POWER GENERATION FROM RICE HUSK

A Thesis by

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POWER GENERATION FROM RICE HUSK

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<u>CERTIFICATE OF RESEARCH</u>

*This thesis titled "**POWER GENERATION FROM RICE HUSK**" submitted by **AHMED IMTIAZ ANANDO (170011016)** has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical Engineering.*

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Declaration

I hereby declare that this thesis entitled "***POWER GENERATION FROM RICE HUSK***" is an authentic report of study carried out as requirement for the award of degree B.Sc. in (Mechanical Engineering) at Islamic University of Technology, Gazipur, Dhaka under the supervision of Dr. Mohammad Monjurul Ehsan, Associate Professor, MPE, IUT in the year 2022

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

AHMED IMTIAZ ANANDO

170011016

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ABSTRACT

The alarming rate at which the deposit of non-renewable or fossil energy resources are depleting around the whole world has been nudging us in the direction of green energy for quite a long time. Considering the upcoming energy crisis in the near future, we have no choice but to divert our focus on renewable energy resources to meet the power demand of an ever-growing global population and industry. Rice husk is a by-product of producing rice from paddy which is consisted of about 20% mass percentage of rice. It is a biomass with low energy density and low bulk density. Due to these properties, it is not efficient or viable to directly combust rice husk as a fuel. In order to improve the fuel characteristics of rice husk and convert it into a coal-like fuel, different thermochemical pretreatment technologies can be implemented. Previously, there have been many studies and researches on pretreatments of rice husk. Most of these studies were experimental. This paper reviews four of the most common of such technologies namely, gasification, torrefaction, pyrolysis and hydrothermal carbonization including multiple sub-categories of each technology. All of these processes are successful in improving the fuel characteristics of rice husk such as higher heating value or calorific value, moisture content, fixed carbon, etc. The second section of the thesis covers the field of power generation using the pretreated rice husk samples as fuels. For the simulation, Recompressed Supercritical CO_2 Brayton Cycle with Reheating was chosen. A basic comparison among different pretreatments was shown in terms of power output from the cycle when rice husk undergone corresponding pretreatments was used as fuel for the heat input. The economic and exergy analysis of the thermochemical processes were out of the scope of this thesis thus, this study only focuses on the energy analysis of producing power from rice husk. The results found out of the study shows that each of the thermochemical processes has its own advantages and serves the goal, which is to improve the fuel properties of rice husk. Further investigation on other aspects can help the community understand which process will be better suited for a particular purpose.

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LIST OF ABBREVIATIONS

HHV	Higher heating value
ASTM	American Standard
LHV	Low heating value
IGCC	Integrated gasification combined cycle
BGPG	Biogas gasification and power generation
LCA	Life cycle analysis
GHG	Green-house gas
HTC	Hydrothermal carbonization
m_i	the mass of raw biomass
C_{pw}	the specific heat of as-received biomass
T_0	the ambient temperature
h_{upd}	the heat utilization efficiency factor
L	the latent heat of vaporization of water at reaction pressure
M_f	the moisture fraction of the as-received biomass
C_{pd}	the specific heat of the dry biomass
T_t	the torrefaction temperature
$h_{u,pdh}$	the heat utilization efficiency of the post-drying section
H_{loss}	the heat loss to the environment parameter describing the amount of
X_t	heat absorbed during torrefaction
M_{Ydb}	the mass yield after torrefaction on a dry basis
C_{pt}	the specific heat of torrefied biomass
T_p	the temperature of the products leaving the cooling stage

CHAPTER ONE

INTRODUCTION

Rice is the second most vital food crop right after wheat. In Asia, 60-70% of calories required for more than two billion people, is provided by rice [1]. Nevertheless, this crop is grown immensely all around the world. Reported by the United States Department of Agriculture in 2021, the global rice production was 697.7 million tons which is one of the highest in the recent times [2]. The major rice producing countries include China, Bangladesh, Indonesia, India, Vietnam and Thailand [3]. Estimation shows that from every ton of rice harvested, we get about 0.20-0.33 tons of rice husk [4]. In other words, rice husk accounts for 20-33% weight percentage of rice. Which means that in 2021, about 139.54-230.24 million tons of rice husk was produced worldwide as a solid biomass. The most common practice especially in Bangladesh and India is to parboil the rice followed by dehusking. However, research states that removing the husk prior to parboiling reduces 40% of the energy required for parboiling [5]. The majority of produced rice husk is either burnt or used as fuel for parboiling and cooking.

Open combustion of rice husk is detrimental to the environment. This combustion emits a significant amount of harmful particles such as polycyclic aromatic hydrocarbons and dioxins along with gases like CO, CO_2, NO_x and SO_2 [4], [6]. Apart from emissions, rice husk is not suitable as feedstock either due to high silica, lignin, ash content and low nutrient [7], [8]. Because of these characteristics of rice husk, many countries have put rice husk to use as biofuel in the last couple of decades. Thailand, India and Malaysia have implemented technology of power generation from rice husk [9], [10]. Extensive research and studies have been conducted for turning rice husk to value-added products such as briquettes, bioethanol, biogas, biochar, activated carbons, catalysts, geopolymers, cement, etc. [11]–[18].

Since raw rice husk do not have good fuel characteristics, converting raw rice husk to coal-like biofuel and increasing its higher heating value (HHV) through various thermochemical pretreatments have been attempted and recorded as well as comparison between different pretreatments of rice husk in various aspects [19]–[33] This paper discusses in detail some known thermochemical pretreatment processes of rice husk namely; gasification, torrefaction, pyrolysis and hydrothermal carbonization including some sub-categories of each process. The discussion is done based on studies and researches on these processes all around the world. The aim of this review paper is to summarize important information and data regarding upgradation of rice husk for future use, making it easier to find for anyone looking for these facts and saving the trouble of collecting information from several sources.

The section following the review of the thermochemical processes presents a simulation of a power cycle run by the energy gained from the combustion of rice husk undergoing different pretreatments. The power cycle chosen for the simulation was Recompressed Supercritical CO_2 Brayton cycle with Reheat. The coding for the simulation was done on Python and was validated by comparing previous similar works [34]–[36]. For calculation, required assumptions were made based on available data and the need for simplification.

Proximate analysis of raw rice husk originating in different countries have been given in *Table 1*. All the analysis was carried out by ASTM standard methods that is accepted in fuel industries globally. Calorific value was determined using bomb calorimeter in most of the cases.

Table 1: Raw rice husk proximate analysis

Properties	Bangladesh [23], [37], [38]	India [39]–[41]	Malaysia [42]–[44]	China [45]–[47]	Thailand [48], [49]
Higher Heating Value (HHV) (MJ/kg)	16.30 – 16.70	13.10 – 13.35	15.49 – 17.90	15.30 – 16.25	14.98 – 16.80
Water content (wt%)	6.98 – 12.4	7.12 – 7.90	5.56 – 6.70	6.86 – 8.69	8.30 – 10.30
Volatile matter (wt%, dry basis)	62.84 – 79.52	55.85 – 60.20	55.90 – 57.55	59.44 – 73.50	55.60 – 69.30

Fixed carbon (wt%, dry basis)	15.09 – 18.10	15.24 – 19.50	20.30 – 22.21	14.70 – 16.30	16.80 – 20.10
Ash content (wt%, dry basis)	12.69 – 22.07	13.10 – 23.50	14.16 – 17.10	11.40 – 17.00	13.90 – 14.00

The scope of the study was only limited to the technical feasibility of thermochemical pretreatments of rice husk. The economic or environmental effect of such pretreatments were out of the scope of the study and thus, not discussed in this thesis project. However, it can be confidently said that this research lays an important base for further investigation on rice husk and the improvement of fuel properties of rice husk through various conversion technologies. The simulation and power generation part also plays significant role in helping the community get a basic concept on the potential of rice husk as a biomass and source of power generation. This research also summarizes different studies previously done on rice husk that can be considered as a groundwork for future studies without the need to collect and analyze so many information from different sources.

The report is divided into five chapters. This first chapter is followed by literature review where various key aspects are discussed from many sources. The third chapter is the methodology that describes the steps undertaken for completion of the study which is followed by the results and comparative analysis. Finally, the conclusion briefly overviewing the complete report.

