ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

BRIQUETTING OF WOOD SHAVINGS AND COAL SLURRY

M.Sc. Thesis

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Energy Science and Technology Division

Energy Science and Technology Programme

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M.Sc. THESIS

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AĞAÇ TALAŞI VE KÖMÜR ŞLAMININ BRİKETLENMESİ

YÜKSEK LİSANS TEZİ

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Osman Alper İştotan, a M.Sc. student of ITU Institute of Energy student ID 301111020, successfully defended the thesis entitled "BRIQUETTING OF WOOD SHAVINGS AND COAL SLURRY, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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FOREWORD

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ABBREVIATIONS

ASTM	**:** American Society for Testing and Materials
CMD	**:** Carbonized MDF Dust
DTG	**:** Differential Thermogravimetry
DSC	**:** Differential Scanning Calorimetry
DTA	**:** Differential Thermal Analysis
MDF	**:** Medium-Density Fiberboard
PSC	**:** Pencil Shavings Charcoal
TG	**:** Thermogravimetry
TS	**:** Turkish Standards

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BRIQUETTING OF WOOD WASTE AND COAL SLURRY

SUMMARY

Energy is becoming more and more important in the world politics. Turkey is a country whose current deficit is widening due to its energy need. Turkey needs to find variety of alternative fuels to reduce its dependency to outside energy resources. New alternative fuels must be local, cheap and sustainable. In this study, two resources that match these criteria are chosen; wood waste and coal slurry. Wood waste is a residue of wood based industry and coal slurry is a byproduct of coal processing. Both of them are abundant and widely found all over Turkey. A fuel, made by using wood waste and coal slurry can be an alternative to our energy need. In order to create a fuel, briquetting method will be used because of its simple process steps and low energy requirements.

Coal is of the main energy resources of Turkey and it is mainly used for electricity generation and industrial purposes. Coal has various preparation process and some of them include washing and curing with a liquid. After these processes, a mixture of liquid is generated and this mixture includes coal particles and minerals. This substance is dumped or stored, and it creates environmental and storage problems. Obtaining value from this liquid, and creating a fuel from it, can be a solution for environmental issues and current energy demand of Turkey.

Wood based industry significantly developed in Turkey over the last couple of years. At every step of wood processing, it produces small amount wood shavings. In time these shavings creates health, quality and storage problems for companies. Two types of wood shavings are investigated, in this study. First, one is wood shavings from pencil production and the second one is MDF dust from furniture production. Both of the samples are investigated for their thermal characteristics and tested during briquetting process.

The determination of calorific value is important for our samples because if the calorific value is too low, it may not be suitable for briquette production. So first, coal slurry is researched for its properties and combustion caracteristics. Since coal slurry is a product of coal washing, it has high moisture content, therefore it needed to be dried. After drying process, to obtain a uniform particle size, dried coal slurry is sifted through a 250µm mesh. After discovering that coal slurry has 4114 kcal/kg calorific value, the rest of the analysis could be carried on. To increase the calorific value of coal slurry, carbonization process is applied, but the calorific value of slurry is decreased to 2793 kcal/kg after carbonization. As a result, carbonization was not necessary for coal slurry because the loss of calorific value. Later, coal slurry particles are investigated by using thermal and elemental analysis. The analysis showed us that coal slurry is suitable for briquette production.

In order to choose our wood sample for briquette production, pencil shavings are investigated. Pencil shavings were already dry due to its pre-production drying, so there was no need to dry the samples. Pencil shavings particles size was bigger than

coal slurry, so before sifting them, pencil shaving are reduced in size in a mill chrusher. After reducing the particle size, shavings are sifted from a 250µm mesh to obtain uniform particle size. Obtained pencil shavings are tested for the calorific value and the calorific value was 4263 kcal/kg. Then to increase the calorific value, carbonization method applied to the samples. Pencil shaving nearly doubled in calorific value after carbonization to 7669 kcal/kg, which was promising for our briquettes quality.

Second sample was the MDF dust, and same processes are repeate. MDF is an already dry product, so drying the samples were not necessary. Also MDF dust particle size is already small, there was no needed to mill it before sifting. Sifted from a 250µm mesh, MDF dusts are tested for calorific value and the calorific value was 4269 kcal/kg, which was similar to coal and shavings. Then carbonization is applied to MDF dust and calorific value is increased to 7070 kcal/kg. Althought the percentage increase in calorific value was close, pencil shavings achieved higher calorific value after carbonization.

After analyzing and investigating properties of the samples, the briquetting materials are determined. Four different type of briquette were produced: 100% coal slurry, 90% coal slurry mixed with 10% pencil shaving, 90% coal slurry mixed with 10% MDF dust and 100% pencil shavings only to check our results. All of the briquettes are produced under 10 MPa pressure and the obtained briquettes are tested for compressive strength and water resistance. 100% coal slurry and 100% pencil shaving had better results both water resistance and compressive strength test against the mixtures.

AĞAÇ TALAŞI VE KÖMÜR ŞLAMININ BRİKETLENMESİ

ÖZET

Günümüz dünya politikasında enerjinin önemi gitgide artmaktadır. Türkiye cari açığı enerji yüzünden sürekli büyüyen bir ülkedir. Bu yüzden Türkiye'nin çeşitli alternatif yakıtlar bularak, dış enerji bağımlılığını azaltması gerekmektedir. Yeni bulunacak alternatife yakıtlar yerli kaynaklara dayanan, elde etmesi kolay, ucuz ve sürdürülebilir olmalıdır. Bu çalışmada, bu özelliklere uyan iki farklı malzeme tipi seçilmiştir. Bunlardan biri kömür şlamı, diğeri ise ağaç talaşıdır. Kömür şlamı kömür işlemeden oluşan bir yan üründür. Ağaç talaşı ise ağaç endüstrisinin atıklarıdır. Her iki malzemede Türkiye'nin farklı bölgelerinde rahatlıkla bulunabilmektedirler. Bu iki numuneyi kullanarak üretilecek bir yakıt enerji ihtiyacımıza bir alternatife olabilir. Yakıt üretim metodu olarak düşük enerji tüketimi ve basit imalat adımları nedeniyle briketleme işlemi seçilmiştir.

Türkiye'nin ana enerji kaynaklarından biri kömürdür. Kömür elektrik üretiminden metal sektörüne kadar birçok farklı sektörde kullanılmaktadır. Madenden çıkan ham kömürü birçok işlemden geçerek kullanılabilir hale gelmektedir. Bu işlemlerin başında kırma, öğütme, eleme, temizleme ve yıkama gelmektedir. Her aşamada bir miktar atık çıkmaktadır ve bu çıkan atıkların tesisten uzaklaştırılması gerekmektedir. Yıkama sırasında ortaya çıkan atıklara kömür şlamı denir. Kömür şlamı ham kömürün üzerinde bulunan ince kömür tozlarını ve topraktan gelen mineralleri içermektedir. İçeriği sebebiyle kömür şlamının enerji potansiyeli bulunmaktadır. Dolayısıyla enerji kaynağı olarak kullanılabilir ancak kullanılmadan önce işlenmesi gerekmektedir. Mevcut durumda kömür şlamları ya yeraltı kaynaklarına basılmakta ya da açık havuzlarda depolanmaktadır. Ancak iki şekilde de hem çevresel hem de depolama problemleri oluşmaktadır. Bu nedenlerden dolayı kömür şlamı hem çevresel zararları azaltmak hem de enerji ihtiyacımızın bir bölümüne çözüm olmak için kullanılabilir.

Son yıllarda orman endüstrisi ve mobilya sektörü ülkemizde hızla gelişmektedir. Orman kaynaklı ürünlerin başında kereste ve işlenmiş ağaç ürünleri gelmektedir. Kereste ham şeklinde inşaattan mobilya sektörüne birçok alanda kullanılmaktadır. İşlenmiş ağaç ürünlerinin başında sunta, mdf, osb ve plyood gelmektedir. Bu ürünler plaka halinde üretilmekte ve teknik özelliklerinin belirli olması sebebiyle birçok sektörde kullanılmakdır. Özellikle mobilya sektörü sunta ve mdf kullanımında en üst sıralarda yer almaktadır. Sunta ve mdf işleme kolaylığı ve fiyat avantajları sebebiyle en çok tercih edilen ürünlerdir.

Kereste işleme sırasında ağaç talaşı ortaya çıkmaktadır. Ağaç talaşı mevcut piyasa koşullarında değerlendirilebilen bir üründür. Sunta ve mdf fabrikaları ham ağaç talaşını imalat sürecinde katkı maddesi olarak kullanmaktadır. Ancak ağaç talaşının temiz ve katkısız olamsı gerekmektedir. Eğer ağaç talaşının içinde katkı maddesi veya diğer ürünlerin atıkları bulunursa imalat sürecinde yaşanabiliecek sıkıntılardan dolayı sunta ve mdf fabrikaları bu tip talaşları kabul etmemektir.

İşlenmiş ağaç ürünlerinin kullanılması sırasında ortaya çıkan tozlar, bu ürünlerin imalat sürecinde içeriğine eklenen katkı maddelerinden dolayı tekrar fabrikaya geri verilip kullanılamamaktadır. Bu ürünlerin işlenmesinin her aşamasında bir miktar toz oluşmaktadır. Geri dönüşüm imkânı olmadığından dolayı, bu tozlar birçok fabrikaya depolama ve çevre problemleri yaratmaktadır.

Bu çalışmada orman atıklarından piyasada mevcut durumda kullanım alanı bulunmayan iki farklı atık numunesi seçilmiştir. Bunlardan biri kalem talaşı diğeri ise mdf tozudur. Kalem talaşı imalat süresince boyama, kaplama ve mine eklenmesi gibi işlemlerden geçtiği için içerisinde farklı atıkları bulundurmaktadır. MDF tozu ise içeriğindeki bağlayıcılar nedeniyle kullanılamamaktadır.

Seçtiğimiz numunelerin ısıl değerleri elde edilecek yakıtın değerini belirleyeceği için önemlidir. Eğer ısıl değerler çok düşük ise seçtiğimiz numuneler briket üretimi için uygun olmayabilir. Öncelikle kömür şlamının ısıl değeri ve yanma özellikleri incelenmiştir. Kömür şlamı kömür yıkama işleminden ortaya çıkan bir ürün olduğundan dolayı, içeriğinde nem miktarı fazladır. Bu yüzden elde edilen kömür şlam numunesi öncelikle kurutulmuştur. Kurutma işlemi sonrasında, kömür şlamı 250µm boyutundaki elekten geçirilmiş ve elde edilen numunenin ısıl değeri 4263 kcal/kg olarak elde edilmiştir. Kömür şlamının ısıl değerini arttırmak için karbonizasyon işleminden geçirilmiştir, ancak bu işlem sonrasında kömür şlamının ısıl değerinin 2793 kcal/kg olduğu görülmüştür. Sonuç olarak kömür şlamına karbonizasyon işlemini uygulamanın verimli olmadığı görülmüş ve briketleme işlemi için kömür şlamının ham halinin kullanılmasına karar verilmiştir.

Orman atıklarından ilk olarak kalem talaşının özellikleri araştırılmıştır. Kömür şlamının aksine kalem talaşının numuneleri kurudur, bu yüzden kurutma işlemi yapılmamıştır. Ancak elde edilen numuneler yonga boyutunda olduğu için 250µm elekten geçirilmeden önce öğütülmüştür. Elde edilen numune ısıl değerinin 4263 kcal/kg olduğu görülmüştür. Bu değer kömür şlamının değerine yakındır. Bu yüzden kalem talaşına karbonizasyon işlemi uygulanmıştır ve işlem sonucunda kalem talaşının ısıl değeri 7669 kcal/kg olmuştur. Bu sonuçlara göre kalem talaşının karbonizasyon işlemi yapılarak briket yapımında kullanılmasına karar verilmiştir.

İkinci numune olarak seçilen MDF tozuna kalem talaşına uygulanan aynı işlemler tekrarlanmıştır. Ancak MDF tozu zaten toz halde olduğu için 250µm elekten geçirme işlemi öncesinde öğütme işlemine gerek duyulmamıştır. Elekten geçirilen MDF talaşının ısıl değeri, kalem talaşının ısıl değerine yakın olarark 4269 kcal/kg elde edilmiştir. Aynı şekilde MDF talaşının ısıl değerini arttırmak amacıyla karbonizasyon işlemi uygulanmış ve ısıl değerinin 7070 kcal/kg değerine yükseldiği görülmüştür.

Numuneler ve test sonuçları incelendikten sonra dört farklı nunume ile briketleme işlemi yapılmasına karar verilmiştir. İlk olarak sadece kömür şlamı kullanılarak briket yapılmıştır. Başlangıç basınç değeri olarak 5MPa denenmiş ancak sonuç alınamamıştır. Daha sonra basınç 10 MPa çıkarıldığında düzgün briketler elde edilmiştir. İkinci numune olarak kömür şlamına %10 oranında kalem talaşı yarı koku karıştırılmıştır. Elde edilen karışım başlangıç basıncı olan 5 MPa denenmiş ama başarısız olunmuştur. Basınç 10 MPa değerine çıkarıldığında bu karışımdan briket elde edilmiştir.

