OXY-FUEL COMBUSTION OF SOLID PARTICLES IN THE DROP TUBE FURNACE

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DECLARATION

“I hereby, declare that this manuscript, entitled “*Oxy-Fuel Combustion of Solid fuel Particles in the Drop Tube Furnace*”, is the result of my own work except for quotations and citations, which have been duly acknowledged”.

“I also declare that, to the best of my knowledge and belief, it has not been previously or concurrently submitted, in whole or in part, for any other degree or diploma at Nazarbayev University or any other national or intentional institution.”

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Date: 27.06.2023

Abstract

Oxy-fuel combustion of solid fuel in a laboratory refers to the process of burning solid fuel in the presence of oxygen enriched gas to produce heat and combustion products, with the aim of studying combustion chemistry and/or emissions.

In this laboratory experiment, the combustion of pulverized high and low ash content coals and biomasses from Kazakhstan was studied using a drop tube furnace. The ultimate and proximate analysis was conducted beforehand to determine the composition of ash, moisture, and volatile matter in the solid fuel. The combustion tests were carried out in both air (O2/N2) and oxy-fuel (O2/CO2) environments. A 95cm long quartz tube was used as the Drop Tube and was kept at a temperature between 900 to 1000 °C. The particle size of the fuels was averaged at 400 microns. High-resolution images of the fuel conversion process in the Drop Tube were recorded to analyze the combustion process. To achieve complete burn-out, the remaining oxygen concentration in the flue gas was maintained at 5-7%. The temperature profile of each coal and biomass was taken during the heating zone and used for the thermogravimetric analysis. The results of the experiment are expected to show the flue gas emission at 900 to 1000°C for both air and oxy-fuel environments. These results will be compared to determine the temperature that equates to that of compressed air.

Generally, this experiment will provide valuable insights into the combustion of high and low ash content coals and biomasses gotten from Kazakhstan in different environments. The results will inform future studies on the development of cleaner and more efficient combustion technologies. The use of high-resolution images to study the fuel conversion process will also aid in the understanding of the complex processes involved in combustion. By comparing the results obtained in air and oxy-fuel environments, it will be possible to determine which environment provides the most efficient combustion for these fuels.

Keywords:

Combustion, oxy-fuel, thermogravimetric analysis, drop tube furnace, combustion efficiency.

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Table of Contents

List of Abbreviations

ASU	Air Separation Unit
CCS	“Carbon Capture and Storage”
CCUS	“Carbon Capture Utilization and Storage”
CO	Carbon mono oxide
CO2	Carbon di oxide
CFD	Computational Fluid Dynamics
DTF	Drop Tube Furnace
DTG	Differential Thermogravimetric
DTGA	Differential Thermogravimetric Analysis
EDS	Energy-Dispersive Spectroscopy
FB	Fluidized Bed
IEA	International Energy Agency
NOX	Nitrogen Oxides
IGCC	Integrated gasification combined cycle
MSW	Municipal Solid Waste
PC	Pulverized Coal
RT	Residence Time
RDF	Refuse-Derived Fuel
NGCC	Natural gas combined cycle
SEM	Scanning Electron Microscope
TGA	Thermogravimetric Analysis
VDTF	Vertical Drop Tube Furnace

List of Tables

List of Figures

CHAPTER 1

INTRODUCTION

1.1 Research Background

Recently there have been a significant increase in the CO2 emission from various sources such as coal-fired power plants, heavy industry and many other sectors of the economy[1]. This is thought to be the main driver of the climate change with global warming[2]. Coal is largely anticipated to continue to be one of the key energy sources for many years, especially in the emerging countries, due to its large reserves and inexpensive cost[1]. A prospective “renewable energy” source such as biomass waste materials can be utilized or co-fired in the existing power plants with minimal retrofitting to generate both heat and electricity, which is thought to be carbon neutral[3]. In addition to that, a potential technology such as carbon capture and storage(CCS) with clean fuel conversion processes becoming more popular as a result of the recent growth in environmental consciousness.[4]. The International Monetary Fund has predicted that as wages increased, coal will gradually phase out in favor of cleaner, more convenient, and more effective fuels like oil, natural gas, and, more lately, renewable energy[2]. According to some analysts, the recent rapid rise in the world's population, industry, and economy has been preceded by the growth in search for products and services without regard to quality of life. According to some forecasts, energy consumption will actually increase as a result of this growth in goods and services and will double by the year 2050[5].

1.2 Motivation of the study

Oxy-coal combustion is one of the CCS concept that proposes the recirculation of the flue gas and reuse it with oxygen for conversion of any sort of fuel[6]. As a result, the product gas mainly consists of CO_2 and H_2O, and minor pollutants such as NOx/SOx which typically can be removed from the process. Such alteration and the ensuing shift in the in-furnace gas constituents have an impact on the fuel combustion environment when compared to a typical air-firing mode. Particularly this might affect the parameter like fuel reactivity, burnout rate and overall combustion performance. The time it took for devolatilization to start to occur was unaffected by using CO_2 instead of N_2, but the time it took for coal particles to ignite was prolonged[7]. A promising methods for FB combustion is oxy-combustion sometimes referred to as O_2/CO_2 combustion. In oxy fuel environment, solid fuel is burned under controlled oxygen and recirculated flue gas. This is similar to the normal combustion that occurs place in O_2/N_2 environment. After oxy-combustion, the CO_2 is produced with purity higher than 90% that can fulfil the underground storage requirements[8].

Biomass energy is a form of energy produced or generated by organisms, living or non-living[9]. One of the most popular biomass materials that is used for energy include but not limited to corn, wood, manure and some garbage. The energy from these organisms could be combusted to produce heat and thereafter converted into electricity. Biomass can be similar to coal because energy might not be available after the carbon is half burned.

1.3 Research Objectives

Oxy-fuel combustion is a process in which a fuel is burned in an oxygen-enriched environment. This mixture can either be pure oxygen or a blend of recirculated flue gas. For this experiment the main aim was to perform oxy-fuel combustion of low quality coal (high ash content) in the drop tube furnace. The Objectives for the experiments are as follows

- Perform thermogravimetric, TGA and thermal analysis of fuel samples along with calorimetric values using the bomb calorimeter;
- Setting up a drop tube furnace
- Design of experiment and experimental conditions
- Characterizing the combustion or ignition behaviors fuel samples(coal and biomass), during the tests in a DTF
- Data elaboration and analysis

1.4 Thesis Structure

This thesis is structured into five chapters. The first chapter introduces the topic and the background of what the topic entails, it emphasizes the motivation behind the topic and the research objectives. The second chapter provides a detailed information on past research on the topic and related topics. It emphasizes on the conventional combustion technologies, their advantages and disadvantages. It also points out the best technology that is required for safe and efficient carbon capture. It explores previous studies related to oxy-fuel combustion of solid fuel.

The methodology part described the experimental set-up, fuel selection and preparation, experimental conditions and data collection. Chapter 4 discusses the results and analysis of the data collected such as the combustion efficiency, image analysis, CO_2 emission and the comparison of fuel conversions in DTF. Conclusion and recommendation is discussed in chapter 5. It recapitulates the findings from the experiment, it talks about the limitations and future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Fundamentals of Oxy-Fuel Combustion

A recently developed method for electricity production involves the combustion of fuels with high oxygen content. This approach uses air that has gone through a purification process to remove nitrogen and argon, resulting in an oxygen-rich mixture. This mixture is then combined with the fuel, typically coal or natural gas, in a combustor, producing a stream of carbon dioxide as a byproduct[1].

Oxy-fuel combustion technique reduces CO_2 efficiently, as has been demonstrated by numerous researchers working in this field. The flowchart in Figure 1 depicts the process of generating electricity with CCS using oxy-fuel combustion. This technology uses pure oxygen instead of air to react with carbon in fuel during conversion. This makes sure that CO_2 and water vapor are the predominant components of exit gas (H_2O)[3]. Other emissions, such as NOx, SOx, have dramatically decreased in the interim.[10] Additionally, Oxy-fuel combustion significantly reduces CO_2 emissions from the exhaust.

2.2 CCS Overview

The International Energy Agency (IEA) predicts that Carbon Capture and Storage (CCS) technology could reduce carbon emissions from coal combustion by over 90% and be responsible for the largest reduction in emissions by 2050, contributing to a 13% decrease in total emissions. The three main methods of CO_2 capture in CCS are pre-combustion, oxygen-fuel combustion, and post-combustion. This technology is seen as a crucial step towards limiting global temperature which was found to be 2°C per year. The goal of CCS technology is to drastically reduce carbon dioxide emissions. This technology is especially crucial for the ongoing shift from the economy dependent on fossil fuels to the innovative sustainable energy future[10]. The larger carbon capture, utilization, and storage (CCUS) technique, which consists of the following: CO_2 capture at substantial stationary sources (such as coal-fired plants), application of the CO_2 that was caught “such as gas injection for enhanced oil recovery”, petrochemicals' raw materials, transporting the CO_2 captured in storage locations, injection-based long-term CO_2 storing at the storage location (sequestration)[11]. The difference and the benefits that exist between this three type of carbon capture and storage will be emphasized in the following paragraph.

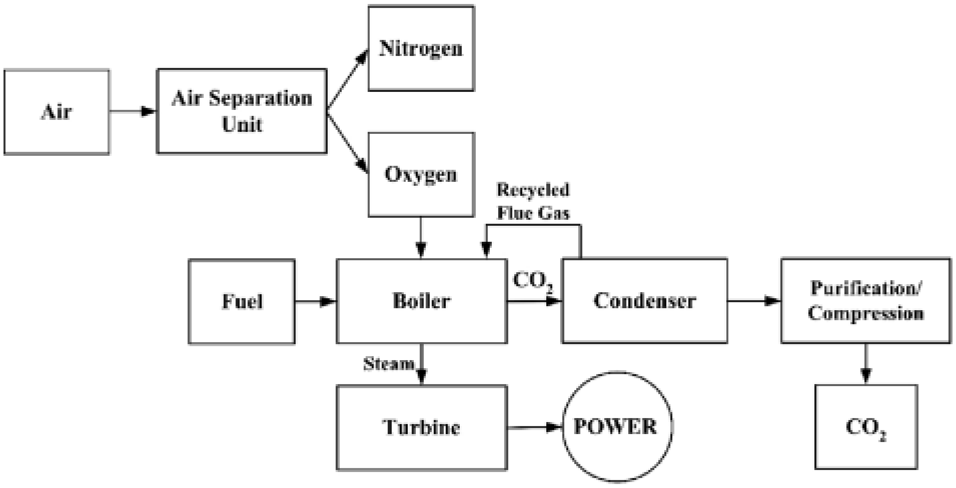


Figure 1. *A flow diagram depicting the oxy-fuel technology used for power generation with carbon capture and storage (CCS) in a general sense*[10]

2.2.1 Pre Combustion Capture

Pre-combustion capture is based on integrated gasification combined cycle (IGCC) technology. The aim of this technology is to generate syngas through partial oxidation, which is high in hydrogen (H_2) and carbon monoxide (CO). The CO is then oxidized to carbon dioxide (CO_2), increasing the concentration of CO_2 in the syngas[12]. The generated H2 is used as fuel for combustion in the boiler, and the remaining CO_2 is removed from the syngas through physical adsorption or chemical absorption. This process results in a higher concentration of CO_2 and reduced emission of pollutants like C, S and others that are removed from coal before combustion. However, the complex nature of the system and high operating and investment costs are some of the challenges associated with this technology[13].

2.2.2 Benefits and Limitations of Pre-Combustion Capture.

High efficiency and extremely straightforward removal of carbon from fossil fuels are just two of the significant benefits of pre-combustion capture. The increased concentration of CO_2 found in syngas enhances the effectiveness of adsorption, which can lead to the creation of a fuel that is potentially less harmful to the environment. Furthermore, this technology has been thoroughly examined by scientist in anticipation of wide implementation and commercialization. Additionally, it can be easily incorporated into existing facilities thereby reducing the cost of implementation[1].

However, the base gasification process has a higher overall capital cost than traditional pulverized coal power plants. Pre-combustion capture has several significant challenges, including the limited number of facilities that use integrated gasification combined cycle technology, challenges associated with using fuels that contain high levels of hydrogen, and difficulties with transferring heat effectively[12].