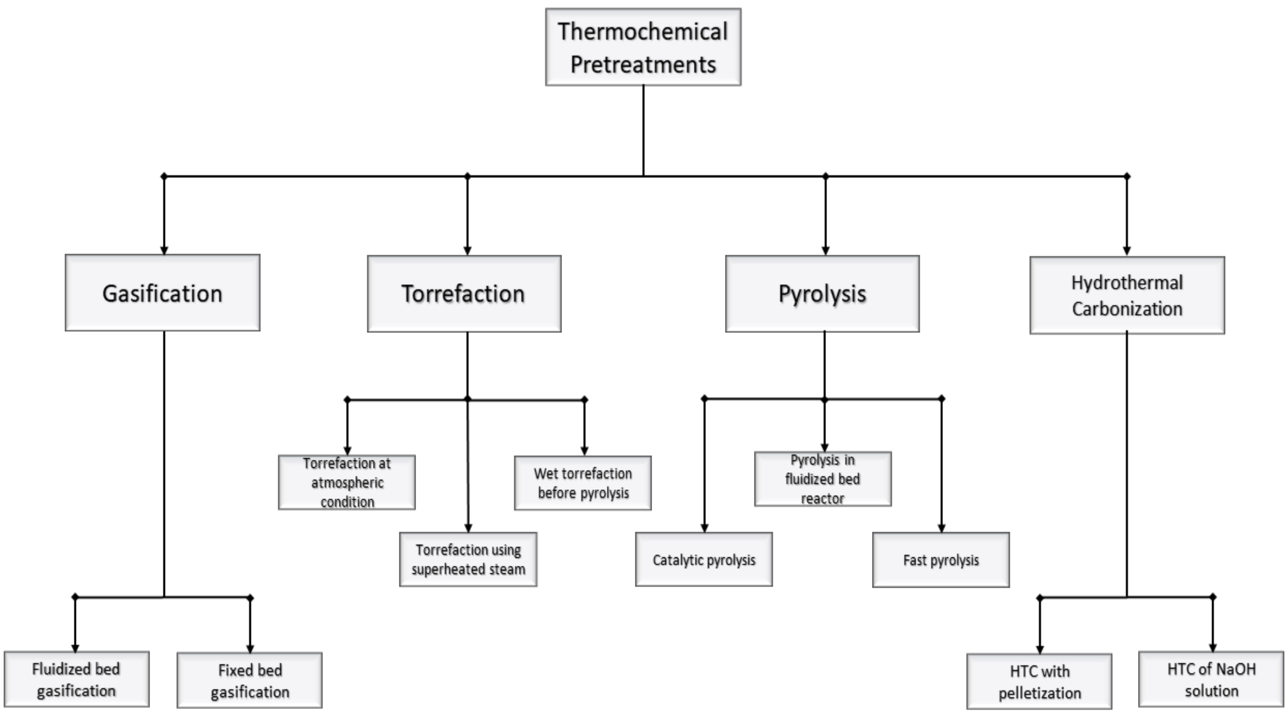

Figure 2.1.1: Summary of the thermochemical processes discussed

CHAPTER TWO

LITERATURE REVIEW

2.1 GASIFICATION

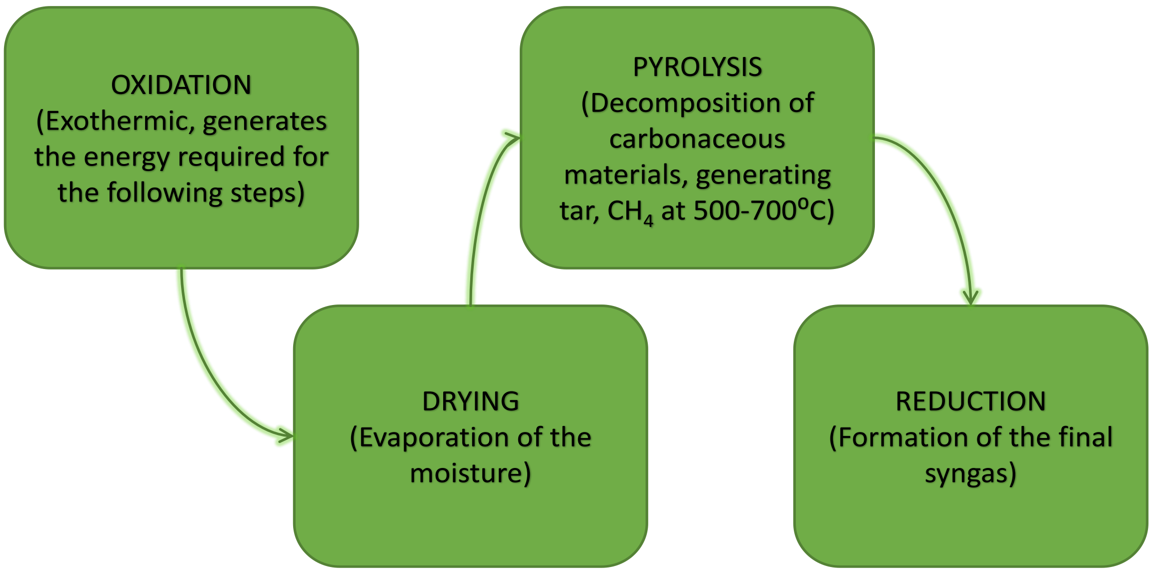

Figure 2.1.1: Flow chart of Gasification process steps

Gasification is a process that converts biomass- or fossil fuel-based carbonaceous materials into gases, including as the largest fractions: nitrogen (N), carbon monoxide (CO), hydrogen (H), and carbon dioxide (CO_2). Gasification using different types of gasifiers is a common pretreatment of rice husk. It is one of the most mainstream options to producing electricity from different biomass. Several studies on how to increase the low heating value (LHV) and decrease the tar content of the syngas derived from biomass have been conducted throughout the years. One of the most effective ways of achieving this goal was found to be air staged gasification [50]. The key factors of gasification are higher gasification efficiency, lower quantity of dust and tar. The only exothermic reaction in gasification process is the first one; oxidation, which produces the energy that will be required for the next endothermic reactions.

2.1.1 Fluidized Bed Gasification

The largest complete biogas powerplant in Asia, as of 2008, is located in Xinghua, Jiangsu Province, China. It uses rice husk as well as other bio wastes for power. This plant utilizes biomass integrated gasification combined cycle (IGCC) technology. IGCC can be considered as a very promising way of improving biogas gasification and power generation (BGPG) [51], [52]. IGCC technology including a hot-gas-cleaning device, high-pressure gasifier and gas turbine is an advanced power generation technology for large-scale application. This technology has been proven to be at least 40% efficient within the range of 30-40 MW [53], [54]. The key advantages of this technology are fuel flexibility, isothermal operating condition and low operating temperature.

Fluidized bed has about 7.5 times higher combustion intensity than other grate type furnaces [55]. The combustion efficiency, which is the ratio of actual heat released in the combustor over the chemical energy of the fuel, is normally around 80% for such combustors. But an efficiency within the range of 81-98% is reported by Bhattacharya et al. [56]. However, different studies have shown the efficiency to be higher than 95%, which is a result of controlled small-scale gasification [55]. Temperature range of fluidized bed gasification is from 700 °C to 1000 °C and with the increase of temperature, gas productivity also improves from 1.85 to 2.5 Nm^3 [55]. Reports have been made with varying heating value of the producer gas from rice husk between 5-8 MJ/Nm^3 and 4.5-6 MJ/Nm^3 [55] so it safe to assume 5-6 MJ/Nm^3 to be an average heating value of producer gas. Downdraft gasifiers have proven to achieve about 50-60% of cold gas efficiency whereas fluidized bed gasifiers can achieve cold gas efficiency over 60% with 90% carbon conversion efficiency [55]. Nataranjan et al. conducted a research on gasification of rice husk on fluidized bed reactor that resulted in a combustible gas with a heating value of 4-6 MJ/Nm^3, which is slightly higher than that of syngas from gasification of rice husk on a downdraft fixed-bed gasifier [55].

2.1.2 Fixed Bed Gasification

Among the two types of fixed-bed gasifier, downdraft fixed-bed gasifier has proven to generate less tar [57]–[59]. A bench-scale gasification of rice husk and rice husk pellet was performed in 2012. The capacity was 1.5 tons per day. This experiment showed that the heating value of the syngas from rice husk pellet gasification was 1314 kcal/Nm^3 whereas the heating value of the syngas from rice husk gasification was 1084 kcal/Nm^3 [60]. This means that the fuel properties of

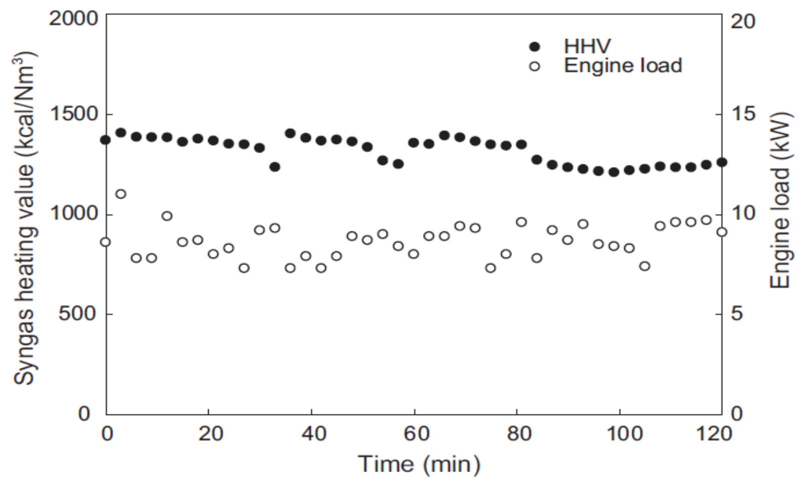

Figure 2.1.2: Power generation from synthetic gas produced by gasification of rice husk pellet

rice husk can be further improved when gasified in form of pellets. This conforms to previous studies done on small-scale gasification of rice husk. Literature on updraft gasification of rice husk strengthens the claim that downdraft fixed-bed gasifier generates less tar. This research further delved into power generation from the syngas produced from gasifying rice husk by generating stable 8-10kW electricity using CD800L reciprocating engine. The graph below shows the power generation capacity using the biofuel produced through rice husk pellet gasification [60]