Üçüncü olarak kömür şlamına %10 oranında karbonize edilmiş mdf tozu eklenmiştir. Başlangıç basıncı olarak 5 MPa denenmiş ancak başarısız olunmuştur. Daha sonra basınç 10 MPa arttırıldığında briket yapımı mümkün olmuştur ancak briket kalitesi kalem talaşı karışımından daha dayanıksız olduğu gözlenmiştir. Son olarak test sonuçlarımızı karşılaştırmak amacıyla yüksek ısıl değeri nedeniyle kalem talaşı nunumesi seçilmiş ve tek başına briketlenmiştir. Kalem talaşı numunesiyle 10 MPa basınçta yapılan briketler diğer briketlere göre daha sağlam olduğu görülmüştür.

Elde edilen briketlerin her birine dayanıklılıklarının belirlenmesi için deneyler yapılmıştır. Basma mukavvemeti deneyi sonrasında %100 kalem talaşı ve kömür şlamında yapılan briketlerin daha dayanıklı olduğu görülmüştür. Sadece kalem talaşı numunesinin basma mukavvemeteti 630 MPa, sadece kömür şlamının basma mukavvemeti ise 275 MPa olarak elde edilmiştir. Karışımlarda ise MDF tozu eklenen şlam kömürü briketin basıncının 310 MPa, kalem talaşı eklenen briketin basıncının ise 65 MPa olduğu gözlenmiştir. Suya dayanıklık analizlerinde ise %100 kalem talaşı ve %100 kömür şlamı briketlerinin karışım briketlerine göre daha dayanıklı oldukları görülmüştür.

1. INTRODUCTION

The topic of alternative fuels is gaining more and more importance at the current situation of the world. Developed countries are investing on alternative energy resources and trying to improve the share of the alternative energy in their energy consumption. Alternative fuels can substitute for fossil fuels in heating or electricity production. Germany is a leading country in alternative fuel consumption, and has an electricity production from alternative fuels to total of 25.4% in 2014 [1].

Turkey is a developing country and like other developing countries, its energy demand is growing every year. At the current situation, energy resources are not covering local energy need, therefore Turkey’s current deficit is widening every year [2]. Turkey needs variety of alternative fuels reduce it is foreign energy dependency. New alternative fuels must be local, low cost, and abundant. In this study, two resources that matches these criteria are chosen, wood waste and coal slurry. Wood waste is a residue of wood-based industry and coal slurry is a by-product of coal processing, both of them are abundant and easily found. In order to obtain a consistent and durable fuel, briquetting process is chosen due to its simple process and low energy requirements. By briquetting, those two waste materials, a fuel will be obtained which can be used as an alternative fuel.

Wood based industry significantly developed in Turkey over the last couple of years. At every step of wood processing, a small amount wood shaving is generated. Furniture production of Turkey is based on wood-based panel production increased to 7.5 million m3 by year 2011 in Turkey [3]. Although there is no actual way to determine dust amount of each process collected shavings are usually stored in filters or silos that can give an approximate total amount.

Currently, there is no way to use wood shavings. Municipalities are collecting from companies to send it to disposal. As an alternative fuel compound, wood shaving are suitable since there is no extra cost to collect it.

Coal is one of the main fuel that is widely used in Turkey. Turkey coal production was 71.4 million ton in 2011 [4]. Coal slurry is a by-product of coal processing. After the mining operation, coal slugs are washed to get rid of the unwanted minerals and waste materials. Therefore, it is a mixed product but it has a calorific value so it can be used as a fuel. Due to its moisture content, it needs to be dried and then processed. Now most of the refractory brick factories use it in their production, however the amount of coal slurry exceeds their usage [5].

Briquetting is a method of compacting and compressing materials by applying pressure to a desire shape, in order to increase density and create a durable form [6]. In order to produce a briquette according to standards, materials will be dried to a required moisture level. After drying, material samples will be reduced to a desired size by using a fine sieve, to have a uniform size of each particle. Finally, dried and homogenous samples will be used to make briquettes. Finally, briquettes will be tested according to standards.

2. WOOD

Introduction To Wood

Wood is defined as a fibrous and porous structural tissue found in stems and roots of trees and other woody plants [7]. Wood is used in various forms in human life, such as fuel for heating or cooking, a structural material for construction or raw material for furniture and paper production.

The total amount of living organic plant matter of the world is nearly $1.24x10^{12}$ tonnes and it is assumed that 80% of this amount is processable wood [8]. The amount of wood surfacing the world is enough, for it to be called abundant. Additionally, the annual wood growth is $1.1x10^{10}$ tonnes per year [8]. The amount and the growth rate of the wood is one of the main reasons of why wood is one of the main renewable sources of earth.

As a renewable source, wood is widely used all around the world. There are mainly two ways to use wood as a fuel source; raw or processed. Raw wood resources as are wood logs, chips, branches and forest bottoms, which consist small pieces from each. This type of usage is very common however with the advancing technology people are leaned more and more towards processed way of using wood as a resource.

Processed methods to use wood as renewable fuel are more efficient and controllable, such as briquetting, and pelleting. These two methods are common because they consists mechanical processes that can be applied to different types of woods. Besides briquetting and pelleting, there are other methods such as gasification, pyrolysis, and charcoal production.

Wood Properties

Wood has mainly 3 components, cellulose, hemicellulose and lignin [9]. The rest is extractives and inorganic constituents that binds and protects the wood [10]. Cellulose and Hemicellulose content is around 50% - 75%, and lignin content of wood varies from 22%-43% for different wood types [8]. Cellulose and hemicellulose are organic compounds, and they function as structural components. Cellulose content of wood is mainly important in paper industries [10].

Lignin is a carbon based molecule in which phenyl propane units (C_9) are linked with C-C or C-O bonds. [8]. The quantity of lignin content is important because of two reasons: High lignin content make wood more durable, therefore a better structural material; lignin has more energy than cellulose because of its carbon structure therefore high lignin content woods has more calorific value [11].

Wood Shavings

Forestry industry and wood processing generates wood shavings during each process of woodworking. In 2001, approximately 3.5 cubic kilometers of wood were harvested, and dominant usage was for furniture and building construction [8]. Different type of woods used in different productions, therefore every wood shaving has its own characteristics. Generally three types of wood used in the industry; tropical woods, softwoods and hardwoods [9]. Each type of wood generates wood shavings in different shapes and sizes during various processes such as sawing, sanding as given in Table 2.1 and Table 2.2 [12]. Dusts and shavings size differentiates between five μm - 5 cm for different type of wood [12].

Table 2.1: Particle size distribution of dust generated from sawing operation.

	Number Distribution (μm)		
% under	Pine	Oak	MDF
10	6.2	1.1	5.6
25	11.9	1.9	9.0
50	20.0	5.7	15.0
75	30.0	11.3	24.5
90	48.3	19.3	36.2
Mean	18.6	4.9	14.5
Mode	30.0	8.9	15.0

Table 2.2: Volume distribution of dust generated from sawing operation.

Volume (mass) Distribution (μm)			
% under	Pine	Oak	MDF
10	33.2	15.1	22.6
25	47.3	22.7	31.8
50	72.2	32.9	43.8
75	103.7	43.4	54.7
90	128.7	52.2	69.1
Mean	68.0	30.3	41.2
Mode	80.0	37.7	48.2

MDF

MDF is an acronym for Medium-Density Fiberboard. It is produced by shredding wood in to dust from and compacting into a panel shape with resin and different binders, by applying high temperature and pressure. There are other types of fiberboards but due to its machinability and homogenous structure MDF is the most common material used in furniture production [13].

Definition of medium density in MDF name is not referring to its density; rather it is a definition of the wood fibers used in the production. The density of an MDF board varies according to manufacturer between 500 kg/m^3 and 1000 kg/m^3 [14]. Different types of MDF are available on the market; some of them are thick as 50 mm to be used in door production, some they are 18 mm to be used in furniture production.

MDF production starts with tree logs and branches collected from forests. First, all the wood is debarked to be rid of the unwanted outer surface of wood, and then sent into a chipper where it is reduced in size [13]. Wood chips are grinded in defibrator with high pressure and temperature and later mixed with resin and binders. Finally, the compound is heated to get rid of the excess moisture and compacted to a desired thickness of panel [13].

Due to its fibrous core, MDF processing generates fine dust. This dust must be collected to a filter or a silo to create a healthy working environment for workers and keep the machines running dust free. The collected dust amount is enough to be used as a fuel resource even it is calculated with five percent dust for every cubic meter of MDF board.

Pencil Production

Pencils are one oldest writing tools know. It is produced and used in various shapes, size and colors. Before the invention of modern pencil, old civilizations were using pieces of lead to write on papyrus papers and [15]. After the discovery of graphite in fifteen century, and gluing of wood slabs in eighteen century, the current shape of pencil is born [15]. Pencil production divides into two parts; core production from powder compounds and body production from wood materials. Core production starts with a clay and graphite mixture [16]. The powder mixture is extruded to a mold to give its round shape and desired diameter. The extruded mixture is then cut to its required length to fit the wood slabs [16].

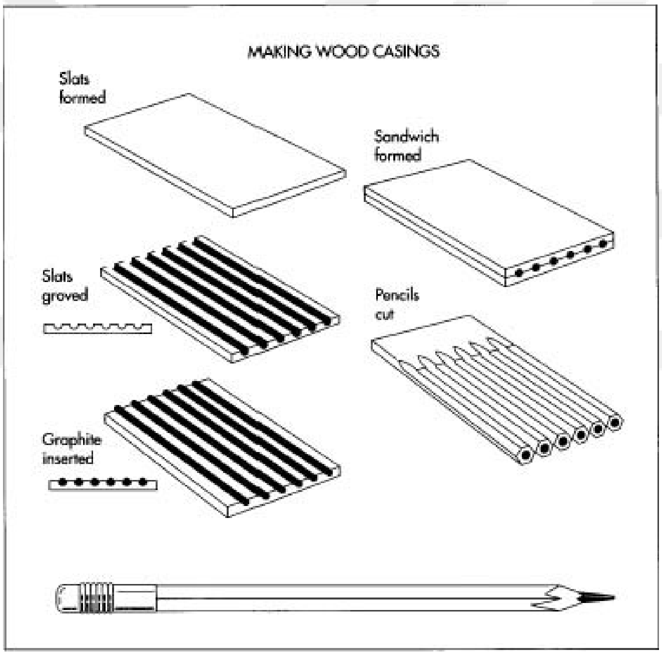

Figure 2.1: Pencil production steps.

Body of pencil is made from different woods. Wood choice is a company decision and characteristic however cedar and linden are the most common wood types [15]. At the beginning of production, wood slabs are cut to a half thickness of a pencil because later two half of slab will make one complete body. Then the slabs are grooved with a semicircular shape to fit the cores inside the grooves as seen in Figure 2.1 [16].

As a final step, graphite cores are fitted in the slab grooves and two slabs are glued and compressed. Glued parts are left to dry and then saw according to required shape [16].

Once pencil body is finished, the pencil tip is sharpened and takes its final form as seen in Figure 2.2 [15].

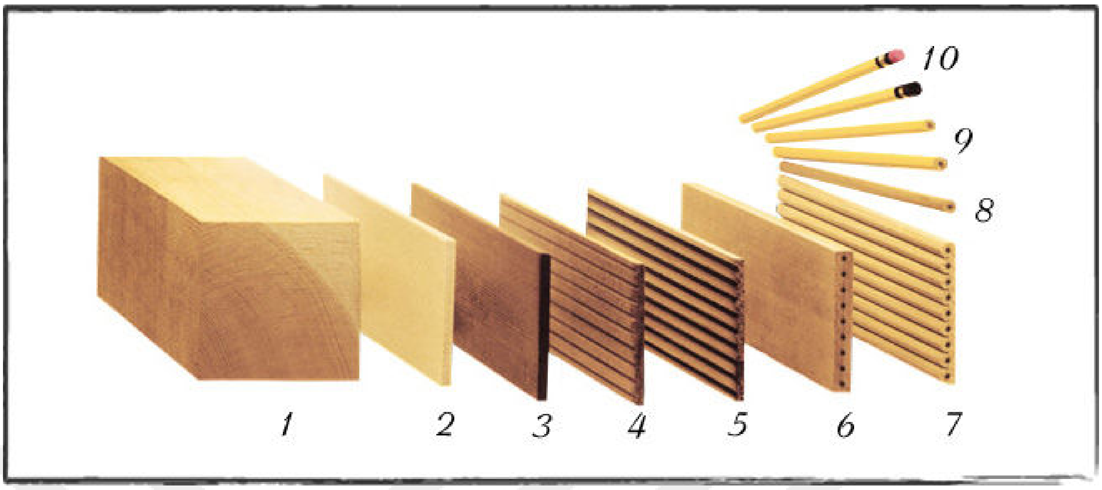

Figure 2.2: Slab production steps.

During each step of the slab production, a significant amount of wood is processed. The volume difference between wooden block and final pencil shape is the amount of generated shavings.

3. COAL

Coal

Since its discovery coal become one of the primary of energy source to civilizations, and it is used many different applications such as heating, cooking and metalworking. Proven coal reserve of the world is approximately 900.000 million tonnes and coal consumption is increasing every year [17]. Due to the increase of coal consumption, coal prices and near tripled over twenty years [17]. Nowadays, coal is mainly used for electricity generation, steel production, and cement manufacturing [17].

Coal is an organic formation that has heterogeneous properties and a complex structure [8]. Coal is mainly carbon-based material but due to its complex structure, other elements are found in it such as hydrogen, oxygen and sulfur [18]. Coal can be divided into two parts; macerals is the organic matter and minerals are the inorganic substances [8]. For each type of coal, macerals and mineral composition is different but the association between them shows a pattern that helps us define coal types [8].