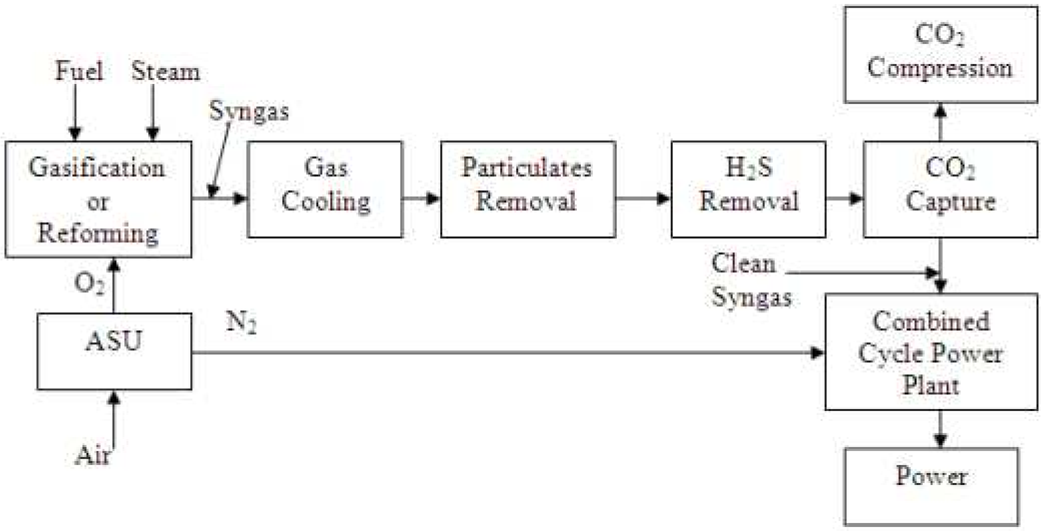


***Figure 2**. Technological process for Pre-combustion Capture*[14]

2.2.3 Post Combustion Capture

The process of post-combustion capture entails the removal of harmful substances such as particulate matter, sulfur oxides, nitrogen oxides, and carbon dioxide from the exhaust gases generated by power plants that utilize coal or natural gas. To accomplish this, a separation unit is added to the existing firing system. CO_2 can be sequestered using low-temperature distillation, chemical absorption, or gas membrane separation technologies. The technology is mature, making it relatively straightforward to implement in current coal-fired power plants. [14]. However, because of the relatively low CO_2

concentration in flue gas from coal-fire, a significant amount of flue gas must be treated by the capture container after combustion. Physical adsorption has a poor CO_2 recovery rate and a small adsorption capacity, in contrast. Chemical adsorption requires significant amounts of energy for regeneration, thus it is expensive to operate. Large-scale industrial applications are challenging because the membrane separation technique is not yet developed.[1]

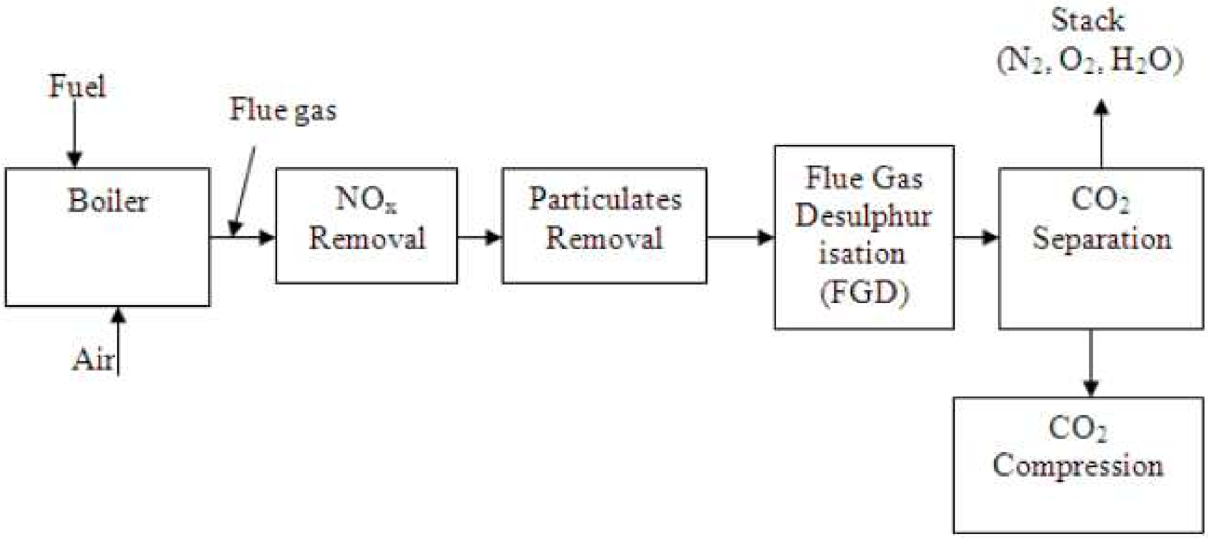


Figure 3. *Post-combustion capture technology in power plants*[14]

2.2.4 Benefits and Limitations of Post-Combustion Capture

The maturity of post-combustion carbon capture technology is a crucial advantage over other carbon capture systems [11]. Due to the fact that it was developed before “World War II”, this technique also serves as the most cutting-edge carbon capture technology. This implies that, should the need arise, there are established procedures for ensuring that the technology is effectively implemented into industrial applications for maintenance. Another benefit is how easily the technology can be used in both new and old plants[6]. The low carbon capture efficiency of this technique, in another sense, is a significant disadvantage as a result of the low CO_2 content in the flue gas. Another drawback is that the method is often associated with a high amount of parasitic infestation and costly production of electricity.

2.3 Oxy -fuel Combustion Capture

Oxy-fuel CCS research has expanded due to greenhouse gas emissions and climate change concerns. Oxygen-fuel combustion (CCS) outperforms "pre and post-combustion capture" for CCS. Oxy-fuel combustion technology is a cost-effective and cutting-edge CO_2 collection method for coal-fired plants[15]. Oxy-fuel combustion increases flue gas CO_2 to facilitate sequestration and compression. Instead of air, the combustion chamber receives recovered flue gas (primarily CO_2) and pure oxygen. This increases flue gas CO_2 production, lowering capture costs. Oxy-fuel combustion has higher combustion efficiency, full fuel combustion, lower exhaust volume, and lower NOx emissions than air combustion[1]. The US's Argonne National Laboratory reported that oxygen-fuel combustion technology requires boiler modifications. Thus, the system requires a cheap initial cost and can run at scale provided the technology is developed. Oxy-fuel combustion reduces CO2 emissions[14].

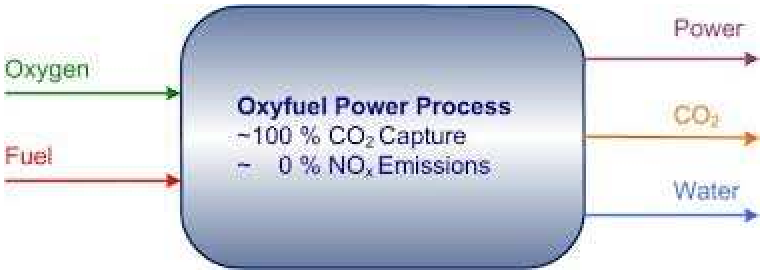


***Figure 4**. Oxy-fuel Combustion process.*

Adopted from http://hardwareparts.mfgmachined.com/why-oxyfuel.html

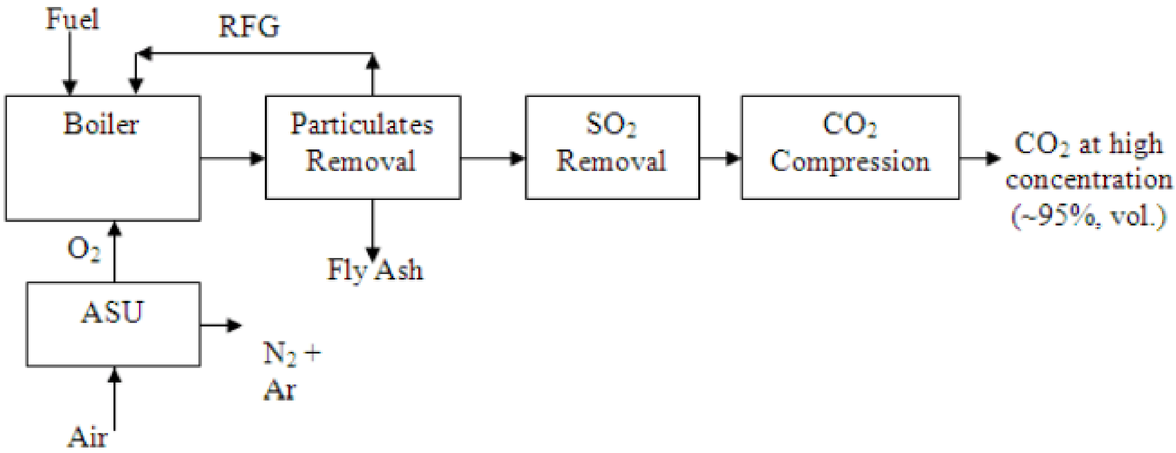


***Figure 5**. Oxy-fuel combustion capture technology in plants*[14]

2.3.1 Benefits of Oxy-Fuel Combustion

Burning fuel with oxygen rather than air is referred to as oxygen-fuel combustion, and it results in a greater concentration of carbon dioxide in the exhaust gases. This strategy contributes to a reduction in emissions of NOx and an increase in the quality of CO_2 output. Producing oxygen in its purest form, however, calls for a considerable amount of energy and can cause temperatures to soar. A significant quantity of the flue gas must be reused in order to keep the temperature at a level that is acceptable. In addition, the procedure necessitates the utilization of a device for the separation of air, which results in increased expenses as well as an increased need for energy[16].

2.3.2 Advancements in the study of Oxy-Fuel combustion in furnaces and boilers

In the year 1982, the concept of utilizing oxy-fuel combustion in coal-burning power plants in order to produce high-purity CO_2 was first put forward[1]. This technique includes burning coal in a combination of CO_2 and oxygen rather than in regular air, which has the potential to aid in CO_2 recovery and minimize emissions of air pollution. Since that time, scientists have been investigating the possibility of using furnaces and boilers that use oxy-fuel combustion. Recent developments in the study of the drop tube furnace are outlined in the following table for your convenience. This particular research subfield is quite essential. In a nutshell, the primary focus of current research has been on analyzing the many advantages and disadvantages associated with oxy-fuel combustion in drop tube furnaces.

Table 1. Summary of Recent Research on Oxy-Fuel Combustion

Publication Year	Type	Summary of Focus	Author(s)
2010	Review and Experiment	Focuses on the fundamentals of combustion, such as temperatures of flames and “heat transfer, ignition and burnout, emissions”, and the characteristics of fly ash, when examining the information that has	[17]

		been published about the oxy-fuel process.	
2017	Experiment/Modelling	This study has demonstrated that pulverized coal, biomass, and their blends may be characterized effectively and simply by using VDTF testing in conjunction with image processing techniques.	[18]
2019	Experiment	Using the TGA, DTR, and flat-flame burner, the inquiry comprises trials with low and high heating rates (FFB). The information helped to assist the creation of a thorough kinetic model for the conversion of coal in air and oxy-fuel atmospheres.	[4]
2019	Experiment	Physical and Chemical Behavior of Byproducts and Emissions Resulting from Biomass Oxy-fuel Combustion in DTF	[19]
2020	Modelling	This study uses CFD for modelling Oxy-fuel Combustion technique in power plants	[14]
2020	Experiment, Modelling and Simulation	Evaluation of a one-dimensional numerical model that was constructed to support experimental research on coal and biomass combustion in a drop tube furnace. The model was based on the literature.	[20]

2021	Review	This paper examines the most innovative carbon capture method for coal-fired boilers using oxygen-fuel combustion.	[13]
2021	Review	Oxy-fuel burning in internal combustion engines for carbon capture and storage	[10]
2021	Experiment	This study aims to "examine the thermal and combustion characteristics of RDF samples" and their component parts that were collected from MSW dumps in Nur-Sultan.	[21]
2022	Review	This review focused on changes to power generating systems that use "oxy-fuel combustion, including Several advanced oxy-fuel configurations, pressurized oxy-fuel combustion, and flue gas enriched oxy-fuel combustion".	[1]

2.4 Proximate and Ultimate analysis of Coal Samples

Coal is a combustible and carbonaceous solid materials that results from plant decomposition. By comparing the color of the various sorts of coal—brown to black, respectively, it may distinguish between high-rank and low-rank coal[13]. The source of vegetation includes substantial woody plant antecedents as well as low plant forms like moss. Although the carbon content of coal provides the heating value, other parameters, such as moisture content, ash content, and sulfur content play a significant influence in defining the rank for a particular source of coal[22]. In order to establish coal rank, demonstrate the "ratio of combustible to incombustible constituents", or otherwise proxy analysis measures moisture, fixed carbon, volatile matter, and the ash contained in coals to establish the foundation for trading, evaluating and making other transactions related to coal for different objectives. Ultimate analysis is a convenient way to report the major organic elemental composition of coal. For this analysis, a coal sample is burned in an analyzer, which calculates the weight percentages of carbon, hydrogen, nitrogen, sulfur, and ash in the coal sample.

Table 2. Modified "Proximate and Ultimate analysis" of different coals from different regions[23],[13]

PROXIMATE ANALYSIS(wt. % dry basis)	Australian Coal	Columbian Coal	Brazilian Coal(Bituinous)	Pakistan	US Coal(Pittsburge)	Nigerian Coal
Ash	10.4	26.5	32	34.83	22.2	20.02
Fixed Carbon	74.4	42.2	40.3	36.24	77.8	28.98
Volatile Matter	15.2	31.3	27.66	20.35	0	52.65
ULTIMATE ANALYSIS(wt. % dry basis)						
Carbon	88.1	76.7	77.4	61.9	66.2	53.27
Hydrogen	4.7	5.7	5.6	5.18	8.6	4.97
Nitrogen	1.9	1.4	1.7	1.16	2.66	2.67
Sulphur	0.7	1.4	0.7	0.69	4.9	1.82
Oxygen	4.6	14.9	14.6	11.01	22.1	12.43

A portion of the original mineral substance in coal that does not burn is represented by the ash content. For steam coals and their application in industrial furnaces, ash output is a crucial factor. Lower heating (Calorific) value is correlated with greater ash yield. High ash content in coal decreases its thermal efficiency, hinders combustion, and lengthens the burning process[21].

The amount of coal that needs to be burned in a solid condition is represented by the fixed carbon. Understanding fixed carbon is useful when choosing combustion equipment since its shape and hardness indicate a fuel's caking qualities. The fixed carbon content is used to measure the amount of char produced during thermochemical conversion. Once the volatile materials have been removed, there remains a solid residue that can be burned. The yield of char produced during the thermochemical conversion process increases as fixed carbon concentration increases[24]. The most prevalent volatile substances in coal are sulfur dioxide, carbon dioxide, and water. When the fuel is heated and easily ignites, Volatile matter is forced out, helping the ignition of the coal. The basic rule is that coal burns more slowly and gets harder to ignite when the Volatile Matter declines and the fuel ratio (fuel ratio = fixed carbon/Volatile Matter) rises. Low volatile coal requires less turbulence during burning and takes longer to finish than high volatile coal. The burners near one side of the furnace roof feed the primary air and coal vertically downward. The gas outlet runs along a predetermined path through a different side of the roof.

2.5 Experiment in the drop tube furnace

The combustion characteristics of solid fuels, such as coal and biomass, are commonly investigated using a Drop Tube Furnace (DTF), where a sample is burned in a high-temperature environment and the resulting reaction products are analyzed to determine important parameters such as ignition temperature and burnout time[25]. Another technique called Thermogravimetric Analysis (TGA) can evaluate the weight loss of the samples that can help to evaluate combustion behavior of fuels. The fuel had a high calorific value and could be used as a substitute energy source. The researchers also found that the fuel had high volatile matter and low ash content, which made it suitable for burning.[21].