A lab-scale experiment was also done in Bangladesh very recently. Rice husk was preheated in an oven for 5-7 hours and 105–115 °C. The pretreated rice husk had 10% moisture content which was enough for gasification. It took 1.38 hours for gasification of 5kg rice husk at a temperature range of 650–810 °C. The temperature of the syngas at the outlet varied from 157 °C to 178 °C. The lower heating value (LHV) of the syngas generated from rice husk gasification was 933.6 kcal/Nm^3, with a 60% cold gas efficiency. The composition and the LHV of the syngas was found to be in agreement with the study mentioned above and the fuel cost of gasification of per kg rice husk was 5.45$ [37]. The study also claimed that a large-scale rice husk gasification plant can be operated with a larger feed rate of around 50 kg/h, compared to 3.6 kg/h, by using the same gasifier mechanism. It is estimated that medium-sized mills have the capacity to produce 171 MW electricity given that there are 540 rice mills operating in Bangladesh generating 30 tons of rice husk on average on a daily basis [37]. Another study suggests that Bangladesh has the potential of meeting a demand of 300 MW of power from rice husk gasification plants, considering 2 kg rice husk consumption for each unit electricity generation [23].

2.2 TORREFACTION

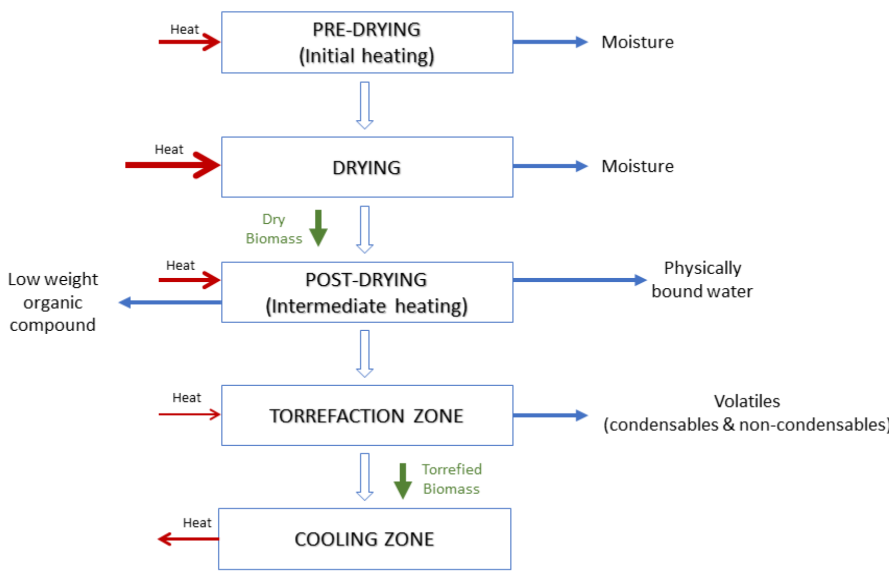

Figure 2.1.1: Steps flowchart of Torrefaction process

Torrefaction is a thermal treatment of lignocellulosic waste biomass at low temperature which improves the fuel properties of solid biomass such as energy density and longer shelf life and turns the biomass into useful feedstock for further thermal treatments like gasification [61]. Torrefaction decreases the ash content and oxygen carbon ratio of biomass and improves properties corresponding to energy conversion techniques such as combustion, co-combustion with coal or gasification [61]. Torrefied biomass also ignites quicker than raw biomass. Up to 96% energy content of the raw biomass can be retained in torrefied biomass. Torrefaction increases the heating value of the biomass while also removing a significant amount of moisture from it.

Table 2: Heat equations for different stages of torrefaction [62]

Stage	Pre-drying	$\text{Qpd} = \frac{\text{m}_\text{i}\text{C}_\text{Pw}(100 - \text{T}_0)}{h_{upd}}$
	Drying	$Q_d = \frac{LM_f m_i}{h_{ud}}$
	Post-drying	$\text{Qpdh} = \frac{\text{m}_\text{i}(1 - \text{M}_\text{f}) \times \text{C}_\text{pd}(\text{T}_\text{t} - 100)}{h_{u,p\,dh}}$
	Torrefaction	$Q_{torr} = H_{loss} + m_i(1 - M_f)X_t$
	Cooling	$Q_{cool} = m_i(1 - M_f)M_{ydb}C_{pt}(T_t - T_p)$

2.2.1 Torrefaction at Atmospheric Condition

Ahiduzzaman et al. conducted a study on torrefaction of rice husk at inert atmosphere, at different torrefaction temperature and residence time [61]. The results were increased mass and energy yield as well as increased calorific value. The amount of increment varied with torrefaction temperature and residence time. The study revealed decreased volatile content and increased fixed carbon with the increase of temperature which confirms the similar findings, in case of bamboo, made by Sridhar et al. Same findings were also reported by Almeida et al. Lowest volatile matter was found to be 24.68% at 300 °C and 30 minutes of residence time. At the same time, highest fixed carbon was 32.58% which is almost twice as the fixed carbon of raw biomass (15.09%) [61]. An increase in ash content has also been seen from 22.07% to 42.74% [63].

Effect of torrefaction on mass yield was also quite significant. Mass yield is the ratio of mass after torrefaction and mass of the original sample. Unlike carbon content or volatile matter, mass yield was the lowest at 300 °C and 30 minutes of residence time with only 50%. The highest mass yield was 90% and was achieved with 10 minutes of torrefaction at 200 °C temperature [61].

This can be interpreted in terms of mass loss with increased torrefaction residence time and temperature. Similar results have also been reported previously [63], [64].

Generally, calorific value increases with higher temperature and longer residence time [63], [65], [66]. However, this is not the case with rice husk. The calorific value increases at higher

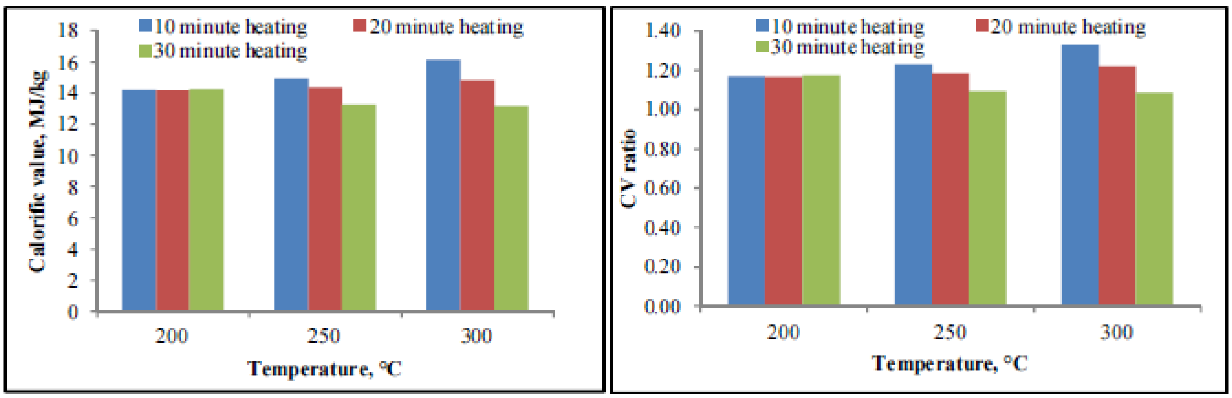

Figure 2.2.2: Calorific value (left) and value ratio (right) of raw and torrefied rice husk at varying temperature and residence time

temperature but shorter residence time and the highest calorific value was 16 MJ/kg at 300 °C and 10 minutes heating duration [61]. Torrefied rice husk has a hydrophobic nature which is proven by moisture removal during torrefaction. The moisture content of raw rice husk decreased from 9.07% to the lowest 1.46% at 300 °C and 30 minutes and the highest 2.81% at 200 °C and 10 minutes of torrefaction [61].

The key factor that defines fuel quality is the energy yield. It is defined as the product of mass yield and calorific value. Energy yield of torrefied rice husk ranges from 55% to 105% and is inversely proportional to temperature and residence time [61]. More than 100% energy yield has been observed after torrefaction at 200 °C for 10, 20 and 30 minutes of duration. This is an indication of the removal moisture and non-energy volatile content during the process. In terms of energy yield only, the most optimum torrefaction parameters are 200 °C and 10 minutes. The relation of temperature and residence time with energy yield has been confirmed by other studies as well [67]. Considering the effect of temperature and residence time on all the factors, the calorific value shows a more complex behavior than the other factors. For better calorific value and energy yield, the best option would be torrefaction of rice husk at 200 °C and for 10 minutes.