Three hundred and sixty million years ago, surface and layers of the earth started to change, due to earth tectonic movements. Vegetation in swamps, which are located at surface, shifted to different layers earth crust and due to increasing temperature and pressure, they changed their structure, which lead to beginning of coal formation [18]. This era is called Carboniferous Period and it lasted more than seventy million years [18].

Coal properties changes according to pressure and temperature conditions it faced during time. All coal formation starts as a peat and organic matters are broken down to form coal structure. Cellulose is digested by bacteria and fungi to humic compound. Humic compounds are transformed by partial combustion or biochemical charring in order to form coal [8].

Coals ranks starts from peat that is soft and has brown to black colors. Peat transforms in to lignite, which is harder than peat and has a light black color. Lignite transforms into sub-bituminous coal and then to bituminous coal, and finally bituminous coal transforms into anthracite that has shiny black color. As coal transforms it structure changes, its fixed carbon content increases, and volatile matter percentage reduces. As the carbon content changes, the calorific value of coal also increases from lignite to anthracite, up to 8.500 kcal/kg as seen in Table 3.1 [8].

Table 3.1: Analytical data of different stages of coal formation.

Analytical Parameter	Peat	Lignite	Sub-bituminous Coal	Bituminous Coal	Anthracitic Coal
Moisture %	>75	38.7	31.2	3.7	1.0
Carbon, wt%	58.2	71.40	73.40	82.60	92.20
Hydrogen , wt%	5.63	4.79	4.86	4.97	3.30
Nitrogen, wt%	1.94	1.34	1.16	1.55	0.15
Sulfur, wt%	0.21	0.60	0.31	1.50	0.98
Oxygen, wt%	34.02	21.87	20.27	9.38	3.37
Heating Value (kj/kg)	23 500	28 500	29 400	30 600	35 700

Coal Processing

Coal processing starts with mining and there are two types of mining; surface mining or underground mining [19]. The decision of which type of mining will be used is determined by the geological and topographical conditions of coal seam [8]. In the general view of the world, underground mining is more commonly used [19]. For example, 80% of the mines in Australia and 67% of the mines in USA are underground mines [19].

After the mining process, gathered coal is not ready for use, because it includes different minerals and other compounds such as clay, sand, sulphur [8]. Cleaning of the mined coal is important to get rid of the all unwanted material, in order to increase its efficiency and help burning process [19]. Washing is a common method of cleaning coal. Washing process increase thermal properties, reduces waste material after burning, and lowers emissions [19]. The washing processes generate a by-product that is called coal slurry that consists coal particles and other minerals [8].

Coal Slurry

According to the desired requirements, coal passes from different process to achieve the standards. Some of the mined coal is used for heating and some of them is used for electricity generation [20]. Coal that is used for electricity generation undergoes several steps, so the ash content after burning is reduced and emissions levels are adjusted [21]. During the process of washing of coal, it generate a water and coal mixture called coal slurry.

Coal slurry is a by-product of coal mining and coal preparation process [20]. It includes fine coal particles, minerals and dirt from mining process [20]. Coal slurry is mixture of solid and liquid, it cannot be treated neither solid nor liquid, therefore it is not easy to transport [22]. Coal slurry is a dangerous substance because it does not decompose in time or biologically degrade [21]. One of the main issues of coal slurry is chemicals that are used during process of coal purification. These chemical are usually carcinogen and harmful to nature [20].

Coal processing plants produces considerable amounts of coal slurry each day. There are different ways to confine coal slurry. It can be stored in artificial lakes that are called impoundments. However, storing massive amounts of slurry can creates problems like overflows or damaging surrounding nature [23]. Another way of elimination coal slurry is injection method. Watering coal slurry eases the transport by pipelines, so it can be pumped to underground mines to be stored. In this method, coal slurry can leak to underground water reserves and pollute our potable water. In addition, the chemicals that are infused to coal slurry damages the soil, consequently natural life above it [23].

4. BRIQUETTING

Briquetting Methods

Briquetting is a method of compacting and compressing materials to obtain a compact, durable and stable form [24]. Briquetting has different methods and various preparation steps in order to produce desired form. Mainly there are 3 types of briquetting machines; hydraulic, mechanical and screw briquetting as seen in Figure 4.1 and 4.2 [25].

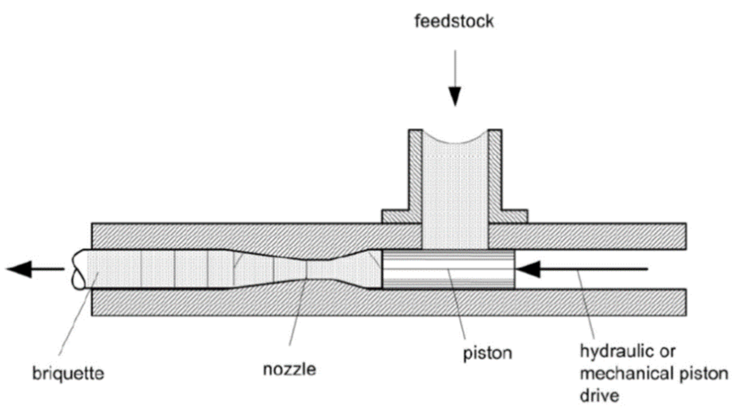

Figure 4.1: Hydraulic and mechanical press working principle.

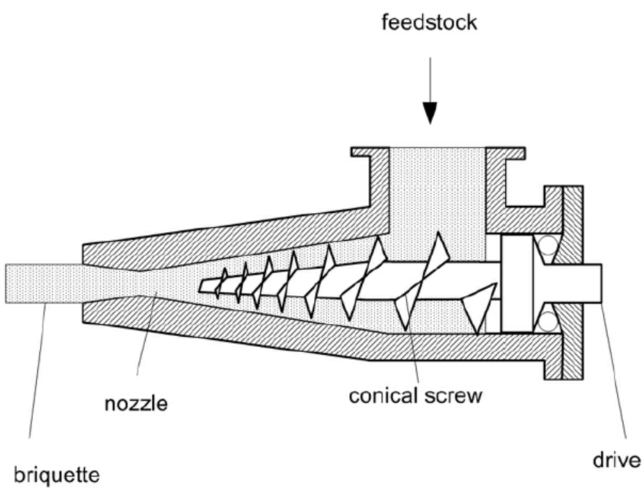

Figure 4.2: Screw press working principle.

4.1.1 Hydraulic briquetting machines

Hydraulic briquetting machines consist of a piston driven with a hydraulic power source and a metal die with the output shape. Material is fed into briquetting chamber and then compressed with hydraulic piston to the nozzle, passing through the metal die, the material is compacted and briquette is formed. Hydraulic briquetting method is commonly used in various industries due to its low operation costs and power consumption, an example machine shown in Figure 4.3 [25].

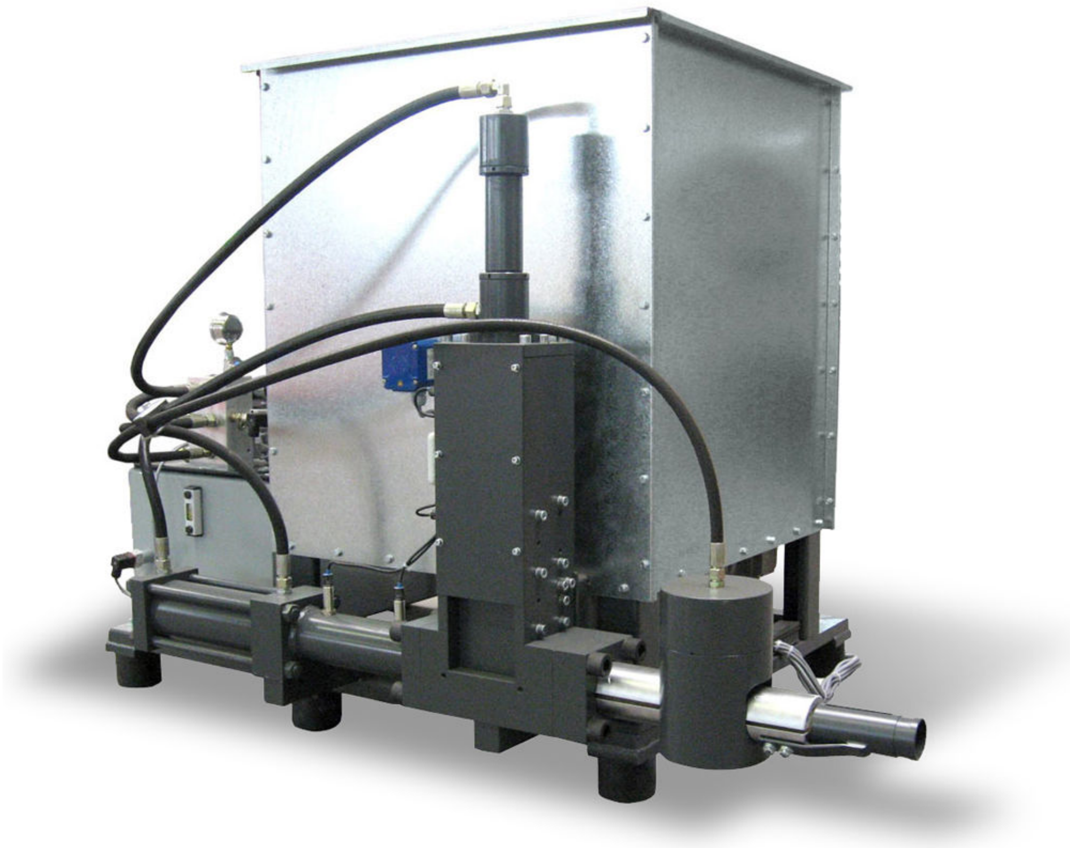

Figure 4.3: Hydraulic briquetting machine.

4.1.2 Mechanical briquetting machines

Mechanical briquetting is similar to hydraulic briquetting but instead of a hydraulic power unit, it uses an eccentric shaft to create pressure. Material is fed into briquetting chamber and with the power from the eccentric shaft; material is compressed to the nozzle. Mechanical briquetting presses are generally used in briquetting plants because of its high output capacities [25]. An example machine can be seen in Figure 4.4 [27].

Figure 4.4: Mechanical briquetting machine.

4.1.3 Screw briquetting machines

Screw briquetting machines with consists of a metal screw with an extended shaft and a nozzle to give shape to the briquettes. Material is fed on the screw and the screw pushes the material to the nozzle. Screw press are rarely used due to its high operations cost for spare parts and high power consumption to output ratio [27].

Advantages of Briquetting

Briquetting is a widely used process in every industry for different purposes. Briquetting can be used to create biofuels from agricultural wastes [28]. Or it can be used to reduce the volume of bulk material that will eventually reduce transport and storage costs [29]. Energy industry uses briquetting to increase density, reduce moisture content and increase calorific value [30]. Every industry has its own reasons to use briquetting and the potential of briquetting process is growing. The briquetting process is simple however; it has many factors that effect the quality of the final product. Some of the important factors are preheating, moisture, particle size, shape, binders, temperature [31]. All of these factors are aiming to obtain better briquettes for specific conditions, therefore some of them are effective to some materials and some of them do not make any difference to adjust [31].

Similar Briquetting Studies

Baolin produced coal briquettes without any binder and testes the results of different briquetting conditions such as pressure, temperature and pretreatment on briquette quality. The results showed that the pressure applied for briquette production increased compressive strength of briquette. At 150°C, optimum briquetting strength is achieved. Optimum strength of briquette is obtained when the moisture content of the coal is between 14–16%. Briquette strength is higher if the particle size is lower than 125µm. [32]

Felix researched about the potential of biomass briquetting in Brazil. The study showed the potential of wood briquettes as an alternative fuel from economical perspective. Only 12% of the total wood residues are briquetted, therefore a small percentage of the potential is used. The market of wood briquettes is developing with customers such as restaurants, bakeries and brick factories [33].

Gürbüz Beker mixed lignite coal and agricultural and wood residues with molasses as a binder. The ratio was 80-88% lignite, 12-20% residues such as sawdust, sunflower shell and paper wastes and 8% of binder. The results were satisfying, mechanical strength of the briquettes were adequate [34].

Demirbaş researched factors such as compressive strange, calorific value, combustion behaviors effecting quality of briquettes from sawdust and pulp reject. The results showed that briquettes produced at 350 MPa and 15% moisture content had compressive strength 49.5 MPa [35].

Debdoubi from Morocco produced briquettes from esparto, which has a low moisture content due to its nature. To increase the heating value they applied pyrolysis, consequently reduced the volatile matter, and increased strength of the briquettes. The study showed that combustion characteristics of briquettes resembled of coal properties because of pyrolysis [36].

5. EXPERIMENTAL STUDIES

Samples

5.1.1 Coal slurry

Coal slurry is obtained from Amasra Coal Facilities. After washing of the coal, the water is collected at the bottom, in a tank. During time, a small amount of moisture evaporates, and leaves a sludge. Coal slurry sample were first dried at 110°C to reduce the moisture content. After drying, the samples are sifted through a 250 µm fine mesh to obtain consistent particle size as seen in Figure 5.1.