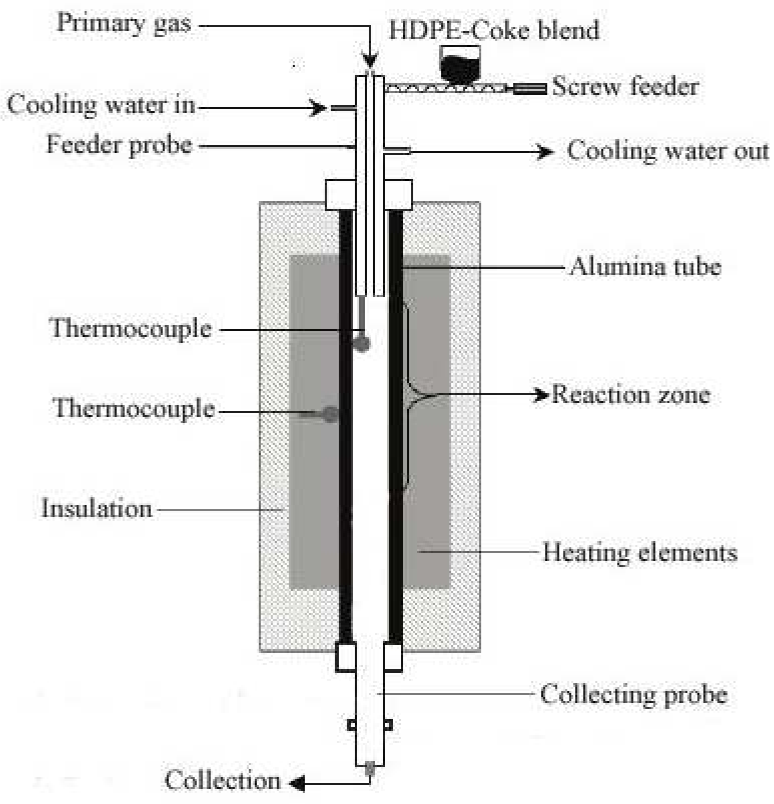


***Figure 6**. Schematic of a vertical drop tube furnace*.[26]

In a study that focused on four different fuels, namely, beech wood, oak wood, wheat straw, and coal, and investigates their combustion characteristics under different conditions.

The results of the study show that the combustion behavior of the fuels varies significantly depending on the fuel type and combustion conditions. Beech and oak wood showed a relatively stable combustion behavior with a well-defined char burnout zone, while wheat straw showed a high rate of volatile release and a relatively low burnout efficiency[23]. Coal, on the other hand, exhibited a highly efficient combustion process with a low amount of unburned carbon.

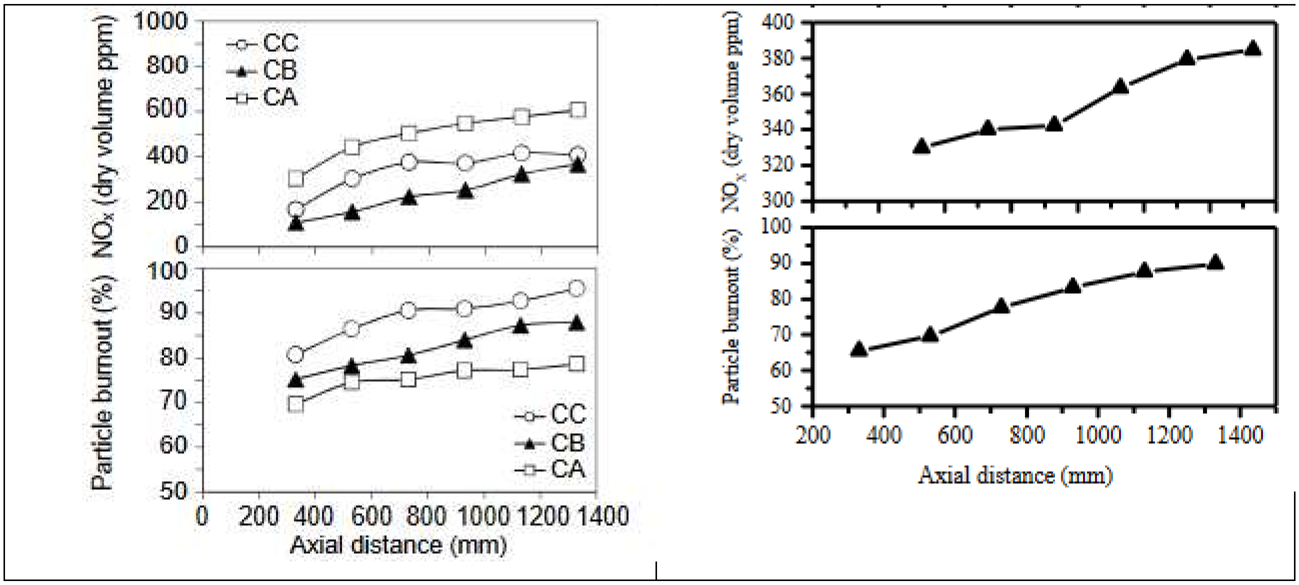


Figure 7*. Profiles of the three coals' temperatures, gas species concentrations, and burnout along the DTF's axis (b) profiles of temperature, gas species concentration, and particle burnout along the drop tube furnace's axis.*[23]

The study also highlights the importance of the experimental setup and conditions in determining the combustion behavior of solid fuels. The use of a drop tube furnace, which allows for controlled heating rates and residence times, was found to be an effective method for studying the combustion behavior of solid fuels.

The combustion of coal and biomass fuels has been extensively studied in recent years due to the increasing demand for renewable energy sources and the need to reduce greenhouse gas emissions. TGA has been used to investigate the combustion properties of various coal and biomass fuels, including coal, wood, straw, and agricultural waste. The results of these studies have shown that coal and biomass fuels have different combustion characteristics, with biomass fuels generally having lower ignition temperatures and higher burnout times than coal. [17] Provides an overview of the oxy-fuel combustion technology for solid fuels. The authors describe the basic principles of oxy-fuel combustion, the advantages and challenges associated with the technology, and the current state of the art. The study found that the main challenge of oxy-fuel combustion is to maintain stable flame conditions while avoiding carbon dioxide recycling.

The temperature of the char particle was gauged during the combustion tests using both pre-calibrated two-color pyrometer and a flexible thermocouple[27]. According to the findings, the pore structure of the char produced in an H_2O environment was superior to that produced in a CO_2 and N_2 atmosphere. The burnout time reduced and the particle temperature increased as expected as the oxygen content increased. Burnout times for the various ranks of coal char were as follows: anthracite > bituminous coal > lignite[27]. Intriguingly, compared to O_2/CO_2 and O_2/N_2 combustion, O_2/H_2O combustion may accomplish a shorter and a lower of char concurrently regardless of the environment or oxygen level. The ignition and burning characteristics of individual particles from two types of biomass waste and three types of coal were evaluated in the hot combustion byproducts of a CH4-fueled Hencken burner [3]. The flue gas was injected with particles of lignite, bituminous coal, anthracite, and residues of corn and wheat straw, all of which were between 125 and 150 um in size. The study examined the temperature and oxygen content of flue gas, using a combination of nitrogen and oxygen, as well as carbon dioxide and oxygen. Images of individual burning particles were captured using an ICCD camera equipped with a filter that only allows light with a wavelength of 430 nm to pass through, and the CH* chemiluminescence was also captured in a time-resolved manner.[3],[17]. The findings demonstrate that whereas bituminous coal and anthracite particles lit heterogeneously in both cases, biomass and lignite particles ignited uniformly. For the biomass and lignite particles, the volatiles were gas-phase-combusted in an engulfing flame around the particle, and the char was then oxidized heterogeneously. The coal particles burned more quickly than the biomass particles. With an increase in their volatile content, the igniting delay time for the three coals dropped practically linearly. All solid fuels took longer to ignite when CO_2 took the place of N_2, and volatiles burned off more slowly[19]. In another study, concentrated was on the outcomes of burning pulverized coal and biomass fuels in a Visual Drop Tube Furnace, where a combustion flame created by continuous fuel input was viewed and captured using a high speed camera. The fuel igniting properties have been successfully translated by the automatic picture post processing method used to quantify the data. According to the findings of the coal combustion experiments, the decrease in the fuel's volatile content is connected with an

The materials and residues from in-nature were assessed using TG/DTG (thermogravimetric/derivative thermogravimetric), SEM pictures, and EDS analyses (energy-dispersive spectroscopy). Some of the most significant morphological variations in the in natural materials were seen in the SEM pictures[21],[28]. The TG/DTG curves in naturally occurring pine sawdust and the residues produced by various thermochemical processes (conventional and oxy-fuel combustion) in DTF are shown in Figures (a) and (b) below. The natural sample's DTG curve (b) shows well-defined peaks at 328 and 460 degrees Centigrade, which correspond to maximal combustion rates and can be attributed to the thermal degradation of holocellulose and remaining lignin. Crystalline samples are often characterized by thin peaks and elongation.

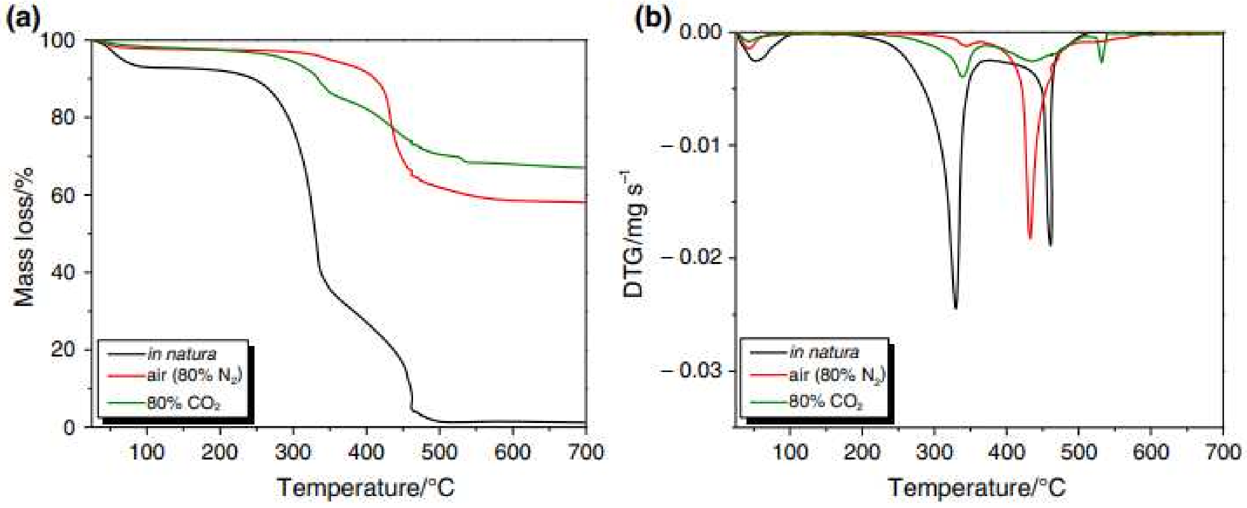


Figure 8. *Shows the TG and DTG curves for in-nature samples and pine sawdust residues following combustion using conventional fuel (80% N2) and oxy-fuel (80% CO2) in DTF.*

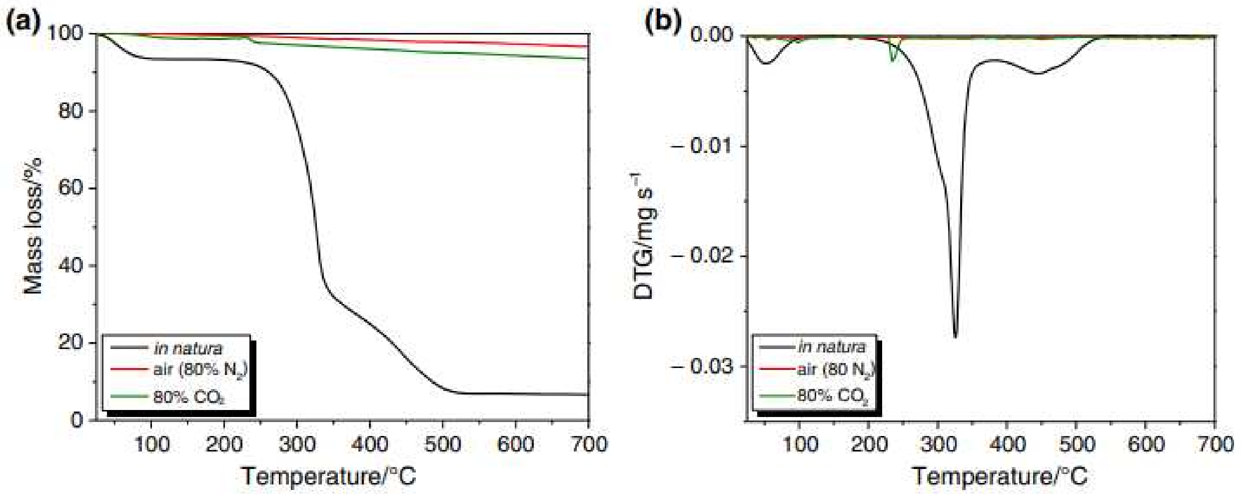


Figure 9*. TG for (a) and DTG for (b) curves of the in- natura samples and sugarcane bagasse residues after conventional combustion (80% N2) and oxy-fuel combustion (80% CO2) in DTF.*

Nitrogen does not participate in combustion[21]. It is a harmful component because it increases stack temperatures by absorbing heat from the combustion process. Reduced combustion efficiency are a result of both high CO levels and extra air. While combustion in oxy-fuel environment makes the combustion highly efficient even though the oxygen also absorbs heat from the combustion process.

Similar to this, the study contrasts in-nature samples of sugarcane bagasses burned in conventional combustion at 80% N2 with oxy-fuel combustion at 80% CO_2 in a drop tube furnace using thermogravimetric analysis (TGA) and derivative thermogravimetric analysis (DTGA). The temperature in the experiment is 700°C, the heating rate is 10°C/min, the sample weight is 10MG, and the flow rate of the synthetic air is 100 liters per minute[28]. The graph above shows the results, which show a "Shoulder" about 310°C, which denotes a significant hemicellulose content as well as the simultaneous breakdown of hemicellulose and cellulose. The "Shoulder" for the oxy-fuel combustion of sugar cane bagasse was not found; instead, a peak was seen at 445° that was attributed to the remaining lignin breakdown. Other research comparing various biomasses and coals have been conducted by various authors, and most of the results of TGA analysis are comparable[21].

