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Review

Potential of Coal–Water Slurries as an Alternative Fuel Source during the Transition Period for the Decarbonization of Energy Production: A Review

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Abstract: Coal–water slurry or coal–water mixture (CWS or CWM) is a complex solid–liquid dispersion. Several research works have been done concerning the production and use of CWSs being developed worldwide in several different governmental, industrial and academic facilities. In the present paper, studies on the developments achieved in the past three decades with regard to the field mentioned above are systematically reviewed, with particular regard to several different aspects during the combustion process. The structure and properties of the coal are highlighted, as are the different additives used and their adaptability with different types of coal, where the particle size distributions are of great importance in determining both the slurryability of coal and the rheological behavior of a produced CWS for its intended characteristics. At a time when there is much debate about the end of the age of coal as a primary source of thermal and electrical energy, alternative forms of use that can contribute to the reduction of pollutant emissions, as well as particles, in the atmosphere offer alternatives that may allow us to continue using coal, at least during this transition period until a viable alternative is found. In-depth knowledge of these coal slurries may allow, in the future, the development of similar products produced from fuels derived from biomass, such as charcoal or torrefied biomass.

Keywords: decarbonization of energy production; coal–water slurry; coal–water mixture; rheological behavior

1. Introduction

One of the most significant scientific challenges presently is to generate power in the most efficient and economical way possible. To fulfill this objective, several different techniques for using fuels in solid, liquid, and gaseous forms have been developed [1]. The first oil crisis in the 1970s attracted widespread interest in coal conversion technologies. The aim of these studies was to replace oil with coal. Subsequently, several in-depth research studies were conducted, with emphasis on coal gasification, liquefaction, and combustion. On the other hand, together with these studies, recently, many studies were also conducted on coal–liquid mixtures, which are also called coal–liquid slurries [2]. Many of these production technologies are already commercially available. Coal–liquid mixtures are widely presented as an alternative to oil consumption, and for this reason, their market position is entirely linked to oil prices [3]. A typical coal–water slurry or mixture (CWS or CWM) is formed from the following [4]:

- 50–75% of coal, with a maximum particles size of approximately 300 μm;
- 25–50% of water;
- 1% of additives, such as dispersants or surfactants.

However, when a finely ground coal is mixed with water, the behavior of the resulting slurry flow can vary, changing the solid particle concentration and the interfacial properties of the water. An ideal CWS with a higher coal load must present static and dynamic stability, as well as low viscosity [5].

The atomization will also affect the rheological behavior of a CWS in a power plant furnace. The efficient use of a CWS is only possible when the slurry is prepared to allow a maximum solid load with higher viscosity and maintains a uniform concentration. Therefore, to study whether a particular CWS is suitable to be used as a fuel, rheological studies of the slurry must be conducted beforehand [6].

Nowadays, fast-growing energy consumption worldwide makes the efficient and cleaner use of coal a necessity. With the actual increment of mining mechanization and washing processes, large amounts of fines are available and can provoke serious environmental problems if not properly managed [7]. Several different uses of these coal fines can be identified as the following:

- Direct combustion;
- Briquette production;
- Fuel slurry production.

CWS is an option to be used as a fuel alternative for power production, and the interest in its use is related to economic, logistic, and technological factors. A CWS has several advantages over the common use of micronized coal, one of which is that it can be transported through pipelines over long distances. Obviously, it is necessary to meet several safety requirements during the process; however, its use is justified even from an environmental perspective, since this fuel emits less sulfur and nitrogen oxides. No special conditions are required for storage or transport, so loading and unloading costs are virtually nonexistent. Thus, this option presents itself as an excellent alternative to heavy oil, which can be replaced by CWM [8].