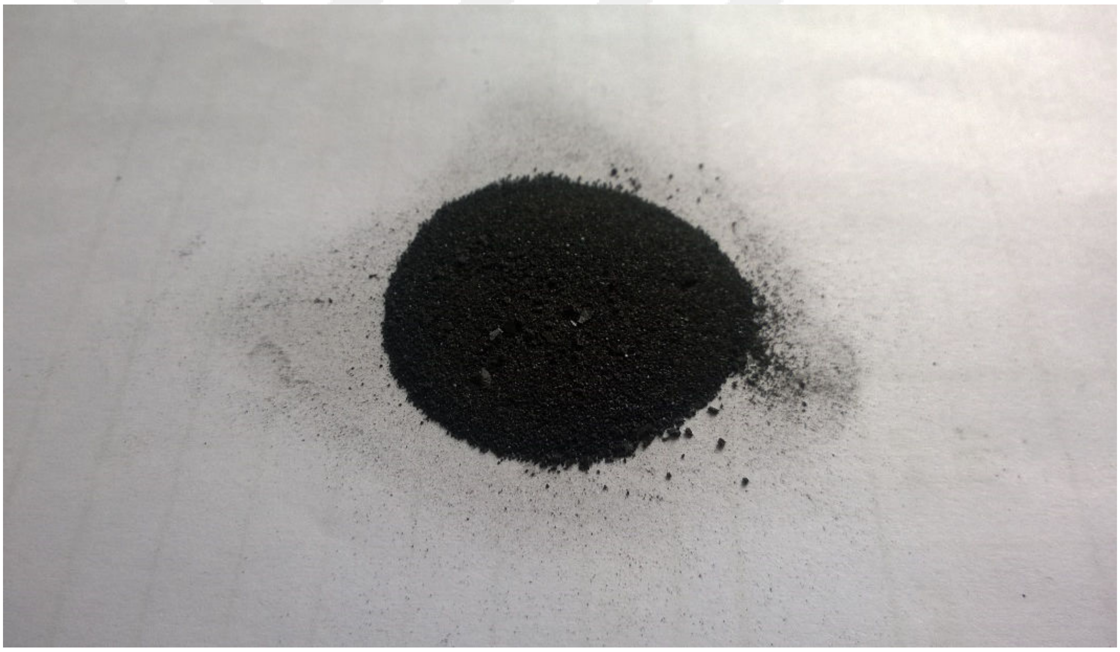

Figure 5.1: Coal slurry.

5.1.2 Pencil shavings

The biggest pencil manufacturer in the Turkey produces 150 million pencils per year. Pencil production starts with linden tree slabs. Slabs are grooved and divided into separate pencils. Factory has a dust collection systems and a storage silo where the dust generated during these steps are collected.

During the process of pencil processing, traces of graphite core is also collected in the storage silo. Our samples are collected from their storage silos. Samples are first milled and then sifted in a 250 µm fine mesh to obtain a consistent particle size as seen in Figure 5.2. Linden tree that is used in the production is already dry, so further drying was not necessary.

Figure 5.2: Pencil shavings.

5.1.3 MDF Dust

MDF is the most common used particleboard type in Turkey. Most of the furniture producers use MDF as a material. Our samples are collected from a local furniture producer. Panel saw machines generates dust at every cut as seen in Figure 5.3.

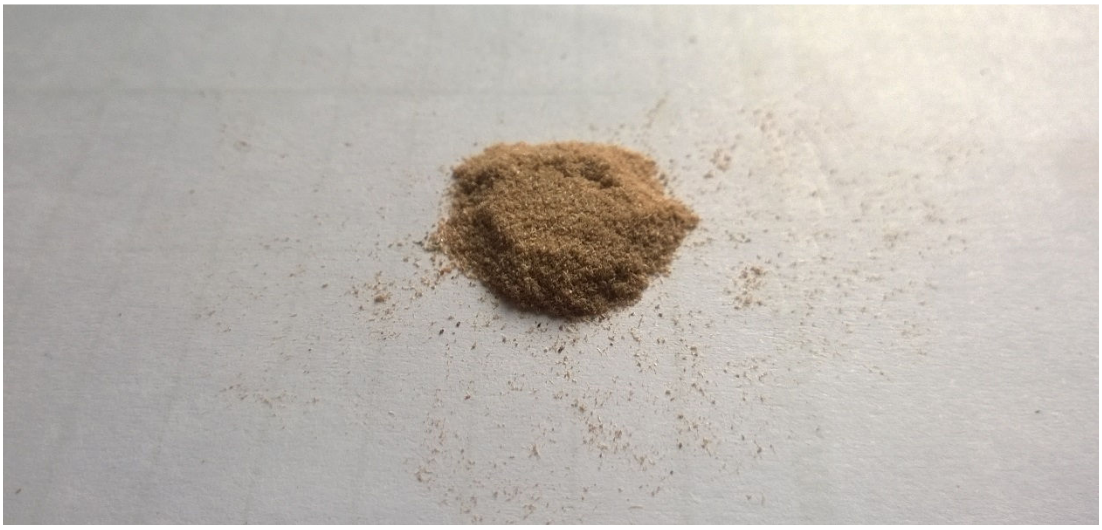

Figure 5.3: MDF dust.

Experimental Equipment

5.1.4 Elemental analysis equipment

Elemental analysis are made with a Leco TruSpec® CHN model analyzer with an S module as seen in Figure 5.4. All the samples are prepared to be tested properly and results are compared.

Figure 5.4: Leco TruSpec® CHN model with a Leco TruSpec® S module.

5.1.5 Calorimeter

Calorific value of the samples obtained by using an IKA C2000 Basic Calorimeter as seen in Figure 5.5.

Figure 5.5: IKA C2000 basic calorimeter.

5.1.6 Proximate analysis equipment

Proximate analyses are made by using SDT Q6000 analyzer equipment as seen in Figure 5.6. All the samples are tested for combustion, proximate and nitrogen analysis. For every sample TG, DTG, DSC and DTA analysis are conducted.

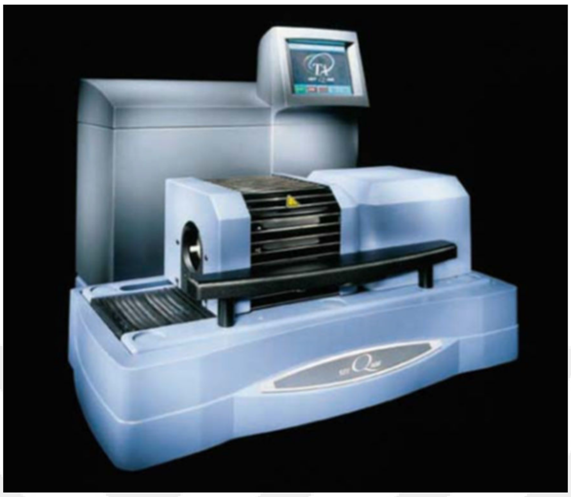

Figure 5.6: SDT Q6000 analysis equipment.

5.1.7 Briquetting equipment

Briquettes are produced by using metal die in a Maekawa lab scale hydraulic press as seen in Figure 5.7.

Figure 5.7: Maekawa lab scale hydraulic press.

Carbonization Process

5.1.8 Tube furnace

For the carbonization process, a vertical tube furnace is used as seen in Figure 5.8. Temperature and gas flow are important, therefore during the experiment, we monitored the gas flow, and temperature constantly to ensure the experiment result to be accurate.

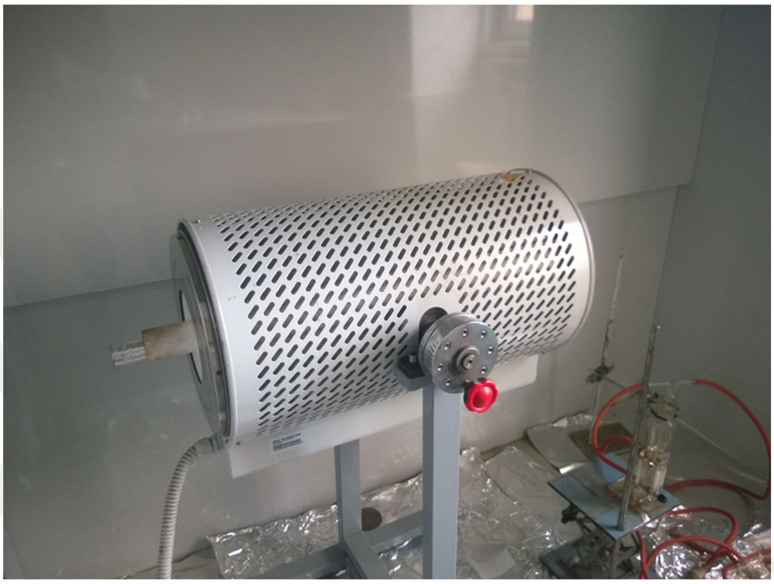

Figure 5.8: Tube furnace.

5.1.9 Carbonization of the samples

Pencil shavings and MDF dusts are sifted through a 250-µm fine mesh and then placed in vertical tube furnace. Carbonization experiment is carried out under nitrogen atmosphere. Nitrogen is fed to the furnace at a rate of 100 cc/min. The process start by heating the samples 40°C/min rate up to 600°C. When the furnace temperature reaches 600°C, temperature kept stable for 2 hours and then left for cooling. Raw and carbonized samples are given in Figure 5.9 – 5.12.

Figure 5.9: Pencil shavings.

Figure 5.10: Carbonized pencil shavings.

Figure 5.11: MDF shavings.

Figure 5.12: Carbonized MDF shavings.

6. RESULTS AND DISCUSSIONS

Calorific Value Analysis

Each sample is tested in a calorimeter to obtain its calorific value according to ASTM standards [37]. Coal slurry calorific value determined as 4114 kcal/kg, which can be seen at Table 6.1. To increase the calorific value of coal slurry, carbonization process is applied however; the calorific value of coal slurry is decreased 32% down to 2793 kcal/kg. The results showed that carbonizing coal slurry is not efficient; therefore, it is decided to use coal slurry without any carbonization.

Calorific value of pencil shavings and MDF dust is determined with the calorimeter and their calorific values were respectively 4263 kcal/kg and 4296 kcal/kg. Carbonization is applied both of the samples and results were satisfying. Pencil shavings calorific value is increased 79% and reached 7669 kcal/kg. MDF dust calorific value is increased 64.5% and reached 7070 kcal/kg as seen in Table 6.1. Both of the sample showed good calorific value increase after carbonization, therefore instead of using the raw samples, it is decided to use the carbonized samples. Since carbonization of coal slurry is not efficient, carbonized pencil shavings and carbonized MDF dust will be mixed with unprocessed coal slurry.

Table 6.1: Calorific value analysis results of the samples.

Samples	Gross Calorific Value (kcal/kg)
Coal Slurry	4114
Carbonized Coal Slurry	2793
Pencil Shavings	4263
PSC	7669
MDF Dust	4296
CMD	7070

Elemental Analysis Results

Each of the samples are analyzed in elemental analysis machine according to ASTM standards [38] [39]. The results can be seen in Table 6.2. Before carbonization process, highest carbon content can be seen in coal slurry sample. After carbonization PSC, carbon content increases 75% and up to 86.12%. MDF dust carbon content was 48.19% and after carbonization, it increased 72% reaches up to 83.23%. Higher percentage of carbon is increase is determined in pencil shavings.

Hydrogen content determined in pencil shavings and MDF dust samples are respectively 6.22% and 6.10%. After carbonization, hydrogen content of pencil shavings is reduced to 2.49%, showing a decrease of 60%. MDF dust showed a similar behavior and its hydrogen content reduced to 2.54% with a decrease of 58% as seen it Table 6.2.

Oxygen content of pencil shavings sample is determined as 38.31%. After carbonization, oxygen content is reduced to 10.49% showing a decrease of 72%. Oxygen content of MDF dust is determined as 40.99%, and after carbonization, oxygen content is reduced to 9.34% showing a decrease of 77%. As seen from table 6.2, oxygen content of CMD has the lowest ratio between our samples.

Nitrogen contents of pencil shavings and MDF dust determined respectively 0.01% and 4.38% as seen in Table 6.2. After carbonization, nitrogen content of pencil shavings is increased to 0.46%, which might be caused from nitrogen atmosphere pyrolysis process. Nitrogen content of MDF dust is increased to 4.43%, which shows a small increase less than 1%. Sulfur content of pencil shavings showed a very small change after carbonization as seen from Table 6.2. However, sulfur content of the MDF dust showed 25% increase after carbonization.

Table 6.2: Elemental analysis results of the samples.

Experiment Samples	Elemental Analysis (%)				
	C	H	O	N	S
Coal Slurry	58.79	3.36	36.41	0.73	0.71
Pencil Shavings	48.97	6.22	38.31	0.01	0.45
PSC	86.12	2.49	10.49	0.46	0.44
MDF Dust	48.19	6.10	40.99	4.38	0.34
CMD	83.23	2.54	9.34	4.43	0.46

Proximate Analysis Results

Proximate analyses of the samples are determined according to ASTM standarts as seen in Table 6.3 [40]. Highest moisture content can be seen in MDF dust as 7.68% and lowest moisture contents can be seen in coal slurry as 1.81%. The reason of coal slurry has a 1.81% moisture content is because it is dried before analysis. Pencil shavings had a 6.33% moisture content but after carbonization moisture, content is reduced to 1.72%. Moisture content of the pencil shavings shows a 72% decrease that is what is expected after carbonization process. In addition, MDF dust moisture content was 7.68% before carbonization and it decreased down to 5.41%.