In a study of a combination of biomasses and coals, the ignition and combustion properties of individual particles of two types of biomass waste and three types of coal were studied by analyzing the hot combustion byproducts of a CH4-fueled Hencken burner. The flue gas was injected with particles of lignite, bituminous coal, anthracite, and residues of corn and wheat straw, all of which were between 125 and 150 m in size. The flue gas had an average temperature of 1550 K and a mean oxygen content of about 15 mol%. Environments of synthetic air and CO_2/O_2 were used for the studies. An ICCD camera with a 430 nm band-pass filter was used to take images of the single burning particles' CH* chemiluminescence that were temporally resolved[23]. The findings demonstrate that whereas “bituminous coal and anthracite particles ignited heterogeneously in both N_2/O_2 and CO_2/O_2 environments, biomass and lignite particles” ignited uniformly. For the biomass and lignite particles, the volatiles were gas-phase-combusted in an engulfing flame around the particle, and the char was then oxidized heterogeneously. The coal particles burned more quickly than the biomass particles[27]. With an increase in their volatile content, the igniting delay time for the three coals dropped practically linearly. All solid fuels took longer to ignite when CO_2 took the place of N_2, and volatiles burned off more slowly. All solid fuels burned with significantly less intensity in the CO_2/O_2 environment than it did in the N_2/O_2 environment[3].

There are very many published experimental work done on oxy-fuel combustion. Most of which are done with different kinds of biomass from different regions of the world, different forms of coal and a combination of coal and biomasses. The review of these literatures cannot be over emphasized as the aim of this work is to carry out oxy-fuel combustion on biomasses and coals available in Kazakhstan. Among the work that will be carried out include Pyrolysis, TGA, Burnout time of different coals, Modelling and Validation of results.

The combustion of solid fuels, such as coal and biomass, produces CO_2 as a byproduct. The amount of CO_2 produced can be influenced by the type of oxygen (or air) used in the combustion process. When oxy-fuel is used, the concentration of O_2 can be controlled, potentially leading to a higher percentage of CO_2 production compared to when normal air (O_2/N_2) is used. Increasing the O_2 percentage in the oxy-fuel mixture can increase the amount of CO_2 produced.

2.6 Image Processing of Combustion capture

The complexity of flames and related phenomena can be better understood by oxy-fuel studies performed in drop tube furnaces. In order to evaluate combustion efficiency, emissions, and flame characteristics, accurate measurement and analysis of flame temperature is required. Researchers may investigate the combustion process in great depth with the help of photographs of the flames thanks to image processing tools, which are both non-invasive and inexpensive[18]. Taking good pictures of a flame is the first step in doing a temperature analysis. Images of flames have been captured using a wide range of imaging modalities, from high-speed cameras and infrared cameras to laser-induced fluorescence. For a reliable depiction of the flame structure and temperature distribution, these pictures are usually taken at varying exposure durations and in carefully regulated experimental circumstances.

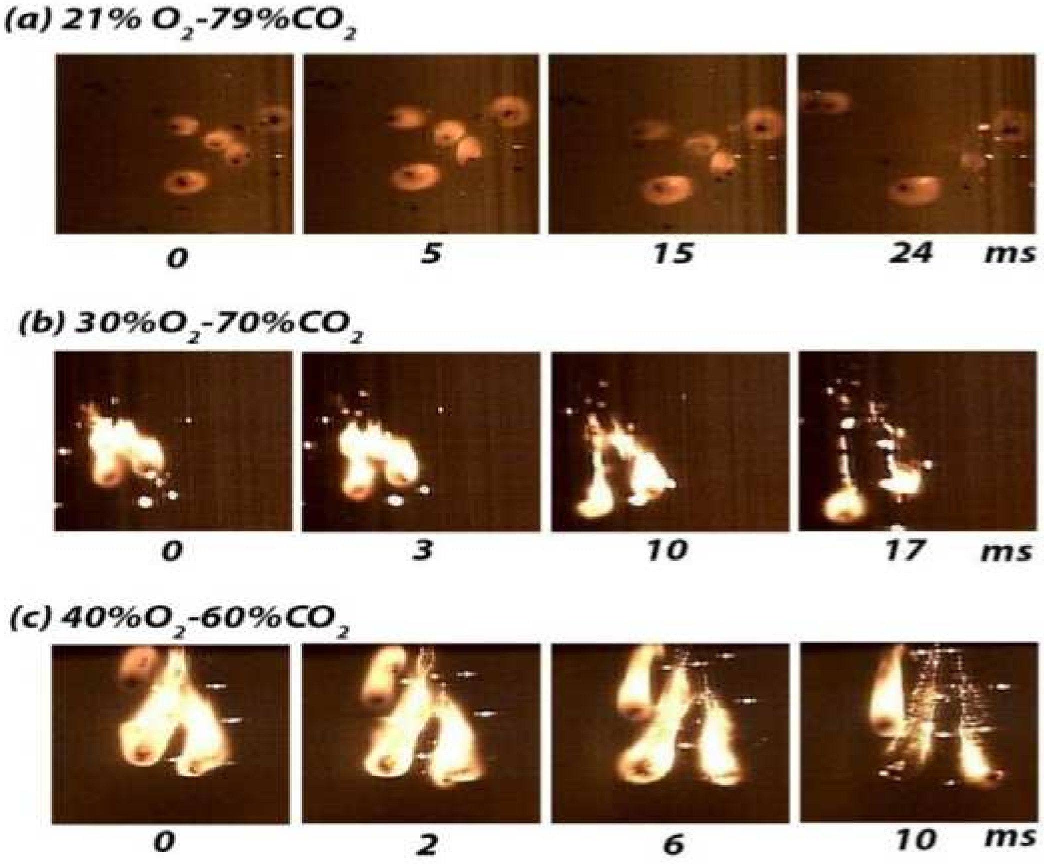


Figure 10. *Image of different oxy-fuel combustion*[29]

Preprocessing is critical for improving flame images by removing unwanted noise and artifacts that can interfere with analysis. Picture denoising, augmentation of contrast and brightness, picture registration, and background subtraction are all common preprocessing techniques. These methods enhance flame visibility and allow more precise temperature estimation[18]. Estimating the temperature of a flame is an important part of the image processing required for oxy-fuel research. Gray-level-based methods, color-based methods, and spectrum analysis techniques are only few of the many that have been proposed in the literature for temperature estimation. The color-based approaches take advantage of the spectrum features of the flame, while the gray-level methods use the intensity information in the photos to estimate the temperature[30]. The temperature distribution within a flame can be accurately mapped using spectral analysis methods like flame emission spectroscopy. Accurate temperature estimation requires validating image-based observations against known temperature benchmarks through the process of calibration. Thermocouples, pyrometers, and reference flames of established temperatures are used in calibration procedures. In order to ensure the accuracy of the image processing methods, the estimated temperatures are checked against the calibrated readings. Recent developments in image processing techniques have greatly increased the accuracy and efficiency of flame temperature estimation, but this improvement has not come without its share of challenges. Among these is the use of convolutional neural networks and other machine learning methods for analyzing fire pictures. But there are still obstacles to overcome, such as distorted images from flame flickering, segmenting flames in complicated surroundings, and balancing precision and computing complexity.

CHAPTER 3

METHODOLOGY

3.1 Elemental Analysis of Coal samples

In order to determine the key physical and chemical properties of the Ekibastuz coal and Shubarkol coal, a comprehensive fuel analysis was conducted. The fuel analysis included determination of ash content, moisture content, volatile matter, and fixed carbon.

3.2 Ash Content Determination

The ash content of the coal samples was determined using the standard ISO 18122:2015E method. In this method, a known weight of coal sample was combusted in a muffle furnace at a temperature of 525°C for 30minutes. The ash residue was collected, weighed and the ash content was calculated as the percentage of the original weight of the sample.

3.3 Moisture Content Determination

The moisture content of the coal samples was determined using the standard ISO 18134-3:2015E method. In this method, a known weight of coal sample was dried in an oven at a temperature of 110°C until a constant weight was obtained. The moisture content was calculated as the difference between the original weight of the sample and the weight after drying, expressed as a percentage of the original weight.

3.4 Volatile Matter and Fixed Carbon Determination

The volatile matter and fixed carbon content of the coal samples was determined using the standard ISO 18123:2015E method. In this method, a known weight of coal sample was combusted in a bomb calorimeter under controlled conditions. The volatile matter was calculated as the percentage of the original weight of the sample that was lost during combustion, while the fixed carbon was calculated as the difference between the original weight and the weight of the ash and volatile matter[31].

3.5 Sample Preparation

A representative sample of Ekibastuz coal and Shurbakol coal was obtained from the mine site. The sample was crushed and sieved to obtain a particle size of 150-300um. The prepared sample was used for the fuel analysis.

Figure 11. *Samples of Shubarkol, Ekibastuz coals as well as wheat straw*

3.6 Quality Control

Quality control measures were taken to ensure the accuracy and reliability of the fuel analysis results. Duplicate samples were analyzed for each coal type and the average of the duplicates was used for data analysis. The standard reference materials were also analyzed to verify the accuracy of the analysis method. The purpose of the fuel analysis was to determine the primary physical and chemical qualities of the Ekibastuz coal and the Shubarkol coal. These properties included the amount of ash, the amount of moisture, the amount of volatile matter, and the amount of fixed carbon. In order to evaluate the acceptability of the coals as potential sources of energy and to compare the coals' behavior when they are burned, the results of the fuel analysis will be employed.

Table 3. **Summary of Proximate and Ultimate analysis of Shubarkol and Ekibastuz coal**

Proximate analysis (wt. %)	**Shubarkol coal**	**Ekibastuz coal**
Moisture content	2.19	1.37
Fixed carbon	50.16	40.13
Volatile matter	46.5	22.38
Ash content	7.33	36.125
Ultimate Analysis (wt.%)		
Ash	7.33	36.13
Carbon	70.93	50.22
Hydrogen	5.05	3.10
Nitrogen	1.81	1.40
Sulphur	< 0.01	0.60
Oxygen	22.20	8.56

Wheat Straw

Proximate Analysis (wt. %)	
Moisture	3.08
Fixed carbon	11.90
Volatile matter	77.69
Ash content	7.33
Ultimate Analysis (wt. %)	
Ash	7.33
Carbon	49.5
Hydrogen	6.2
Nitrogen	0.6
Sulphur	0.2
Oxygen	36.17

Ultimate analysis:

- The ultimate analysis involves determining the carbon, hydrogen, nitrogen, sulfur, and oxygen content of the substance. Here are the steps
- Carbon determination: Weigh 1g of the sample, heat it in a combustion tube, and pass it through a carbon dioxide absorbent. The increase in weight of the absorbent gives the carbon content.
- To determine the amount of hydrogen, take one gram of the sample, weigh it, then heat it in a combustion tube and run it through a water absorbent. The amount of hydrogen that has been absorbed can be calculated based on the rise in the absorbent's weight.
- Nitrogen determination: Weigh 1g of the sample, heat it in a combustion tube, and pass it through a nitrogen absorbent. The increase in weight of the absorbent gives the nitrogen content.
- To determine the amount of sulfur, take one gram of the sample, weigh it, then heat it in a combustion tube before putting it through a sulfur absorbent. The amount of sulfur present can be calculated using the increase in the absorbent's weight.
- Oxygen determination: Subtract the sum of the carbon, hydrogen, nitrogen, and sulfur content from 100 to get the oxygen content.

3.7 Interpretation of results

The results obtained from the proximate and ultimate analysis can be used to assess the fuel quality of the substance. The higher the fixed carbon content and the lower the moisture and ash content, the better the fuel quality. For the ultimate analysis, the carbon content is the most important factor, as it is the primary contributor to the energy content of the fuel.

Overall, the proximate and ultimate analysis can provide valuable information for industries that use these substances as fuel. By knowing the fuel quality of a substance, they can optimize their operations and reduce their environmental impact.

3.8 Thermogravimetric Analysis

Thermogravimetric analysis (TGA) is a technique used to investigate the thermal stability of a material by measuring the weight loss as a function of temperature or time under controlled conditions. In this methodology, we will discuss the TGA of Shurbakol coal, Ekibastuz coal, and wheat straw. The assumed operating parameters are as follows:

1. Temperature range: 30°C to 900°C
2. Heating rate: 10°C/min
3. Atmosphere: Nitrogen (purity 99.99%)

Equipment:

Thermogravimetric analyzer (TGA) equipped with a high-precision balance, a furnace, and a gas flow system, sample crucibles (alumina or platinum), Sample holder

Figure 12. *Thermogravimetric Analyzer*[32]

3.9 Procedure

Preparation of samples:

- Coal samples: Shurbakol coal and Ekibastuz coal are ground to a particle size of 500-600 microns and stored in a desiccator to maintain the moisture content.
- Wheat straw samples: Wheat straw is ground to a particle size of 250-300 microns and stored in a desiccator to maintain the moisture content.

3.10 Sample loading

- Coal samples: About 25 mg of coal samples are loaded into the alumina crucible and sealed with a lid.
- Wheat straw samples: About 5-10 mg of wheat straw samples are loaded into the platinum crucible and sealed with a lid.

3.11 TGA measurement

The sample crucibles are loaded onto the sample holder and placed inside the TGA furnace.

The TGA is purged with nitrogen gas (99.99%) at a flow rate of 20 ml/min to remove any atmospheric moisture. The TGA is programmed to heat the samples from 30°C to 900°C at a heating rate of 10°C/min under a constant flow of nitrogen gas. The weight loss of the samples is continuously recorded as a function of temperature.

