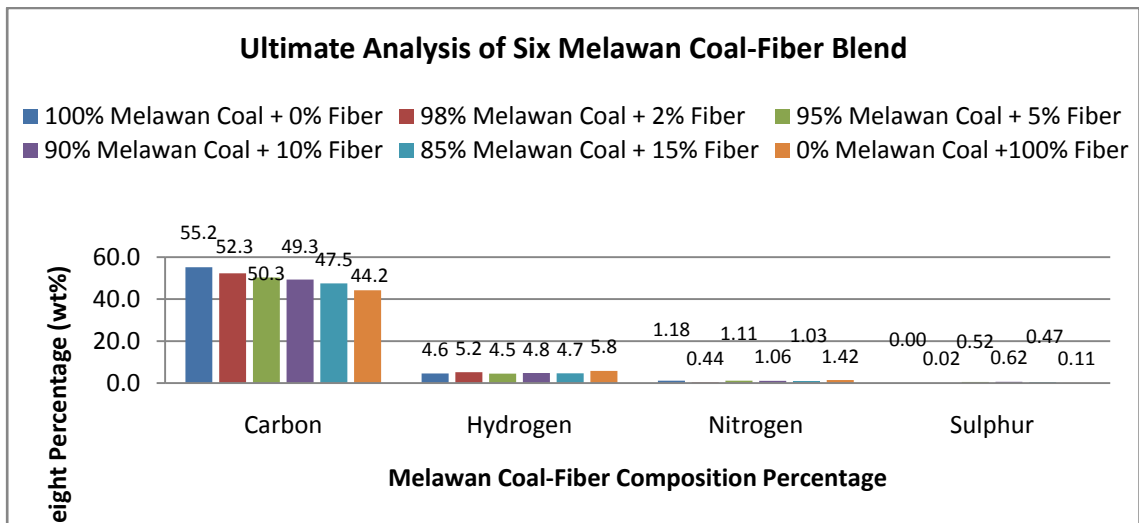
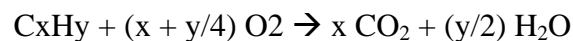


Figure 4.4: Ultimate Analysis of Six Melawan Coal-Fiber Blend

4.1.2 Discussion

According to the results obtained from the ultimate analysis, the carbon content as well as nitrogen and sulphur is decreasing as more percentage of biomass is added into the coal. Consequently, the combustion equation below shows that if the carbon content of the fuel decreases, the amount of carbon dioxide released as a bi-product of combustion decreases.



4.2 Proximate Analysis

4.2.1 Results

The results were analyzed using bar charts in Figure 4.5, Figure 4.6, Figure 4.7 and Figure 4.8 according to the types of composition. Tabulated form of the results is incorporated in Appendix B.

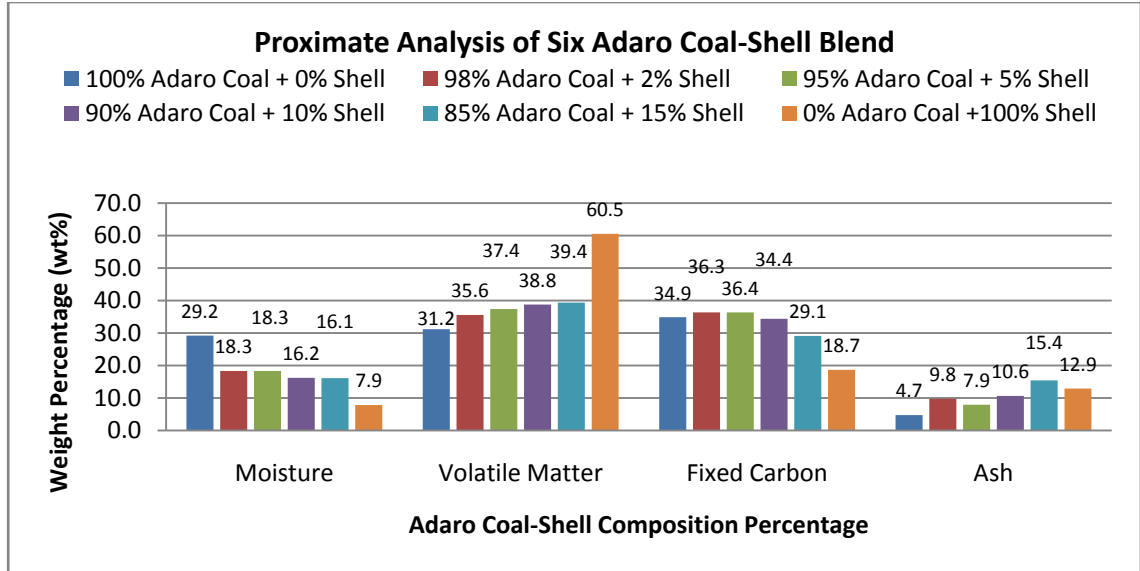


Figure 4.5: Proximate Analysis of Six Adaro Coal-Shell Blend

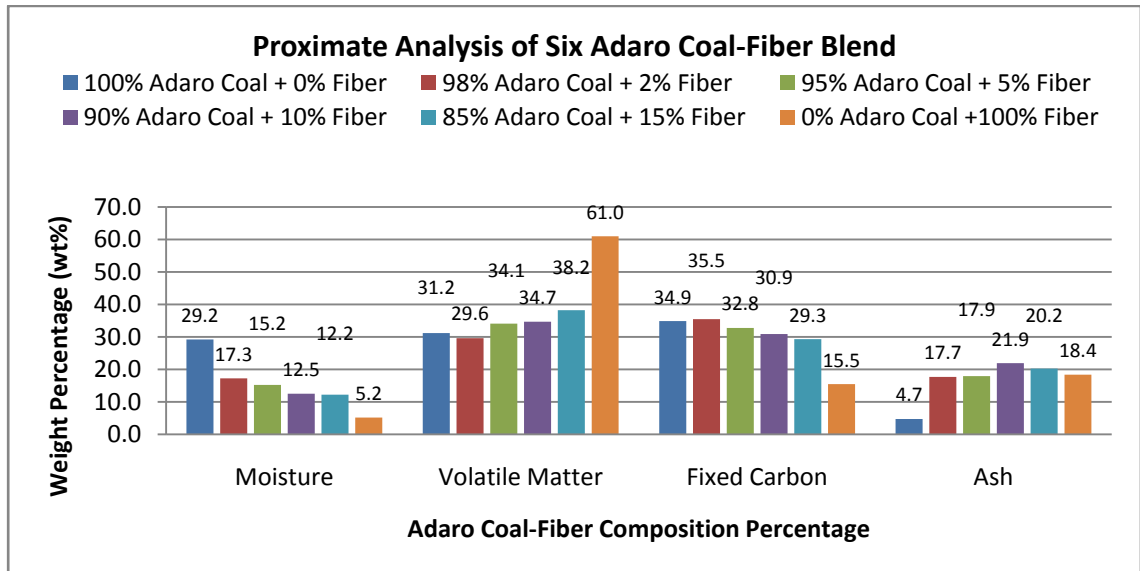


Figure 4.6: Proximate Analysis of Six Adaro Coal-Fiber Blend

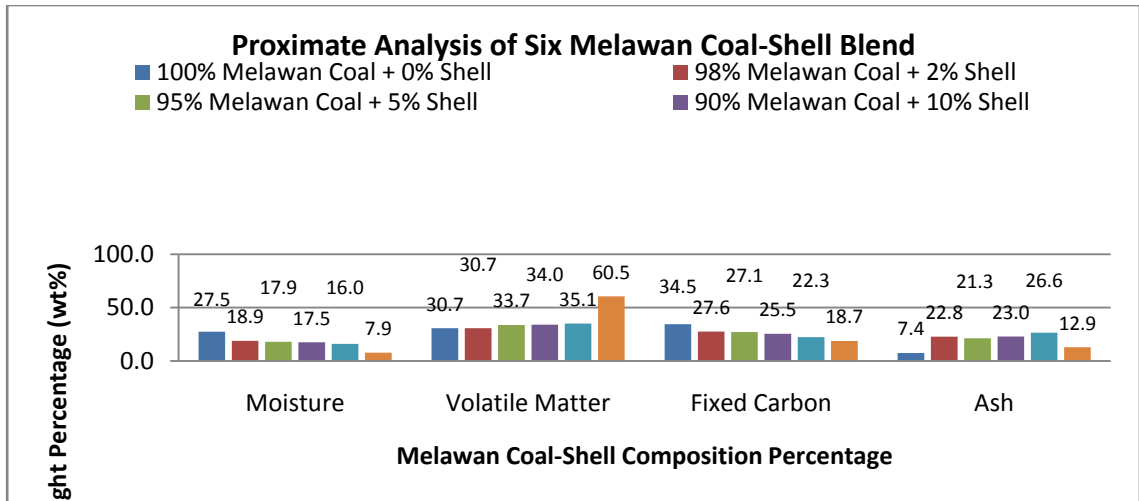


Figure 4.7: Proximate Analysis of Six Melawan Coal-Shell Blend

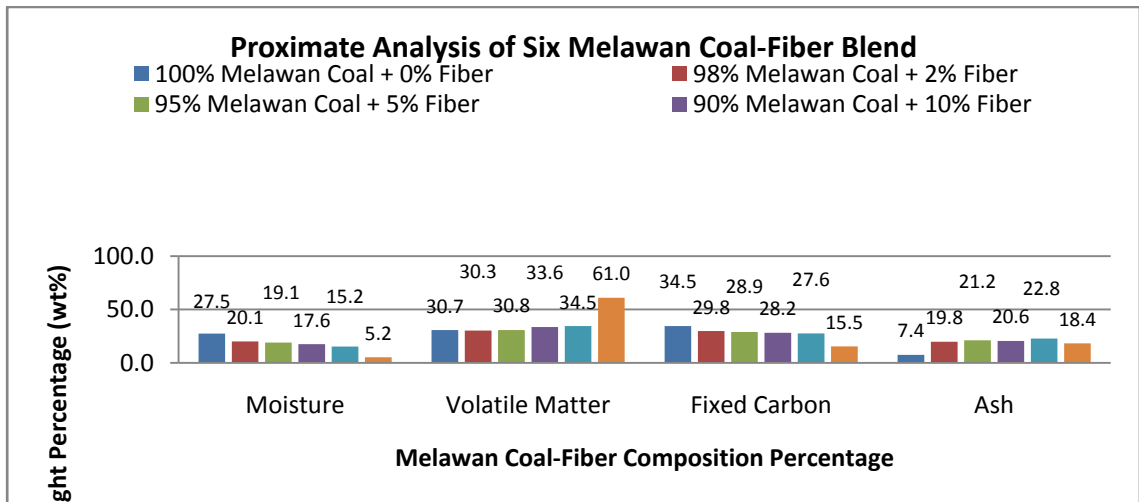


Figure 4.8: Proximate Analysis of Six Melawan Coal-Fiber Blend

4.2.2 Discussions

According to the results obtained from the proximate analysis, the percentage of moisture and volatile matter are decreasing meanwhile the percentage of fixed carbon and ash are increasing as more percentage of biomass is added into the coal. Usually, the ashes from coal firing are sold and used, but the ashes produced in biomass firing cannot be sold for profit due to large quantity but low quantity. Therefore, the amount of biomass inserted into the coal for co-firing has to be controlled to produce high quality ashes.

4.3 Calorific Value Analysis

4.3.1 Results

The results were analyzed using bar charts in Figure 4.9 according to the types of composition. Tabulated form of the results is incorporated in Appendix C.

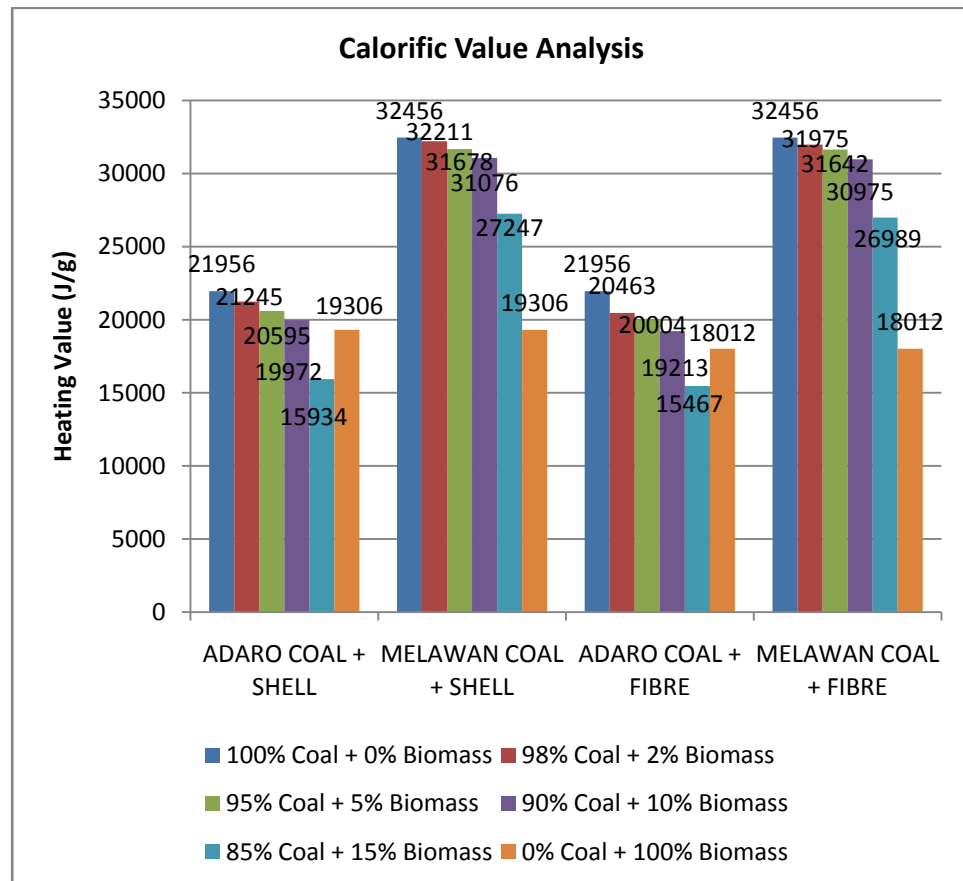


Figure 4.9: Calorific Value Analysis of Twenty Coal-Biomass Blend

4.3.2 Discussion

The results show that the lower percentages of coal in coal-biomass blend would give lower heating values. This shows that higher amount of biomass incorporated into the burning of coal will produce lower heat content, thus reducing the combustion temperature. As a result, the steam generated will not be able to produce the power required for optimum electricity generation in power plants.

4.4 FLUENT Simulation

4.4.1 Computational Fluid Dynamics

The model for the flame occurs is the burner in the furnace. GAMBIT will be use to model the burner and draw in two-dimensionally to scale. The model is adapted from TNB Kapar, Selangor. The real dimensions of the furnace are approximately given by height is 11 m, width is 7 m and length is 9 m. The model of the furnace will be created using a control volume of 7 m by 1.45 m [11].

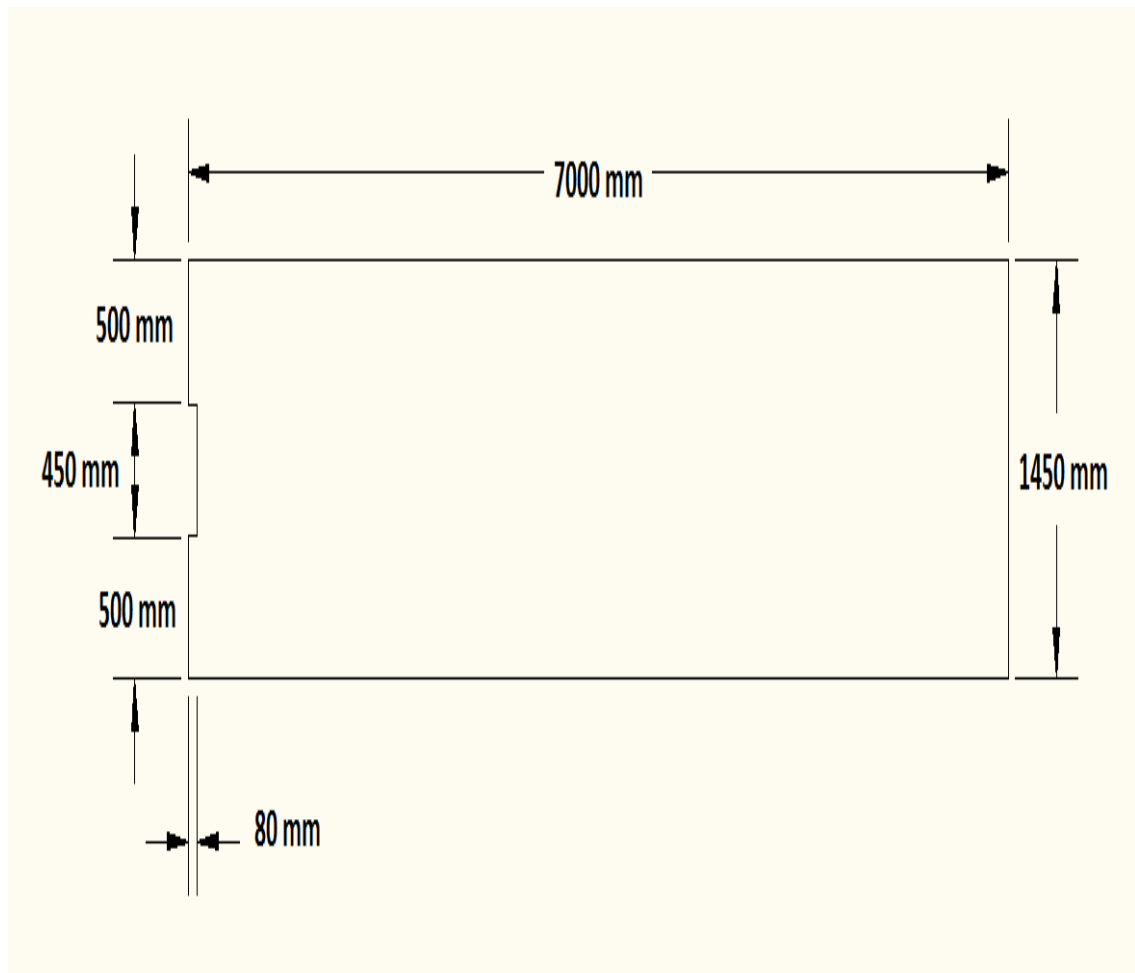


Figure 4.10: Dimension of Burner Model [12]

FLUENT simulation demonstrates three types of results; temperature profile, carbon dioxide concentration, and nitrogen concentration for each percentage of fuel blend in an injector of a burner.

4.4.2 Temperature Profiles

4.4.2.1 Results

Figure 4.11 shows an example of combustion temperature profile for the fuel blend of 90% of Melawan coal and 10% of shell. The other combustion temperature profile is incorporated in Appendix D.