This will result in a 105.3% energy yield and 90% mass yield although a slightly lower calorific value ratio of 1.08 [61]. It is also noteworthy that torrefaction at static air pose very insignificant harm to the environment and the flue gas of torrefaction contains 7-8% of oxygen which makes the flue gas viable as a torrefaction media when supplied to the reactor directly [61].

2.2.2 Torrefaction Using Superheated Steam

Study has been done on torrefaction of rice husk in superheated steam tester in Myanmar [68]. The tester had two layers of heating zones and one layer on cooling zones. The temperature of the layers varied from 300 °C to 600 °C. The experiment included torrefaction at three different temperature (150, 180 and 250 °C) for the same duration, 45 minutes. The result varied in the solid mass residue also called mass yield. The standard mass yield or solid mass residue was set to be 80% and the parameters were changed during the process to meet the minimum mass residue standard. The mass residual rate was the highest (87.18%) at 140.1 °C and the lowest (51.07%) at 234.4 °C [68]. Heat retention rate or calorific value ratio was also 90.2% after torrefaction at 140.1 °C. Energy loss was the highest in case of torrefaction at 234.4 °C [68]. With the increase of temperature, an increase in the ratio of the pyrolysis gas's energy to the energy of the solid residue was observed. Although, the low heating value or LHV of the torrefied rice husk was the highest after torrefaction at 234.4 °C which was 17.2 MJ/kg. This was almost 1.16 times the LHV of raw rice husk.

The composition of rice husk was also affected by torrefaction and the effect varied with varying temperature. This observation was somewhat complex. At 234.4 °C, the fixed carbon content increased to 41.7% which is 16.8% in raw biomass [68]. However, ash content also increased side by side from 19.7% to 39%. Carbon content is good for efficient combustion while ash content inhibits combustion. Moreover, volatile matter also decreased at higher temperature from 63.5% to 19.3%.

Table 3: Summary of results obtained from torrefaction using superheated steam at varying temperature [68]

Parameters	Raw rice husk	Torrefied rice husk		
		234.4 °C	176.3 °C	140.1 °C
Ash (%)	19.7	39	26.7	22.5
Moisture content (%)	9.09	7.15	5.67	5.65
Volatile content (%)	63.5	19.3	48.5	57.6
Fixed Carbon	16.8	41.7	24.8	19.9
High heating value (MJ/kg)	15.94	17.65	16.68	16.36
Low heating value (MJ/kg)	14.84	17.2	15.78	15.35

From *Table 3*, it can be said that torrefaction at 234.4 °C increases carbon content, which improves calorific value, but also increases ash content while decreasing mass residue. When torrefied at 140.1 °C, heat retention and solid mass residue was increased significantly. But the LHV was a little less with 15.35 MJ/kg compared to torrefaction at 234.4 °C which achieved 17.2 MJ/kg LHV. Thus, it can be concluded that torrefaction of rice husk in superheated steam tester yields better result when the temperature is 140.1 °C [68].

2.2.3 Wet Torrefaction Prior to Pyrolysis

Wet torrefaction is a pretreatment that is carried out in hot compressed water with a temperature ranging from 150 °C to 260 °C and a pressure slightly higher than the vapor pressure at the corresponding temperature [69]. Wet torrefaction increases energy density, heating value and grindability of biomass [70], [71]. This has been proven for different biomass feedstocks such as loblolly pine wood, eucalyptus wood and aspen wood and it was claimed that wet torrefaction improves the quality of biomass feedstocks for subsequent thermochemical processes [72]–[74]. An experiment in China studied the effects of wet torrefaction on pyrolysis product of rice husk and showed that the quality of the pyrolysis products are improved when the rice husk is wet torrefied before the pyrolysis compared to the pyrolysis of raw rice husk [75]. The temperature range was from 150 °C to 240 °C and the torrefaction duration was 60 minutes, followed by pyrolysis of pretreated rice husk. Prior to pretreatment, the rice husk sample was dried at 105 °C temperature. Wet torrefaction decreases the atomic oxygen to carbon ratio [76].

The experiment resulted in a decrease of mass yield to 47.9% at 240 °C temperature from 86.7% at 150 °C temperature. Energy yield also decreased with increase in wet torrefaction temperature. Energy yield after wet torrefaction at 150 °C was around 90% which fell down to around 55% after wet torrefaction at 240 °C. The energy density, however, showed opposite trend to that of energy or mass yield. With higher temperature of 240 °C, the energy density was the highest at 112% while the lowest energy density being 101% for wet torrefaction at 150 °C [75].

Ash content decreased from primarily from 11.8% for raw rice husk to 10.9% for wet torrefaction at 150 °C but with further increase in temperature, the percentage increased to 15.5% for wet torrefaction at 240 °C [75]. The reason behind this result is the decomposition of organic components and low solubility of rice husk ash during wet torrefaction [77], [78]. Volatile content of raw rice husk and for wet torrefaction at 150 °C was found to be 73.5% and 76.9% respectively. But gradually decreased to 63.0% for wet torrefaction at 240 °C. The improvement of quality of rice husk with increased temperature can be seen in terms of carbon content. The highest recorded fixed carbon content was 21.5% for wet torrefaction at 240 °C and the lowest recorded was 14.7% at 150 °C. Higher fixed carbon is a sign of higher quality fuel but it is also essential to make sure that higher ash content and/or lower volatile content do not outweigh the advantage of higher fixed carbon. Due to higher fixed carbon, rice husk pretreated at 240 °C has increased higher heating value (HHV) of 18.1 MJ/kg compared to the same sample pretreated at 150 °C of 16.2 MJ/kg. Furthermore, higher pretreatment temperature yields decreased atomic O/C and H/C ratios due to dehydration, decarboxylation and demethanation reactions.

After pyrolysis of pretreated (wet torrefaction) rice husk, noticeable change was seen in the composition of pyrolysis products compared to raw rice husk. Bio-oil had the highest yield with 45.4% among the pyrolysis product for wet torrefaction at 150 °C, but the biochar and non-condensable gas yield had decreased. In case of wet torrefaction at 240 °C, biochar had taken 42.7% composition of the pyrolysis product while bio-oil yield dropped to 30.2% [75]. HHV of bio-oil increased and moisture content decreased as the torrefaction temperature went up. This signifies that an enhanced bio-oil quality can be achieved by wet torrefaction prior to pyrolysis.

Biochar obtained from pyrolysis of rice husk contained significantly more ash content than biochar obtained from other biomass [79]. The HHV and the ash content of biochar for different temperature of wet torrefaction was almost the same. Based on the discussion above, it can be concluded that on one hand wet torrefaction before pyrolysis improves the quality of bio-oil by removing moisture and enhancing HHV, on the other hand, the biochar that is obtained from pyrolysis of rice husk after wet torrefaction, regardless of the torrefaction temperature, is not an efficient solid fuel [75]. *Figure 2.2.3* shows the physical properties of bio oil obtained from pyrolysis of raw rice husk and torrefied rice husk [75]; where, RH depicts raw rice husk and RH150, RH180, RH210 and RH240 depict rice husk wet torrefied at 150 °C, 180 °C, 210 °C and 240 °C respectively.

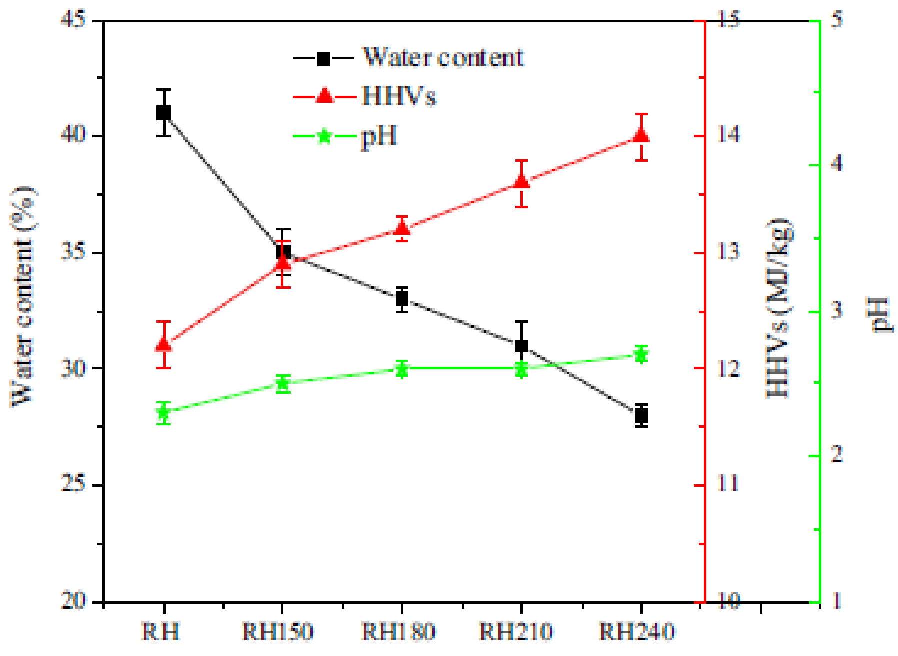

Figure 2.2.3: Water content, pH and HHV of bio oil from raw and torrefied rice husk

2.3 PYROLYSIS

Pyrolysis is a thermo-chemical process where biomass is converted into liquid, solid and gaseous fractions. It is done by heating the biomass in an inert environment to a temperature around 500 °C. The liquid product is more commonly known as bio-oil. Bio-oil is a fuel in liquid form, consisting of a mixture of oxygenated and aromatic compounds [80]. With a heating value of 36.03 MJ/kg, bio-oil is substantially more suited as a fuel than raw rice husk which has a heating value of 10.61 MJ/kg [81]. Bio-oil can be further converted into various biochemicals and transportation biofuels [82]–[87]. The downsides of bio-oil are poor thermal stability of the oil and corrosivity. Lowering the oxygen content and removing alkali metals are ways to upgrade the bio-oil. There have been experiments and research of power production using pyrolysis process [88], [89].

