Sieve Analysis and Determination of Grain Size Distribution of Coal for Identifying Ideal Sieving Time When Performing Coal Beneficiation Using Gravity Separation

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Abstract
The beneficiation of coal through gravity separation plays a key role in industry, allowing for particle size distribution determination and separation of coal into various sizes for future combustion in boilers, and separation of impurities. For a complete combustion an industrial suspension boiler using bituminous coal requires an average particle size of 45μm and 80 to 85% of particles to be less than 200mesh. This size requirement varies depending on the type and size of boiler and the rank of coal being used; a fixed bed (stoker) combustion method requires an average particle size of 0.25in, a fluidized bed requires an average particle size of 0.04in, a suspension combustion method requires an average particle size of 45μm. The purpose of this experiment was to determine the ideal amount of time for a sieve shaker to run, in order to achieve a more accurate reading of particle distribution for combustion in a common industrial suspension boiler or determine if another type of boiler may be ideal, based on size distribution. This size distribution was found using sieve analysis, passing a known quantity of coal through sieves of decreasing size using various durations (5, 10, 15, and 20 min) in a sieve shaker; then measuring the quantity of coal left in each sieve and calculating the percentage of coal that fell between that sieve size. For each time period, little variability between particle distributions below the average grain diameter of 0.1in was found, leading to the conclusion that 5 min of sieve shaking was necessary for extraction of particles for usage in suspension boilers for power generation. This was only roughly 2±0.1% of the coal sample, leading to the conclusion that more comminution would be required to achieve a larger usable amount. Roughly 38±0.8% of the coal sample would be suitable in a fluidized bed boiler, which suggested that this level of comminution was suitable for fluidized combustion. A fixed bed boiler required an average size of 0.25in, which was outside of the range of average size measured by the sieves used. However, it is safe to assume that less than 20±2% would be usable in fixed bed boiler.

Introduction
The beneficiation of coal promotes homogeneity in the size of pulverized coal after comminution, as well as helping with the separation of impurities that result in ash and sulfur production when coal is burned. (1-2) One method of beneficiation is gravity separation via the screening of coal particles through sieves of decreasing size. (1) Depending on boiler type and combustion method, a different particle size of coal may be required for efficient combustion; a fixed bed (stoker) combustion method requires an average particle size of 0.25in, a fluidized bed requires and average particle size of 0.04in, a suspension combustion method requires an average particle size of 45μm with typically less than 2% by weight greater than 50 mesh (300μm), 60 to 70% less than 200mesh (74μm) for lignites and subbituminous coals, and 80 to 85% less than 200mesh for bituminous coals. (3) An expected pyritic sulfur reduction after beneficiation of a ICO coal can range from 22 to 72%, an ICO coal also has been known to show a reduction in ash yield of 78% after beneficiation. (1) In industry, the separation of coal sizes and resulting homogeneity of size at each separation after beneficiation allows for the coal to be effectively and efficiently utilized, while also reducing ash and sulfur output upon combustion. (1-2)
The experiment was conducted using a batch sieve shaker and U.S.A. Standard and Tyler sieves to separate a known amount of a representative sample of coal. Using varying durations of gravity separation, the ideal sieve shaker time was determined and the

Theory
To perform a gravity separation via sieving, the coal sample must be riffled first. The purpose of riffling coal is to obtain a representative sample of the coal, this is in order to maintain reproducibility to make the experiment as repeatable as possible. (12) Riffling works by separating a sample into smaller portions that are combined into one gross lot for analysis, the number of stages of riffling depends on the size of the sample, the larger the sample, the more stages the sample will have to undergo. (12) The difference between Tyler and U.S.A. Mesh designations is the wire size used in each sieve type, resulting in a different gap size, the difference in gap size can be found in Figure 1. (11) Round and square openings of mesh holes also factor in to correction of size, as a square opening is 1.25 times as large as a round opening. Using these sieves and correction factors, an analysis may still be rejected if the percentage mass loss or gain after analysis is over 2%. (11)

Methods
There is no way to practically reproduce this experiment due to the variability of each split of coal due to transportation, handling, and the method in which the coal is obtained. (11) Riffling the coal sample three times in order to obtain a representative sample of coal. Placed roughly 200g of coal into series of U.S.A. Standard and Tyler sieves descending in size (4, 8 [Tyler], 16, 30, 50, 100 [Tyler], 200, 400, -400 [left over]). Placed sieves in sieve shaker for 5, 10, 15, and 20 minute durations in order to separate coal and determine difference in distribution based on duration. Weighed contents of each individual sieve to determine percentage of coal lying within sieve size, which was then used to determine particle size distribution.
Results and Discussion

When comparing distributions after gravity separation, little variability in the fraction of coal in each sieve was found, especially at smaller sizes below 0.1 in, as seen in Figure 2. Variability between the graphs begins around an average grain diameter of 0.1 in, the largest variability was found at higher sizes around 0.14 in, ranging from 22% at 20 minutes to 26% at 5 minutes. This implies that after a longer period of time, more grains were able to pass through the largest sieves, allowing for a more accurate distribution. However, in an industrial setting, this level of accuracy may not be necessary, as each graph is extremely similar below average diameters of 0.1 in. This lack of necessity for accuracy is especially true when average grain sizes of 45 μm are concerned, like in bituminous suspension boilers, which are the most common in power generation. Therefore, a 5 minute sieving may be suitable for industrial power generation purposes, as longer gravity separation will most likely cost more money and time, for a small amount of accuracy in a size range that is not of concern in most cases. However, only about roughly 2 ± 0.1% of this coal would be suitable for combustion in a suspension boiler, as seen in Figure 3, more comminution would be required to achieve a larger usable amount. Roughly 38 ± 0.8% of this coal would be suitable in a fluidized bed boiler, suggesting that this level of comminution is adequate for fluidized combustion purposes. It is unclear how much of this coal would be suitable for combustion in a fixed bed boiler, as a fixed bed boiler requires an average size of 0.25 in, which was outside of the range of average size measured by the sieves used. However, it is safe to assume that less than 20 ± 2% would be usable in fixed bed boiler.