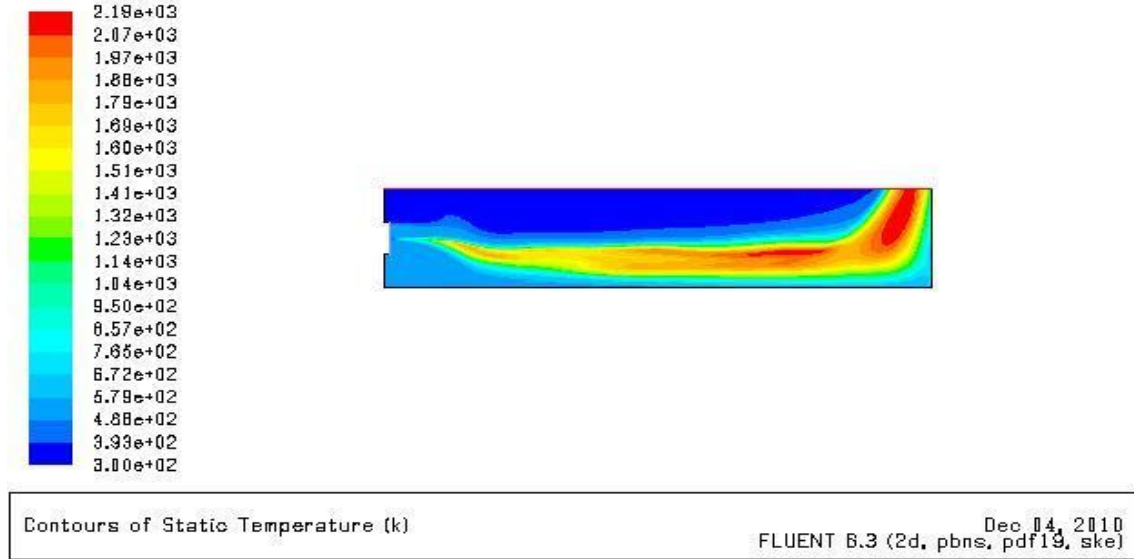


Figure 4.11: Combustion Temperature Profile for the Fuel Blend Of 90% of Melawan Coal and 10% of Shell

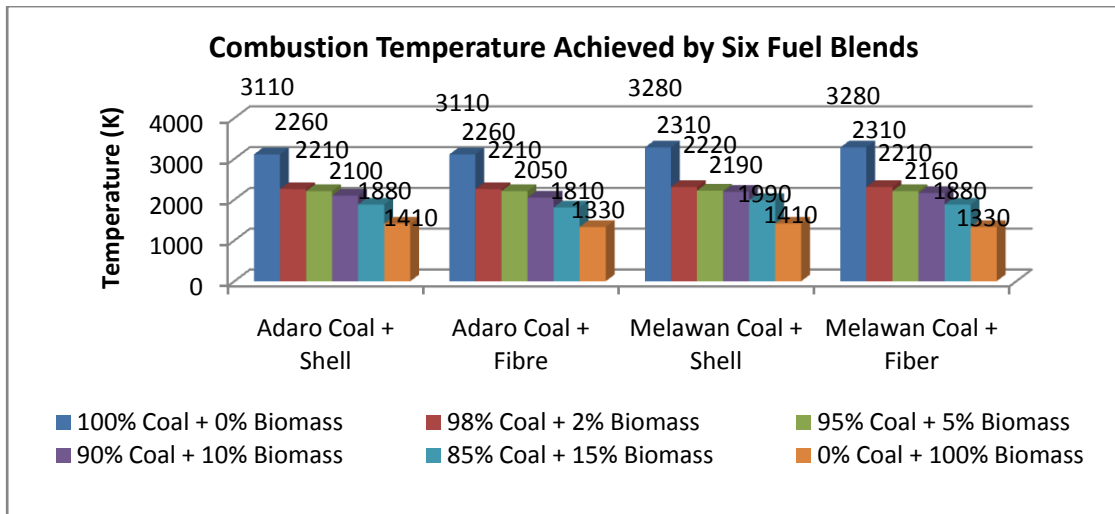


Figure 4.12: Combustion Temperature Achieved by Twenty Fuel Blend

4.4.2.2 Discussions

Through the result from Figure 4.12, it is able to see that all fuels are producing temperatures around the optimum temperature which is above 2000K [11] and therefore, provided with amounts of excess air, the combustion temperature of these fuels can be lowered to suit the boiler requirements. From the temperature contour in Figure 4.11 shows that the fuel rich zone is located at the center of the peak flame temperature and the temperature is decreasing with increasing biomass percentage. This is caused by high moisture and volatility of biomass which in turn reduces the flame temperature of fuel rich zone and similarly decreases the amount of thermal NO_x produced due to oxidization of atmospheric nitrogen atoms at high temperatures.

4.4.3 Nitrogen Concentration

4.4.3.1 Results

Figure 4.13 shows an example of nitrogen concentration profile for the fuel blend of 90% of Melawan coal and 10% of shell. The other nitrogen concentration profile is incorporated in Appendix E.

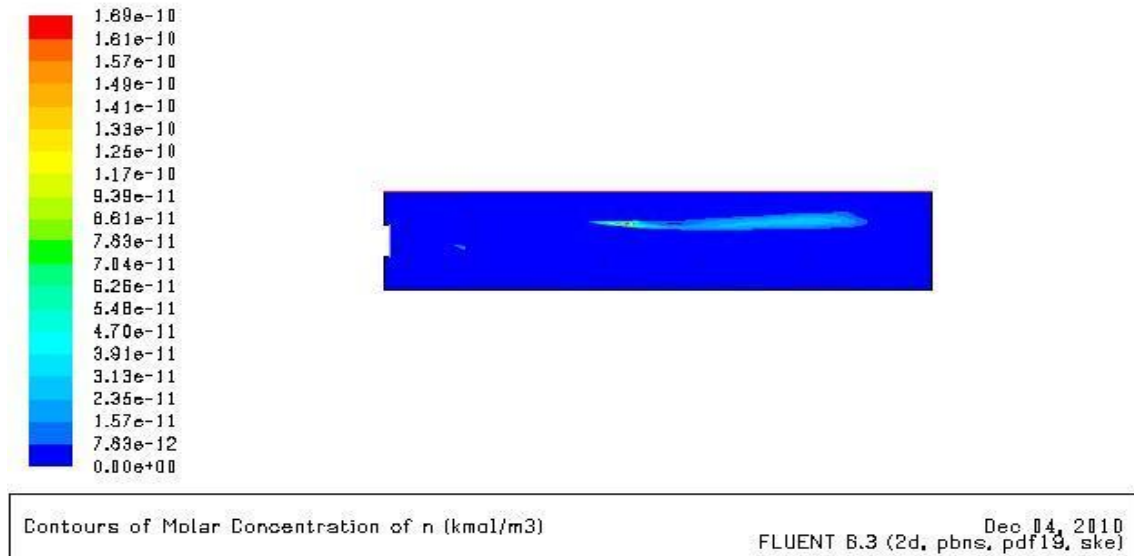


Figure 4.13: Nitrogen Concentration Profile for the Fuel Blend of 90% of Melawan Coal and 10% of Shell

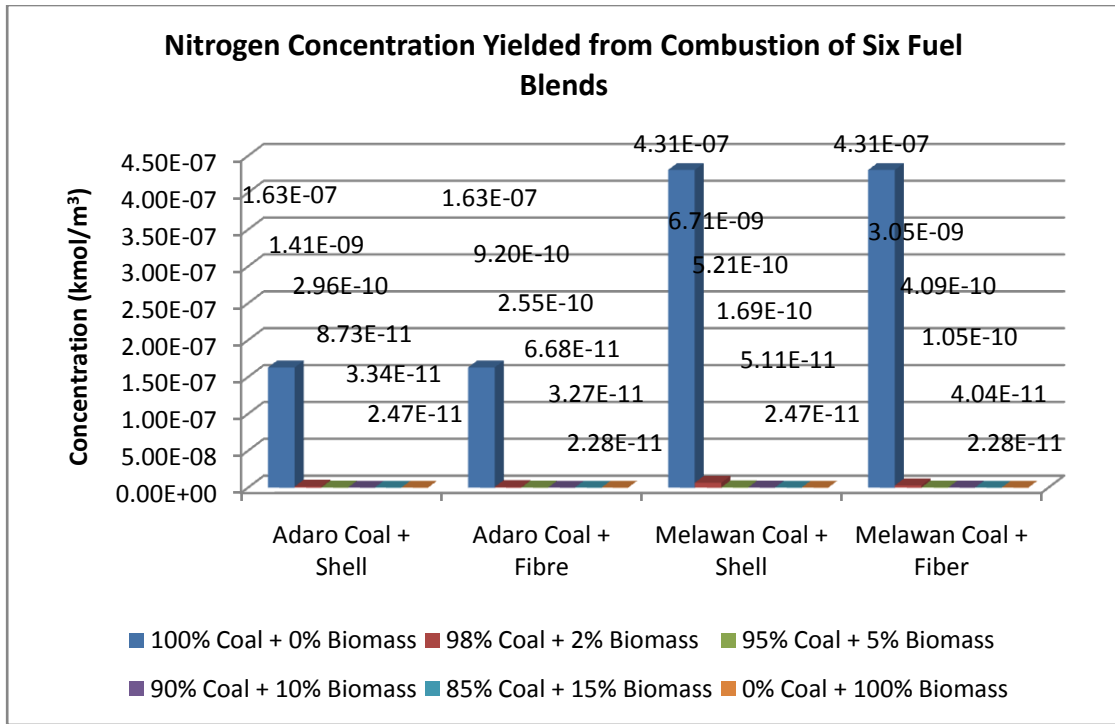


Figure 4.14: Nitrogen Concentration Yielded from Combustion of Twenty Fuel Blends

4.4.3.2 Discussions

The result from Figure 4.14 shows that the nitrogen concentration reduces with the increase of biomass percentage. The reduction in nitrogen concentration generally reduces the amount of NO_x produced due to the lessen amount of nitrogen atoms that is able to react with oxygen molecules to form NO_x in spite of forming due to high combustion temperatures.

4.4.4 Carbon Dioxide Concentration

4.4.4.1 Results

Figure 4.15 shows an example of carbon dioxide concentration profile for the fuel blend of 90% of Melawan coal and 10% of shell. The other carbon dioxide concentration profile is incorporated in Appendix F.

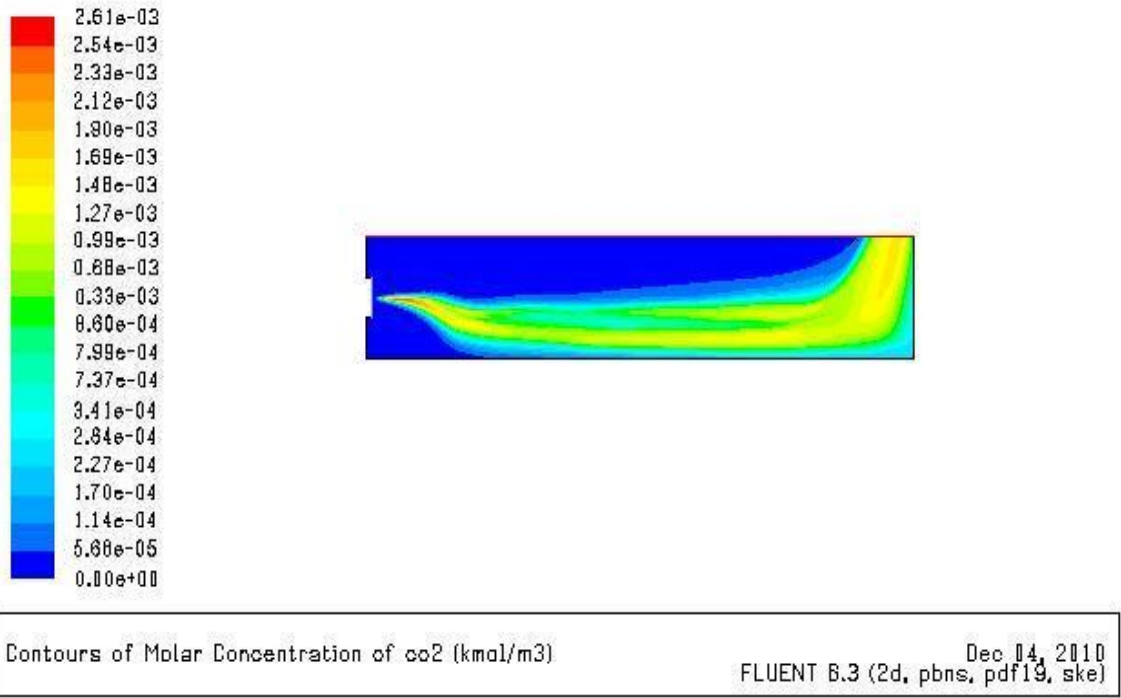


Figure 4.15: Carbon Dioxide Concentration Profile for the Fuel Blend of 90% of Melawan Coal and 10% of Shell

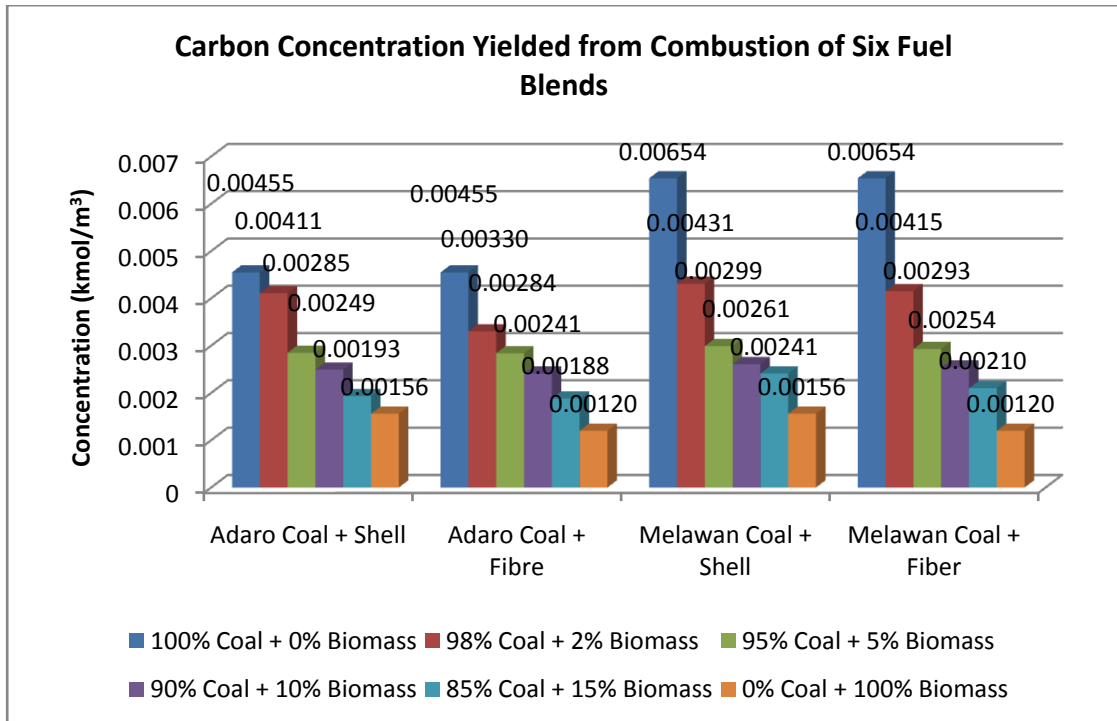


Figure 4.16: Carbon Concentration Yielded from Combustion of Twenty Fuel Blend

4.4.4.2 Discussions

The result from Figure 4.16 shows that the carbon dioxide concentration reduced with the increased of biomass percentage in the fuel. The amount of carbon dioxide produced through the combustion of biomass is generally returned to the carbon dioxide cycle of the atmosphere as it is of equal amount to the carbon dioxide used in the plant cycle. From the ultimate analysis, the carbon content of coal is the highest and is reducing as more percentage of biomass is blended with coal. The carbon dioxide concentration is showing the same trend.

4.5 Gas Analysis

4.5.1 Results

The results from simulation were verified by an experiment using bomb calorimeter and gas analyzer. The results are shown in form of bar chart in Figure 4.17 and Figure 4.18. The tabulated form of the results is appended in Appendix G.

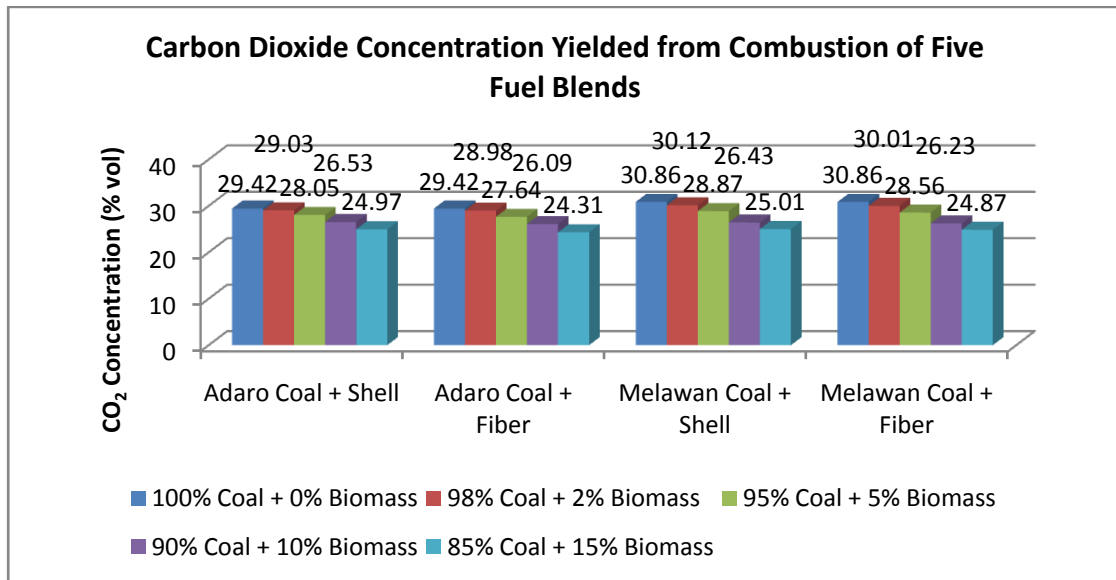


Figure 4.17: Carbon Dioxide Concentration Yielded from Combustion of Twenty Fuel Blends

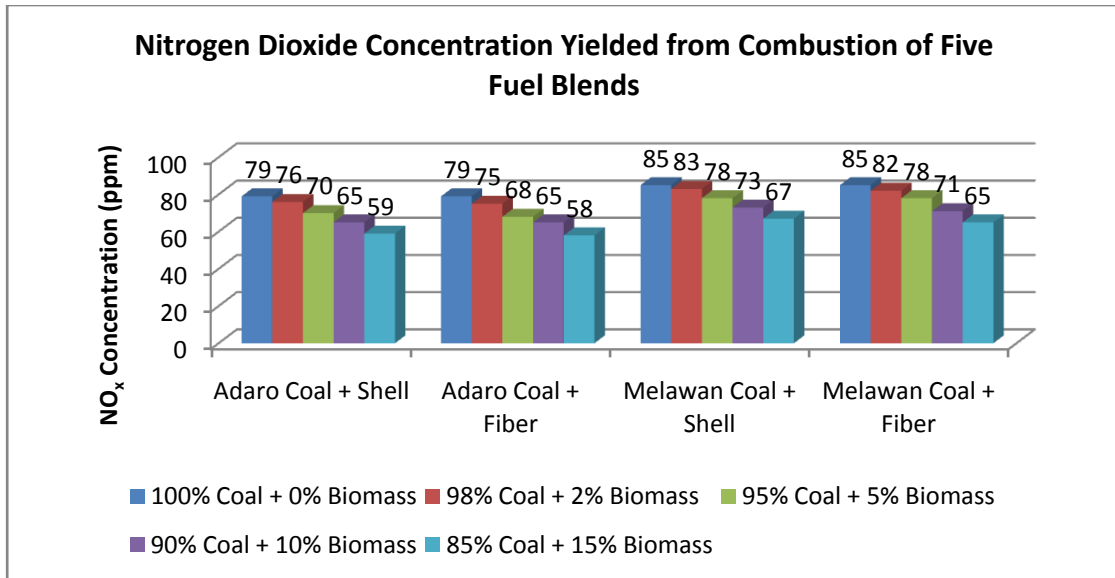


Figure 4.18: Nitrogen Dioxide Concentration Yielded from Combustion of Twenty Fuel Blends

4.5.2 Discussions

The results from Figure 4.17 and Figure 4.18 show that the increment of biomass in the fuel reduces the concentration of carbon dioxide and nitrogen oxide. This reduction is due to less significant amounts of carbon and nitrogen elements in shell and fiber. The calculation for percentage reduction of the CO₂ and NO_x is shown in Appendix H. Referring to the result attached in Appendix G; the oxygen level is at constant value of 25% volume due to the condition in the bomb calorimeter that allows for complete combustion.