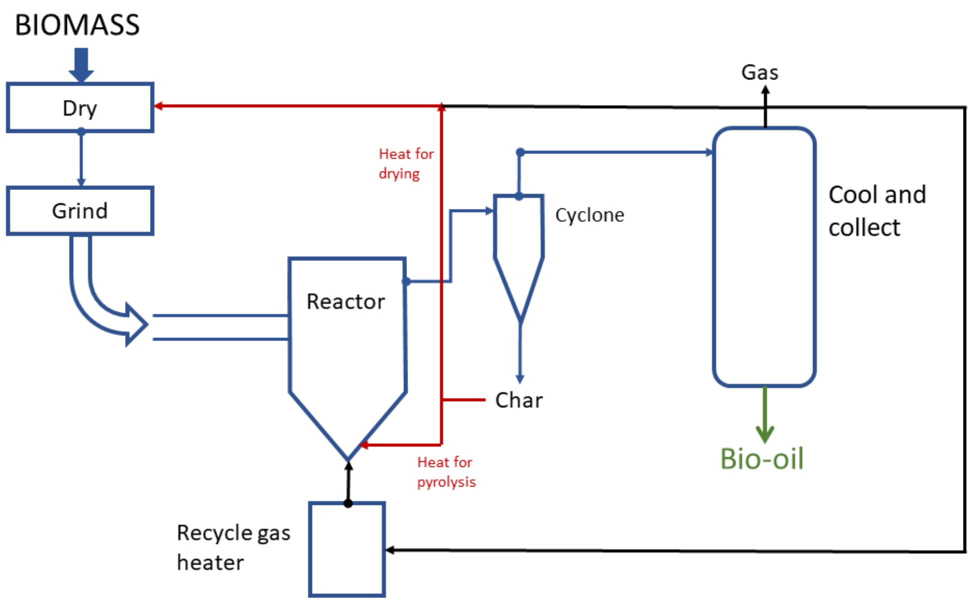

Figure 2.3.1: Common schematic of pyrolysis in fluidized bed reactor

2.3.1 Catalytic Pyrolysis

Pyrolysis of rice husk at high temperature (900 °C) and in presence of Ni-based catalyst has been studied [90]. The produced bio-oil can be a direct alternative of heavy fuel for power generation. Solid by-product of pyrolysis, biochar, which is a coal like material, can also be used as fuel for electricity generation [91]. When pyrolysis of rice husk was performed in fluidized bed pyrolyser, with glass beads and Ni-based catalyst as components of the bed, the process yielded a final product consisting of 30% bio-oil and 38% biochar in weight. The operating conditions were 900 °C, 10 bar of pressure and 20 minutes of reaction time. The energy content or calorific value of the bio-oil was 22 MJ/kg and for the biochar, it was 21 MJ/kg [90]. The energy yield was about 84.9% [88], [89].

Unrean et al. also assessed the economic and environmental aspects of catalytic pyrolysis of rice husk and compared them with hydrothermal carbonization. The comparison was done based on the cost of producing 1 MJ of energy. It was revealed that the cost of producing 1 MJ energy through this process was $0.043, fairly less than the cost of established fossil-fuel burning technology ($0.070/MJ) [88]. 1 ton rice husk with calorific value of 15 MJ/kg yielded 0.24 ton bio-oil with 22 MJ/kg energy content, while consuming 3.028 kWh electricity and 26.93 kg chilled water [90]. Per ton rice processing requires $540.85 including material, utilities and transportation cost ($20.36/ton) but installation and maintenance costs were not included [92], [93]. The plant was assumed to be working 11 months a year and capacity of the plant was 300 ton, in accordance to the fuel demand of pilot-scaled biomass power plant [94]. Raw materials and feedstock were assumed to be transported within 100 km while assessing transportation costs, based on the optimum economic distance for transporting biomass [95].

Unrean et al. assessed the life cycle analysis (LCA) and eco-efficiency of the catalytic pyrolysis model using SimaPro model [90]. LCA is an integrated method of determining the emissions from every stage of a production process chain, from raw material treatment to downstream fate of products [95]. Due to low solid loading condition of pyrolysis, 9 ton water was required for processing only 1 ton dry rice husk [94], [95]. Increasing the solid loading condition will definitely reduce the water footprint, improving the overall efficiency of the process.

GHG emissions throughout life cycle of pyrolysis was about 4.5 ton CO_2-equivalent/ton rice husk and almost half of the emissions took place during the conversion process of rice husk [94], [95]. The reason for selecting this unit is that almost 98% of the emissions are CO_2 while other GHGs consist of the rest 2% [96]. Final emission result of fuel production from pyrolysis process ended up to be 426.3 gCO_2-eq/MJ fuel which is still very less than it is in case of direct combustion (795.5 gCO_2/MJ fuel) [94], [95]. Although total emission would be less if LCA analysis covered rice cultivation stage, as the plantation utilizes CO_2 for photosynthesis [97]. Based on the IPCC GWP 100a, carbon footprint for catalytic pyrolysis process is 0.426 kg CO_2-eq/MJ [98].

2.3.2 Pyrolysis in a Fluidized Bed Reactor

The effects of pyrolyzing rice husk on a fluidized bed reactor with glass beads as fluidizing media have been studied in Taiwan [89]. After drying the rice husk at 50 °C oven, rice husk was fed into the reactor at 600 °C temperature, at different rates which resulted in different yield percentage of char, bio-oil and biogas. The most 'clean' chars were yielded when the feeding rate was 10 g/min [89] and carrier gas/Nitrogen flow rate was 40 L/min. The highest bio-oil mass fraction is around 30% at 10 g/min feeding rate.

Table 4: The composition of the three-phase products from the rice husk pyrolysis

Feeding rate (g/min)	Carrier gas flow rate (L/min)	Char (%)	Bio-oil (%)	Gas (%)
10	30	30.65	20.42	48.93
10	40	38.52	29.44	32.04
20	30	33.63	19.83	46.54
20	40	31.63	27.14	41.23

2.3.3 Fast Pyrolysis

Fast pyrolysis is when biomass is rapidly heated to a high temperature, at a very fast heating rate, in the absence of oxygen. It utilizes heat to decompose biopolymeric fractions under ambient pressure and inert atmosphere at a temperature range of 450-500 °C within 1 second [99]. Fast pyrolysis yields almost 75% bio-oil in weight which is an indication of a high efficiency thermo-conversion process [100]. It is possible to produce bio-oil or pyrolysis oil from by conducting fast pyrolysis in fluidized/fixed/conical spouted bed as well as in rotary kilns and ablative reactors

[101], [102]. Chang (2020) did an extensive review on the effects of different pretreatments of rice husk prior to bio-oil conversion through fast pyrolysis [3]. The pretreatments were washing, torrefaction (dry and wet) and combination of these two. The result showed that in terms of HHV and decreased minerals and moisture content, water washing dry torrefaction of rice husk followed by microwave assisted fast pyrolysis is the best thermo-chemical treatment of rice husk [3]. The final effect of this combined treatment was around 30% decrease in moisture content and more than 40% increase in biochar yield.

2.4 HYDROTHERMAL CARBONIZATION

Hydrothermal carbonization or HTC is a thermal conversion process that takes place in a relatively low temperature that converts biomass to a carbon-rich solid with high energy density [103]. The converted solid mass is known as carbonized solid with an energy density that is similar to that of coal [103]. Till date not many studies have been done on hydrothermal carbonization of rice husk. Among them, most of the studies have been conducted on small sample on a laboratory scale which necessarily could not be scaled up to industrial level with acceptable accuracy.