3.12 Experimental Conditions

- Heating rate = 5°C/min
- Length of quartz tube = 95cm
- Heating zone = 65 cm
- Thickness of quartz tube = 3mm
- Pressure = 1.5bar
- Flowrate = 1l/min
- Particle size = 400microns
- Weight of sample = 3g
- Temperature = 900°C to 1000°C

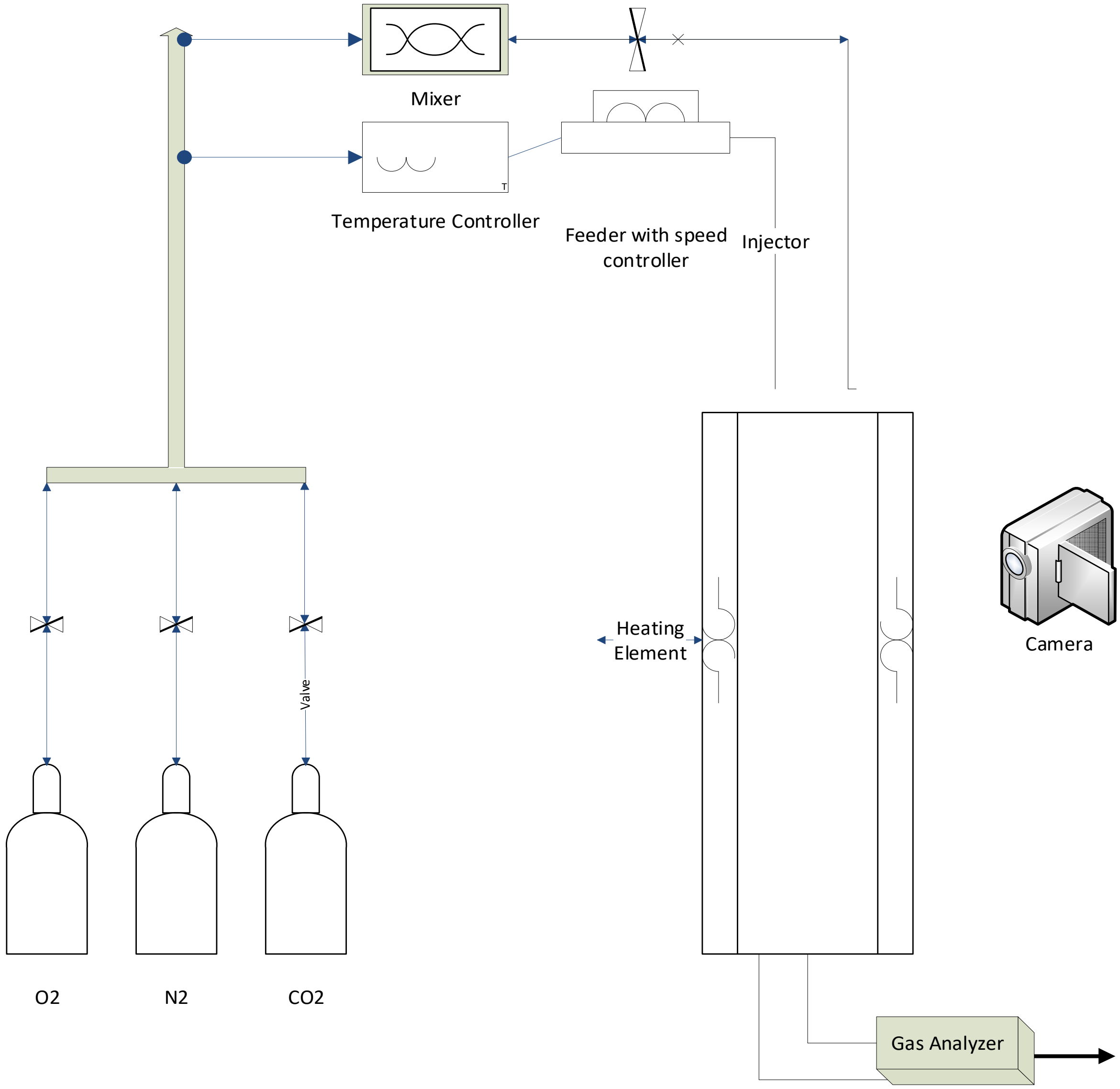


Figure 13*. Schematic diagram of a drop tube furnace*

3.13 Description of a Drop Tube Furnace

The study of high-temperature phenomena including combustion, gasification, and pyrolysis can be carried out in a drop tube furnace as shown in figure 6, which is a specific kind of high-temperature furnace. The operation of this furnace is based on the free-fall of a sample material inside of a quartz tube while the temperature is maintained at a constant level. The drop tube furnace that was employed for the execution of this methodology has a quartz tube that is 60 centimeters in length and has an internal diameter of 36 centimeters and an external diameter of 38 centimeters. Temperatures ranging from 30 to 3000 degrees Celsius are possible within the furnace thanks to its adjustable heat settings.

The needed temperature may be reached in the furnace thanks to a heating element that is constructed out of a high-temperature resistant material such as silicon carbide[20]. This element delivers the necessary heat to reach the desired temperature. After being placed in a sample container, the material to be tested is then loaded into the top of the furnace using a loading mechanism. The sample holder is constructed in such a way that it will keep the sample from moving around or being disturbed in any way while it is falling freely. As soon as the sample is put into the furnace, it is allowed to fall freely through the quartz tube while the temperature is being carefully maintained. The temperature is monitored and controlled using a thermocouple and a PID controller, which guarantees that the temperature will be accurately controlled and will remain steady throughout the experiment. When the sample reaches the bottom of the furnace, it is removed and placed in a collection receptacle so that it can be analyzed further [33]. The collection vessel is designed to capture the sample without any loss or contamination, allowing for accurate and precise analysis of the sample.

CHAPTER 4

RESULTS AND DISCUSSIONS

The weight loss of the samples is plotted against temperature. The thermograms obtained are analyzed for the onset temperature, peak temperature, and weight loss of each stage of the thermal degradation. The thermal degradation of the samples is characterized by different stages of weight loss, which correspond to different types of reactions occurring in the samples.

Shubarkol Coal

The graph of Shubarkol coal's weight decrease indicates two separate stages, as can be seen. The coal's moisture is lost during the first stage, which starts when the temperature is below 200 °C. The decomposition of organic materials in the coal causes the second stage, which happens between 200°C and 800°C. As a result of the relatively substantial weight loss during this stage, it can be concluded that the coal contains a sizable amount of volatile matter. The coal's leftover carbon is burned during the last step of weight loss, which takes place above 800°C.

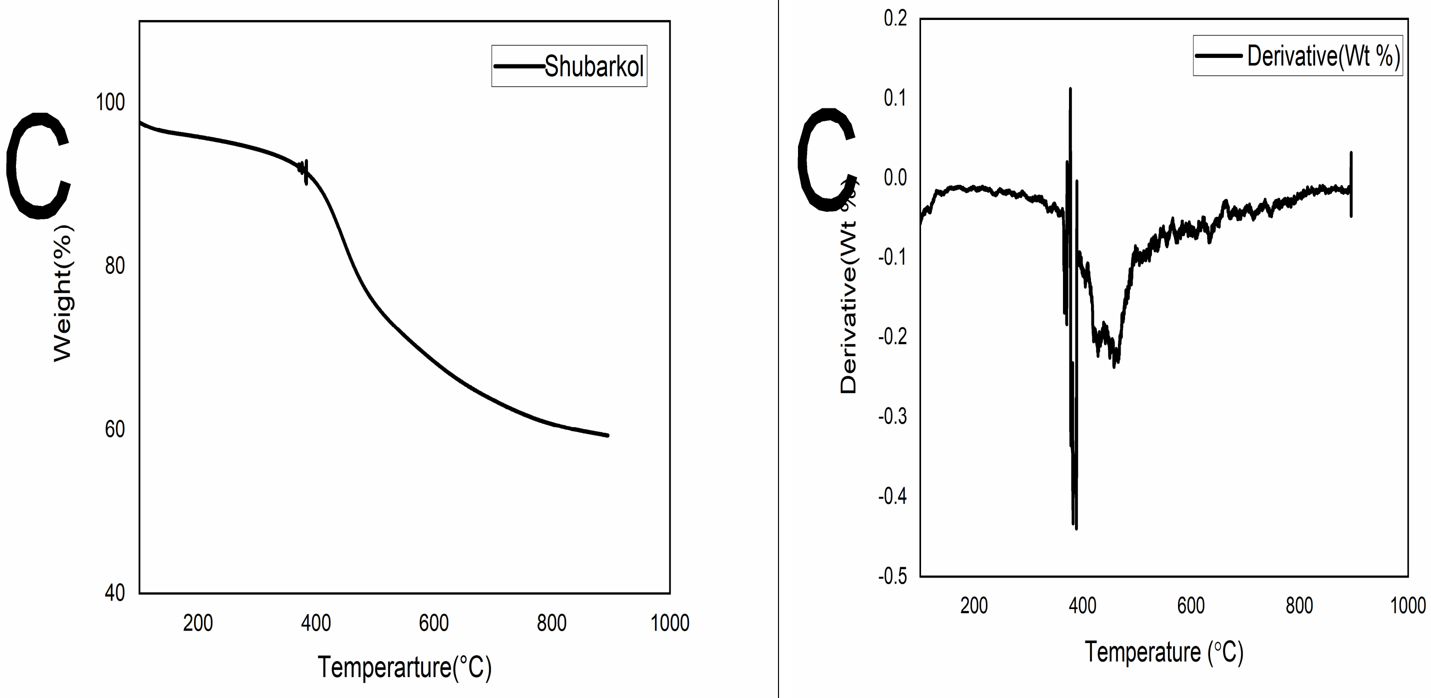


Figure 14. *TGA and DTGA curves for Shubarkol coal*

The graph illustrates that the DTGA curve for Shubarkol coal has two peaks. The degradation of hemicellulose and cellulose in the coal is linked to the first peak, which rises between 200°C and 380°C. The second peak, which happens between 400 and 800 degrees Celsius, is connected to the breakdown of lignin and other high molecular weight substances in coal. The TGA and DTGA analysis of Shubarkol coal in a nitrogen atmosphere are consistent with the high volatile matter concentration and good quality of this coal when compared to earlier investigations

Ekibastuz Coal

The weight loss curve of Ekibastuz coal exhibits three separate stages, as shown by the graph in figure 4.2. The coal's moisture is lost during the first stage, which starts when the temperature is below 100°C. The decomposition of volatile stuff in the coal causes the second stage, which happens between 100°C and 700°C. The comparatively small weight loss during this step shows that the coal contains just a small amount of volatile matter. The coal's leftover carbon is burned during the last step of weight loss, which takes place above 700°C.

The graph also demonstrates that the Ekibastuz coal's DTGA curve has three peaks. The coal's internal moisture decomposes at a temperature between 100°C and 200°C, which causes the first peak to appear. The degradation of hemicellulose and cellulose in the coal is responsible for the second peak, which appears between 200°C and 400°C. The third peak is connected to the breakdown of lignin and other high molecular weight chemicals in the coal, which takes place at a temperature between 500°C and 850°C.

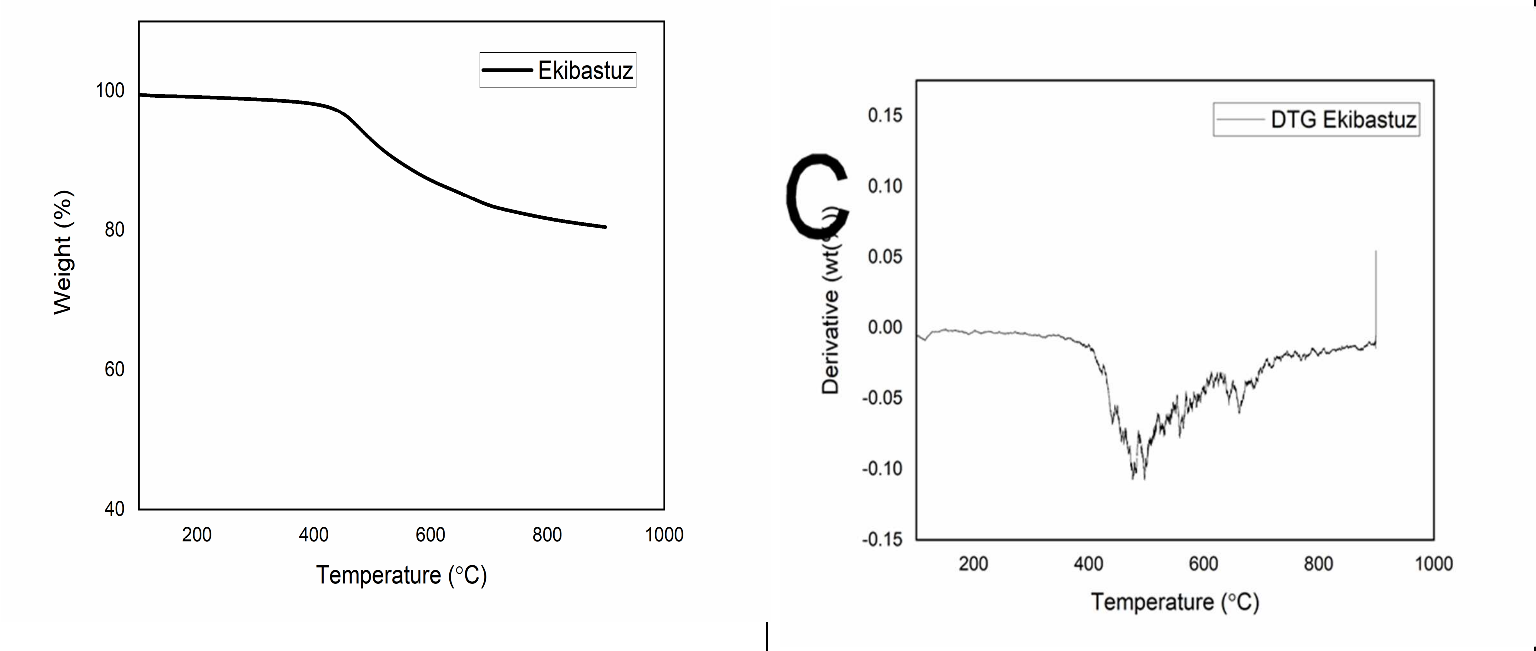


Figure 15. *TGA and DTGA of Ekibastuz coal*

Wheat Straw

Figure 16 depicts weight losses of wheat straw. The loss of moisture from the wheat straw happens in the first stage, which starts when the temperature is below 100°C. The degradation of hemicellulose and cellulose in the wheat straw causes the second step, which takes place between 100°C and 400°C. As a result of the weight loss that occurs at this stage being so significant, there must be a lot of volatile stuff present in the wheat straw. The degradation of lignin and other high molecular weight substances in the wheat straw is linked to the last stage of weight loss, which takes place above 400°C.