This verifies the reduction in carbon dioxide and nitrogen concentration from the simulation. The comparison for nitrogen content is more complicated than carbon dioxide content due to various factors affecting the NO_x emission. NO_x refers to all oxides of nitrogen. The formation of NO_x relies solely on high temperature and the availability of unused oxygen.

There are three types of formation for NO_x:

- Thermal NO_x: formed by the reaction of atmospheric nitrogen and oxygen at high temperature.
- Fuel NO_x: formed by oxidation of fuel bound nitrogen.
- Prompt NO_x: formed by reaction of hydrocarbon fragments with atmospheric oxygen.

Results from simulation and experimentation slightly differ due to a number of reasons such as:

- Simulation is done in perfect conditions and does not have any external factors such as ambient temperature, humidity and wind.
- Simulation simulate solely based on the input assigned compare to the experimentation that depend on a lot of factors including errors in equipment; where the equipment can never be 100% accurate, and human error (a mistake) occurs when the experimenter, make a mistake such as when the experimenter set up experiment incorrectly, misread an instrument, or make a mistake in a calculation.
- Simulation needs input from experimentations that might have some errors that make the simulation results not 100% reliable.

The gas analysis proves that FLUENT simulation is reliable to predict the temperature profile, carbon dioxide emission concentration and nitrogen oxide emission concentration.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objectives of this project have been achieved throughout this project. This project has concluded that:

- Types of biomass resources available in Malaysia are mainly from domestic wastes, agricultural residues (most abundant), animal wastes, effluent/wastewater, and wood chips.
- Coal co-firing with biomass reduces the carbon dioxide concentration and temperature in the furnace compare to coal firing only.
- The increase of biomass in the blend reduces the carbon dioxide concentration and temperature in the furnace.
- Simulation of combustion of coal and coal with biomass has been done using CFD method and the results have been verified with gas analysis experiment.
- The suitable range of blending ratio between coal and biomass for optimum power generation is 90:10.
- The best candidate for coal to be co-fired is Adaro Coal due to low carbon dioxide and nitrogen oxide emission, but still able to generate at least the optimum temperature of 2000K.
- The best candidate for biomass to be co-fired is shell due to less reduction of heat generation with a reasonable carbon dioxide and nitrogen oxide emission.

5.2 Recommendations

These are some recommendations for future work that could probably be carried out to enhance the understanding about coal-biomass co-firing and to further improve the accuracy of results.

- Perform other types of co-firing methods. There are other two types of co-firing that should be an option for co-firing method. This actually might increase the efficiency of the fuel.
- Use various types of biomass. There a lot of biomass sources in Malaysia that can be used to be co-fired with coal. This might show that there are other biomass that can reduce more carbon dioxide and nitrogen oxide while do not have any significant reduction with the heat generation.

CHAPTER 6: REFERENCES

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CHAPTER 7: APPENDICES

APPENDIX A: Results for Ultimate Analysis

Percentage (Adaro Coal % - Shell %)	Weight (g)	Carbon (Weight %)	Hydrogen (Weight %)	Nitrogen (Weight %)	Sulphur (Weight %)
100% - 0%	1.896	55.77	4.749	0.768	0.072
98% - 2 %	1.898	53.61	4.831	0.662	0
95% - 5%	1.756	48.05	4.721	0.638	0.075
90% - 10%	1.763	47.74	4.407	0.645	0.042
85% - 15%	1.763	47.54	4.738	0.572	0.019
0% - 100%	1.607	46.57	5.876	0.899	0.102

Ultimate Analysis of Adaro Coal - Shell Composition Percentage

Percentage (Adaro Coal % - Fiber %)	Weight (g)	Carbon (Weight %)	Hydrogen (Weight %)	Nitrogen (Weight %)	Sulphur (Weight %)
100% - 0%	1.874	53.1	4.69	0.694	0.056
98% - 2 %	1.896	50.52	4.799	0.629	0.071
95% - 5%	1.616	48.65	4.704	0.708	0.069
90% - 10%	1.576	48.05	4.721	0.638	0.075
85% - 15%	1.877	47.06	4.718	0.675	0.055
0% - 100%	1.505	44.23	5.783	1.421	0.114

Ultimate Analysis of Adaro Coal - Fiber Composition Percentage

Percentage (Melawan Coal % - Shell %)	Weight (g)	Carbon (Weight %)	Hydrogen (Weight %)	Nitrogen (Weight %)	Sulphur (Weight %)
100% - 0%	1.746	52.32	5.231	0.436	0.021
98% - 2 %	1.831	51.47	4.32	1.081	0.585
95% - 5%	1.863	50.96	4.165	1.067	0.585
90% - 10%	1.527	47.88	4.719	0.977	0.472
85% - 15%	1.546	47.42	4.828	0.885	0.504
0% - 100%	1.607	46.57	5.876	0.899	0.102

Ultimate Analysis of Melawan Coal - Shell Composition Percentage

Percentage (Melawan Coal % - Fiber %)	Weight (g)	Carbon (Weight %)	Hydrogen (Weight %)	Nitrogen (Weight %)	Sulphur (Weight %)
100% - 0%	1.831	55.16	4.603	1.176	0
98% - 2 %	1.947	52.32	5.231	0.436	0.021
95% - 5%	1.942	50.3	4.506	1.106	0.515
90% - 10%	1.612	49.31	4.784	1.064	0.616
85% - 15%	1.596	47.47	4.676	1.028	0.465
0% - 100%	1.505	44.23	5.783	1.421	0.114

Ultimate Analysis of Melawan Coal - Fiber Composition Percentage

APPENDIX B: Results for Proximate Analysis

Percentage (Adaro Coal % - Shell %)	Moisture (Weight %)	Volatile Matter (Weight %)	Fixed Carbon (Weight %)	Ash (Weight %)
100% - 0%	29.21	31.2	34.86	4.73
98% - 2 %	18.34	35.56	36.34	9.76
95% - 5%	18.32	37.4	36.35	7.93
90% - 10%	16.22	38.78	34.37	10.63
85% - 15%	16.1	39.35	29.12	15.43
0% - 100%	7.85	60.546	18.675	12.929

Proximate Analysis of Adaro Coal - Shell Composition Percentage

Percentage (Adaro Coal % - Fiber %)	Moisture (Weight %)	Volatile Matter (Weight %)	Fixed Carbon (Weight %)	Ash (Weight %)
100% - 0%	29.21	31.2	34.86	4.73
98% - 2 %	17.25	29.63	35.45	17.67
95% - 5%	15.2	34.1	32.78	17.92
90% - 10%	12.53	34.67	30.89	21.91
85% - 15%	12.21	38.24	29.32	20.23
0% - 100%	5.18	60.995	15.467	18.358

Proximate Analysis of Adaro Coal - Fiber Composition Percentage

Percentage (Melawan Coal % - Shell %)	Moisture (Weight %)	Volatile Matter (Weight %)	Fixed Carbon (Weight %)	Ash (Weight %)
100% - 0%	27.45	30.67	34.45	7.43
98% - 2 %	18.93	30.68	27.61	22.78
95% - 5%	17.92	33.68	27.1	21.3
90% - 10%	17.49	34.04	25.5	22.97
85% - 15%	15.97	35.14	22.3	26.59
0% - 100%	7.85	60.546	18.675	12.929

Proximate Analysis of Melawan Coal - Shell Composition Percentage

Percentage (Melawan Coal % - Fiber %)	Moisture (Weight %)	Volatile Matter (Weight %)	Fixed Carbon (Weight %)	Ash (Weight %)
100% - 0%	27.45	30.67	34.45	7.43
98% - 2 %	20.13	30.34	29.78	19.75
95% - 5%	19.1	30.78	28.93	21.19
90% - 10%	17.56	33.64	28.22	20.58
85% - 15%	15.23	34.45	27.56	22.76
0% - 100%	5.18	60.995	15.467	18.358

Proximate Analysis of Melawan Coal - Fiber Composition Percentage

APPENDIX C: Results for Calorific Value Analysis

Percentage (Adaro Coal % - Shell %)	Weight (g)	Heating Value (J/g)
100% - 0%	0.3138	21956
98% - 2 %	0.3566	21245
95% - 5%	0.3321	20595
90% - 10%	0.3254	19972
85% - 15%	0.3529	15934
0% - 100%	0.3864	19306

Calorific Value Analysis of Adaro Coal - Shell Composition Percentage

Percentage (Adaro Coal % - Fiber %)	Weight (g)	Heating Value (J/g)
100% - 0%	0.3138	21956
98% - 2 %	0.3382	20463
95% - 5%	0.3122	20004
90% - 10%	0.3854	19213
85% - 15%	0.3992	15467
0% - 100%	0.3219	18012

Calorific Value Analysis of Adaro Coal - Fiber Composition Percentage

Percentage (Melawan Coal % - Shell %)	Weight (g)	Heating Value (J/g)
100% - 0%	0.3425	32456
98% - 2 %	0.3754	32211
95% - 5%	0.3145	31678
90% - 10%	0.3798	31076
85% - 15%	0.3057	27247
0% - 100%	0.3864	19306

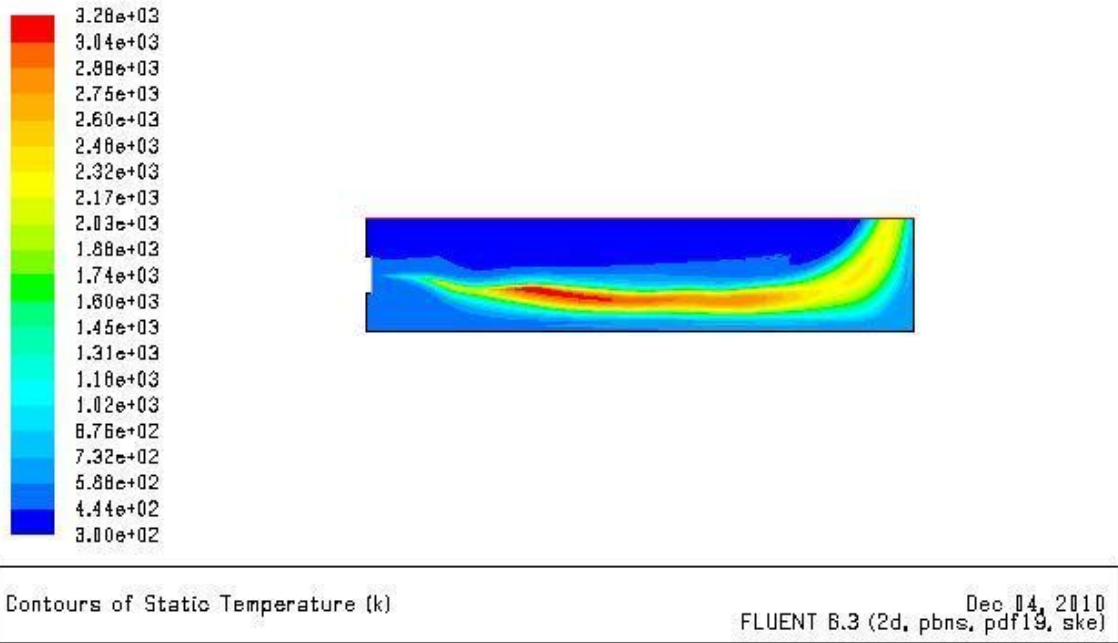
Calorific Value Analysis of Melawan Coal - Shell Composition Percentage

Percentage (Melawan Coal % - Fiber %)	Weight (g)	Heating Value (J/g)
100% - 0%	0.3425	32456
98% - 2 %	0.3721	31975
95% - 5%	0.3854	31642
90% - 10%	0.3862	30975
85% - 15%	0.3526	26989
0% - 100%	0.3219	18012

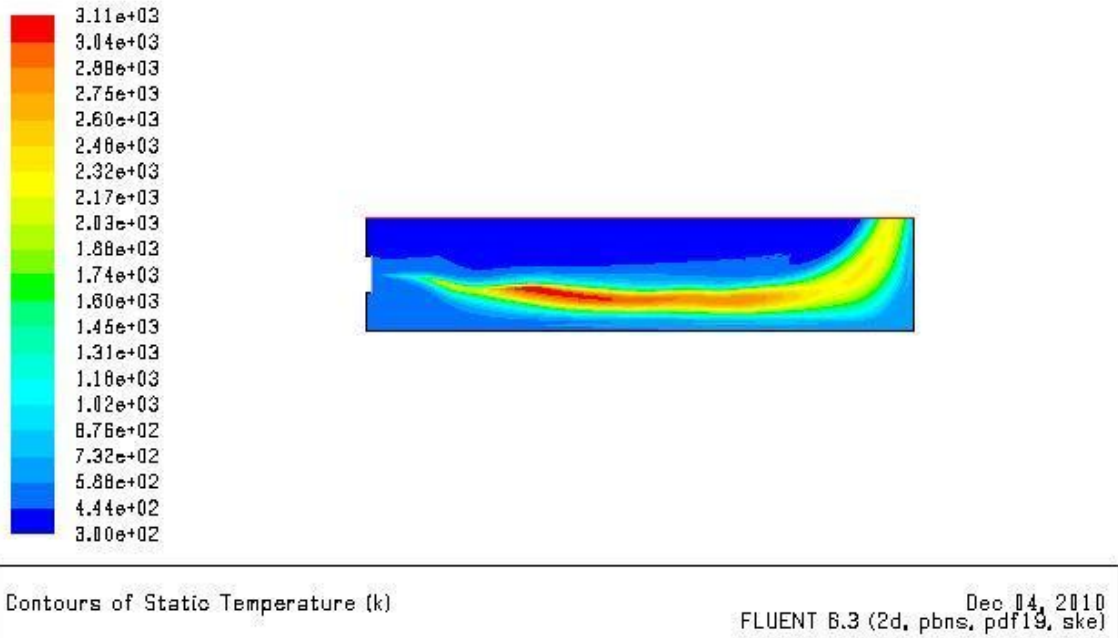
Calorific Value Analysis of Melawan Coal - Fiber Composition Percentage

APPENDIX D: Temperature Profile

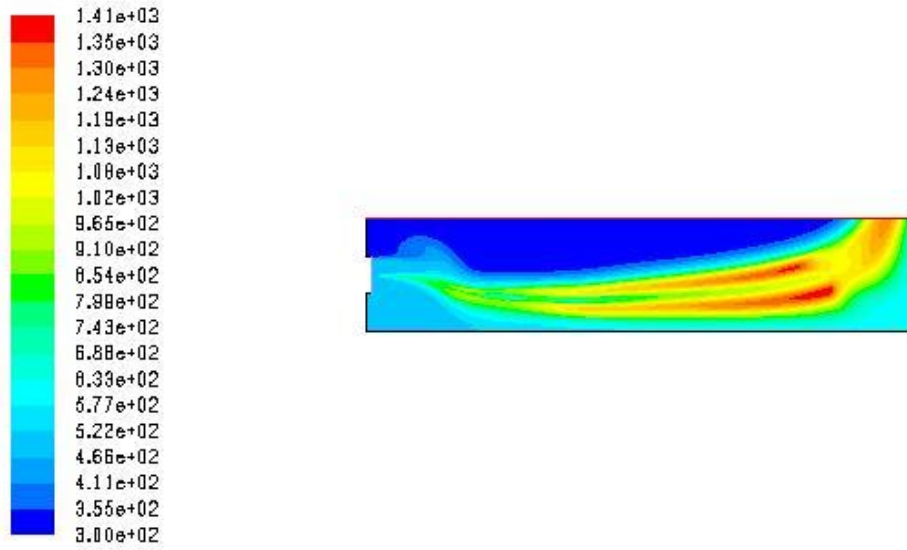
100% Melawan Coal



100% Adaro Coal



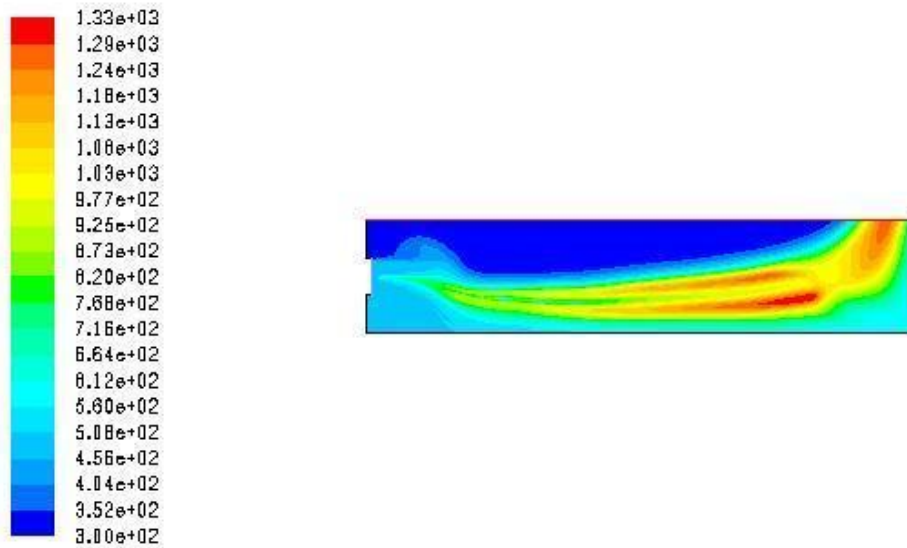
100% Shell



Contours of Static Temperature (k)