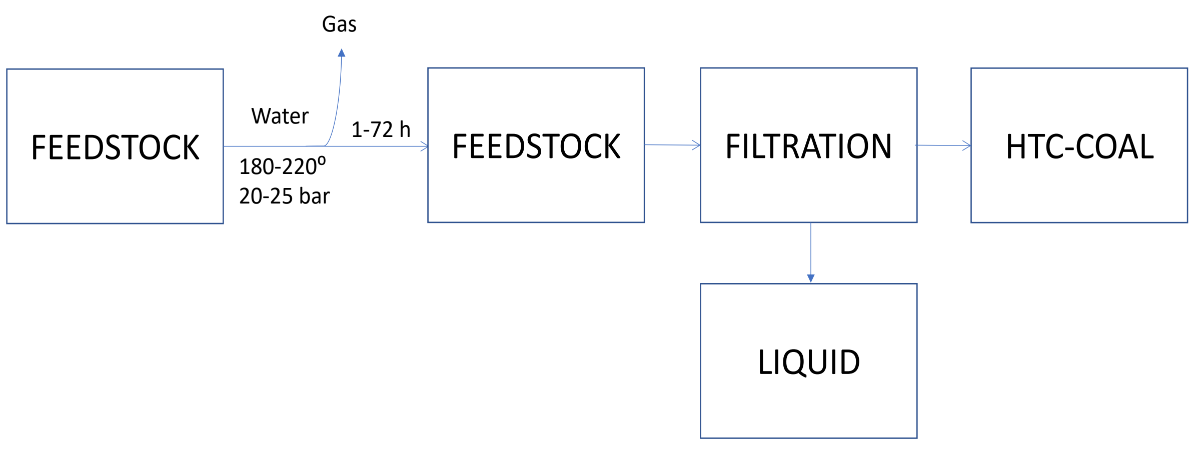

Figure 2.4.1: Process flow of HTC

2.4.1 HTC with Pelletization

Multiple studies have been conducted on hydrothermal carbonization of rice husk previously [104]–[107]. Combining pelletization technology with the result of the previous experiments on HTC of rice husk, Unrean et al compared the result of HTC of rice husk against a couple of other thermochemical conversion processes. The carbonization was conducted at 280°C temperature and 20 bar pressure for 60 minutes reaction time. After drying, the carbonized solid mass was pelletized for 30 seconds at 75°C temperature and 166 bar pressure that yielded the final solid fuel with energy content of 21 MJ/kg.

Table 5: Hydrothermal Carbonization of rice husk

Reaction parameters			End product
Temperature	Pressure	Duration	
Carbonization: 280°C Pelletization: 75°C	Carbonization: 20 bars Pelletization: 166 bars	Carbonization: 60 min Pelletization: 30 sec	Solid fuel: 50% Energy content: 21 MJ/kg Energy recovery: 55.6% Byproducts Hydrolysates: 45% Exhausted gas: 5%

HTC process requires very low utility usage and process water when compared to other typical thermochemical conversion processes [90]. This, combined with higher permissible solid loading, reduce the overall cost of the process. Only 10% of the cost is attributed to material costs.

2.4.2 HTC of Rice Husk Treated NaOH Solution

Cheng et al made a comparison between torrefaction and hydrothermal carbonization of 5 g raw rice husk [68]. The paper mostly focused on ash content ratio and transportation cost both before and after the pretreatments. As solvent of hydrothermally treated rice husk, water and 1.5% NaOH were used. The end result was that HTC results into more reduced ash content ratio and transportation cost than torrefaction [68]. Unlike other pretreatments, during hydrothermal treatment, the products undergo an intense combustion. The heat release is peaked between 240°C and 340°C, followed by entry into a stable condition. The final data of the study is shown in the table below [68].

Table 6: HTC treated with water and NaOH

Amount of sample	Solvent	Temperature	Solid mass	Residual mass	Ash content ratio	Ash content ratio reduction
4.4 g	H_2O	200°C	2.58 g	58.64%	13.96%	29.14%
4.3 g	NaOH	200°C	2.29 g	53.26%	8.87%	54.97%

Compared to 19.7% ash content ratio of raw rice husk, rice husk pretreated with HTC process has very less ash content which is an indication that HTC improves the fuel characteristics of rice husk. Further comparison suggests that rice husk after NaOH-hydrothermal treatment yields solid mass with better efficiency that HTC treated with water [68].

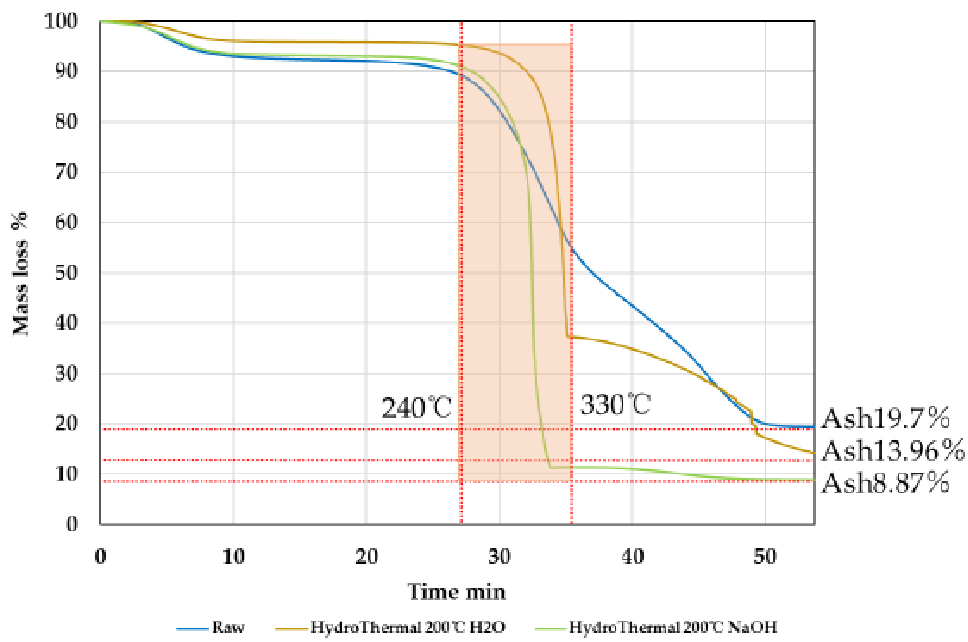

Figure 2.4.2: TG analysis of Hydrothermal Carbonization of rice husk [68]

CHAPTER THREE

METHODOLOGY

3.1 CHOOSING THE THERMOCHEMICAL PROCESSES

The thermochemical processes that were studied and investigated have been elaborately discussed in the previous chapter. After compiling all the information, four processes were filtered out based on the availability of information pertaining to each of the processes that will be needed for the following simulation. The chosen pretreatments are as follows: **Catalytic pyrolysis, Wet Torrefaction before Pyrolysis, HTC with pelletization** and **Torrefaction at Atmospheric Condition**.

3.2 POWER CYCLE SIMULATION

The cycle that was chosen for simulation in this study was Recompression Supercritical CO_2 Brayton cycle with Reheating. The modelling of the cycle was done in python programming language. The parameters were fixed and the values were taken from previous similar works. Supercritical CO_2 was chosen as the working fluid because it is available. It is non-toxic and non-explosive. It does not cause corrosion to different components of the cycle. Additionally, it is easy to extract from solvent. The schematic of the power cycle is shown in *Figure 3.2.1* and *Figure 3.2.2* is the T-s diagram of the said cycle based on the schematic setup.

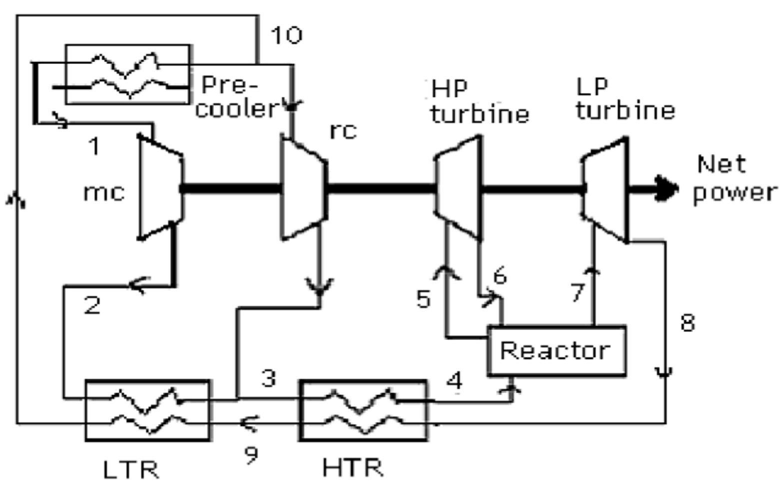

Figure 3.2.1: Schematic diagram of Recompressed Supercritical CO2 Brayton Cycle with Reheating [35]

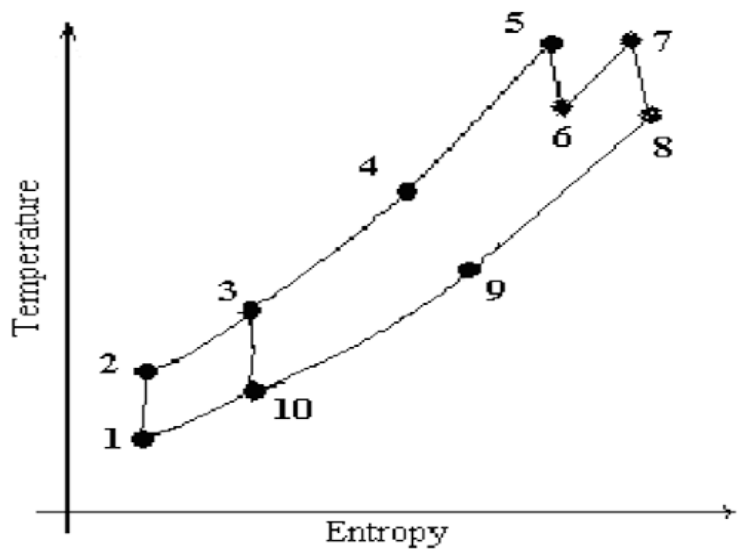

Figure 3.2.2: T-s diagram of Recompressed Supercritical CO2 Brayton Cycle with Reheating [35]

Using the equations from *Table 8*, the simulation was validated. The results were similar to previous simulations done of the same cycle [34], [35], [108], [109].