Volatile matter of the samples can be seen Table 6.3. Coal slurry volatile matter content is 24.80% that is the lowest of our samples. Pencil shavings and MDF dust volatile matter contents are respectively 77.88% and 89.70%. After carbonization volatile matter content of pencil shavings increased to 82.08% with a change of 5%. Volatile matter of MDF dust is decreased from 7.68% down to 5.41% with a decrease rate of 29% as seen in Table 6.3.

Ash content of coal slurry is the highest of our samples with 38.03%. The reason of high ash content is washing process of coal where the coal particles mixed with various inorganic matters. Ash content of the pencil shavings is 5.66% and after carbonization, it reduces to 4.29%. MDF dust nearly has no ash content before and after carbonization.

Highest fixed carbon content is determined in coal slurry with 35.36% as seen from Table 6.3. Fixed carbon content of pencil shavings is 10.13% and after carbonization increases to 11.91% with a rate of 10%. However fixed carbon content of MDF dust increases from 2.61% to 19.57%.

Table 6.3: Proximate analysis results of the samples.

Experiment Samples	Moisture Content %	Volatile Matter %	Ash Content %	Fixed Carbon %
Coal Slurry	1.81	24.80	38.03	35.36
Pencil Shavings	6.33	77.88	5.66	10.13
PSC	1.72	82.08	4.29	11.91
MDF Dust	7.68	89.70	0.01	2.61
CMD	5.41	75.02	0.01	19.57

6.1.1 Coal slurry TG and DTG results

As seen from Figure 6.1 and 6.2, maximum weight loss occurred between 400°C and 650°C. Moreover, maximum weight loss rate occurs at 638°C with rate of 11.38%.

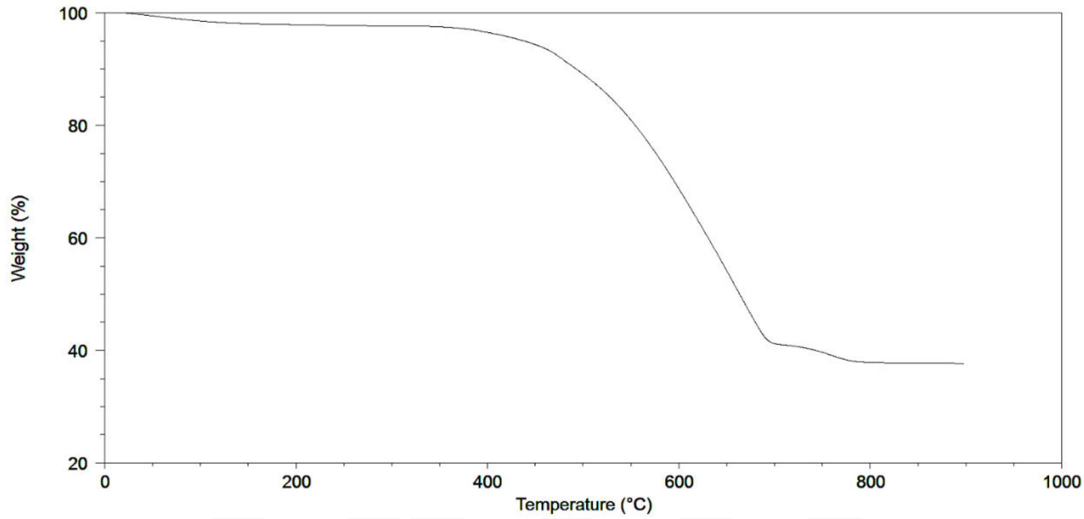

Figure 6.1: Coal slurry TG results.

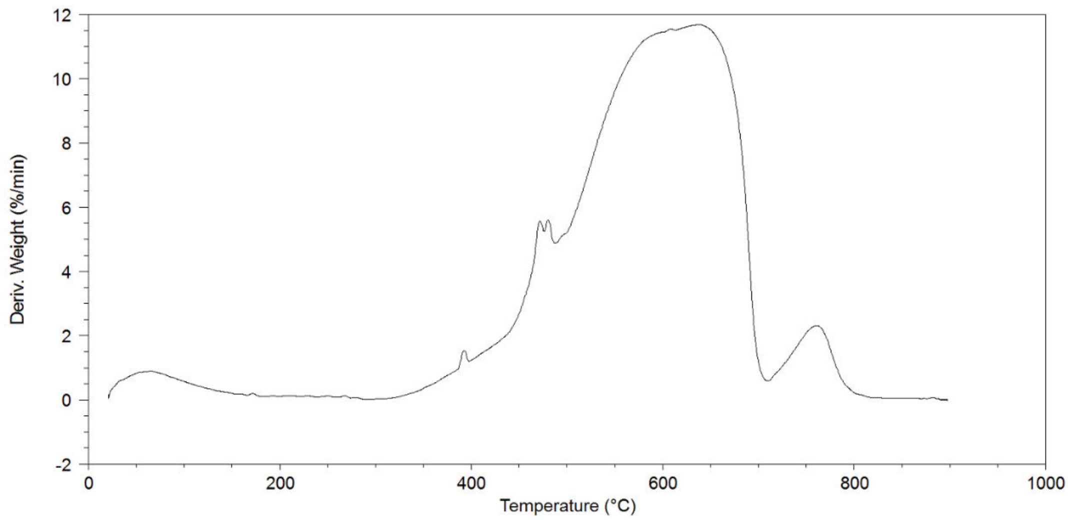

Figure 6.2: Coal slurry DTG results.

6.1.2 Coal slurry DSC and DTA results

As seen from Figure 6.3 and 6.4, the reaction is exothermic and volatile matter and fixed carbon burning peaks are merged.

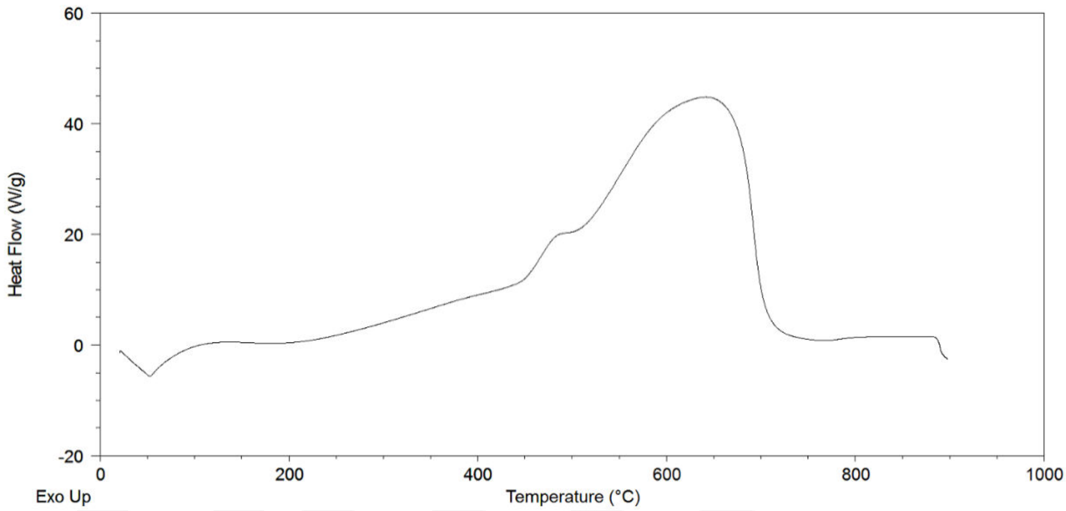

Figure 6.3: Coal slurry DSC results.

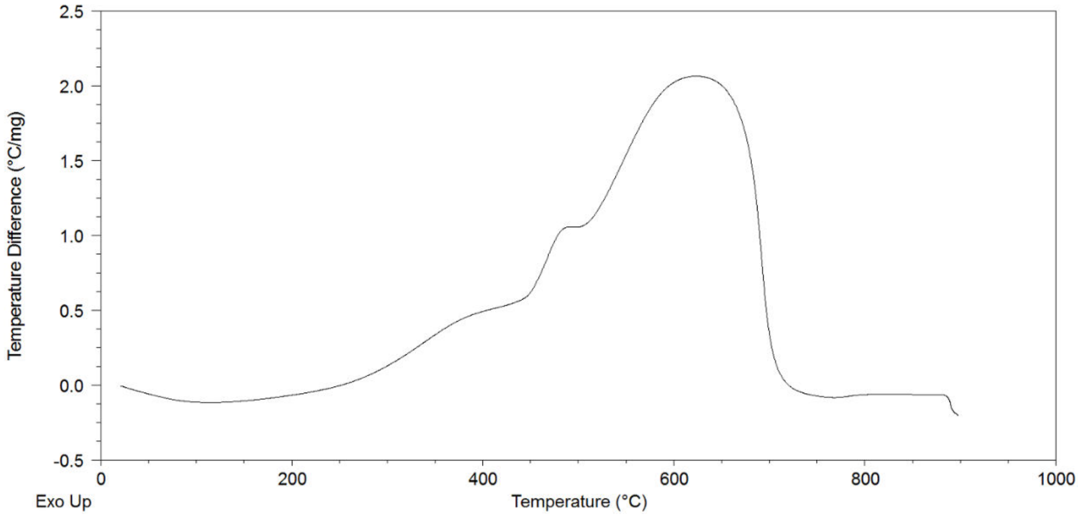

Figure 6.4: Coal slurry DTA results

6.1.3 Pencil shavings TG and DTG results

As seen from Figure 6.4 and 6.5, maximum weight loss occurred between 300°C and 450°C. Moreover, maximum weight loss rate occurs at 348°C with rate of 66.39%.

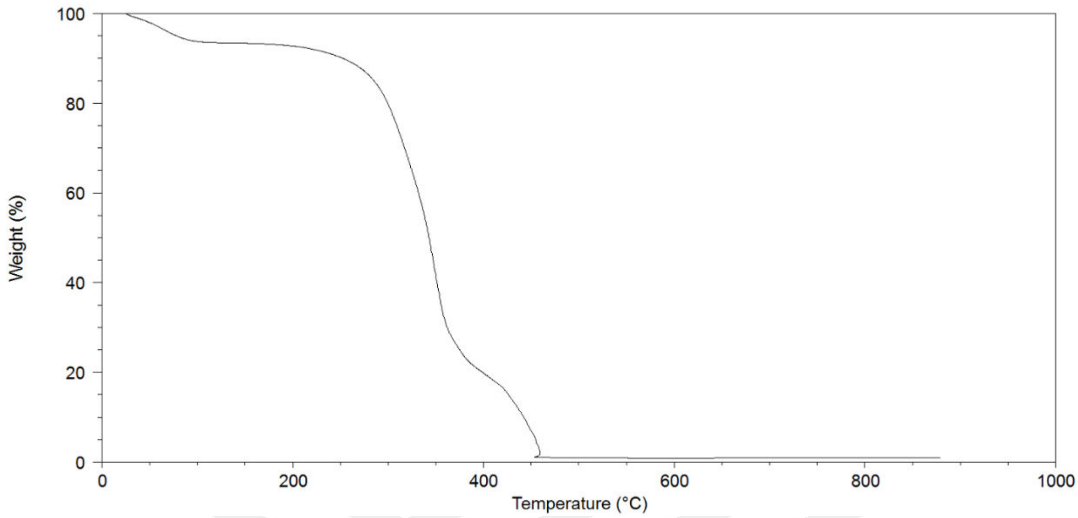

Figure 6.5 : Pencil shavings TG results.

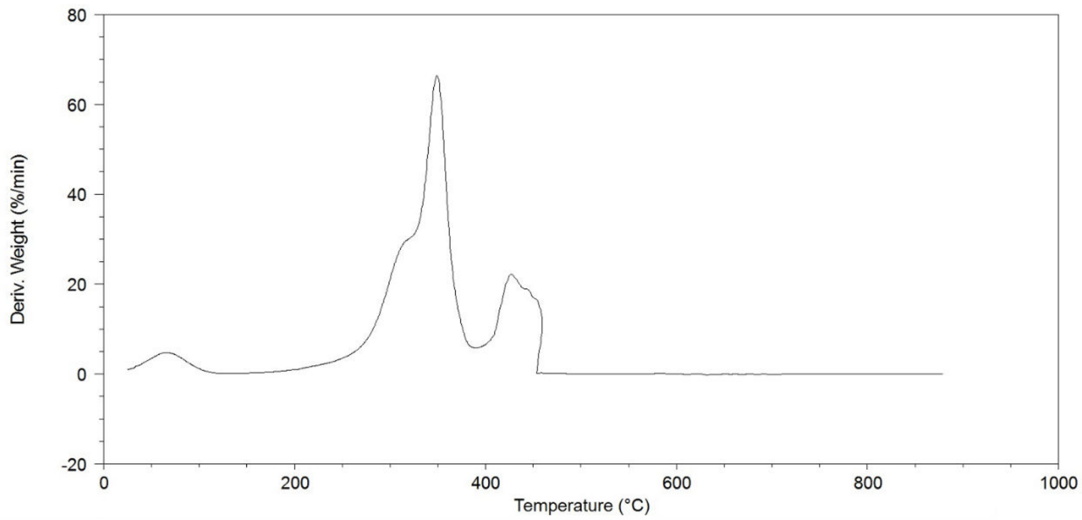

Figure 6.6 : Pencil shavings DTG results.