Dec 04, 2010
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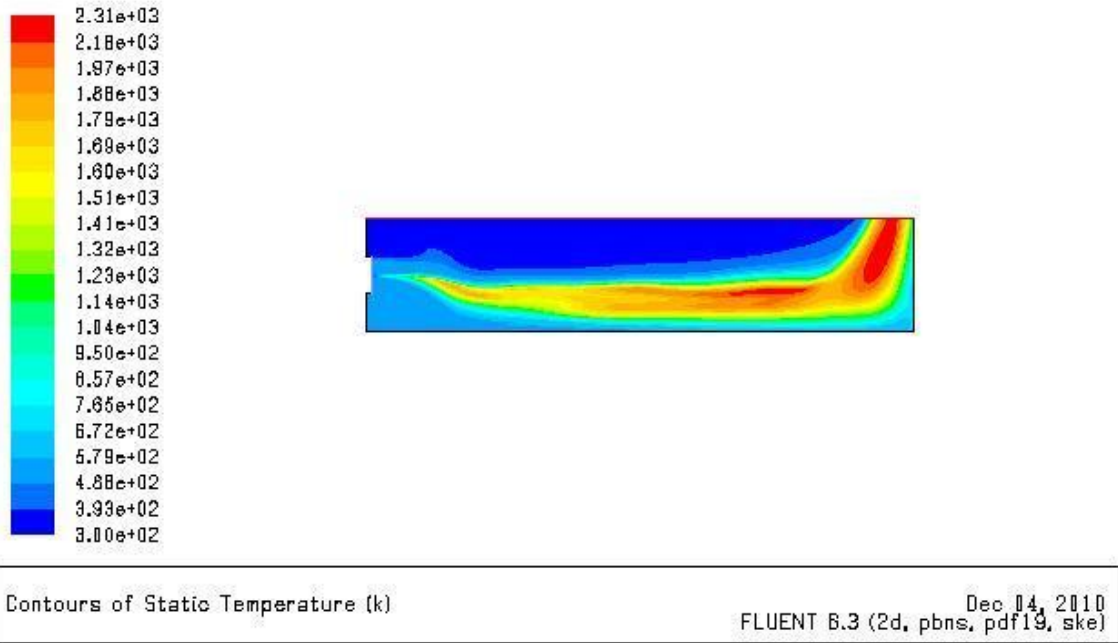
100% Fiber



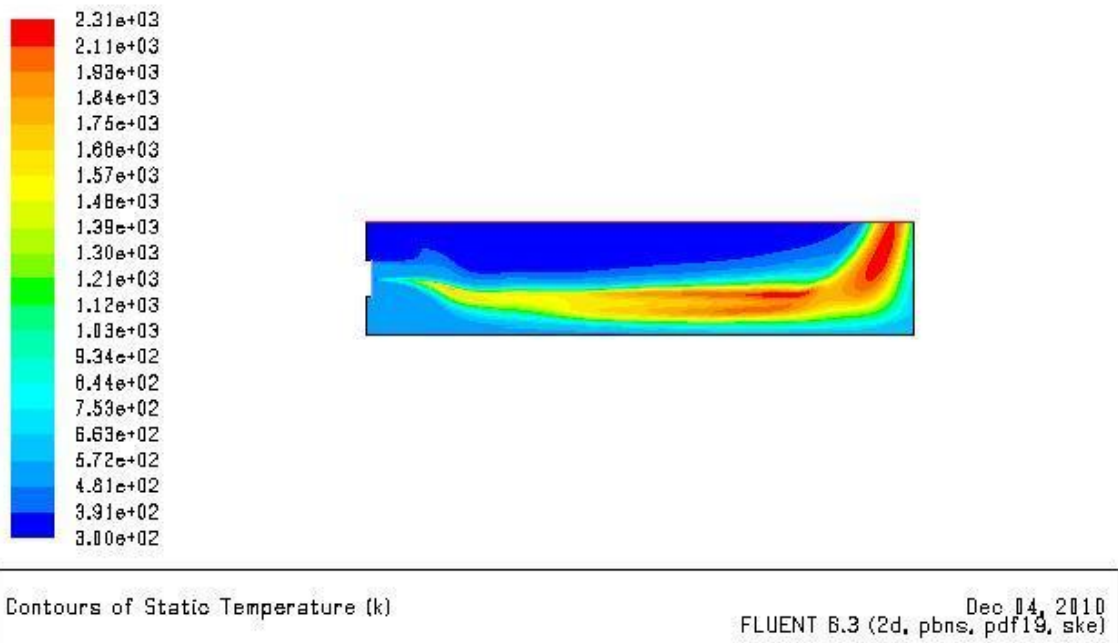
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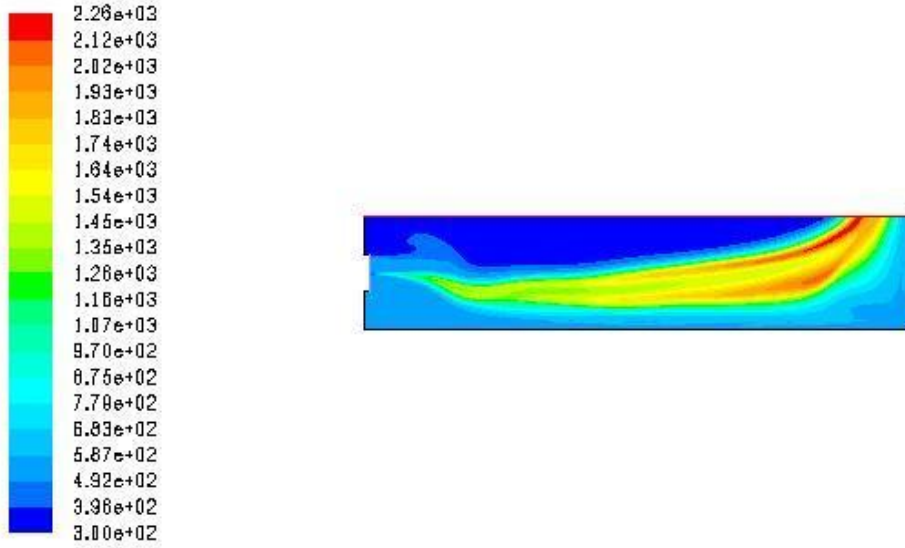
98% Melawan + 2% Shell



98% Melawan + 2% Fiber



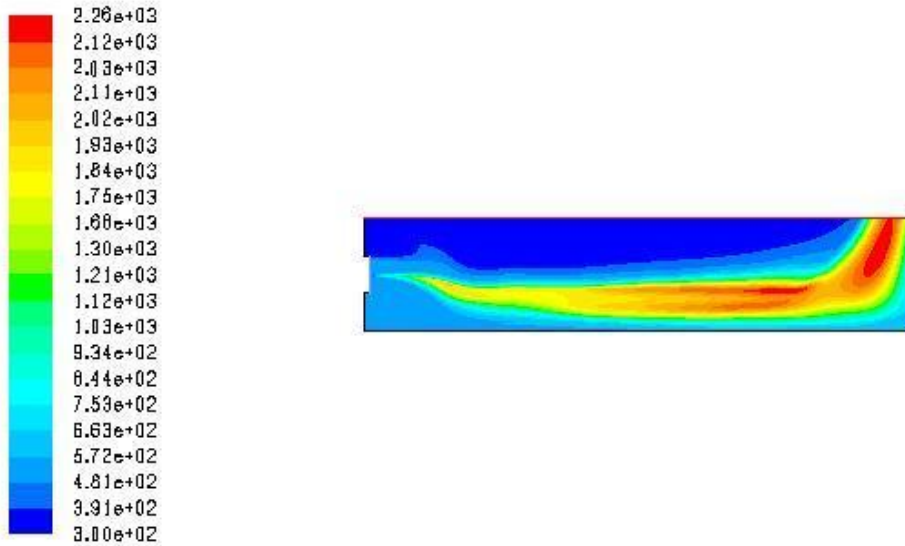
98% Adaro + 2% Shell



Contours of Static Temperature (k)

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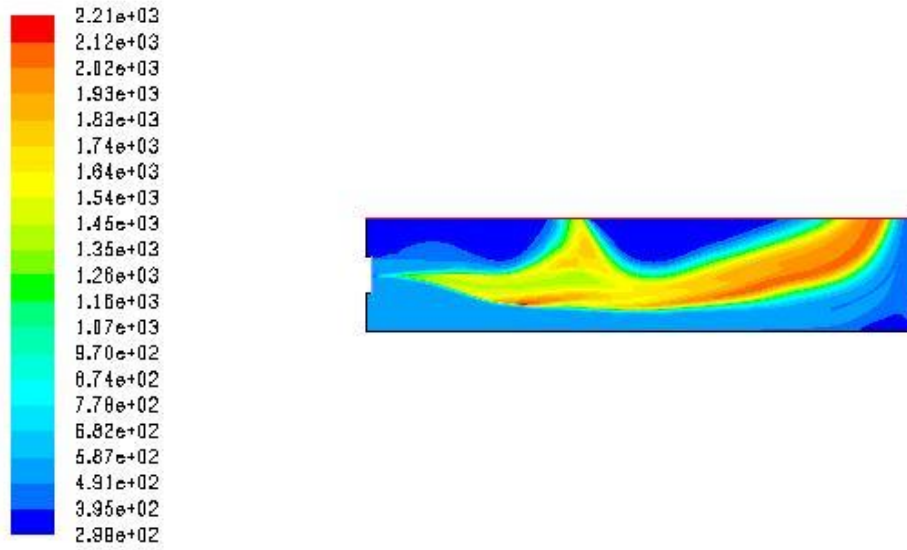
98% Adaro + 2% Fiber



Contours of Static Temperature (k)

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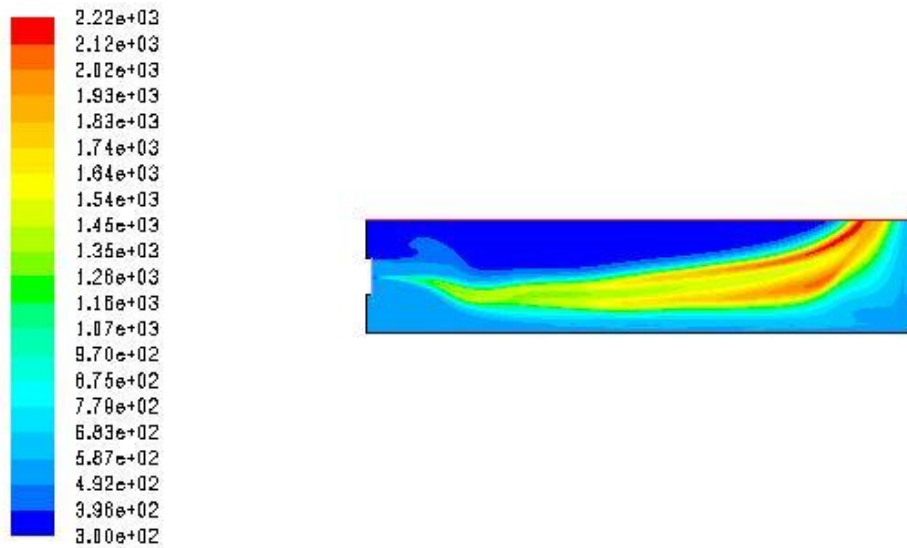
95% Melawan + 5% Shell



Contours of Static Temperature (k)

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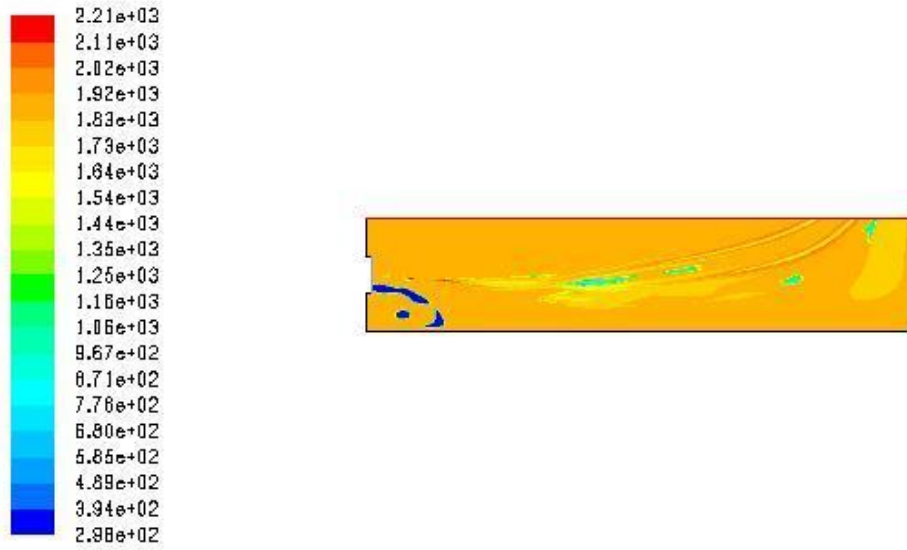
95% Melawan + 5% Fiber



Contours of Static Temperature (k)

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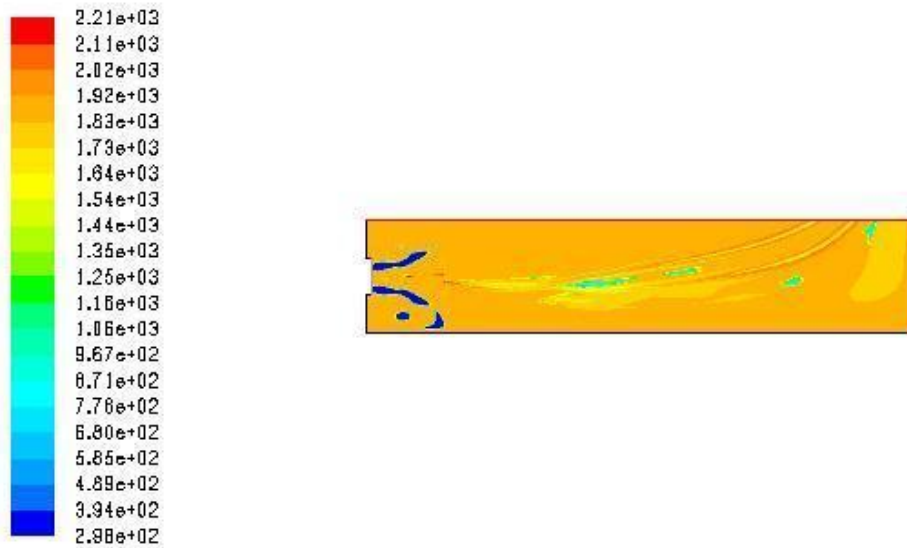
95% Adaro + 5% Shell



Contours of Static Temperature (k)

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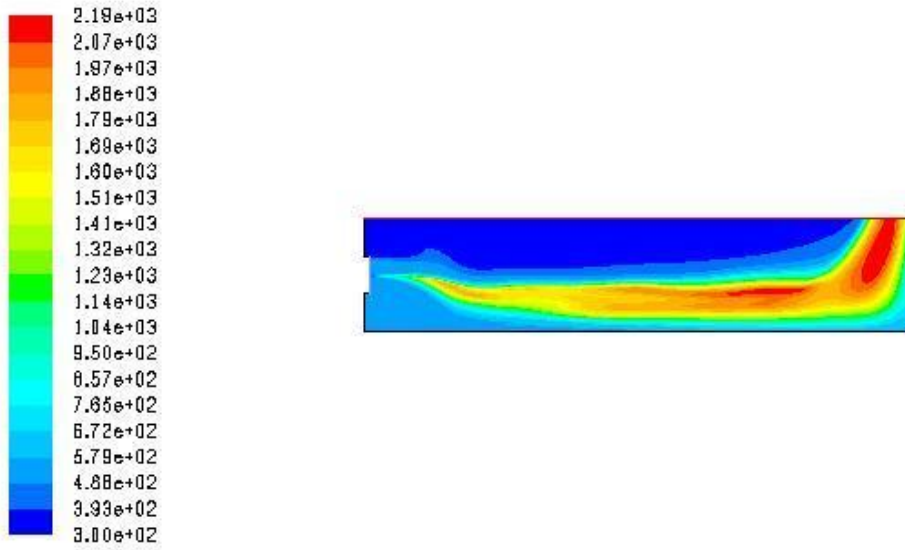
95% Adaro + 5% Fiber



Contours of Static Temperature (k)

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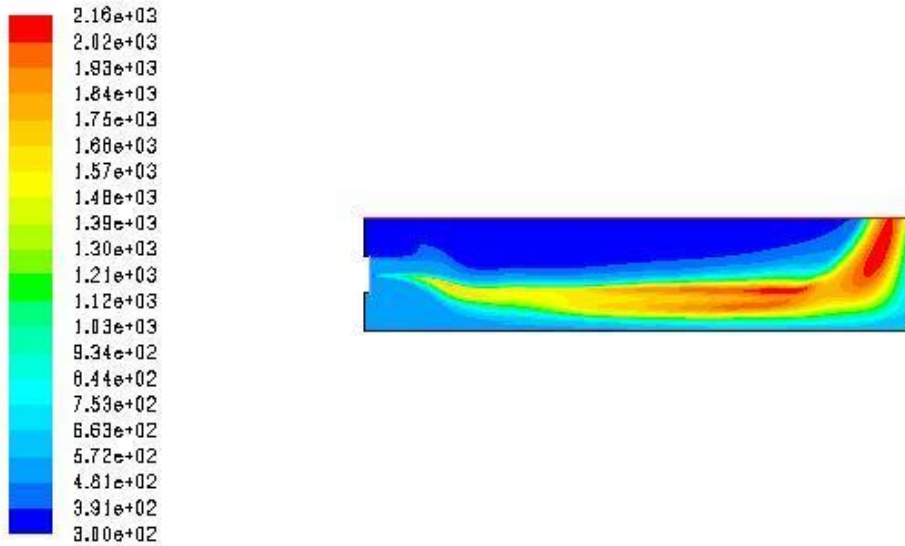
90% Melawan + 10% Shell



Contours of Static Temperature (k)