2. Coal

Coal is formed from biomass of terrestrial origin through the combination of a number of biological, physical, and chemical processes, controlled by factors such as temperature and pressure, over time. Transformations caused by the carbonization processes during the period of time in which this occurs determine their classification in the carboniferous series, which begins with peat, goes on to lignite, sub-bituminous coal, bituminous coal and, finally, anthracite. The relative amounts of moisture, volatile matter, and fixed carbon content vary throughout the carboniferous series. Moisture and volatile matter decrease with increasing degree of carbonization in the inverse ratio of the increase in carbon content [9]:

- Peat is not yet considered a coal and is used as a fuel in some regions, notably in Northern Europe, such as Scotland or Germany. When dehydrated, peat can be used as an absorbent to contain fuel and oil spills. It is also used in agriculture, where it is incorporated into soils to fix and release water slowly.
- Lignite is considered the lowest grade coal and has a heating value that can vary, depending on the humidity, between 9.5 and 19.3 MJ/kg.
- Sub-bituminous coal usually has a heating value within the range of 19.3 to 30 MJ/kg and usually has more moisture, with a fixed carbon content of 35% to 45%.
- Bituminous coal is formed when lignite is subjected to an increase in temperature and pressure. It has a heating value that varies between 25 and 60 MJ/kg. Bituminous coal is the coal most used in the production of electricity and in the iron and steel industry. It has a fixed carbon content of 45% to 86%.
- Steam coal is a coal that is between bituminous and anthracite types and was once widely used as fuel for steam locomotives for trains.
- Anthracite is formed when the pressure and temperature in the carbonization basin are very high. It presents a dark black tint with a metallic luster. It has a heating value close to 60 MJ/kg and has a fixed carbon content between 86% and 97%.

3. Coal–Water Slurries

The mixture of solids and liquids is called slurry. Physical properties of these slurries depend on factors such as size and distribution of the particles, concentration of solids, agitation of the mixture, temperature, and viscosity of the carrier. Water is the most used fluid, but several mineral and vegetable oils, or even biodiesel or alcohol, can also be used [10].

The progressive increase in the price of oil, the difficulties associated with the stability of supply, the growth in consumption and the limited reserves have led to an increase in interest in coal, which remains cheap, abundant, and widely distributed throughout the world. For these reasons, many studies regarding the use of coal slurries as an alternative fuel have been carried out. Coal slurry fuels can be separated into different categories, depending on the type of liquid used to mix the solid coal particles, for example, CWS (coal–water slurry), COS (coal–oil slurry), COWS (coal–oil–water slurry), CMS (coal–methanol slurry), and CMWS (coal–methanol–water slurry) [11].

Among these, CWS can be considered as being the one with the higher economic viability and largest commercial interest [12]. CWS is a mixture of pulverized coal in water, which keeps the stability of the mixture over time, mainly when additives are used. CWS can be used as a fuel for boilers, can replace petroleum for energy conversion and can even be used in diesel engines, as reported in several research and technical documents [13–15]. It is a fuel that, in storage and transportation conditions, is non-flammable and eco-friendly, with good combustion efficiency compared to conventional fuels [16].

In order to obtain maximum efficiency, the concentration of solids in the CWS must be as high as possible, with a minimum viscosity, to allow storage and transportation in pipelines. Optimal stability of a CWS depends on the coal's physico-chemical properties, such as hydrophobicity, particle size, oxygen content, pH, shear rate, stress–shear ratio, porosity, temperature, and surface reactivity of the particles [17].

4. CWS Development

4.1. Early Stages

The first references about CWS appear in the United States during the 1940s, in order to fill the scarcity of resources caused by the war. Subsequently, during the 1974 OPEC (Organization of the Petroleum Exporting Countries) embargo, interest reappeared, which continued until the end of the 1970s, when there was a significant increase in oil prices. During this period, demonstrations were held in an industrial environment in several countries, namely Japan, the United States, England, and Sweden [18]. About 20 CWS production units are, or have been, in operation worldwide [19].

CWS combustion trials were carried out in the 1960s in the United States, Germany, and the Soviet Union. The United States, in the 1980s, actively developed CWS, emphasizing the preparation of the slurries, modernization of boilers, and the development of specialized equipment for handling and transportation [20]. During that period, several private companies that were actively involved in the development and use of CWS abandoned the process as soon as the price of oil dropped sharply [21].

First efforts in the development of CWS focused essentially on the preparation of a fuel with a higher energy density from bituminous coal. First attempts to use low-grade coal (LGC) simply mixed the sprayed LGC directly with water [22]. The results of the tests with LGC showed that its use was not economically viable, mainly because its heating value is very low [23], but the use of additives made the use of LGC in the production of CWS possible [24]. Particle size distribution needs to be adjusted to allow a higher solid load, and added additives decrease viscosity and increase stability. CWS with these properties behaves like liquid fuels that can be pumped, atomized, ignited in a preheated chamber, and burned steadily in a furnace [25].