6.1.4 Pencil shavings DSC and DTA results

As seen from Figure 6.7 and 6.8, the reaction is exothermic and volatile matter and fixed carbon burning peaks can be seen separately.

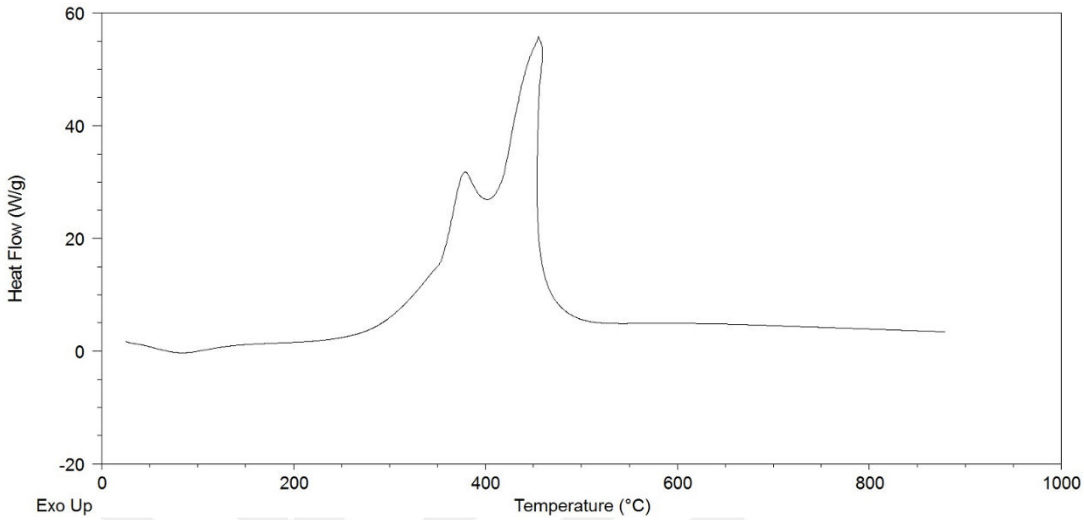

Figure 6.7 : Pencil shavings DSC results.

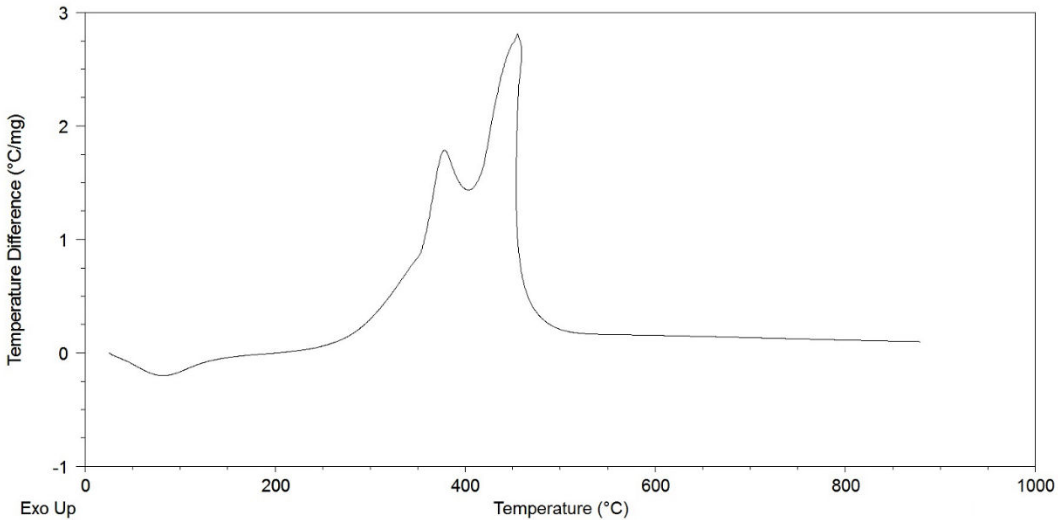

Figure 6.8 : Pencil shavings DTA results.

6.1.5 Pencil shavings charcoal TG and DTG results

As seen from Figure 6.9 and 6.10, maximum weight loss occurred between 400°C and 550°C. Moreover, maximum weight loss rate occurs at 390°C with rate of 26.27%.

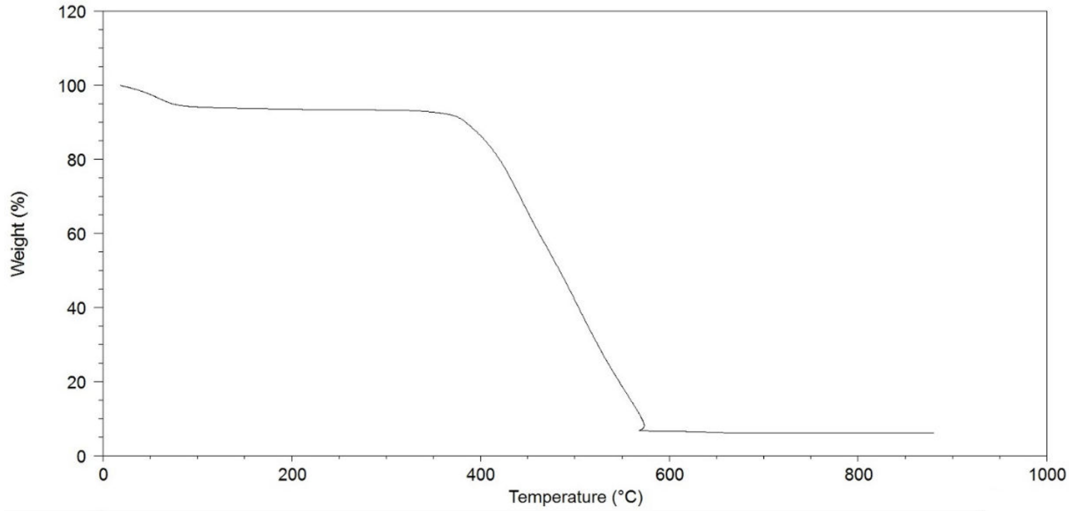

Figure 6.9 : PSC sample TG results.

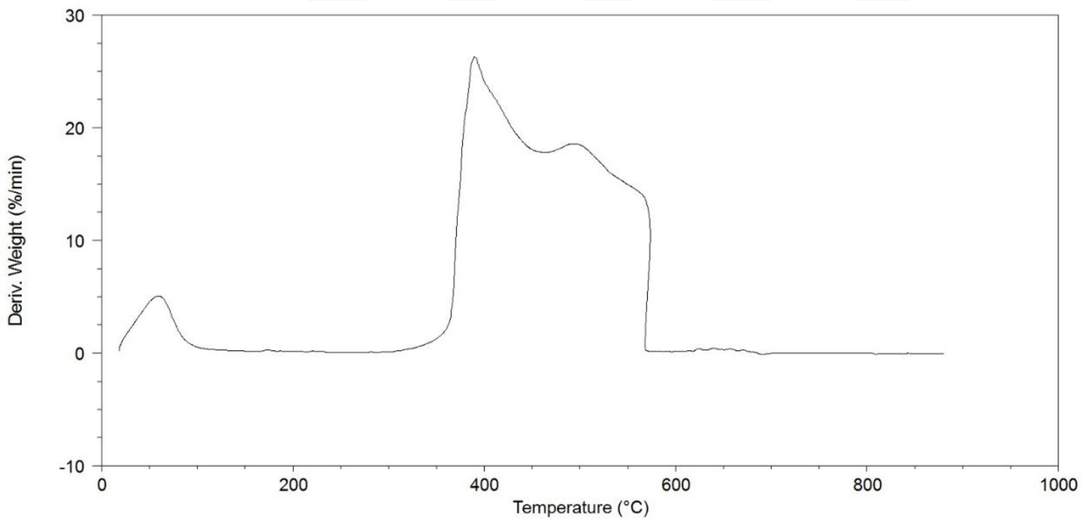

Figure 6.10 : PSC sample DTG results.

6.1.6 Pencil shavings charcoal DSC and DTA results

As seen from Figure 6.11 and 6.12, the reaction is exothermic and volatile matter and fixed carbon burning peaks are merged.

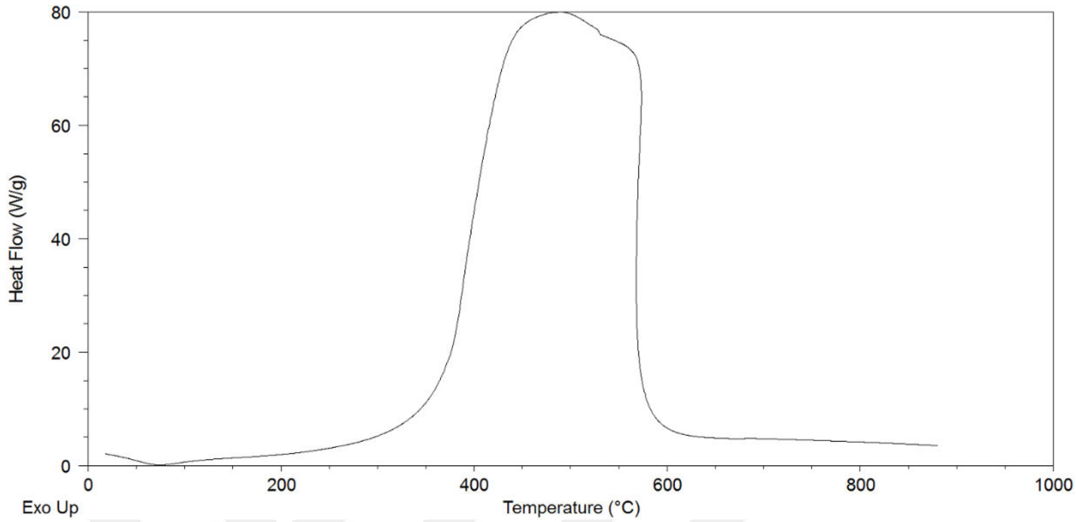

Figure 6.11 : Carbonized Pencil Shavings DSC results.

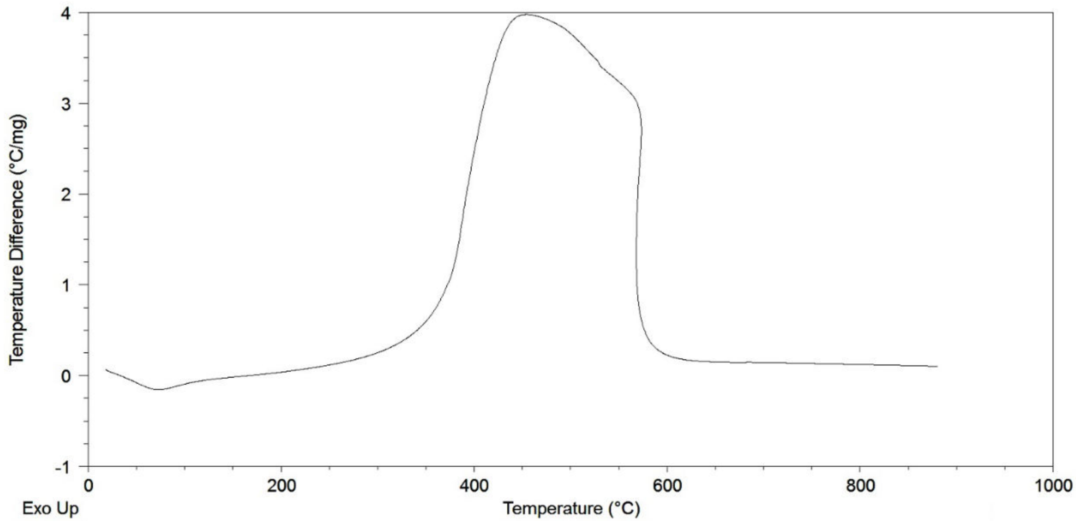

Figure 6.12 : Carbonized Pencil Shavings DTA results.

6.1.7 MDF dust TG and DTG results

As seen from Figure 6.13 and 6.14, maximum weight loss occurred between 200°C and 450°C. Moreover, maximum weight loss rate occurs at 355°C with rate of 49.8%.

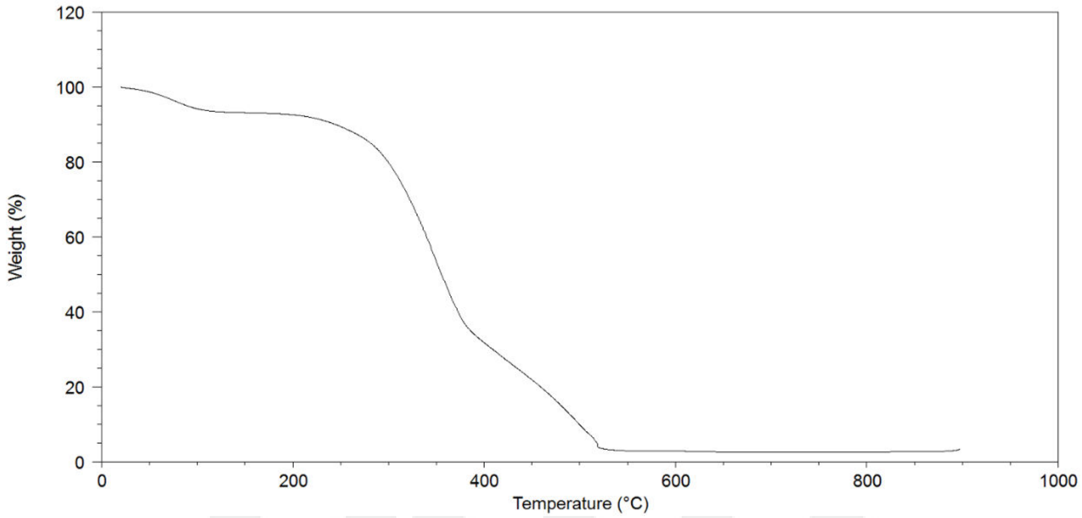

Figure 6.13 : MDF dust TG results.