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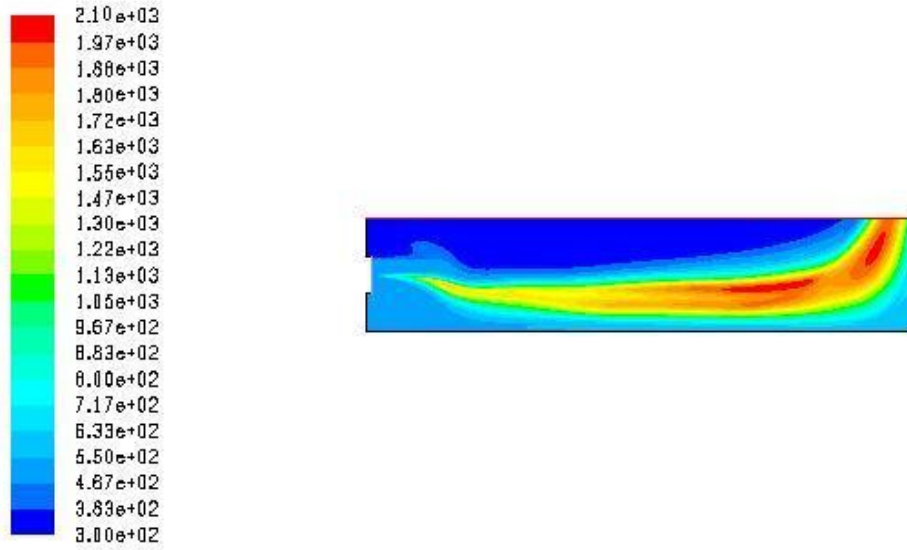
90% Melawan + 10% Fiber



Contours of Static Temperature (k)

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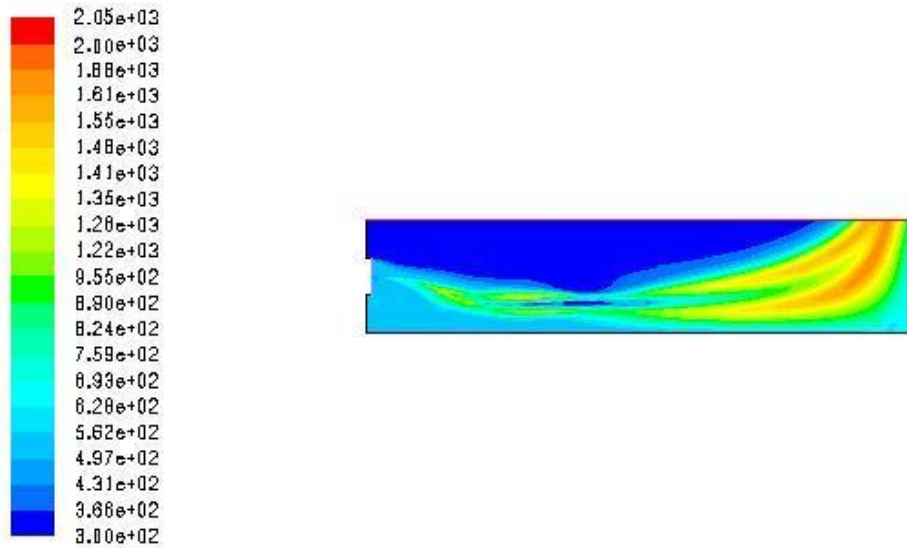
90% Adaro + 10% Shell



Contours of Static Temperature (k)

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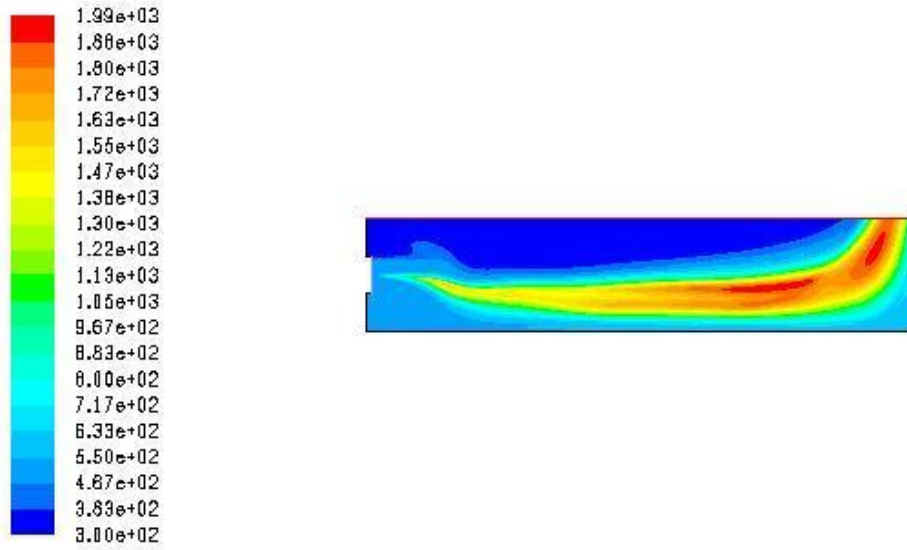
90% Adaro + 10% Fiber



Contours of Static Temperature (k)

Dec 04, 2010
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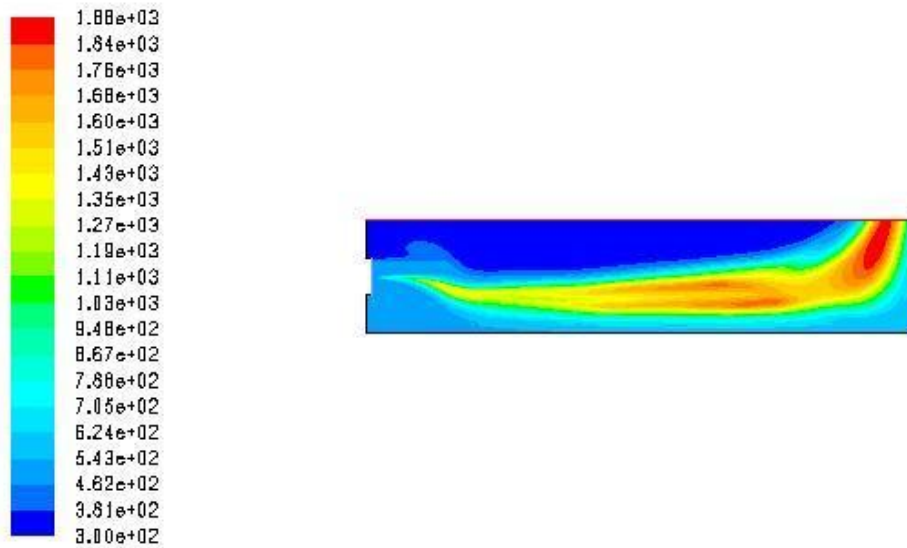
85%Melawan + 15% Shell



Contours of Static Temperature (k)

Dec 04, 2010
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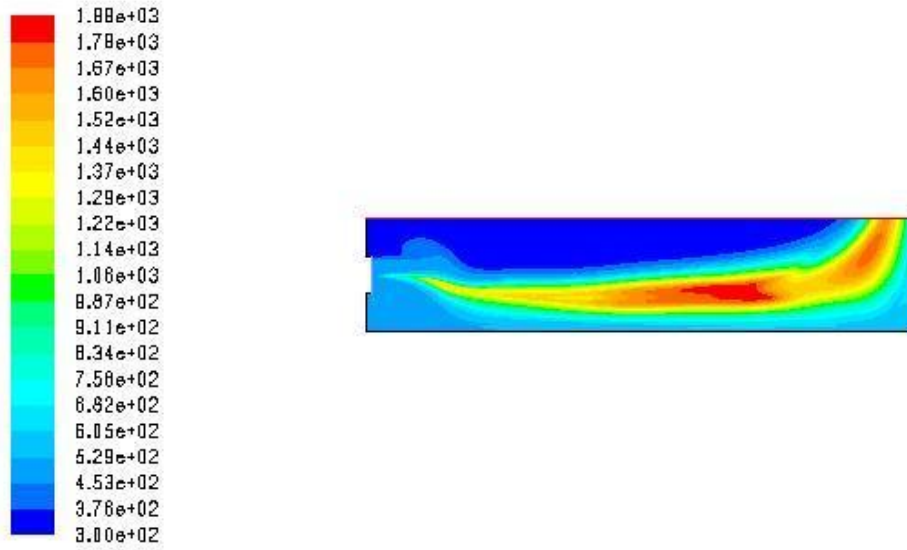
85%Melawan + 15% Fiber



Contours of Static Temperature (k)

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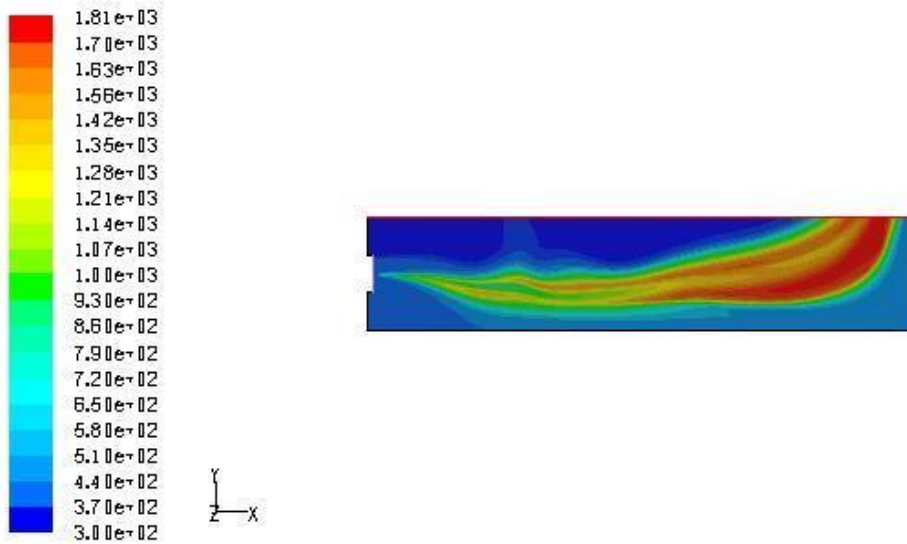
85% Adaro + 15% Shell



Contours of Static Temperature (k)

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85% Adaro + 15% Fiber

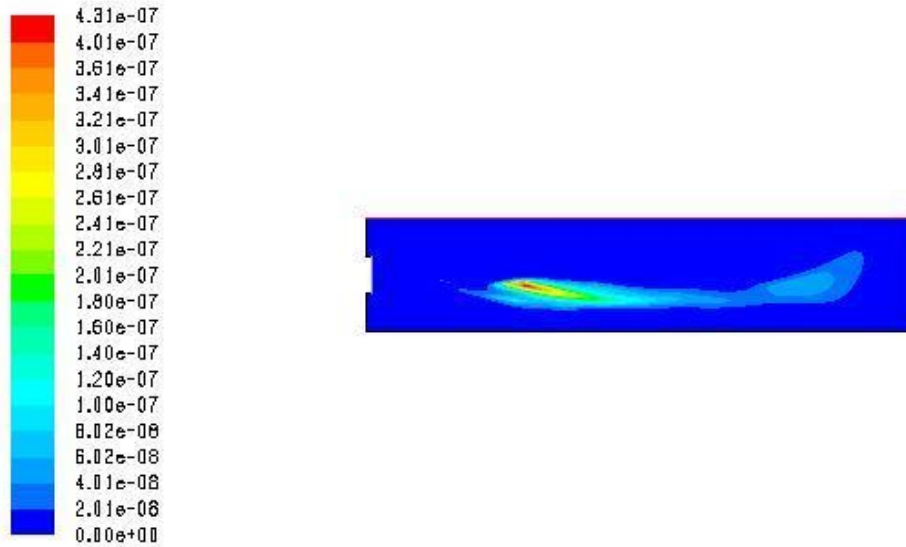


Contours of Static Temperature (k)

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APPENDIX E: Nitrogen Concentration

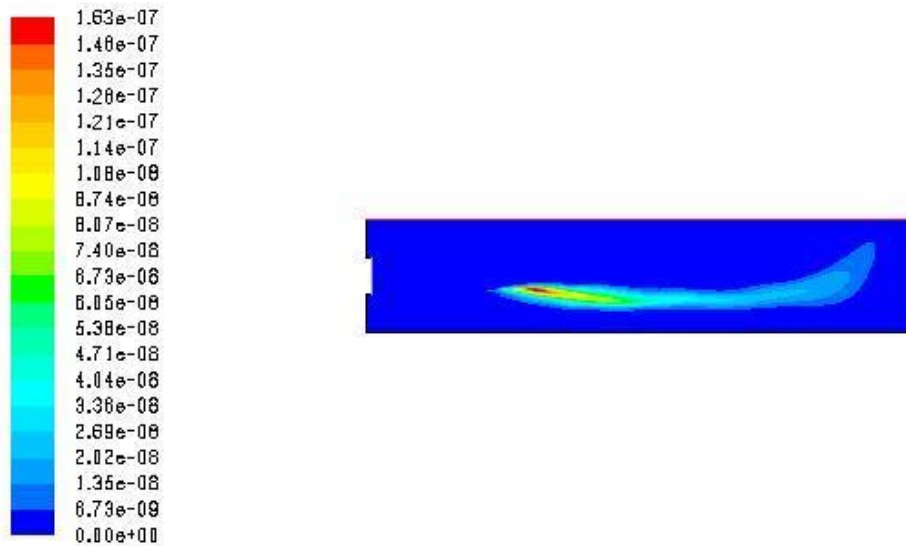
100% Melawan Coal



Contours of Molar Concentration of n (kmol/m3)

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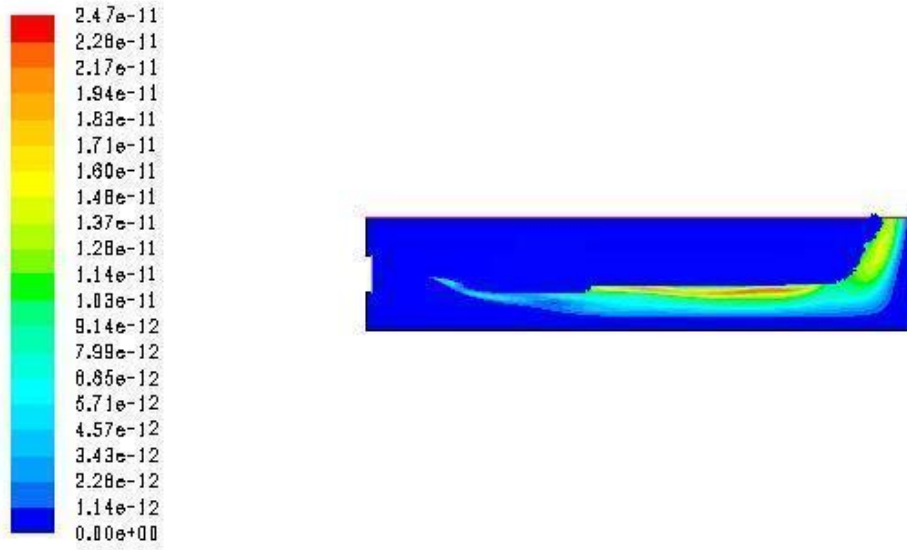
100% Adaro Coal



Contours of Molar Concentration of n (kmol/m3)

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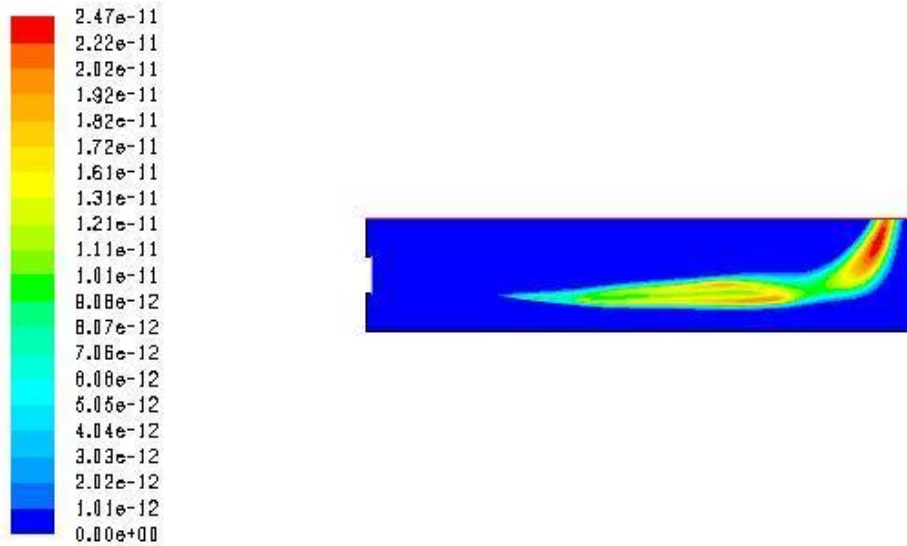
100% Shell



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
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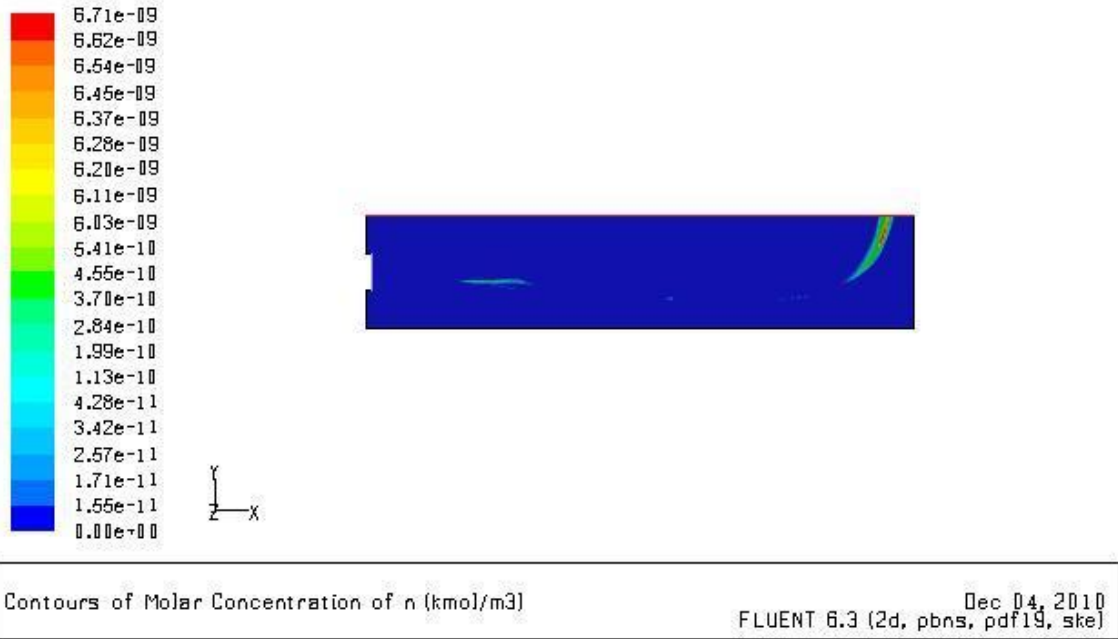
100% Fiber