In the analysis of wheat straw using DTGA in a nitrogen environment. The graph depicts peaks of the wheat straw DTGA curve. The decomposition of moisture in the wheat straw is linked to the first set of peaks, which happens between 100°C and 200°C. The second peak, which happens between 250 and 400 degrees Celsius, is connected to the breakdown of hemicellulose and cellulose in wheat straw. The third peak is connected to the breakdown of lignin and other high molecular weight substances in wheat straw, which takes place at a temperature between 400°C and 600°C.

Important details about wheat straw's thermal stability and breakdown characteristics can be learned from the TGA and DTGA analyses performed under a nitrogen atmosphere.

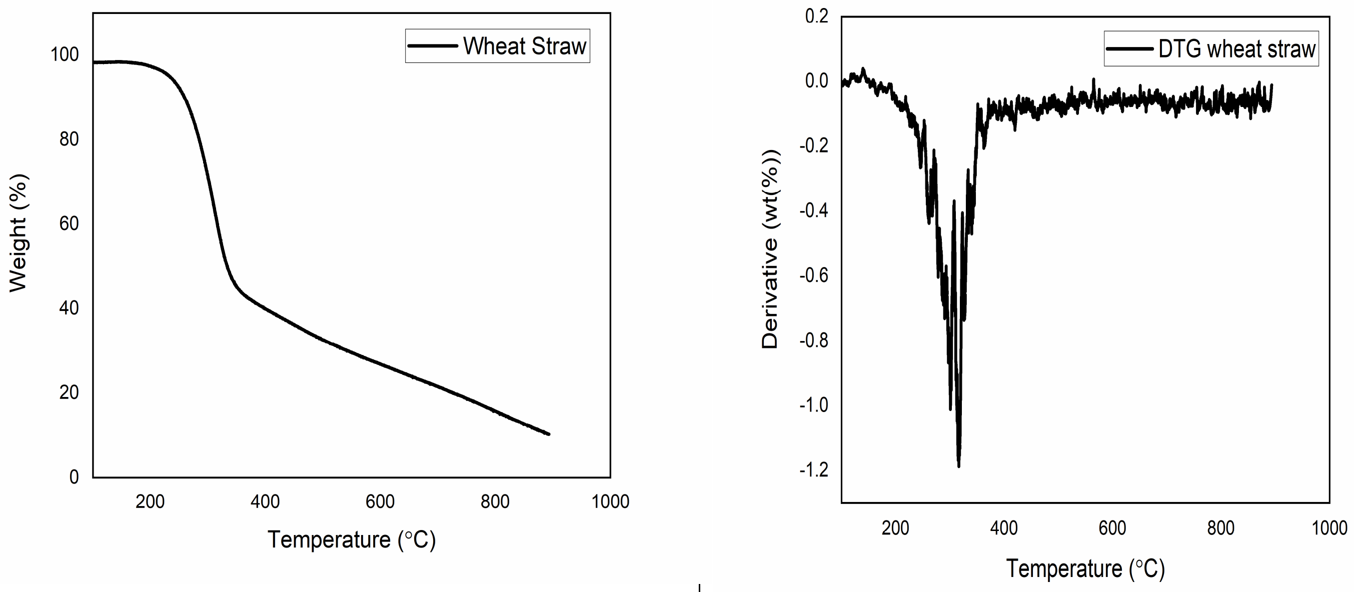


Figure 16. *TGA and DTGA of wheat straw*

Wheat straw could be used as a source of renewable energy through combustion or gasification due to the comparatively high amount of volatile stuff it contains. Wheat straw has a relatively low ash level, which might improve its ability to burn. To completely assess the potential of wheat straw as a solid fuel source, more research is necessary. Overall, the investigation of wheat straw using TGA and DTGA offers significant insights into the thermal behavior of this renewable resource.

4.1 Combustion Data Visualization

After series of experiment in the DTF, data was collected and are appropriately represented in the following graphs.

Combustion in compressed air environment

The three different samples were burnt in the DTF in the presence of compressed air and the concentration O_2 across three different temperatures.

Table 4a. Oxygen concentration seen in the gas analyzers

	900°C	950°C	1000°C
Shubarkol	7%	6.5%	5%
Ekibastuz	7.5%	7%	6%
Wheat straw	5.5%	5.5%	5.5%

Table 4b. CO_2 Concentration

	900°C	950°C	1000°C
Shubarkol	17%	18%	20%
Ekibastuz	18%	19%	20.5%
Wheat straw	19%	19.5%	21%

The results of the CO2 concentrations at different temperatures for the three different forms of fuel (Shubarkol coal, Ekibastuz coal, and wheat straw) reveal that the combustion of these fuels leads to an increasing concentration of carbon dioxide in the gas analyzer as the temperature increases. Higher temperatures encourage more complete combustion, which in turn leads to the generation of carbon dioxide as a byproduct of the combustion process. This is a typical pattern that may be observed during the combustion process.These interpretations shed light on the behavior of CO2 concentrations throughout the burning of a variety of fuels at several different temperatures.

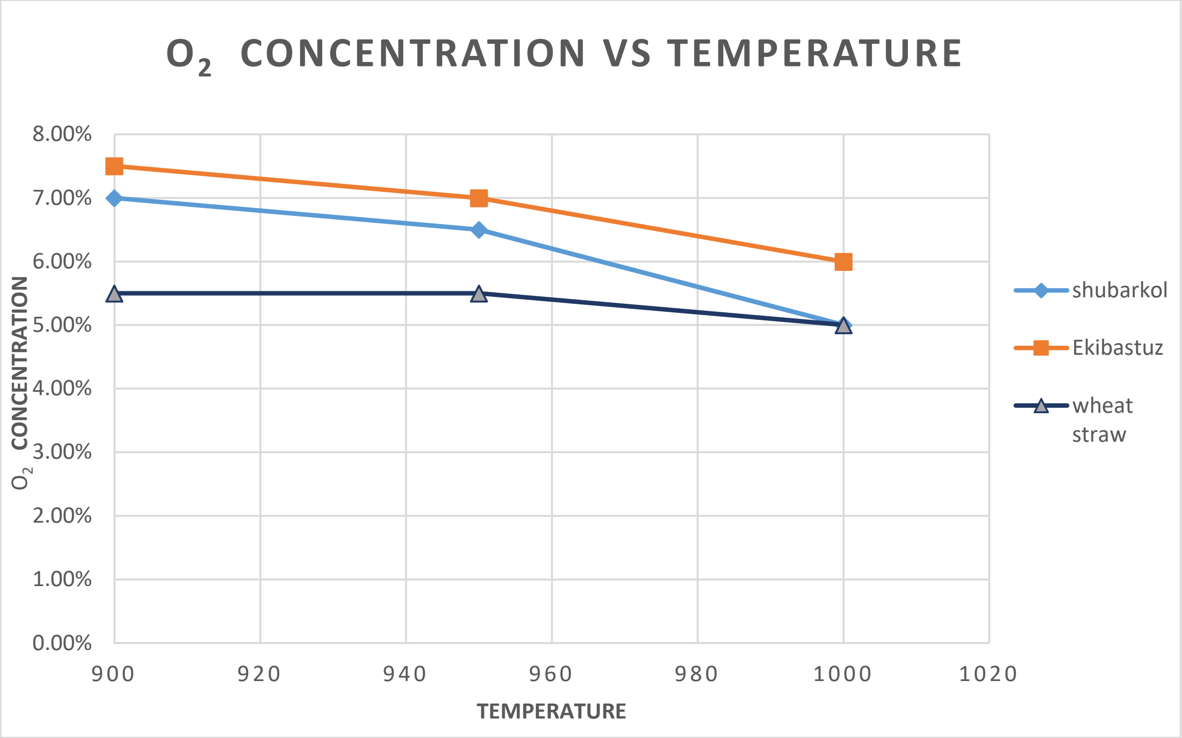


Figure 17a. *Oxygen concentration of different coal and biomass at different temperature (air)*

The results reveal that the oxygen contents in compressed air for both Shubarkol and Ekibastuz coals decrease with increasing temperature. Less oxygen in the gas analyzer means more efficient combustion at higher temperatures. While wheat straw's oxygen concentration remains stable, implying a constant combustion behavior across the studied temperature range, rice straw's oxygen concentration fluctuates.

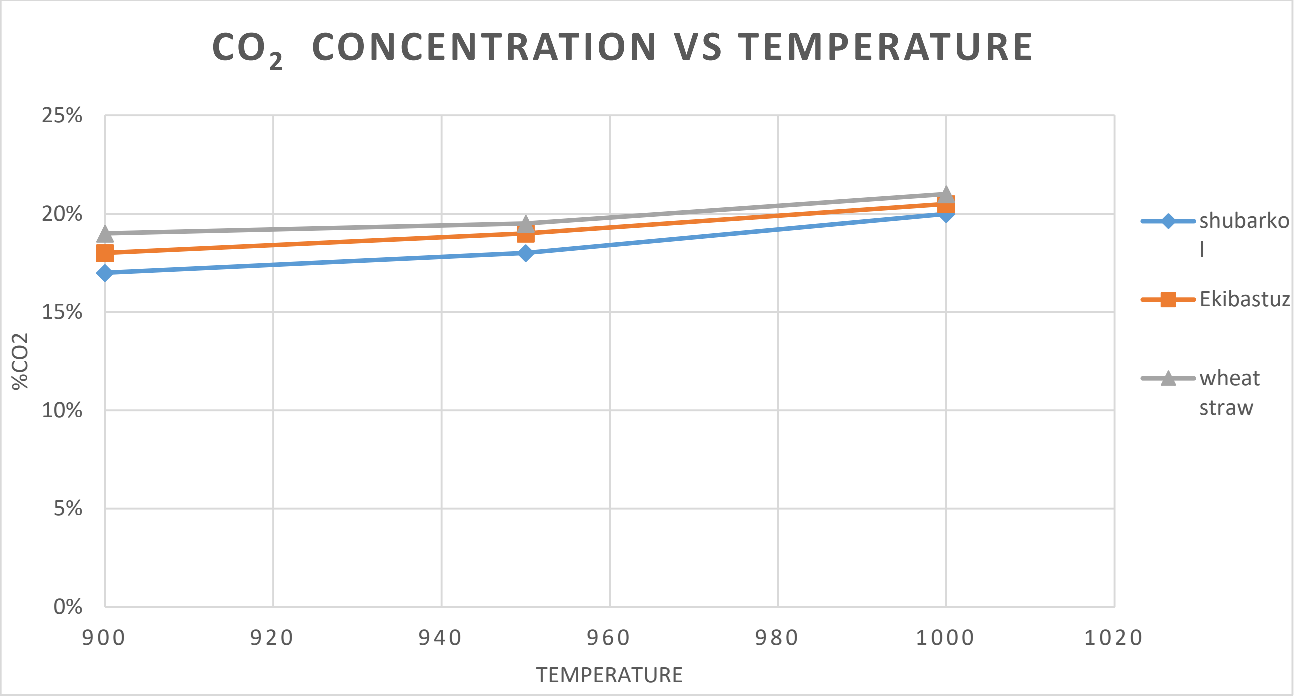


Figure 17b. *CO_2 concentration of different coal and biomass at different temperature (air)*

Table 5. Oxy-fuel case 1(21%O_2 and 79%CO_2)

Oxy 1	900°C	950°C	1000°C
Shubarkol	7%	6.8%	6%
Ekibastuz	7.5%	7.5%	7%
Wheat straw	5.5%	5%	5%

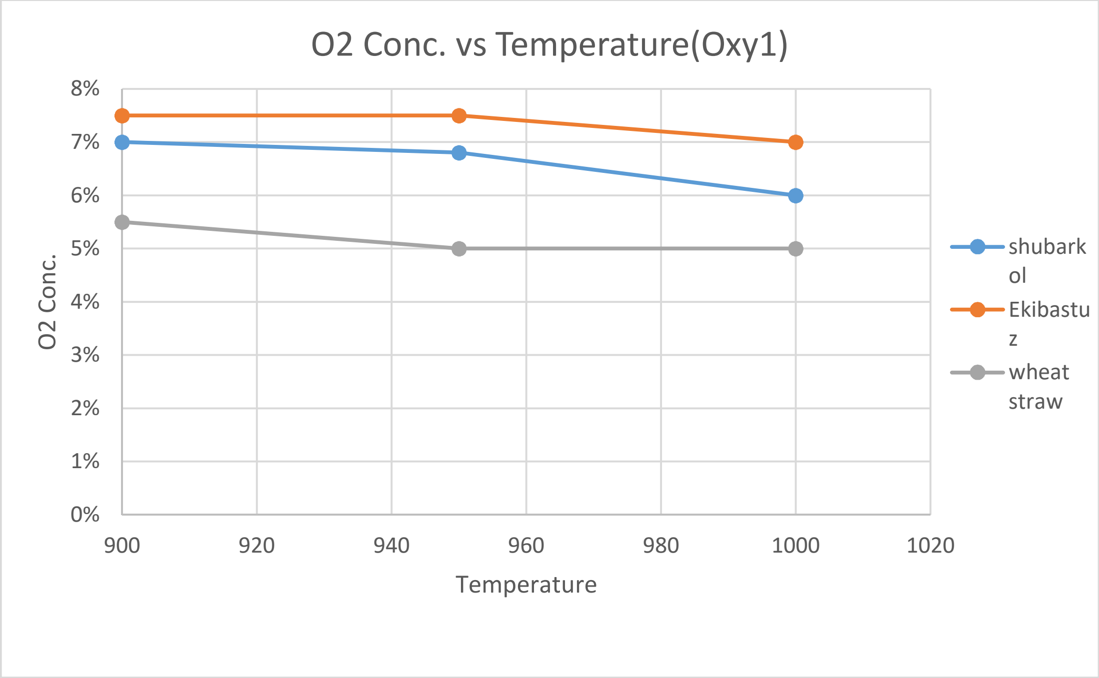


Figure 18*. Oxygen concentration of different coal and biomass at different temperature (oxy-fuel case 1)*

Results reveal that in oxy-fuel combustion settings, oxygen concentrations in the gas analyser change with fuel type and temperature. While the oxygen concentration in Ekibastuz coal remains constant regardless of temperature, it decreases somewhat in Shubarkol coal as the temperature rises. Like Shubarkol coal, the oxygen content of wheat straw decreases as the temperature rises.