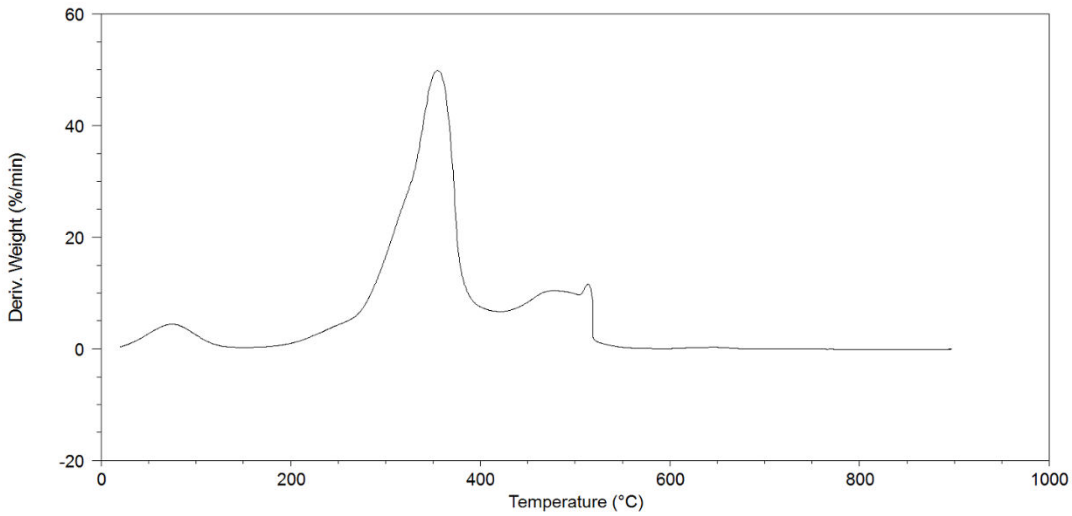

Figure 6.14 : MDF dust DTG results.

MDF Dust DSC and DTA results

As seen from Figure 6.15 and 6.16, the reaction is exothermic and volatile matter and fixed carbon burning peaks can be seen separately.

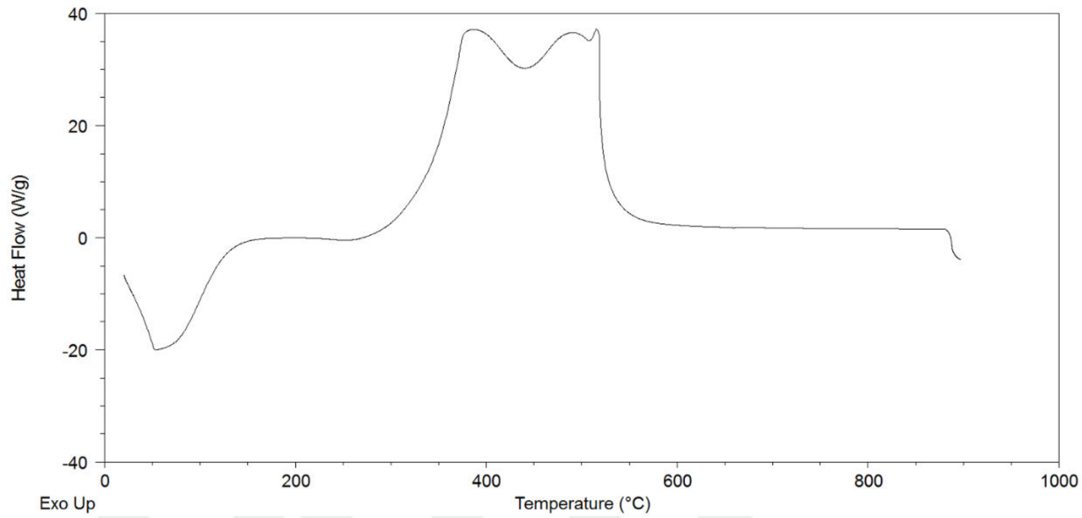

Figure 6.15 : MDF dust DSC results.

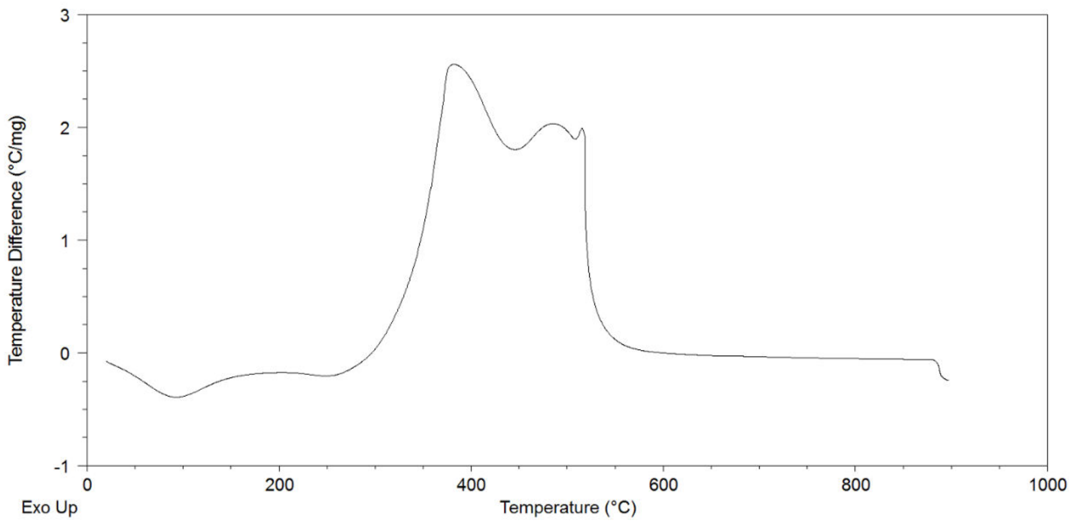

Figure 6.16 : MDF dust DTA results.

Carbonized MDF dust TG and DTG results

As seen from Figure 6.17 and 6.18, maximum weight loss occurred between 350°C and 550°C. Moreover, maximum weight loss rate occurs at 555°C with rate of 16.82%.

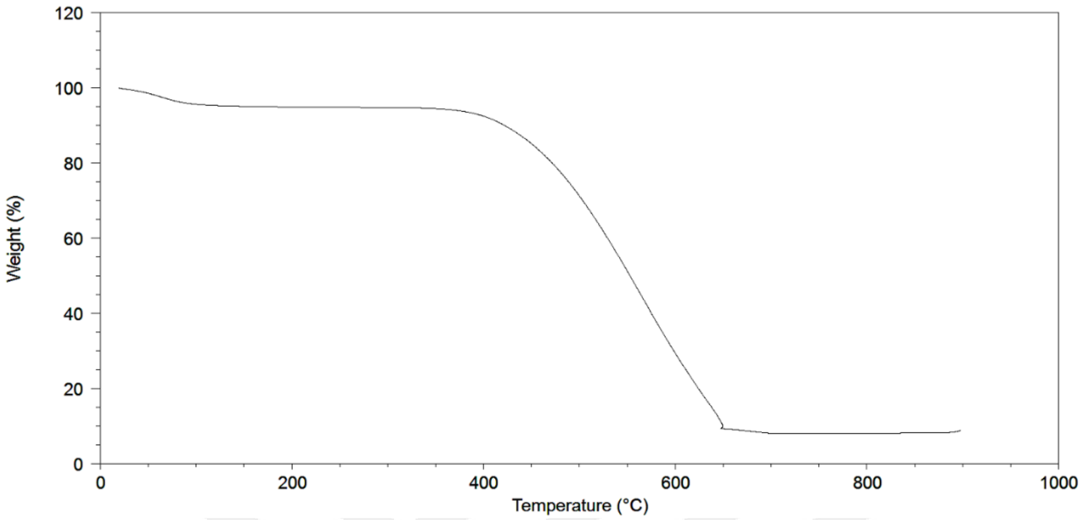

Figure 6.17 : CMD sample TG results.

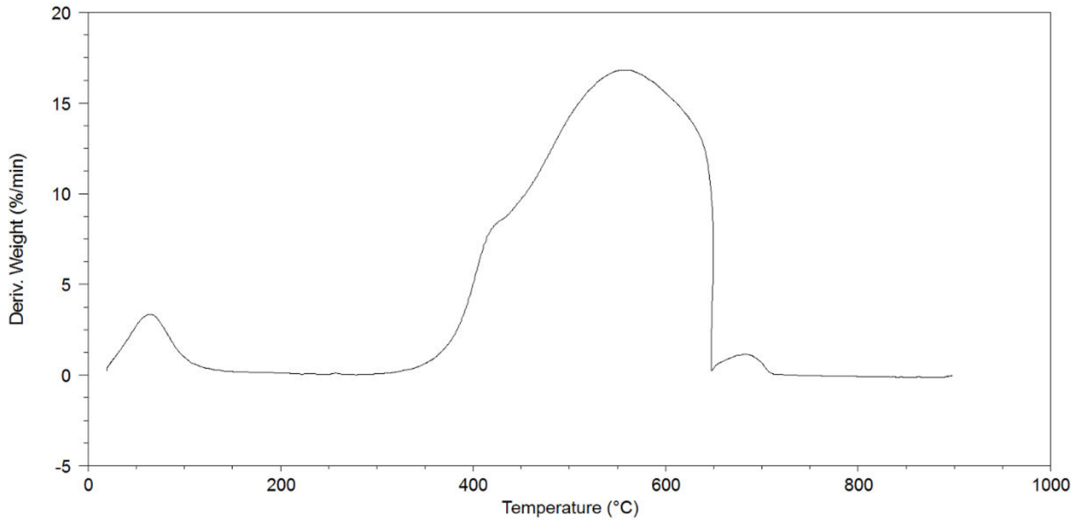

Figure 6.18 : CMD sample DTG results.

6.1.8 Carbonized MDF dust DSC and DTA results

As seen from Figure 6.19 and 6.20, the reaction is exothermic and volatile matter and fixed carbon burning peaks are merged.

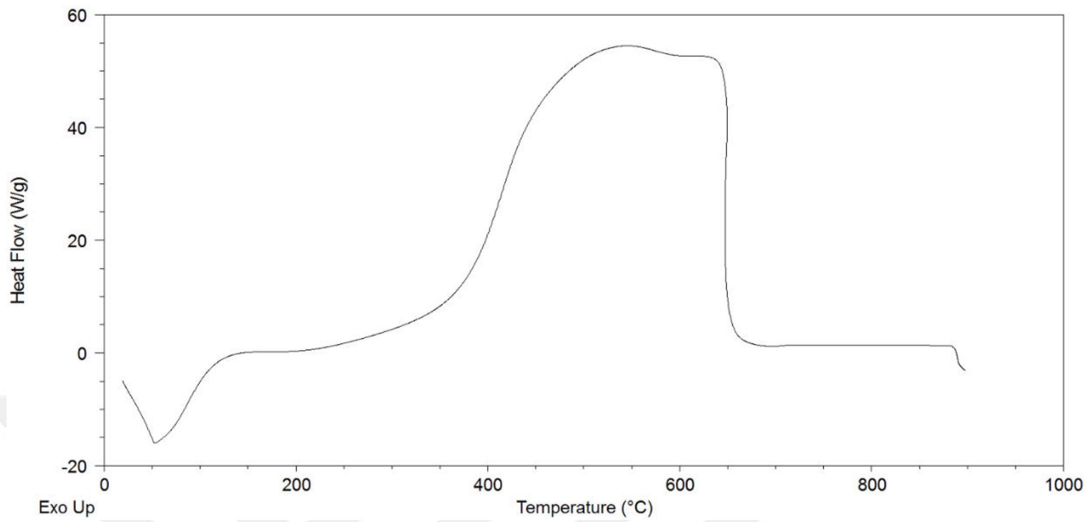

Figure 6.19 : CMD sample DSC results.