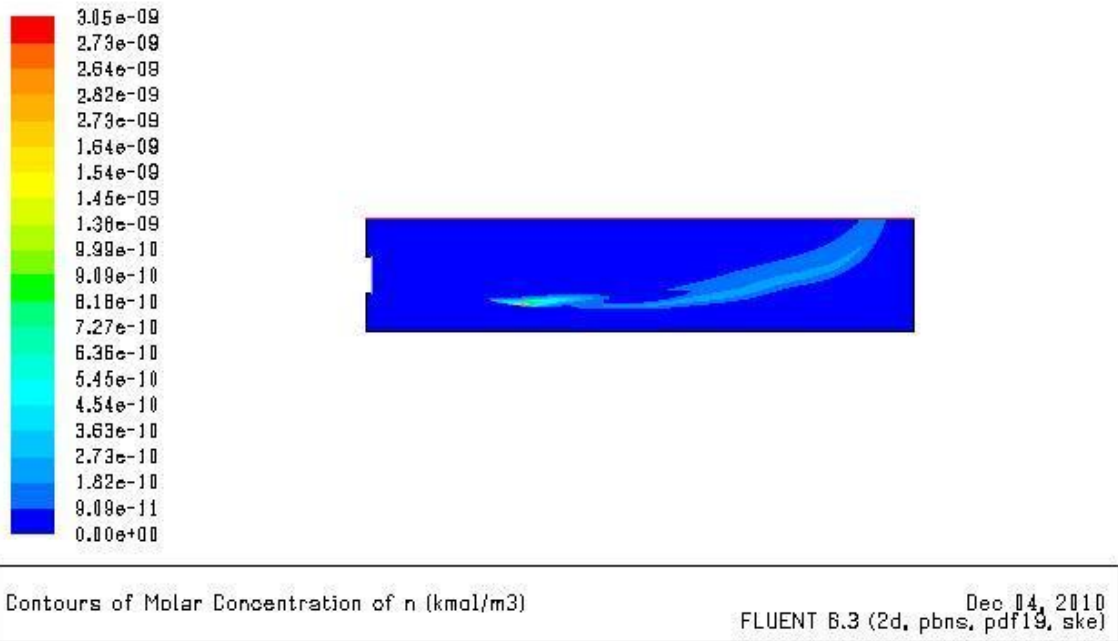
Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