Table 6. Oxy –fuel (case 2) (30%O_2 and 70%CO_2)

Oxy 2	900°C	950°C	1000°C
Shubarkol	7%	8%	9.5%
Ekibastuz	10%	11%	12%
Wheat straw	7%	9%	9%

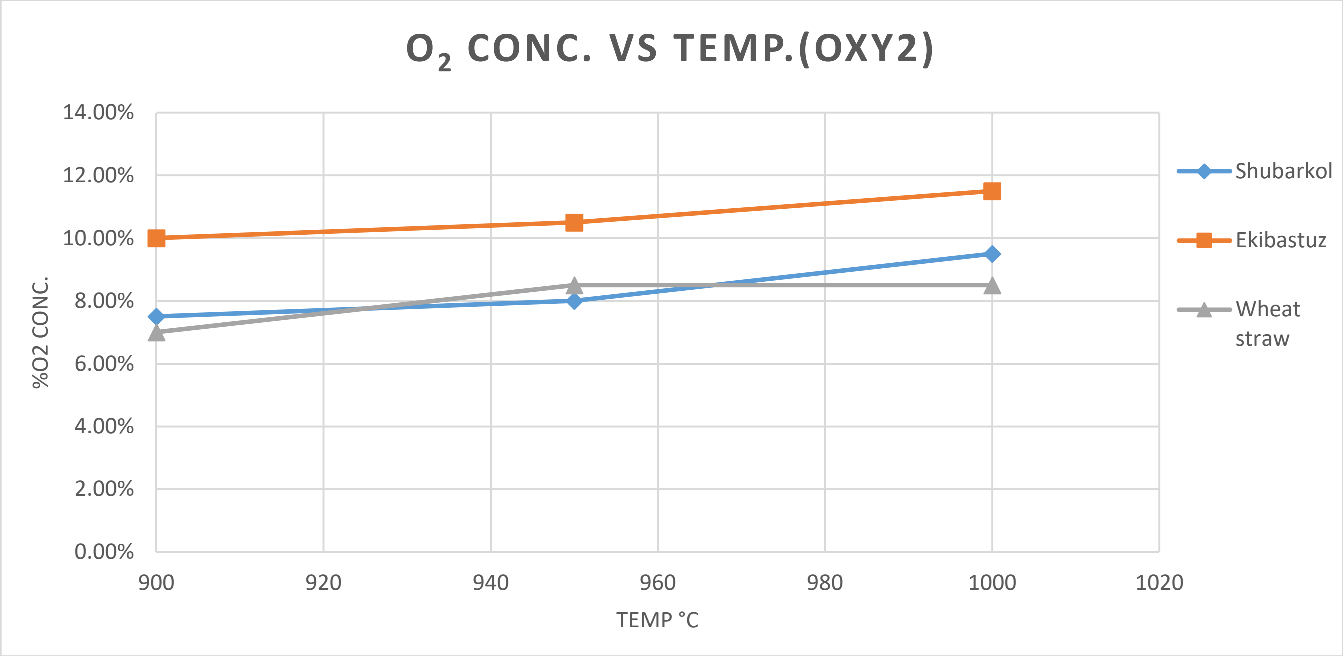


***Figure 19**. Oxygen concentration of different coal and biomass at different temperature (oxy-fuel case 2)*

Gas analyzer results for oxy-fuel combustion with 30% O_2 and 70% CO_2 demonstrate that oxygen concentrations vary for different fuels and temperatures. The gas analyzer shows that the concentration of oxygen in Shubarkol coal, Ekibastuz coal, and wheat straw rises as the temperature rises.The rise in the concentration of oxygen depicts that there is excess oxygen available for combustion. These interpretations enable for a comparison of fuels to be made under situations where oxygen concentrations are held constant at 30% during oxy-fuel burning.

Table 7. Oxy-fuel case 3 (40%O_2 and 60%CO_2)

Oxy 3	900°C	950°C	1000°C
Shubarkol	10.5%	11%	12%
Ekibastuz	12%	13%	13%
Wheat straw	9%	10%	10%

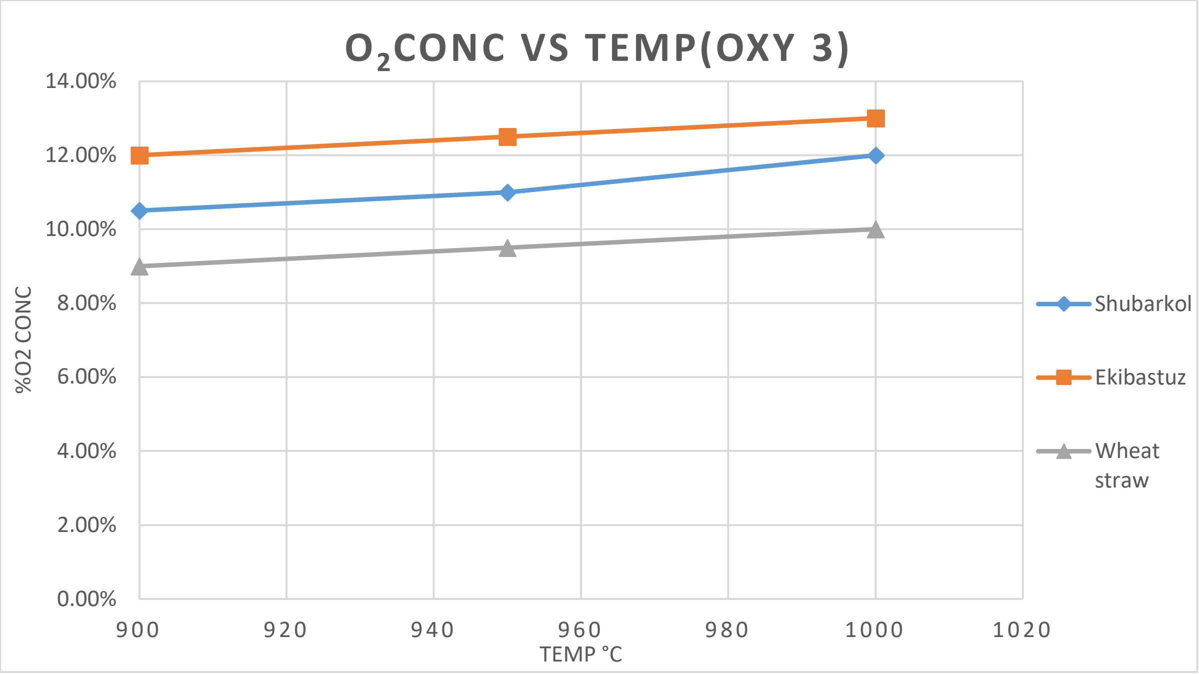


Figure 20. *Oxygen concentration of different coal and biomass at different temperature (oxy-fuel case 3)*

Gas analyzer readings for oxy-fuel combustion with 40% O_2 and 60% CO_2 demonstrate that the oxygen concentration in both Shubarkol coal and Ekibastuz coal rises as the temperature rises. The oxygen concentration in wheat straw increases similarly, though to a lesser extent than in the coal samples. At nearly twice the quantity of oxygen found in air and oxy-fuel, this high oxygen content demonstrates that there is surplus oxygen available for combustion. At 21%, the oxygen content was nearly twice that of air or oxy-fuel. These interpretations shed light on the behavior of oxygen concentrations at various fuels and temperatures during oxy-fuel combustion using 40% O2 and 60% CO_2.

4.2 Combustion Efficiency

Combustion efficiency can be calculated using the following equation.

Combustion efficiency =$1 - [\frac{Ao}{Ai} \times Ci/Co]$ x 100%

Ao and Ai are ash content before and after combustion. Co and Ci represents the carbon content before and after combustion in the DTF.

Table 8. Combustion efficiency in air environment

coal	Shubarkol	Ekibastuz	Wheat straw
Combustion efficiency	91%	86%	100%

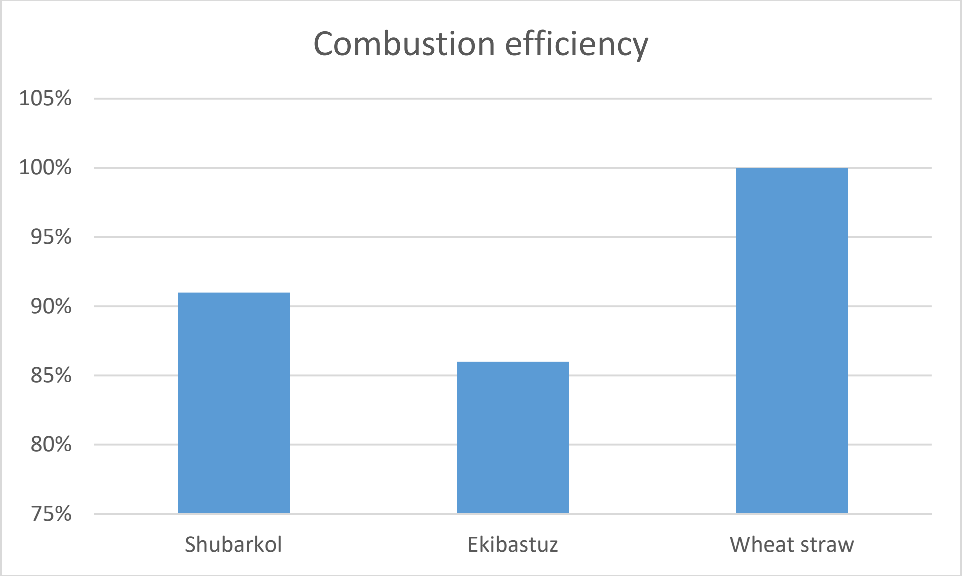


Figure 21. *Combustion efficiencies for fuel*

4.3 General Mass Balance

In the context of experiments involving combustion, "mass balance" refers to the process of taking into consideration both the mass of the fuel and the mass of the products of combustion.

Fuel mass + Air mass = Product mass

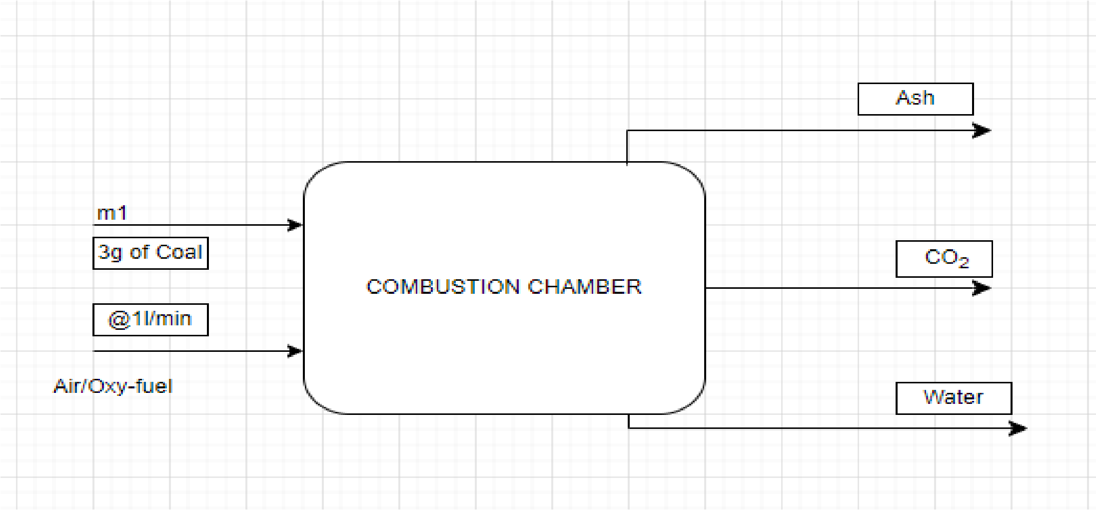
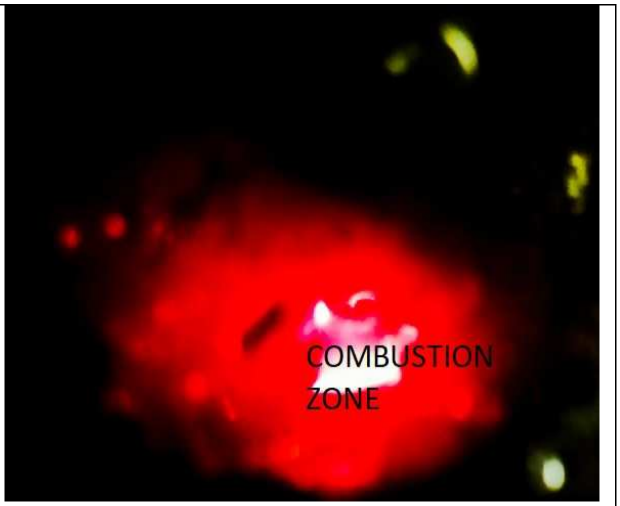