Table 7: Input parameters assumed for the simulation

Parameters	**Values**
Ambient temperature, T_0 (°C)	25
Ambient pressure, P_0 (MPa)	0.101325
Maximum pressure, P_{max} (MPa)	20
Effectiveness of HTR, ε_{HTR}	0.86
Effectiveness of LTR, ε_{LTR}	0.86
Isentropic efficiency of turbine, η_{turb}	0.90
Isentropic efficiency of compressor, η_{comp}	0.85
Turbine inlet temperature, T_5 (°C)	32
Compressor inlet temperature, T_1 (°C)	550

Table 8: Thermodynamic energy equations used in the simulation

Parameters	**Equations**
Effectiveness of HTR	$\varepsilon_{HTR} = \dfrac{\mathrm{h}_8 - \mathrm{h}_9}{\mathrm{h}_8 - \mathrm{h}(P = 9,\ T = 3)}$
HTR energy balance	$\mathrm{h}_8 - \mathrm{h}_9 = \mathrm{h}_4 - \mathrm{h}_3$
Effectiveness of LTR	$\varepsilon_{LTR} = \dfrac{\mathrm{h}_9 - \mathrm{h}_{10}}{\mathrm{h}_9 - \mathrm{h}(P = 10,\ T = 2)}$
LTR energy balance	$(1 - X)\mathrm{h}_3 - \mathrm{h}_2 = \mathrm{h}_9 - \mathrm{h}_{10}$
Mass flow rate of sCO_2	$\dot{m} = \dfrac{\dot{Q}_{add}}{[(\mathrm{h}_5 - \mathrm{h}_4) + (\mathrm{h}_7 - \mathrm{h}_6)]}$
Work input for main compressor	$\dot{W}_{mc} = \dot{m}(1 - X)(\mathrm{h}_2 - \mathrm{h}_1)$
Work input for recompressor	$\dot{W}_{rc} = \dot{m}.X(\mathrm{h}_3 - \mathrm{h}_{10})$
Work output for HPT	$\dot{W}_{HPT} = \dot{m}(\mathrm{h}_5 - \mathrm{h}_6)$
Net work output	$\dot{W}_{net} = \dot{W}_{HPT} + \dot{W}_{LPT} - \dot{W}_{mc} - \dot{W}_{rc}$
Thermal efficiency	$n_{\mathrm{th}} = \dfrac{\dot{W}_{net}}{\dot{Q}_{add}}$

CHAPTER FOUR

RESULTS

3.3 COMPARISON

Table 9: Comparison of different thermochemical processes

Process	Fixed-bed gasification	Torrefaction at atmospheric condition [58]	Torrefaction using superheated steam [64]		Wet torrefaction before pyrolysis	Catalytic pyrolysis [86]		Fast Pyrolysis after water washing dry torrefaction [3]	HTC with pelletization [86]	HTC in 1.5% NaOH solution
Sample amount	5 kg 50 kg/h (large scale) 3.6 kg/h (Lab scale)	N/A	454.6 g 50 g/min		10 g	1 ton			1 ton	4.4 g
Process temperature	650–810 °C	200 °C	140.1 °C		150 °C 105 °C (drying temperature)	900 °C,		450-500 °C	280°C	200°C
Process duration	1.38 hours	10 minutes	45 minutes		60 minutes	20 minutes		1 second	60 minutes	
Heating/calorific value of the final product	933.6 kcal/Nm^3 (LHV of syngas)	14.2 MJ/kg	16.36 MJ/kg (HHV)	15.35 MJ/kg (LHV)	16.2 MJ/kg (HHV)	22 MJ/kg (Bio-oil)	21 MJ/kg (Biochar)	12% increase*	21 MJ/kg	
Fuel cost for process per kg rice husk	$5.45	N/A	N/A		N/A	$0.54			$0.013/MJ	
Energy yield	N/A	105.30%	6.67% loss		90% 101% (Density)	84.90%			55.60%	
Solid residue	N/A	90%	90.20%		86.70%	38% (Biochar)		25% increase*	50%	53.26%
Ash content	N/A	23%	22.50%		10.90%					8.87%
Moisture content	N/A	2.81%	5.65%		34.9% (Bio-oil)			30% reduction*		
Volatile matter	N/A	60.50%	57.60%		76.90%					
Fixed Carbon	N/A	16%	19.90%		14.70%					

As an attempt to summarize the information of previous studies and researches on various thermochemical pretreatments of rice husk, *Table 9* represents charted data of the literatures reviewed throughout this article. It is to be noted that each study or experiment prioritized certain parameters and not necessarily the same ones. Some pretreatments are based on improving certain parameters under specific conditions. Due to this reason, it was not possible to chart the value of any parameter or outcome for each and every one of the processes. Comparing all the processes based on one parameter is, thus, out of the scope of this review paper. However, the goal is not to compare the common thermochemical processes on a single premise, rather, it is to collectively present all necessary information regarding these processes that will help in future prospect and further research.

3.4 SAMPLE CALCULATION

Given above is *Table 9* that compares many of the pretreatments of rice husk that can be found in literatures and previous studies. A sample calculation is shown for pretreatment of a specific amount of rice husk using the selected thermochemical processes.

In 2014, total available rice-husk amount was 4.5 million ton/year. For this basic sample calculation, assuming a torrefaction plant in Naogaon, one of the four major paddy producing zones. About 192,550 ton of rice-husk is produced in Naogaon every year, which means every day, around 527,534 kg rice husk can be utilized for power generation.

Figure 3.4.1, shows the comparison between the four chosen thermochemical pretreatments in terms of power output against pressure ration from the simulation for a sample of 1.5 tons rice husk. It can be seen that wet torrefaction prior to pyrolysis is the most promising of the thermochemical pretreatments with a power output of above 100 kW. On the other hand, the maximum power output when rice husk undergone catalytic pyrolysis, when used as fuel, is the least among the pretreatments. However, in published studies, wet torrefaction before pyrolysis was conducted on a mere 10g of rice husk sample. Since thermochemical processes are not very simple processes, it is not acceptable to assume that end results of such processes will change linearly with the amount of biomass sample. These are very complex processes with varying mechanisms in each of the stages of the operation. Thus, it would be safe to say that the simulation corresponding to catalytic pyrolysis of rice husk is more accurate since the assumptions are made based on an experiment containing 1 ton of rice husk sample.

There is another calculation that assumes that all the rice husk produced in one year in Naogaon region is available for use throughout the whole year. *Table 10* shows the potential of power generation given that rice husk production is uniform every day of the year.

Table 10: Estimated power output of specific pretreatments

Process name	**Sample**	**Residue of solid or gas**	**Amount of final product**	**Energy gained from final product per day**	**Energy gained in MW**
Catalytic pyrolysis	527,534 kg and 1,500 kg (as sample)	38% (Biochar)	200,463 kg and 570 kg	4,209,723 MJ and 11,970 MJ	48 MW and 0.139 MW
HTC with pelletization		50%	263,767 kg and 750 kg	5,539,107 MJ and 15,750 MJ	64 MW and 0.182 MW
Wet torrefaction before pyrolysis		86.70%	457,371 kg and 1,305 kg	7,409,410 MJ and 21,140 MJ	85 MW and 0.245 MW
Torrefaction at atmospheric condition		90%	474,780 kg and 1,350 kg	6,741,876 MJ and 19,170 MJ	78 MW and 0.222 MW