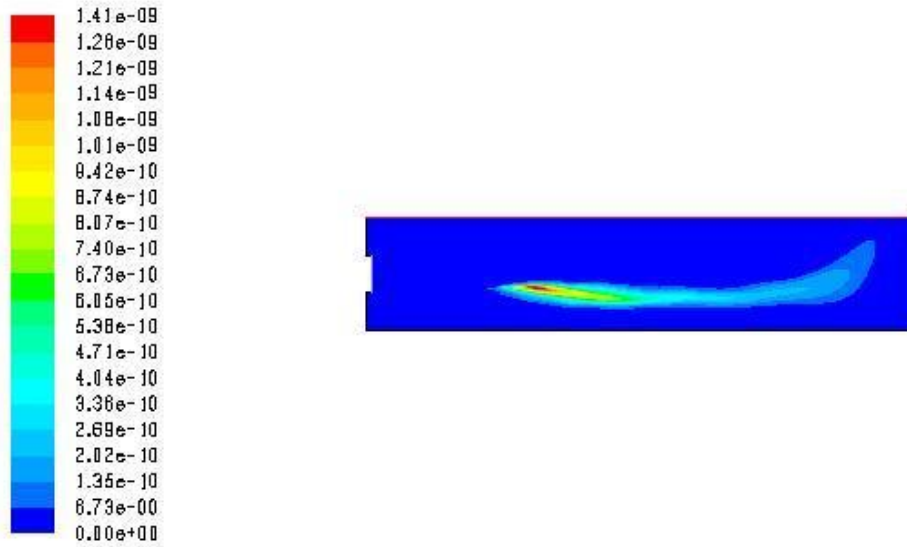
98% Melawan + 2% Shell



98% Melawan + 2% Fiber



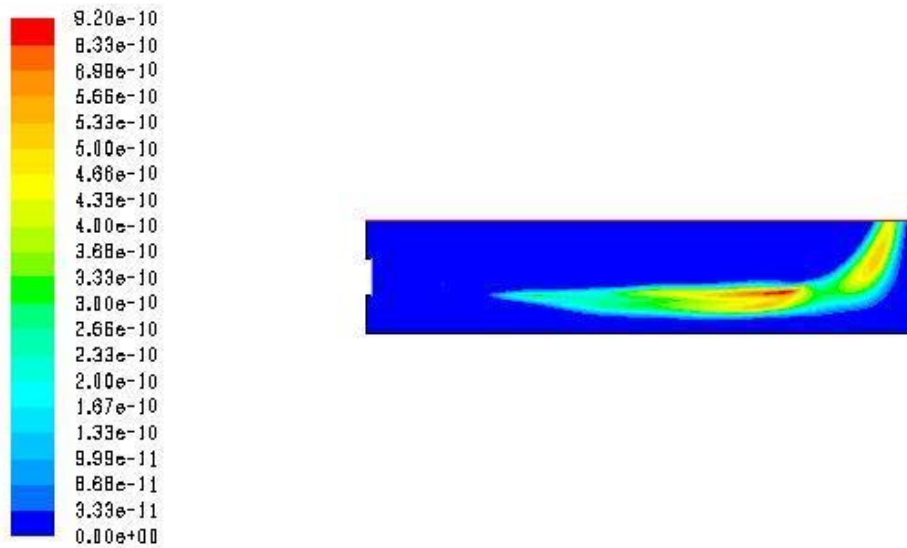
98% Adaro + 2% Shell



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

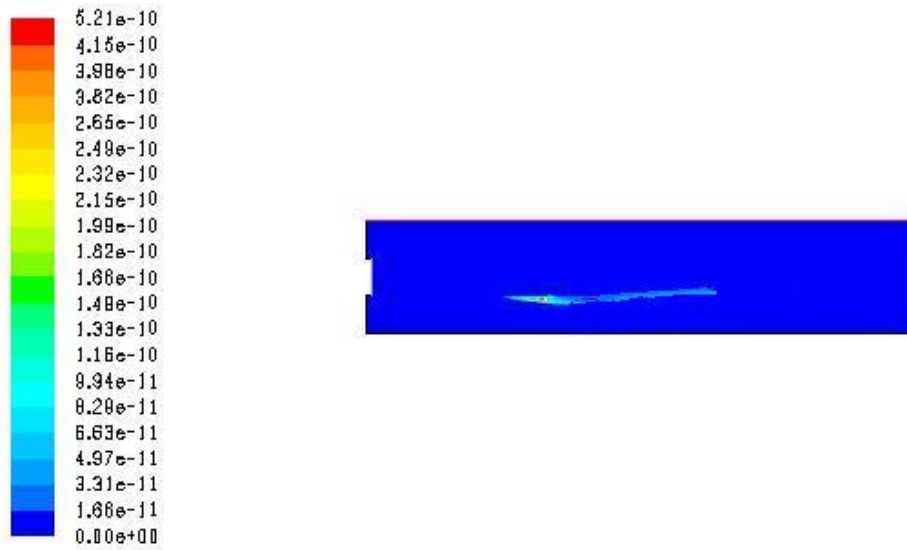
98% Adaro + 2% Fiber



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

95% Melawan + 5% Shell



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

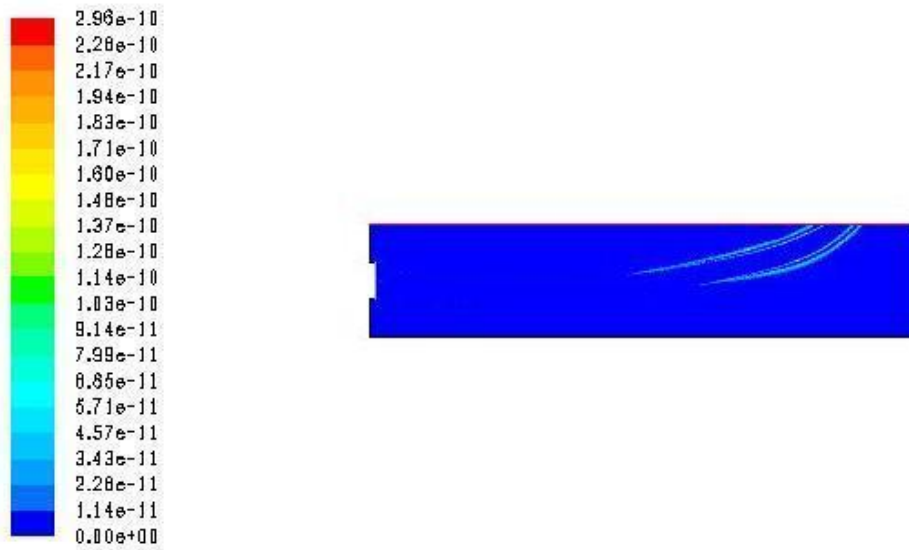
95% Melawan + 5% Fiber



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

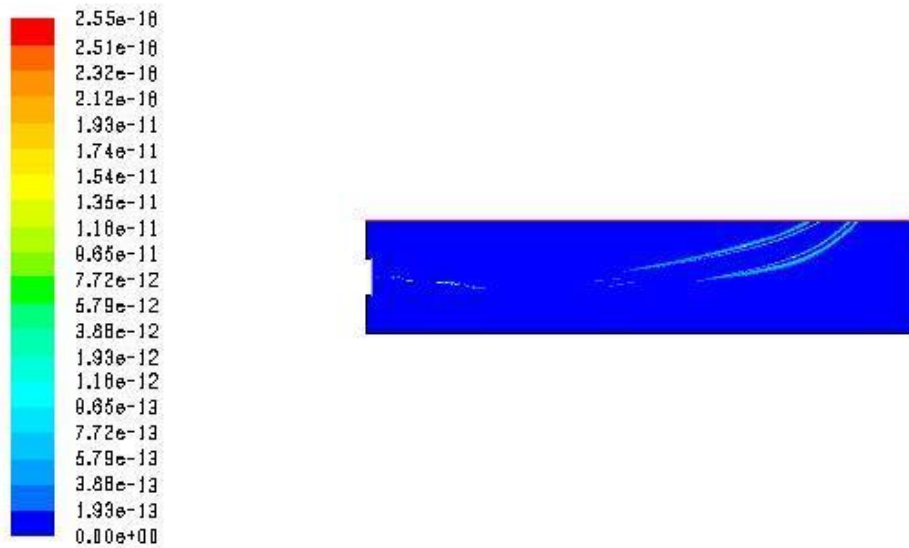
95% Adaro + 5% Shell



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

95% Adaro + 5% Fiber



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

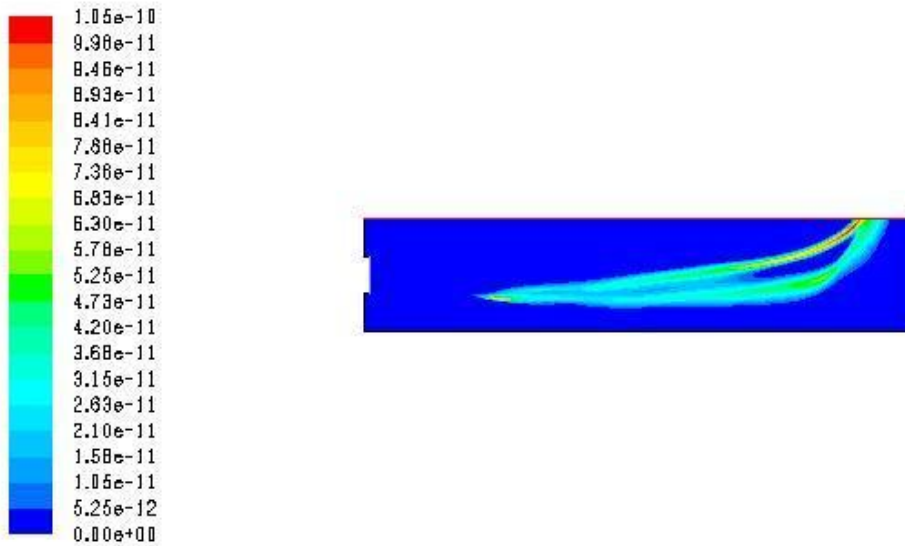
90% Melawan + 10% Shell



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

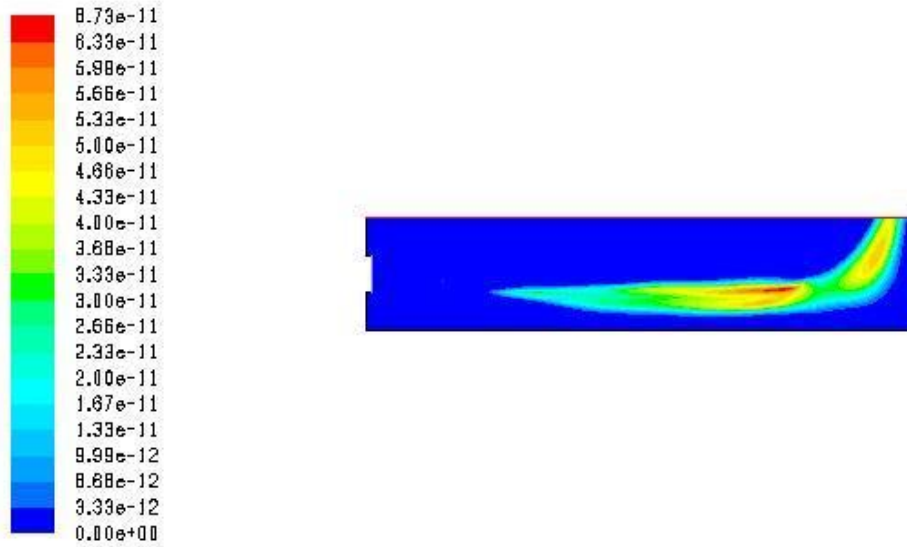
90% Melawan + 10% Fiber



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

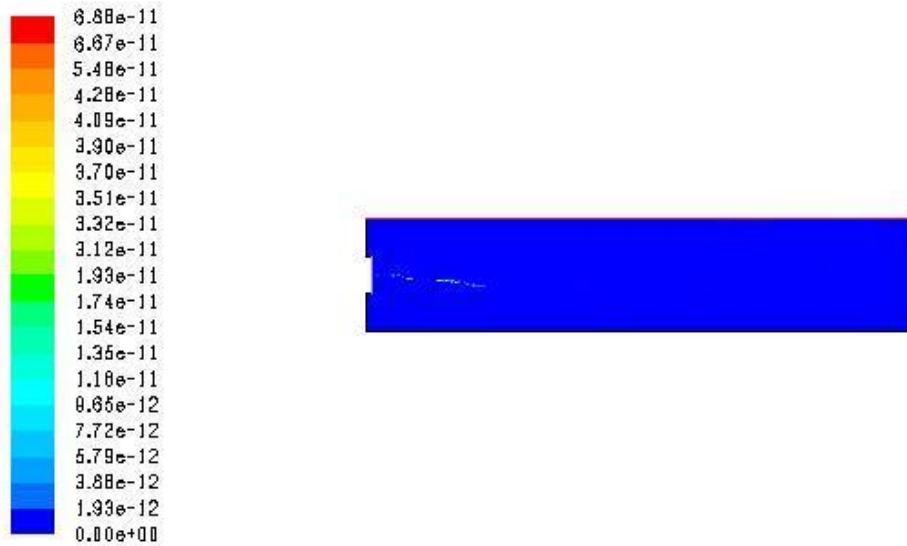
90% Adaro + 10% Shell



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

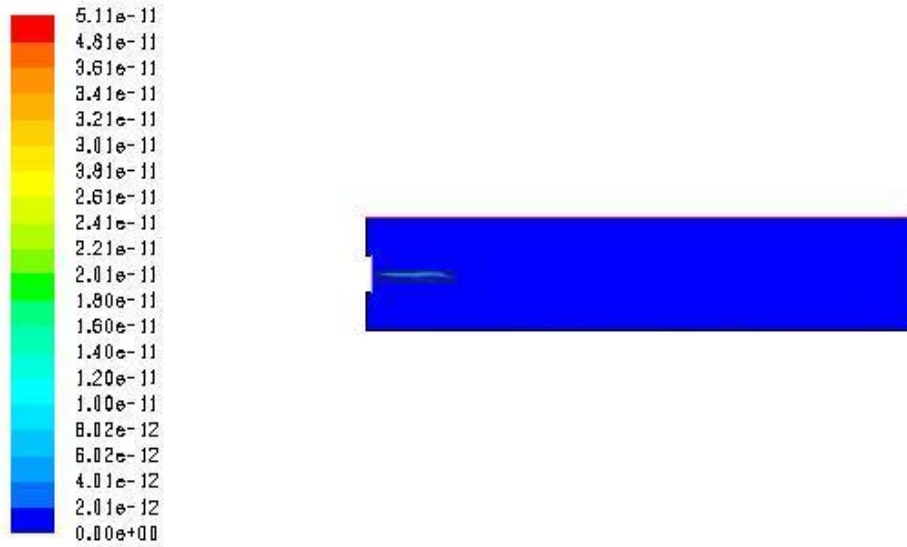
90% Adaro + 10% Fiber



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

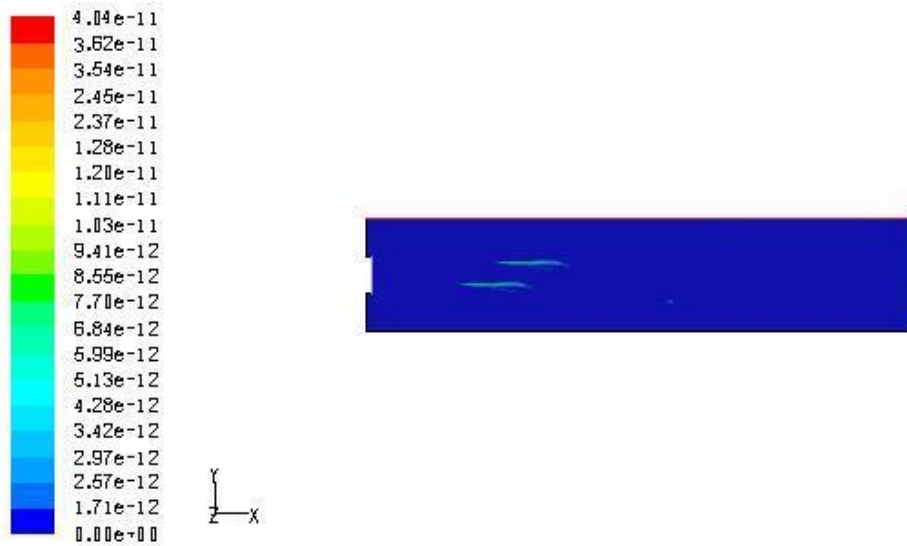
85%Melawan + 15% Shell



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

85%Melawan + 15% Fiber



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

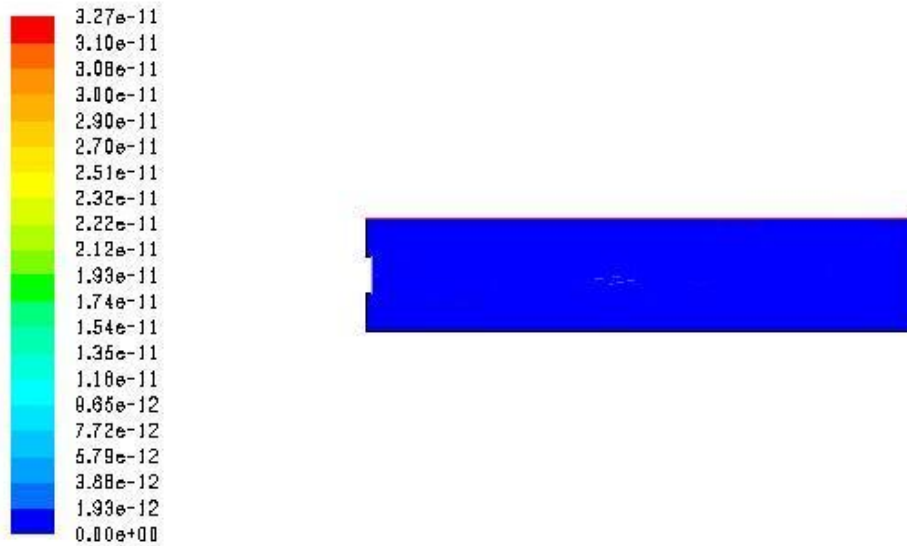
85% Adaro + 15% Shell



Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

85% Adaro + 15% Fiber

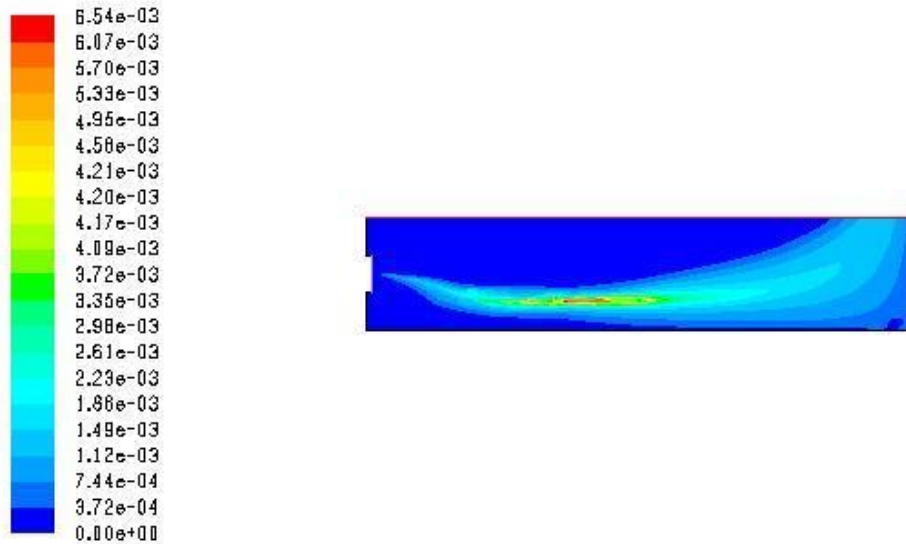


Contours of Molar Concentration of n (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