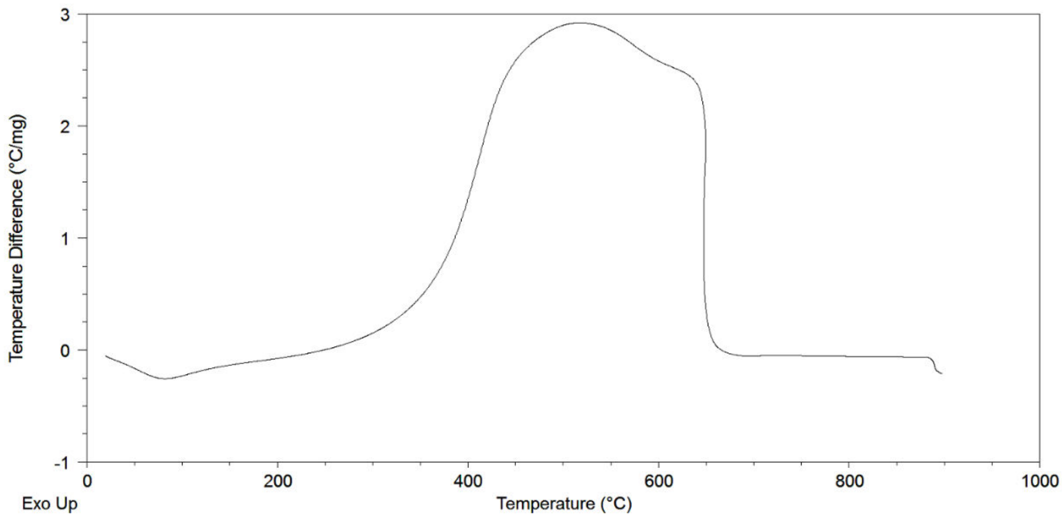

Figure 6.20 : CMD sample DTA results.

Briquetting Process

Briquette production is done manually with a lab-scale hydraulic press by using a die and a metal rod modeling a shaft. Briquetting process is conducted to meet TS 12055 standards [41]. Briquettes are produced at 10 MPa pressure, which was the limit for visible quality briquettes. Five different types of briquettes are tested during production. Regarding the calorific value of the samples, coal slurry is mixed with carbonized biomass samples to produce higher calorific value briquettes.

First, coal slurry is briquetted alone to see its characteristics and observe the changes when the other samples are added. At 5 MPa, it was not possible to make coal slurry briquettes; it was destroyed as the briquette left the die. When the pressure is increased to 10 MPa, it was possible to make briquettes as seen in Figure 6.21.

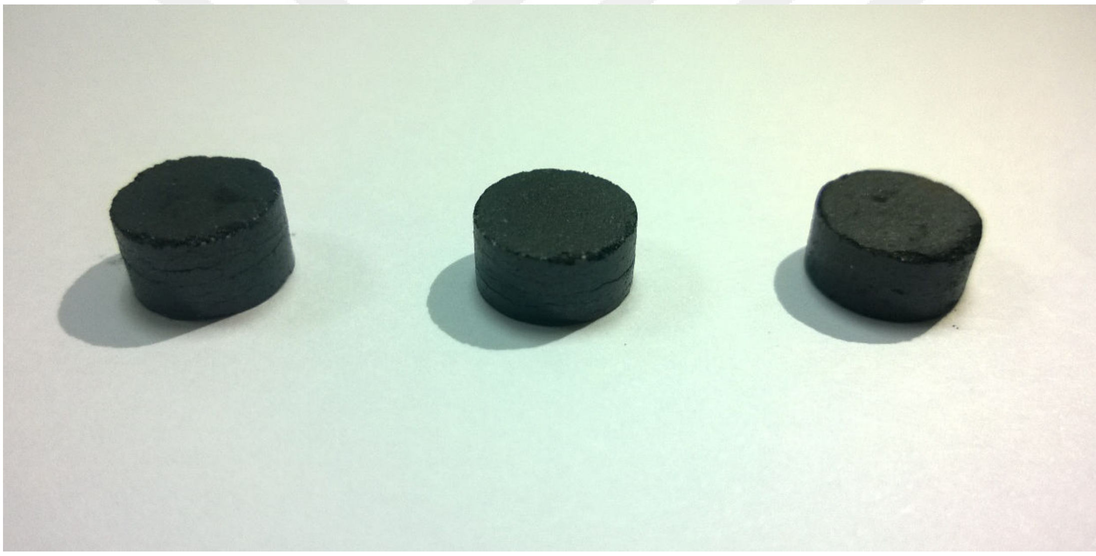

Figure 6.21 : 100% Coal slurry briquettes.

After 100% coal slurry briquettes, 10% pencil shaving and 90% coal slurry is tested. At 5 MPa, it was possible to make briquettes, but at 10 MPa, it was possible to make briquettes as seen in Figure 6.22. To increase the calorific value, 20% pencil shaving and 80% coal slurry is tested, but even at high pressures 10 MPa, it was not possible to obtain strong briquettes.

Figure 6.22 : 90% Coal slurry, 10% CPW briquettes.

Same procedure is repeated for CMD and coal slurry. First 10% CMD and 90% coal slurry is tested at 5 MPa. The problem was the same with the pencil shavings briquettes; it was dissolved as soon as it is taken out from metal die. The pressure is increased to 10 MPa and it was possible produce briquettes as seen in Figure 6.23. To increase the calorific value, 20% percent CMD and coal slurry is tested. At 5 MPa and at 10 MPa, it was not possible to produce briquettes. The limit was the same for CMD, after 10%, briquettes were dissolving.

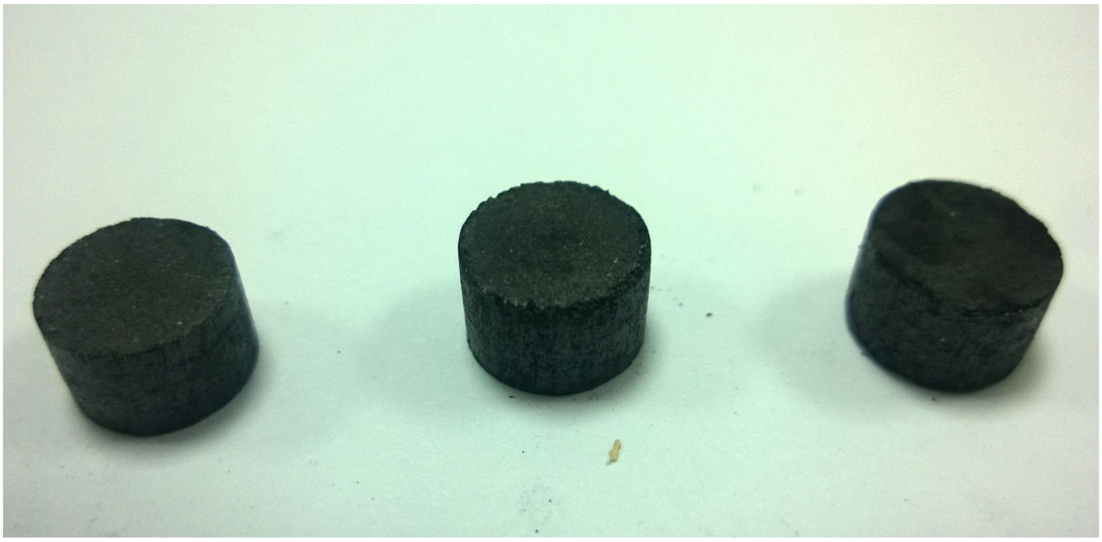

Figure 6.23 : 90% Coal slurry, 10% CMD briquettes.

As a last step, in order to test the briquetting characteristics of selected biomass, pencil shavings are tested for briquetting. 100% pencil shaving are tested at 5 MPa but the result were the same, it was not possible. Consequently, at 10 MPa it was possible to obtain briquettes from the pencil shavings as seen Figure 6.24.

Figure 6.24 : 100% Pencil shavings briquettes.

Briquette Quality Tests

6.1.9 Compressive strength test

Compressive strength of the briquettes are tested in a digital load analyzer according to ASTM standards. Briquette samples are placed between two metal plates and compressed with a constant increasing load until the briquettes starts to crack as seen in Figure 6.25. The pressure at break point noted as compressive strength.

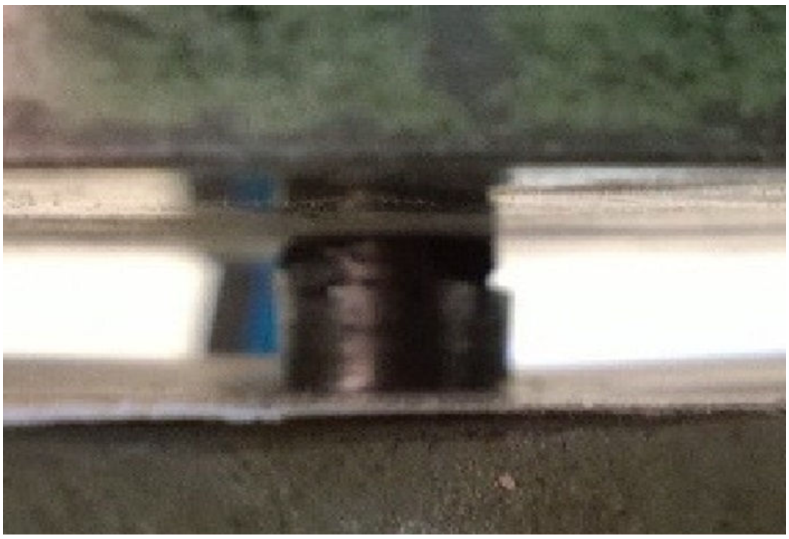

Figure 6.25 : Compressive strength test.

Table 6.4 : Compressive strength test results.

Briquette Samples	Compressive Strengths (MPa)
% 100 Coal Slurry	275
%90 Coal Slurry + %10 CPW	65
%90 Coal Slurry + %10 CMD	310
%100 Pencil Shavings	630

Due to its homogenous structure and fibrous composition pencil shavings briquettes showed the highest compressive strength. Also coal slurry and CMD mixture was higher than the 100% coal slurry briquettes.

6.1.10 Water resistance test

In order to test the water resistance properties of the briquettes accorindg to ASTM standard, briquettes are submerged in to water. Each briquette is observed separately and time is kept to see the dissolving time as seen in Figure 6.26. The time passed until dissolving is noted as water resistance.

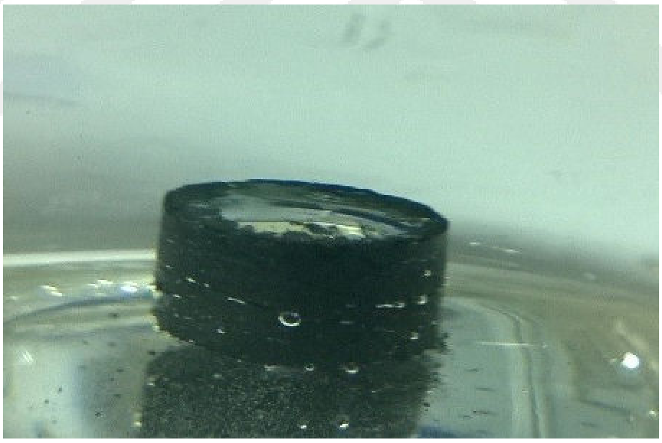

Figure 6.26 : Water resistance test.

Table 6.5 : Water resistance test results.

Briquette Samples	Resistance Time (s)
% 100 Coal Slurry	2950
%90 Coal Slurry + %10 PSC	44
%90 Coal Slurry + %10 CMD	11
%100 Pencil Shavings	195

Coal slurry briquette lasted more than 45 minutes in the water as a highest resistance. Pencil shaving briquettes was the second with 195s. However, briquettes made from mixture of pencil shavings or MDF dust could not resist a minute.

7. CONCLUSION AND RECOMMANDATIONS

In this study, briquetting of coal slurry with pencil shavings and MDF dust are investigated. Recommendations and obtained results are noted below:

- Coal slurry sample obtained from Amasra coal facilities is investigated. Carbonization of coal slurry sample is not efficient because after carbonization calorific value is reduced from 4114 kcal/kg to 2793 kcal/kg.
- Coal slurry sample sifted through a 250µm mesh cannot be briquetted at 5 MPa pressure, however it can be briquetted at 10 MPa.
- Coal slurry has a high ash content because coal slurry is the waste fluid that is used in washing process of coal in order to reduce coal ash content. Consequently, briquetting of coal slurry and pencil shavings or MDF dust will reduce final ash content.
- Among our samples, highest calorific value is obtained at pencil shaving charcoal.
- After carbonization process, it is noted that pencil shavings and MDF dust did not showed a notable change at their sulfur content (less than 1%). Therefore it can be concluded that carbonization of the samples do not have an effect on sulfur content.
- After carbonization process, highest percentage change of carbon content can be seen in pencil shavings with a ratio of 75%.
- It is expected that after carbonization process of wood wastes, hydrogen and oxygen contents should decrease due to reduced volatile matter and moisture content however, pencil waste volatile matter content be increased. It is assumed that the reason is the other materials used during pencil production.

- It was expected that briquettes from coal slurry and wood shavings adhere and stick together [42]. As the ratio of the wood waste increased briquettes became softer.
- The entire tests are conducted according to ASTM standards. Water resistance test showed that homogenous briquetting of the coal slurry and pencil waste results in better briquette quality.
- Compressive strength test showed that briquettes from mixture of coal slurry and pencil shavings or MDF dusts, have lower compressive strengths than 100% coal slurry or pencil shavings briquettes.
- Briquettes made from coal slurry and pencil shavings can reduce $S0_x$, $N0_x$ emissions during combustion due to pencil shavings low nitrogen and sulfur content [43].
- Briquettes from coal slurry and pencil shaving or MDF dust mixtures did not match TS 12055 standards. However, briquettes solves storage and transport problem of samples. Therefore, it can be concluded that briquetting is advantageous for these samples.
- It is noted that increasing briquetting pressure is increasing briquette quality. In this study, it can only be tried pressures up to 10 MPa due to lab scale equipment.
- Binder can help achievieng better quality briquettes [44]. No binder is tested during briquetting process. For further researches, briquetting of these samples with a binder can be investigated.

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