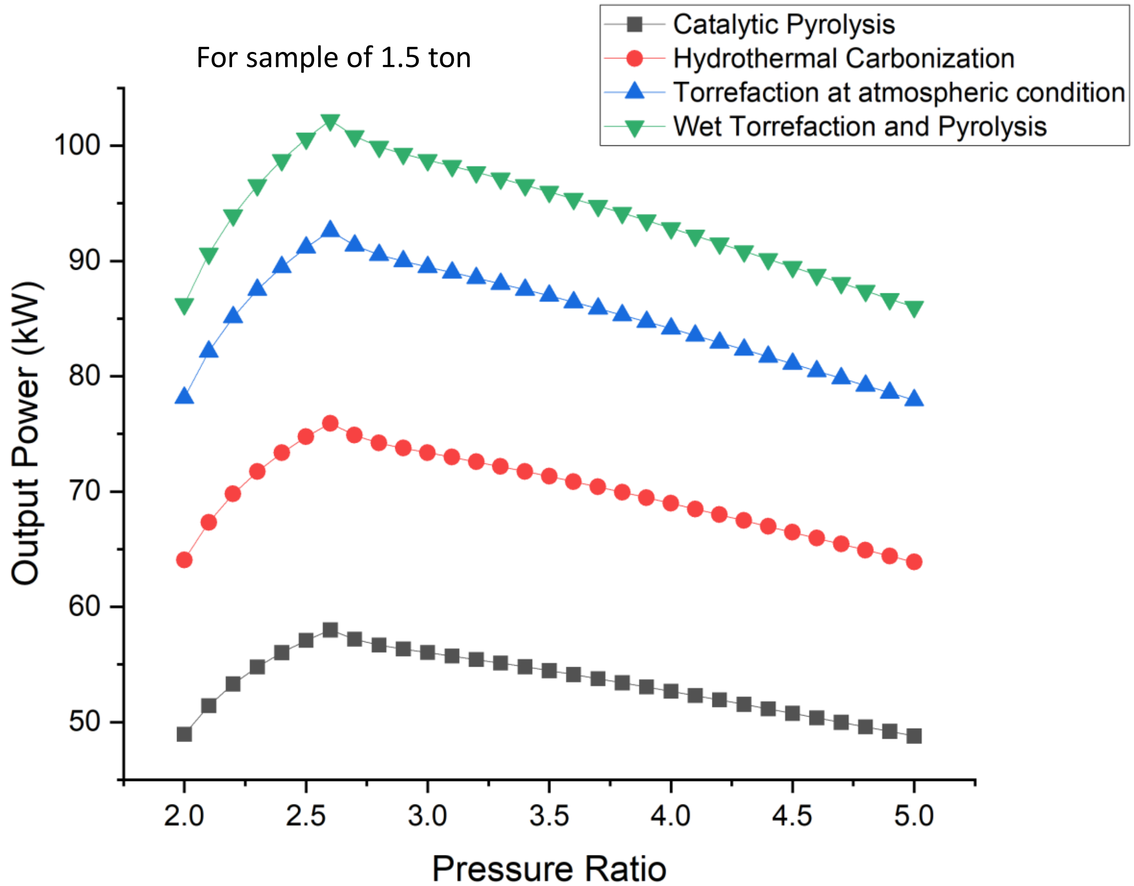

Figure 3.4.1: Power output vs. pressure ratio for different pretreatments

Hydrothermal carbonization with pelletization can also be considered fairly accurate because the research on which the simulation is based on was conducted on 1 ton of rice husk sample. After optimization, the optimized pressure ration was found to be 2.64. *Figure 3.4.2*, gives the same comparison but for a pressure ratio of 2.64.

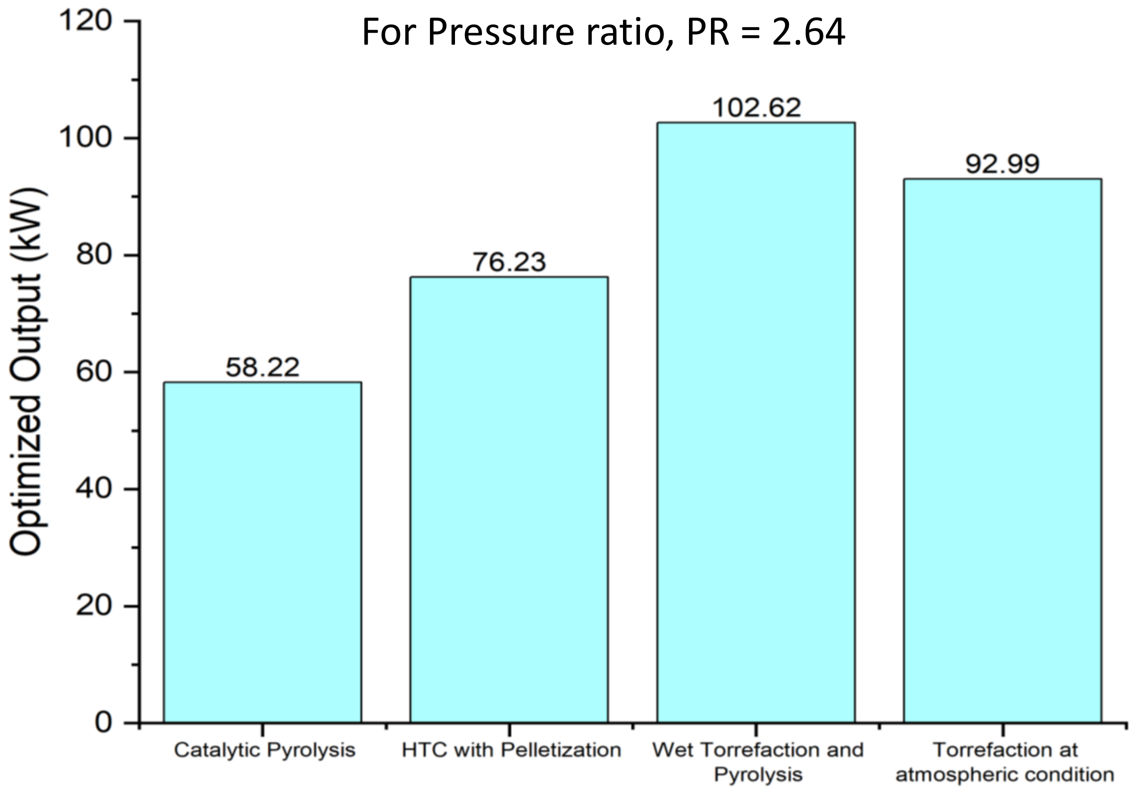

Figure 3.4.2: Maximum power output with optimized pressure ratio

CHAPTER FIVE

CONCLUSION

This paper discusses in length about four known and most common thermochemical pretreatments implemented for upgrading the fuel properties, including subcategories as well as combination of multiple processes. Each of the processes has both cons and pros in different scenarios. In terms of temperature, HTC seems to be the most lenient process in general, followed by torrefaction, intermediate pyrolysis and lastly, gasification. Out of the four processes, the end product for only gasification is a gaseous material or syn-gas or synthetic gas while the rest of the processes yield a carbonaceous solid material known as char. The paper also discusses about combining multiple pretreatment processes for a more efficient or economical way to develop fuel properties, such as torrefaction before fast pyrolysis. All the processes take place in the absence of oxygen or an inert atmosphere except gasification, which is basically a partial combustion of the biomass.

A handful of the discussed processes were chosen for a direct economical comparison based on previous research and experiments found in literature. Since, HTC is comparatively newer and more advance technology, it can be safely said that HTC would be more efficient and viable. However, it should be considered that there not has been any significant work regarding HTC of rice husk on industrial scale.

As long as the end goal is converting low energy-density biomass to an energy-rich material like coal, it can be concluded that all of the thermochemical process serves the purpose. Choosing the best or the most optimum process should be more relied on other factors such as materials, location, resources and available technology.

The final part of this thesis deals with the potential of power generation from rice husk. Although this study has been focused on the global point of view regarding rice husk, the simulation of power generation was based on Bangladesh and the available rice husk in Bangladesh every year. The results show that even if we consider the rice husk produced in only one of the four major paddy producing region, the minimum potential of power generation is around 50 MW per year, given that the rice husk is available throughout the whole year. Combining it with the rice husk produced all around Bangladesh in one year, we can generate almost 200 MW of electricity which is a very promising and large number for our country.

Aside from the aspect of electricity generation, the amount of information on different pretreatments of rice husk can be utilized further for countless studies. More investigation and experiments on these processes will get the scientific community closer to finding the most optimum process suited for certain purpose. This study can be considered as the ground work for further research on rice husk. After all, the human civilization is about to face a massive energy crisis in the near future when all of our fossil fuel reserves start depleting completely. In such a scenario, the only viable and reasonable alternatives for energy sources will be renewable energy sources that include from solar energy to biomass. On comparison, biomass as fuel is much easier and cheaper to use against solar energy although both energy sources are green and have none to very low emission. Researching and working on newer technologies that will help increase the adaptability and usability of biomass as chief fuel source can open up better and new opportunities to make the world safer and more sustainable.

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CERTIFICATE OF RESEARCH

*This thesis titled "**POWER GENERATION FROM RICE HUSK**" submitted by **AHMED IMTIAZ ANANDO (170011016)** has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical Engineering.*

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Declaration

I hereby declare that this thesis entitled "***POWER GENERATION FROM RICE HUSK***" is an authentic report of study carried out as requirement for the award of degree B.Sc. in (Mechanical Engineering) at Islamic University of Technology, Gazipur, Dhaka under the supervision of Dr. Mohammad Monjurul Ehsan, Associate Professor, MPE, IUT in the year 2022

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

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