![Figure 2: Graphs illustrating the average grain size distribution of coal on a regular (a) and semilog (b) scale, after 5, 10, 15, and 20 minutes of time in the sieve shaker.](image-url)
Conclusions
The objective of this experiment was to determine the amount of time necessary for a sieve shaker to run to achieve a more accurate reading of particle distribution for combustion in a suspension boiler; alternatively, if a suspension boiler size distribution was not the dominant size distribution found in this coal, determination of which boiler may be ideal for the majority size based on size distribution was carried out. It was found that only about roughly 2±0.1% of this coal would be suitable for combustion in a suspension boiler, meaning that it was not the dominant size distribution and another boiler would be better suited for the majority of this coal. Roughly 38±0.8% of this coal would be suitable in a fluidized bed boiler, which suggested that most of this coal could be used for fluidized combustion. A time of 5 minutes was determined adequate for gravity separation in the power generation industry, especially dealing with suspension boilers, as most of the variability was seen in higher sizes around 0.14 in, ranging from 22% at 20 minutes to 26% at 5 minutes. When dealing with boilers that require an average size of 0.14 in or above, such as a fixed bed boiler, longer durations of gravity separation may be beneficial to improve accuracy in measurements. Alternatively, if suspension boilers are mainly what the coal is used for, a longer comminution may result in finer pulverization of coal particles and higher small particle yields when separated.

Separate Answers to Provided Questions
1) Coal beneficiation is the treatment of coal to provide homogeneity in size and the separation of impurities that may result in sulfur and ash production when the coal is burned. (1-2) This can be done in a variety of processes, the most common of which is gravity separation by screening macro particles through sieves of varying size. (1) Methods that are more suited for microscopic particle impurities are froth flotation, and oil agglomeration in conjunction with chemical comminution. (1) In froth flotation hydrophobic coal particles are separated from hydrophilic minerals by passing the pulverized coal through water with air bubbles that attach to and separate the hydrophilic minerals. (1) In oil
agglomeration coal particles are selectively coated and agglomerated by fuel oil and separated again by screening. (1) Chemical comminution may prove more effective than mechanical comminution as it can remove impurities using anhydrous ammonia to fragment coal along the boundaries between coal and mineral matter. (1) Beneficiation is valuable industrially due to the need to consistently and homogeneously meet size requirements and preferences in combustion, based on boiler type and combustion method. (2-3) Beneficiation will also reduce the sulfur and ash of a coal after it is burned, due to the separation of impurities, resulting in less combustion byproducts. (1-2) In general, a fixed bed will require an average particle size of 0.25 in, a fluidized bed will require an average size of 0.04 in, and a suspension boiler will require an average particle size of 45 μm. (3) An expected pyritic sulfur reduction after beneficiation of a ICO coal can range from 22 to 72%, an ICO coal also has been known to show a reduction in ash yield of 78% after beneficiation. (1) This large reduction in sulfur and ash content further displays the value and necessity of beneficiation.

2) Biochar is the fine-grained porous form of carbon produced by the combustion of biomass in oxygen lean conditions. (4) Biochar is typically formed by slow pyrolysis at a slow heating rate, and low peak temperature of 450°C to 500°C when the biomass is combusted. (4) Generally, around 35% of the mass of a feedstock will be converted to biochar by this process, the remainder resulting in 30% bio-oil and 35% syngas. (4) The highly porous structure of biochar makes it ideal for addition to soil for agricultural purposes, in order to improve water retention, increase soil surface area, cation exchange capacity, nutrient retention and plant growth. (4-5) Biochar can also be used to help rehabilitate contaminated wetlands and manage and avoid algal blooms in aquatic ecosystems by absorption of chemicals and nutrients respectively. (4) The benefits of soil addition, coupled with its long term stability in soil, make biochar an ideal candidate for carbon sequestration. (5) Turning organic matter into biochar also decreases emission from soil by lowering the rate of decomposition, the CO₂ emission from soil decay exceeds the emissions created by pyrolysis within a few months time. (4)

3) In proppant sands, the size range and regularity of the shape of particles is an important factor, due to its influence on the permeability throughout the fracture. (8) Having a controlled and narrow particle size distribution will increase the conductivity of the fracture, leading to a greater flow of oil or gas up out of the well. (8) A typical proppant size ranges between 8 and 140 mesh, with acceptable ranges from 16-30 mesh, 20-40 mesh, 30-50 mesh, 40-70 mesh, and 70-140 mesh. (8)

4) A biorefinery is a plant, similar to a petroleum refinery, that produces fuels, power, and chemicals from a biomass feedstock. (6) To do so, biomass must first be prepared and treated using biochemical or thermochemical conversion. (6-7) In biochemical conversion the lignocellulosic materials in biomass (lignin, cellulose, and hemicellulose) are broken down using enzymes or chemical processes and fermented to form ethanol. (7) Pretreatment of the feedstock involves heating to break down cell walls to allow for ease of hydrolysis, hydrolysis releases the sugars for fermentation, and fermentation renders the sugars into alcohol over time. (9) In thermochemical conversion biomass is broken down in the absence of air using heat and pressure in the presence of catalysts to form syngas, bio-oil, and biochar. (7) The resulting syngas can be combusted for heat and power, biochar may be used in co-combustion with coal or may be used in agricultural applications, bio-oils may undergo catalyzed reaction to produce alcohols, which can then be distilled in to ethanol for use as fuel. (5, 10)
References