Figure 22. *Mass balance for combustion experiment*

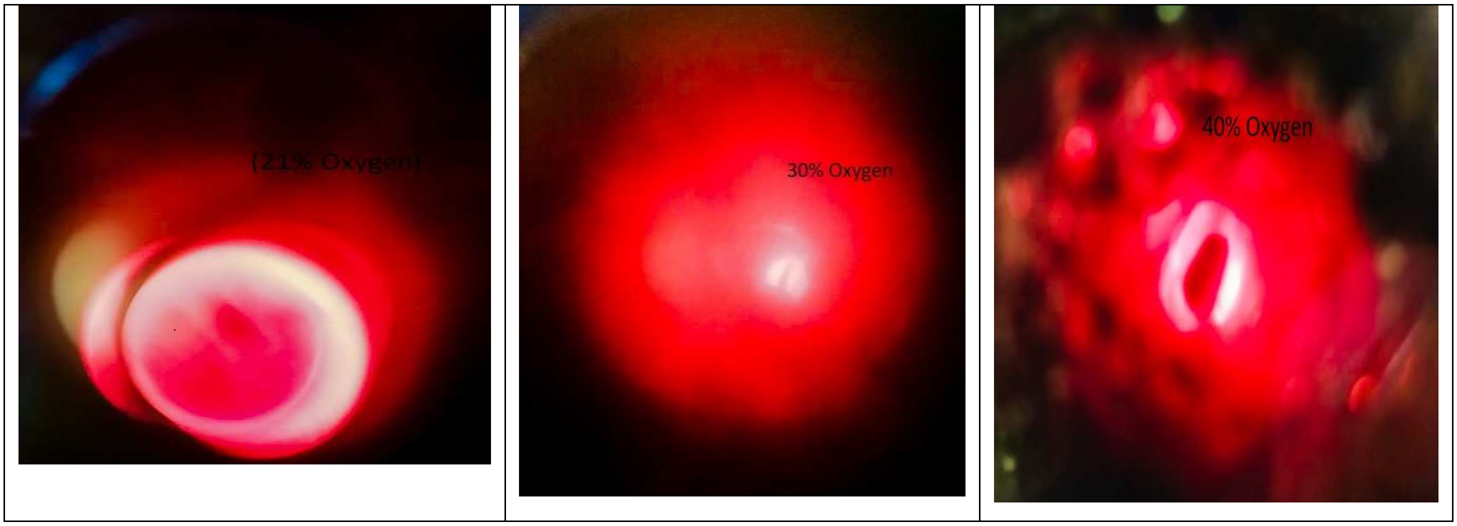
4.4 Images from the Reactor

During the experiment, a high speed camera was used to capture images of flames in the reactor. The pictures clearly show a combustion zone, which is the area where the fuel is being burned. This area seems to be very concentrated, as there is a significant amount of heat present along with active chemical reactions. Within the zone of combustion, flames can be seen flaring up strongly. A variety of colors, including yellow, orange, and blue hues, can be seen in the flames, each of which corresponds to a distinct temperature zone within the flame[29]. Depending on the kind of fuel being burned and the conditions of the combustion, the flames can take on a variety of forms and sizes. Some flames may have a more scattered or concentrated appearance, while others may have the appearance of being more extended.

(a)



(b)



(c) (d) (e)

***Figure 23**. Images showing Combustion of (a) Shubarkol coal in air environment (b) Ekibastuz in air environment (c) Shubarkol in oxy-fuel (21% $O_2$79%CO_2) (d) Shubarkol in oxy-fuel(30%O_2, 70%C O_2) (e) Shubarkol in oxy-fuel(40% O_2 and 60%C O_2).*

Description

The flame structure and heat release characteristics of Shubarkol coal combustion with air and combustion with oxy-fuel are quite diverse from one another, respectively. In combustion processes that use air, the flames typically take on a more tumultuous and extended appearance. The availability of air oxygen is the primary factor that drives the combustion process, which results in a heat release that is generally more gradual and less intense[30]. The flames have a color that is somewhere between yellow and orange, which suggests that the combustion process was not fully completed and that carbonaceous particles were present.

On the other hand, when Shubarkol coal is burned in an oxy-fuel combustion with a mixture of 21% oxygen and 79% carbon dioxide, the structure of the flame goes through substantial transformations. The presence of a greater concentration of oxygen results in a combustion process that is both more precisely controlled and more intense. The flames are turning a bluish color and become shorter as they become more focused. This suggests better usage of the fuel as well as a higher temperature of combustion[31]. When compared to burning with air, oxy-fuel combustion results in a significantly larger release of heat. Because of the increased oxygen content, there is a promotion of a more effective oxidation of the fuel, which leads to a higher flame temperature and increased heat output. A more intense glow can be seen emanating from the combustion zone, which is indicative of the production of considerable amounts of heat radiation[34]. This increased heat release is beneficial for a variety of industrial applications that need high-temperature operations, such as power generation and industrial heating. These applications include industrial heating.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The TGA analysis of Shurbakol coal, Ekibastuz coal, and wheat straw provides valuable information about the thermal stability and behavior of these materials. The operating parameters used in this methodology (temperature range, heating rate, and nitrogen atmosphere) ensure reproducible results and reliable data analysis. The results of TGA analysis can be used to optimize the processing conditions and design of energy conversion systems based on these materials.

To sum up, the TGA and DTG investigations of wheat straw, Ekibastuz coal, and Shubarkol coal reveal important details about their thermal stability and breakdown traits. Several weight loss stages that correspond to various types of reactions taking place in the samples define the thermal degradation of these materials. Compared to Ekibastuz coal, Shubarkol coal includes a significant proportion of volatile stuff. Contrarily, wheat straw has a disproportionately high level of volatile matter, making it a possible renewable energy source. To completely assess the potential of wheat straw as a solid fuel source, more investigation is required. Overall, the TGA and DTGA investigations provide considerable understandings of these materials' thermal behavior, which can be in various applications.

In summary, the combustion tests that were carried out in the Drop Tube Furnace (DTF) utilizing various solid fuels, such as Shubarkol coal, Ekibastuz coal, and wheat straw, provided useful insights into the behavior of combustion and its efficiency under a variety of different settings. The examination of the experimental data and observations led to the discovery of important facts that add to our knowledge of oxy-fuel combustion and the possible uses of this process. In the first step of the process, an analysis of the combustion efficiency of solid fuels in compressed air was carried out. According to the findings, the efficiency of the combustion changed depending on the temperature and the kind of fuel used. Across the temperature range, the Shubarkol coal demonstrated a combustion efficiency that was marginally superior to that of the Ekibastuz coal and the wheat straw. This lends credence to the idea that Shubarkol coal possesses superior combustion properties in terms of achieving full fuel utilization.

In addition, the utilization of oxy-fuel combustion with a mixture of 21% O_2 and 79% CO_2 produced encouraging outcomes. All three solid fuels saw improvements in their efficiency of burning when increased oxygen concentrations were present in the environment. The increased reactivity and use of the fuel can be inferred from the fact that the combustion efficiency improved alongside the rise in oxygen concentration.

The data from the gas analyzer were analyzed, and the results revealed some very helpful insights on the make-up of the combustion products. Indicators of the completion of the combustion and the degree to which the fuel was utilized were found in the gas analyzer in the proportions of CO_2 and O_2. According to the findings, an increase in temperature was accompanied by a rise in concentrations of both CO_2 and O_2; however, concentrations of O_2 dropped. This pattern is anticipated given that greater temperatures encourage more thorough combustion as well as the oxidation of fuel.

On the basis of the results of the tests involving combustion, the following suggestions and recommendations for areas of investigation and development in the future can be made:

1. Additional research into the factors that are unique to the fuel: the characteristics of the combustion products of various solid fuels might vary greatly. It is advised that fuel-specific factors including moisture content, volatile matter, and particle size distribution be investigated in order to understand the impact that these parameters have on the efficiency of combustion and the emissions that are produced.
2. In order to optimize the conditions for oxy-fuel combustion, the experiments were conducted with a constant oxygen content of 21%. In further investigations, the effects of varying O2 concentrations and CO2 dilution ratios on the efficiency of combustion can be investigated.

This would provide insights into the best conditions for obtaining improved combustion efficiency while simultaneously reducing emissions.

3. A comprehensive examination of the byproducts of combustion The accurate characterization of the byproducts of combustion, which may include particulate matter, trace elements, and contaminants, is essential for determining the effect that the combustion of solid fuel has on the environment. In subsequent research, the main focus ought to be on conducting exhaustive analyses of these byproducts in order to devise methods of emission management and mitigation.
4. The ash composition of solid fuels has important implications for both the efficiency of combustion and the disposal of ash. The behavior and utilization of ash need to be evaluated. In subsequent study, the behavior of ash during combustion can be investigated, and potential use options, such as recycling ash for useful purposes, can be investigated for their viability.

The findings from DTF studies provide vital insights into lab-scale combustion, which will be useful when scaling up to industrial applications. The application of these findings to industrial-scale oxy-fuel combustion systems in order to evaluate their practicability, efficiency, and emissions under real-world settings is a potential focus for further research in the future.

As a conclusion, the combustion tests that were conducted in the DTF provided useful insights into the behavior of solid fuels during combustion as well as the potential of oxy-fuel combustion. The findings make a contribution to the existing body of information regarding the efficiency of combustion, emissions, and fuel use. Future research has the potential to significantly improve our understanding of solid fuel combustion by addressing the recommendations described above. This might also contribute to the development of combustion technologies that are cleaner and more efficient, as well as to the creation of energy solutions that are sustainable.

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APPENDIX

Moisture content of Ekibastuz coal

Weight of empty crucible 1 – 17.274g

Weight of empty crucible 2 – 16.168g

Sample in crucible 1 – 1.024g

Sample in crucible 2 – 1.025g

Total weight of crucible 1 and sample – 17.274 +1.024 =18.298g

Total weight of crucible 2 and sample – 16.168 + 1.025 = 17.193g

After heating up to 105 degrees

Weight of crucible 1 + sample = 18.285g

Weight of crucible 2 + sample = 17.178g

Calculations

$\frac{m2-m3}{m2-m1} \times 100$ = Moisture content

m1 mass in grams of empty dish

m2 is the mass of dish plus test portion before heating

m3 is the mass in grams of dish plus sample after heating

Sample 1

$\frac{18.298-18.285}{18.298-17.274} \times 100$ = 1.27%

Sample 2

$\frac{17.193-17.178}{17.193-16.168} \times 100$ = 1.46%

(1.46 + 1.27)/2 = 2.73/2 = 1.365%

Ash Content

Weight of crucible 1 – 36.304g

Weight if crucible 2 – 39.364g

Coal sample in 1 – 1.003g

Coal sample in – 1.034g

Total weight of crucible 1 + sample = 37.304g

Total weight of crucible 2 + sample = 40.398g

After heating to 550±20

Weight plus sample in 1 =36.630 g

Weight plus sample in 2 = 39.772g

m2 mass of dish plus test sample

m3 mass of dish plus ash (after heating)

Calculations

Ash content = $\frac{m3-m1}{m2-m1} \times 100 \ \times 100/(100 - moisture\ content)$

Sample 1

= $\frac{36.630-36.301}{37.304-36.301} \times 100 \ \times 100/(100 - 1.365)$

= 32.25%

Sample 2

= $\frac{39.772-39.364}{40.398-39.394} \times 100 \ \times 100/(100 - 1.365)$

= 40%

Average = 40+32.25 =72.25/2 = 36.125%

Shubarkol Coal

Moisture content

Weight of crucible 1 = 36.288g

Weight of crucible 2 = 39.358g

Weight of sample in 1 = 1.009g

Weight of sample in 2 = 1.002g

Total weight of crucible 1 +sample = 37.297g

Total weight of crucible 2 + sample = 40.36g

After heating up to 105 degrees

Weight of sample + crucible 1 = 37.268g

Weight of sample + crucible 2 = 40.343g

Calculation

Sample 1

$\frac{37.29-37.268}{37.29-36.288} \times 100$ = 2.19%

Sample 2

$\frac{40.367-40.343}{40.367-39.358} \times 100$ = 2.18%

(2.18+2.19)/2 = 2.185%

Ash content

Weight of crucible 1 = 16.165g

Weight of crucible 2 = 17.268g

Weight of sample in 1 = 1.008g

Weight of sample in 2 = 1.006g

Total weight of crucible 1 +sample = 17.173g

Total weight of crucible 2 + sample = 18.274g

After heating up to 550+-20 degrees

Weight of sample + crucible 1 = 16.639g

Weight of sample + crucible 2 = 17.767g

WHEAT STRAW

Moisture content.

Weight of crucible 1 = 43.686g

Weight of crucible 2 = 77.372g

Weight of sample in 1 = 1.003g

Weight of sample in 2 = 1.011g

Total weight of crucible 1 +sample = 44.689g

Total weight of crucible 2 + sample = 78.383g

After heating up to 105 degrees

Weight of sample + crucible 1 = 44.657g

Weight of sample + crucible 2 = 78.353g

$$\frac{78.383-78.353}{77.383-77.373} \times 100 = 2.97\%$$

(2.97+3.19)/2 = 3.08%

$\frac{37.29-37.268}{37.29-36.288} \times 100$ = 3.19%

Ash content

Weight of crucible 1 = 106.451g

Weight of crucible 2 = 113.320g

Weight of sample in 1 = 1.017g

Weight of sample in 2 = 1.009g

Total weight of crucible 1 +sample = 107.468g

Total weight of crucible 2 + sample = 114.329g

After heating up to 550+-20 degrees

Weight of sample + crucible 1 = 106.526g

Weight of sample + crucible 2 = 113.389g

Ash content = $\frac{106.526-106.451}{107.468-106.451} \times 100 \ \times 100/(100-3.08)$

= 7.61%

Ash content = $\frac{113.389-113.320}{114.329-113.320} \times 100 \ \times 100/(100-3.08\ )$

=7.05%

Average = 7.33%

Bomb calorimeter experiment for Shurbakol coal.

Weight of empty crucible -17.628g

Weight of coal – 1.002g

Calorific value of copper wire -2510kj/kg

Distilled water < 25 degrees

Particle size – 100-315 microns

When coal is burned in oxygen, its calorific value, or quantity of energy produced per unit weight of coal, is calculated. In a bomb calorimeter, a measured sample of coal is totally burned.

Calorific Value of Shubarkol coal = 29094.10kj/kg

Calorific value of Ekibastuz coal = 19371.95kj/kg

Proximate analysis and ultimate analysis for wheat straw

Proximate Analysis (wt. %)	
Moisture	3.08
Fixed carbon	11.90
Volatile matter	77.69
Ash content	7.33
Ultimate Analysis (wt. %)	
Ash	7.33
Carbon	49.5
Hydrogen	6.2
Nitrogen	0.6
Sulphur	0.2
Oxygen	36.17