APPENDIX F: Carbon Dioxide Concentration

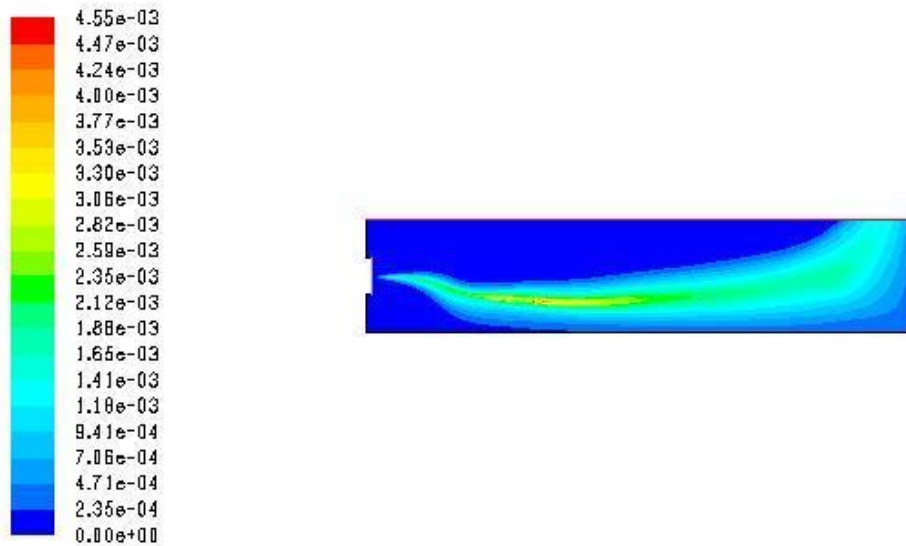
100% Melawan Coal



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

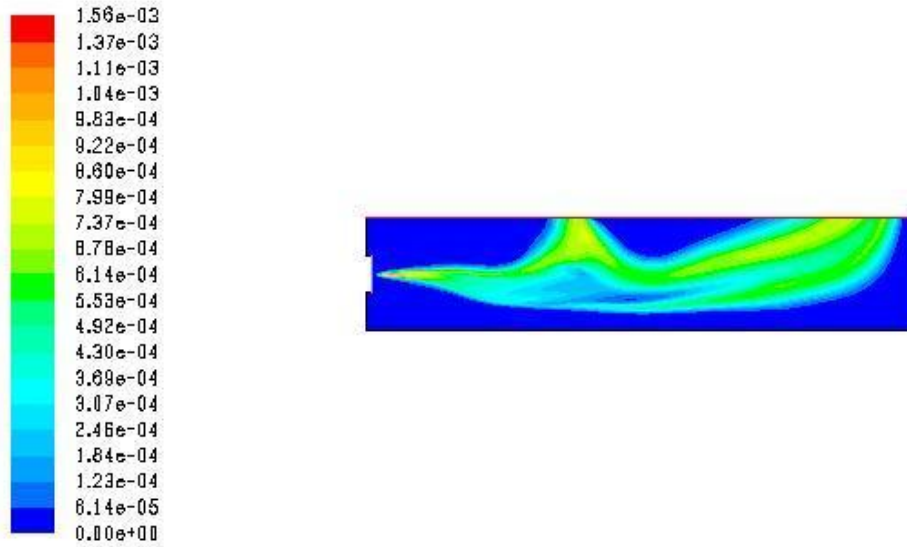
100% Adaro Coal



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

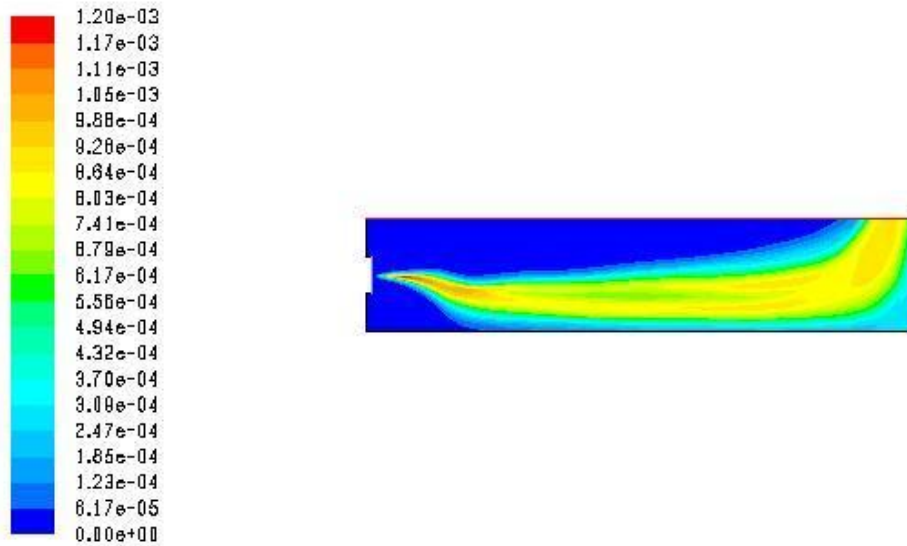
100% Shell



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

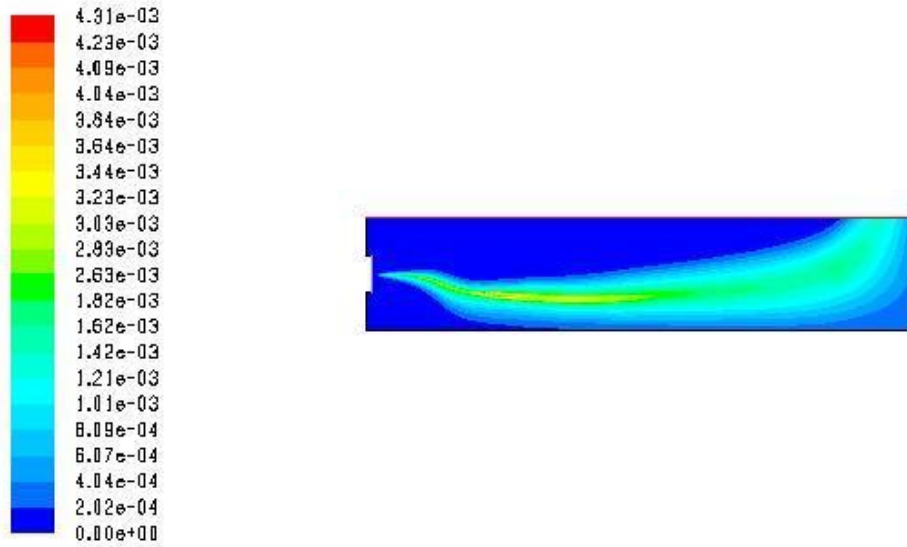
100% Fiber



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

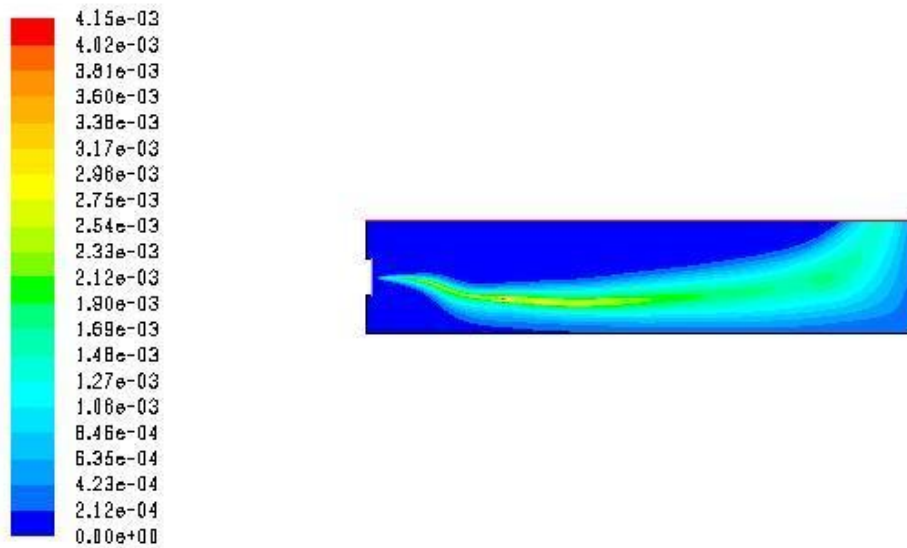
98% Melawan + 2% Shell



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

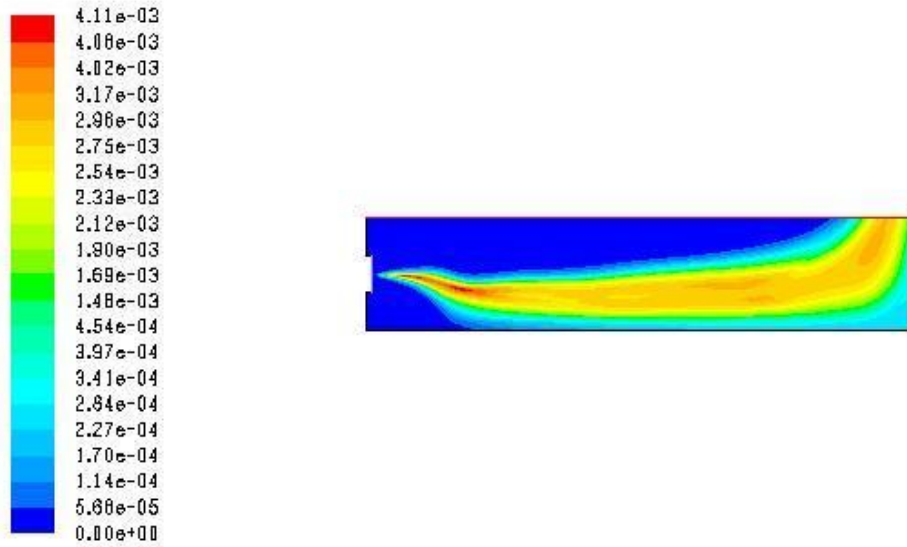
98% Melawan + 2% Fiber



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

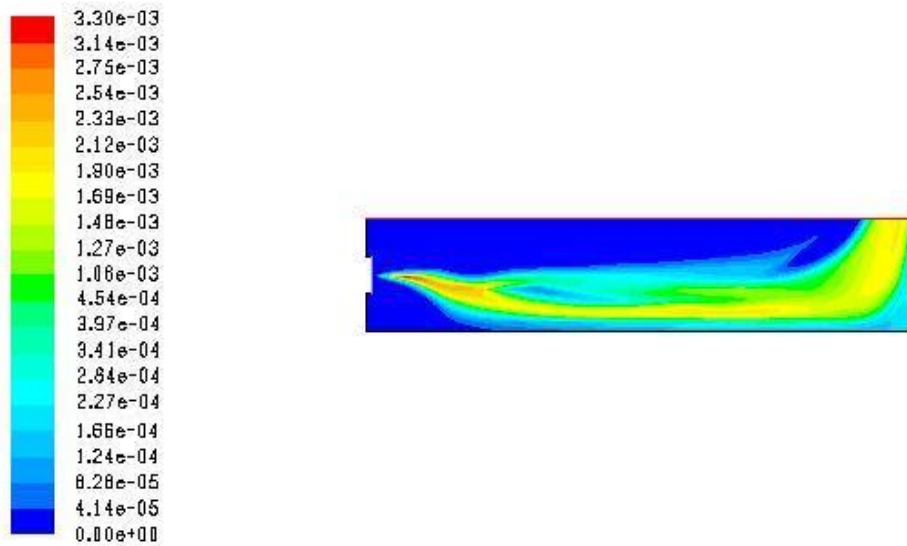
98% Adaro + 2% Shell



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

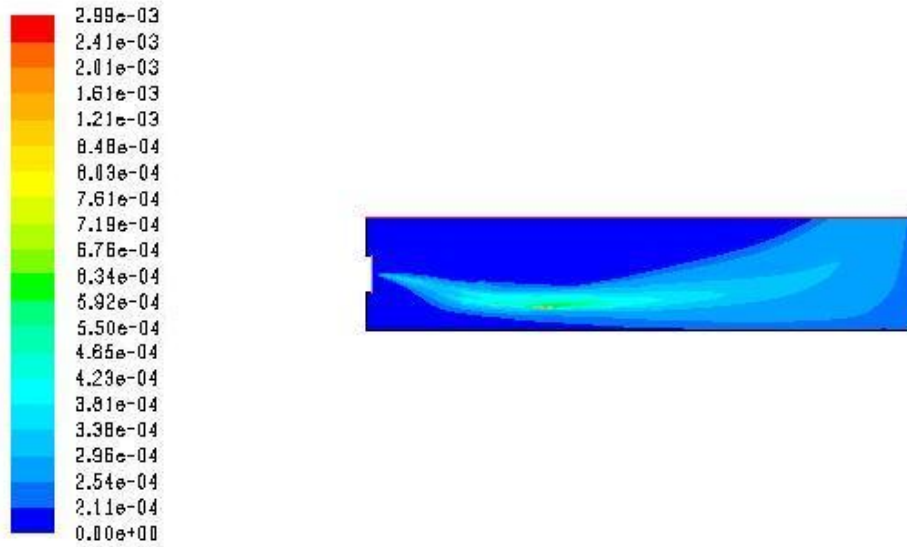
98% Adaro + 2% Fiber



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

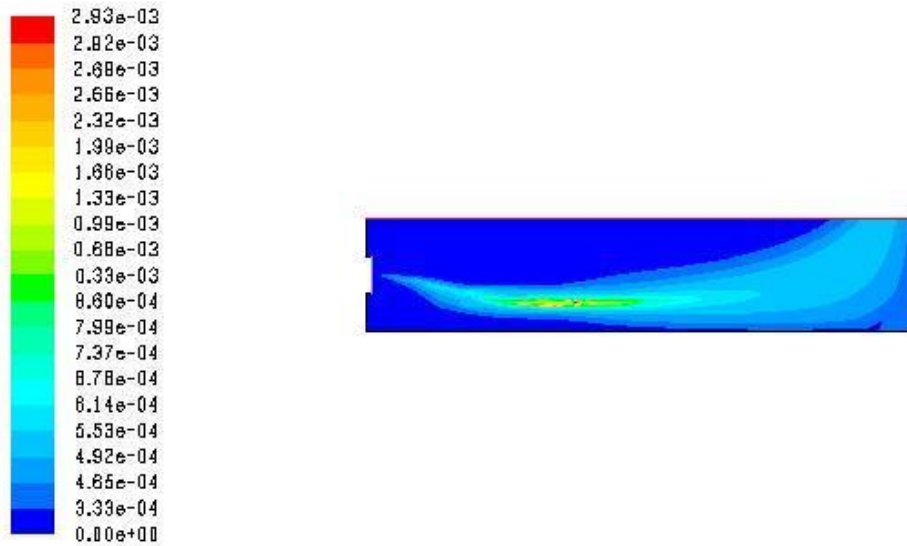
95% Melawan + 5% Shell



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

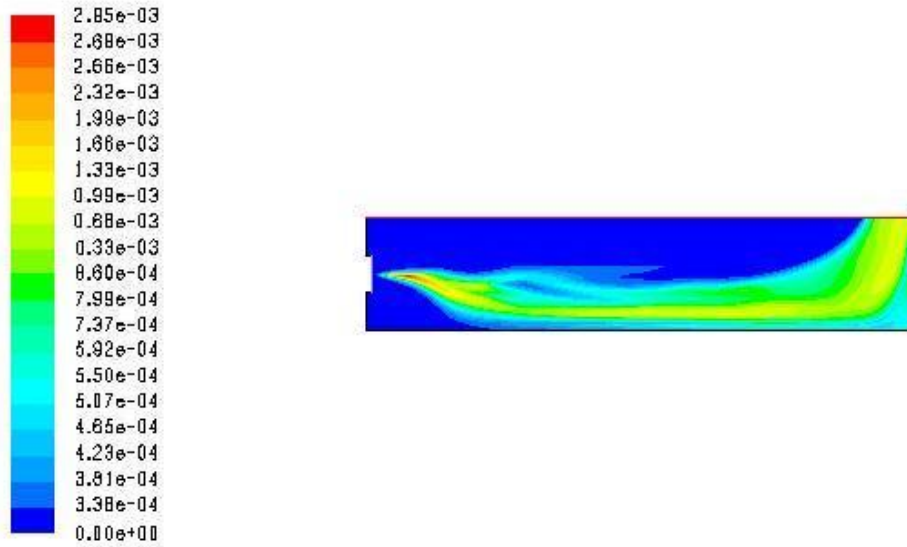
95% Melawan + 5% Fiber



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

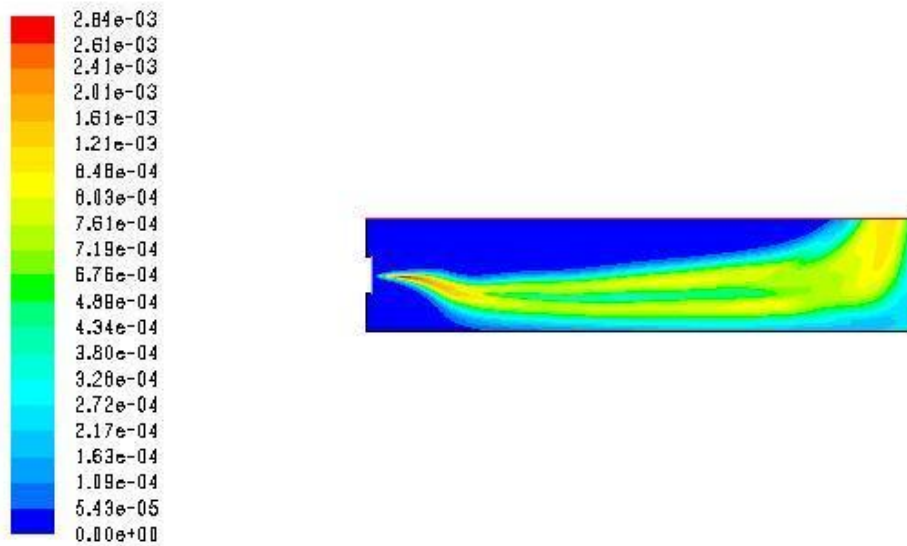
95% Adaro + 5% Shell



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

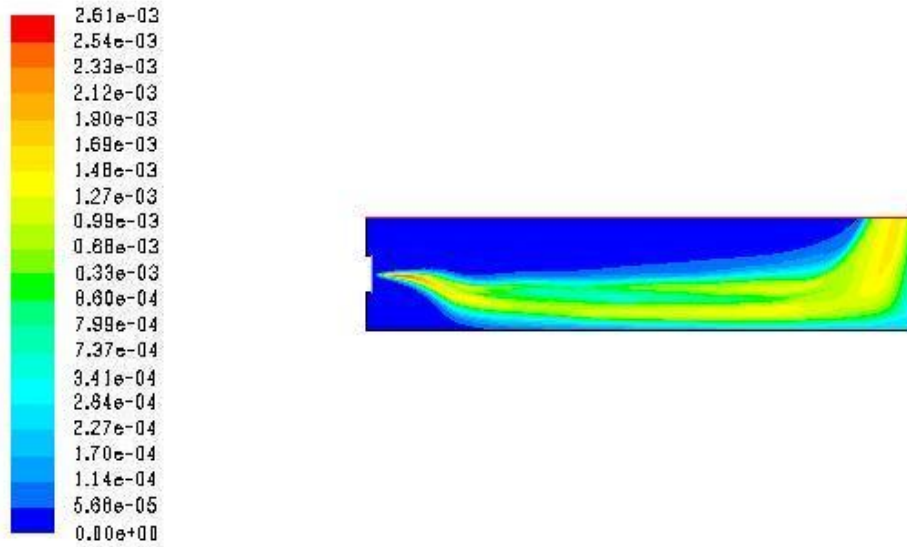
95% Adaro + 5% Fiber



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

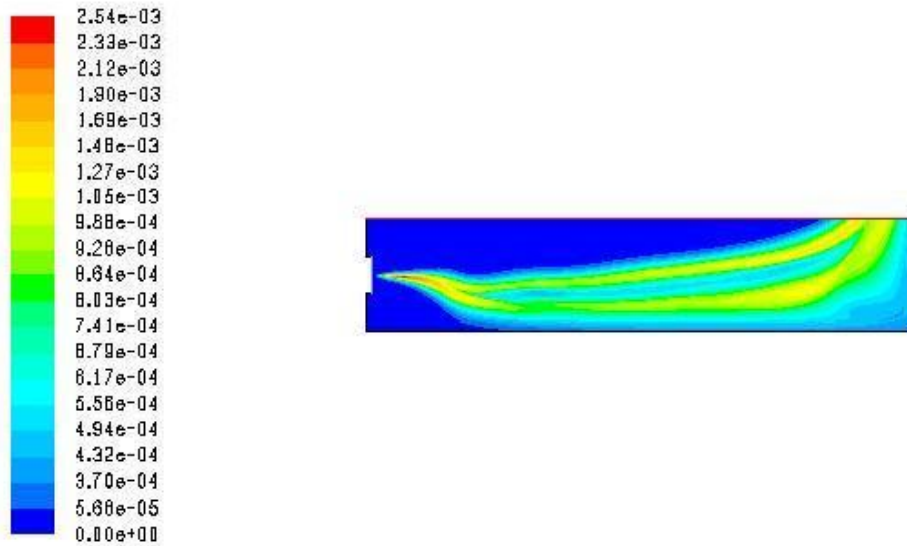
90% Melawan + 10% Shell



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

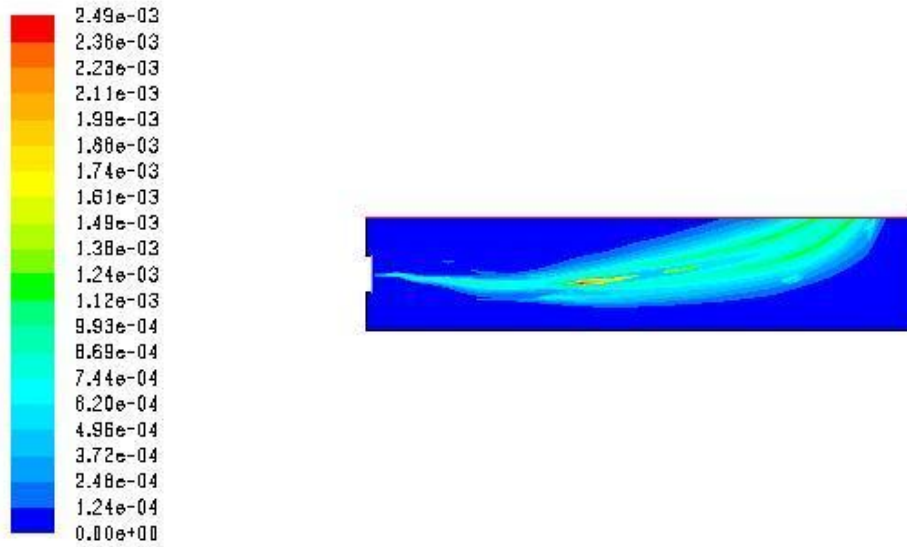
90% Melawan + 10% Fiber



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

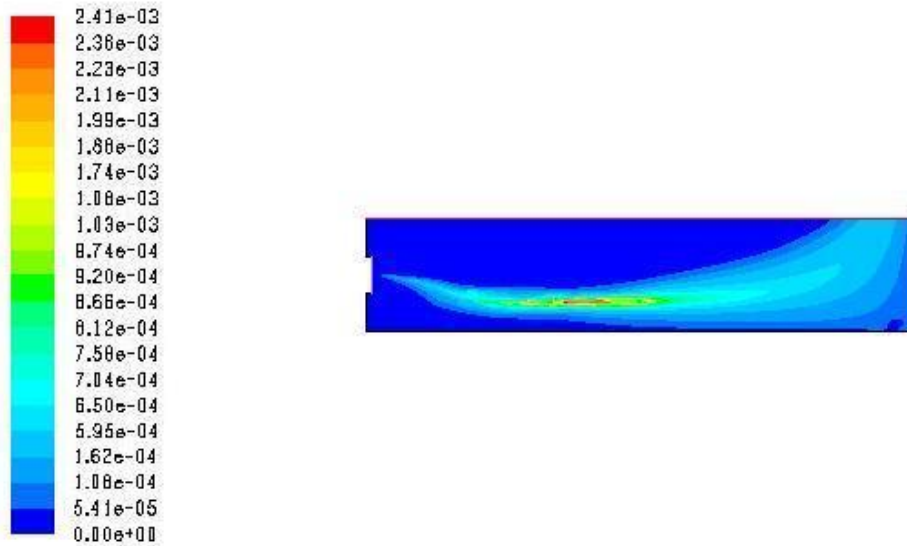
90% Adaro + 10% Shell



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

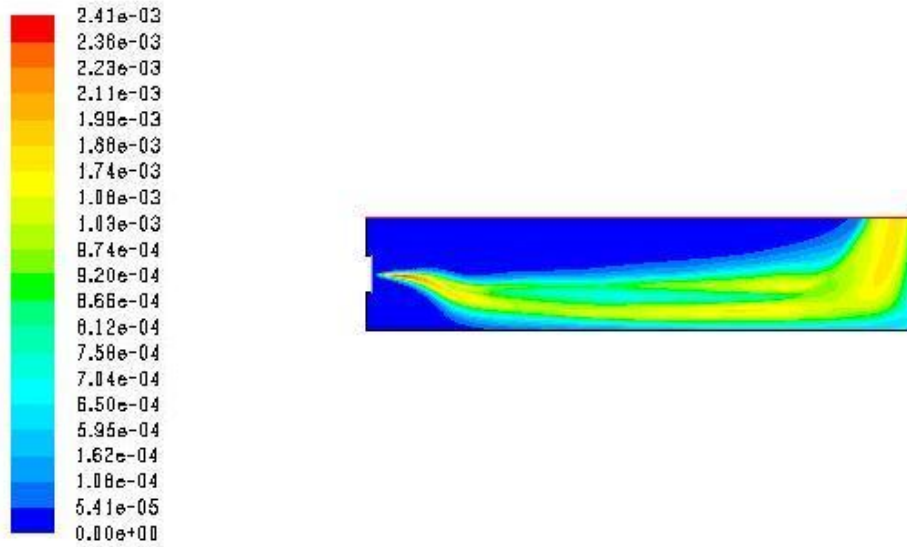
90% Adaro + 10% Fiber



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

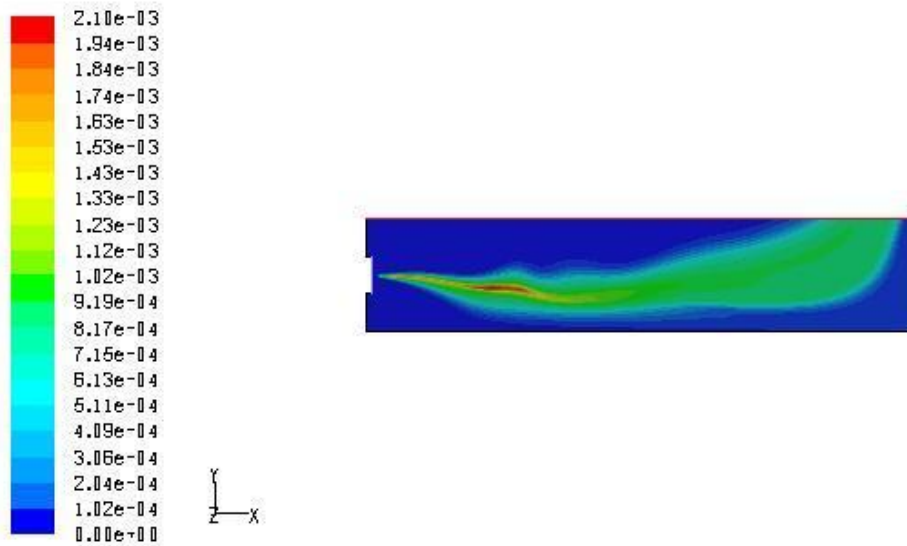
85%Melawan + 15% Shell



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

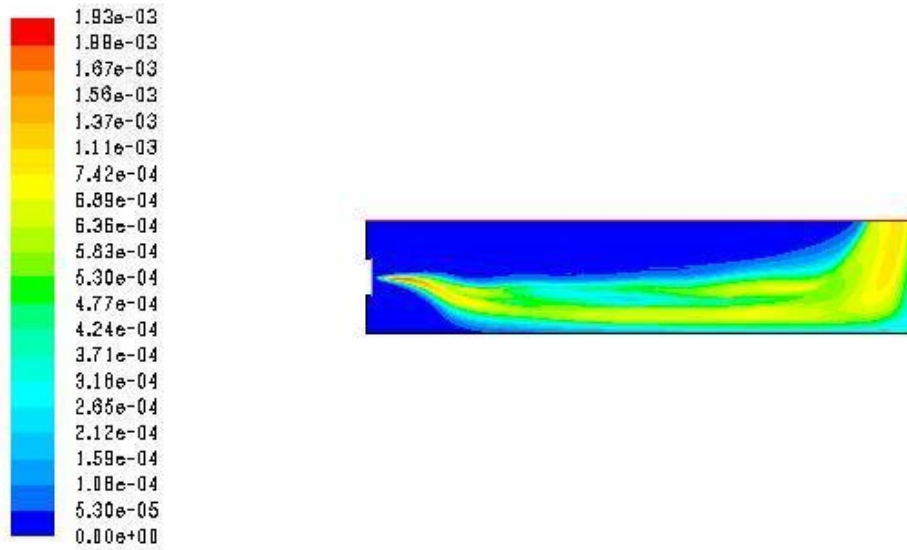
85%Melawan + 15% Fiber



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

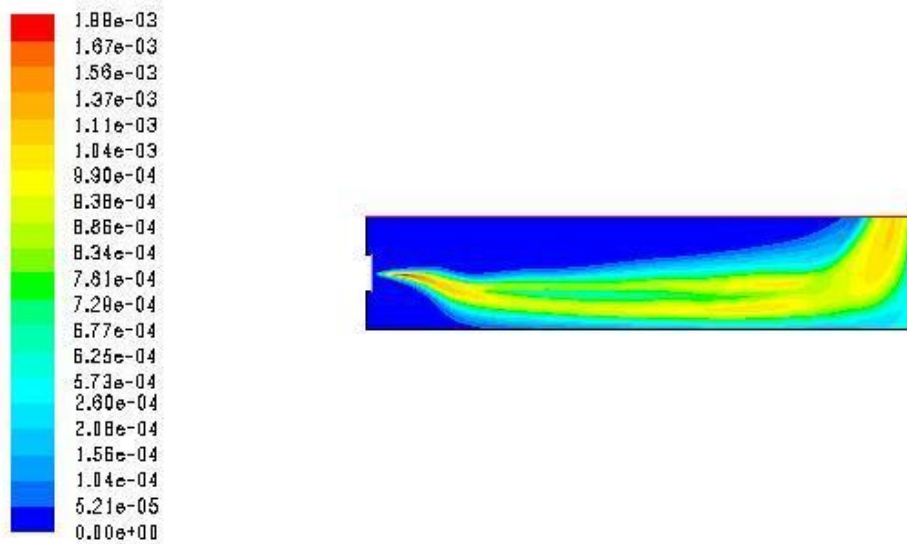
85% Adaro + 15% Shell



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

85% Adaro + 15% Fiber



Contours of Molar Concentration of co2 (kmol/m3)

Dec 04, 2010
FLUENT 6.3 (2d, pbns, pdf19, ske)

APPENDIX G: Results for Gas Analysis

Percentage (Adaro Coal % - Shell %)	Weight (g)	CO ₂ (% vol)	O ₂ (% vol)	NO _x (ppm)
100% - 0%	1.0563	29.42	25	79
98% - 2 %	1.1001	29.03	25	76
95% - 5%	1.0943	28.05	25	70
90% - 10%	1.0003	26.53	25	65
85% - 15%	0.9997	24.97	25	59

Gas Analysis of Adaro Coal - Shell Composition Percentage

Percentage (Adaro Coal % - Fiber %)	Weight (g)	CO ₂ (% vol)	O ₂ (% vol)	NO _x (ppm)
100% - 0%	0.9914	29.42	25	79
98% - 2 %	1.0005	28.98	25	75
95% - 5%	1.0403	27.64	25	68
90% - 10%	1.1032	26.09	25	65
85% - 15%	0.9879	24.31	25	58

Gas Analysis of Adaro Coal - Fiber Composition Percentage

Percentage (Melawan Coal % - Shell %)	Weight (g)	CO ₂ (% vol)	O ₂ (% vol)	NO _x (ppm)
100% - 0%	1.1421	30.86	25	85
98% - 2 %	1.1123	30.12	25	83
95% - 5%	1.0021	28.87	25	78
90% - 10%	0.9857	26.43	25	73
85% - 15%	0.9756	25.01	25	67

Gas Analysis of Melawan Coal - Shell Composition Percentage

Percentage (Melawan Coal % - Fiber %)	Weight (g)	CO ₂ (% vol)	O ₂ (% vol)	NO _x (ppm)
100% - 0%	1.1002	30.86	25	85
98% - 2 %	1.0009	30.01	25	82
95% - 5%	1.0857	28.56	25	78
90% - 10%	1.0543	26.23	25	71
85% - 15%	1.0098	24.87	25	65

Gas Analysis of Melawan Coal - Fiber Composition Percentage

APPENDIX G: Calculation for Percentage Reduction of the CO₂ and NO_x

Percentage Reduction of Carbon Dioxide:

$$\begin{aligned} & \text{CO}_2 \text{ Reduction \%} \\ & = \frac{\text{CO}_2 \text{ Concentration for 100\% Coal} - \text{CO}_2 \text{ Concentration for fuel blend}}{\text{CO}_2 \text{ Concentration for 100\% Coal}} \times 100\% \end{aligned}$$

Percentage Reduction of Nitrogen Oxide:

$$\begin{aligned} & \text{NO}_x \text{ Reduction \%} \\ & = \frac{\text{NO}_x \text{ Concentration for 100\% Coal} - \text{NO}_x \text{ Concentration for fuel blend}}{\text{NO}_x \text{ Concentration for 100\% Coal}} \times 100\% \end{aligned}$$