4.2. Industrial Applications

4.2.1. China

China has extensive coal reserves of various types; therefore, since the 1980s, the CWS has become a key R&D project for the country, where five production units have been built with a capacity of 85,000 tons/year. It was found that the stability of some coals was very low, limiting their utilization. A pipeline with a capacity to transport 7 million tons/year has been built to take fuel from Shaanxi to Xincheng, 338 km, and to Dagang, 853 km. The coal mined in Yanzhou is transferred by train to Rizhou, 300 km away. Then, it is transported in tankers to Japan and stored [26].

4.2.2. Russia

There is great history of the use of CWS in Russia as the successor to the former Soviet Union. The main production point was in the city of Belovo, from where CWS, with a solid fraction of 62%, was transported, using a pipeline, 298 km to Novosibirsk. The dispersion medium used was water (37%), with 1% of surfactant additive. The solid fraction used had a particle size distribution between 20 and 350 μm [8].

4.2.3. United States of America

Several research works and experiments on pulverizing and burning CWS on an industrial-size scale have been conducted in the USA since the 1980s [27–29], proving that CWS can be used safely. Another set of experiments were carried out in 1985 in a coal-fueled boiler with the objective of testing the long-term use of these fuels [30].

4.2.4. Canada

In 1982, the first important CWS test was performed with the cooperation of different entities—The New Brunswick Electric Power Commission and Cape Breton Development Corporation—on the production of a CWS and its use in coal boilers. The obtained results enabled the program to go forward, and the market study conducted demonstrated the existence of an opportunity for the use of CWS. This study also showed that the pulp and paper industry, as a sector, could get more benefits with this new energy source. In 1984 and 1985, Canada Cement LeFarge Ltd. adapted two furnaces from coal to CWS, with the first combustion trial occurring in 1984, and completely converted from coal to CWS after the test [31,32].

4.2.5. Sweden

CWS was tested in several district heating boilers for over 2000 hours in Sundyberg. This test proved that CWS could be an alternative fuel for district heating boilers. After a successful and long-term tests conducted in the period of 1983 to 1985, Kraftringen from Lund signed a contract with Svenska Fluidcarbon. Another agreement was signed with KF/Foodia AB in Staffanstorp near Malmö. The third commercial agreement was signed with the SAB NIFE plant in Oskarshamn [33].

4.3. CWS Research

The development of CWSs and the aforementioned trials demonstrated the concept of using these types of fuels as a potential substitute for conventional oil-derived fuels. In several previous studies, coal-fueled operations have been characterized quantitatively and qualitatively by analyzing their combustion processes and by their products' properties.

Roh et al. (1995) investigated the effects of the type of coal used, solid amount, and particle size on the rheology of CWM. Seven bituminous coals were used in the study, with the particle size distribution obtained by sieving for particles greater than 38 μm and using a Coulter counter for particles less than 38 μm. Rheological tests were conducted using a Haake RV-12 viscometer.The authors found that all the slurries exhibited pseudoplastic behavior. Blending with the coarse coal fraction was useful in reducing the slurries' viscosity, and static stability measurements performed with a rod penetration test revealed that stability was greatest when the same optimum coarse/fine ratio was utilized [34].

Logos et al. (1996) analyzed particle size effects on the flow properties of a Southern Australian CWS. A low-grade Lochiel coal from Southern Australia was used for the preparation of the CWS. The particle size distribution was varied by introducing a coarser fraction of coal into the finer fraction in different proportions. The solid loadings were in the range of 23% to 50% by weight. The authors found that the slurries prepared from only a finer fraction, i.e., under 45 µm, were more viscous than the coal–water slurries prepared from a mixture of coarse and fine particles, with coarse particles varying from 208–279 µm. The ratio of coarse to fine was 40:60 and showed the lower apparent viscosities [35].

Nguyen et al. (1997) analyzed the effect of granulometry of coal particles on the rheology of the slurries. The coals studied included two raw lignites, Lochiel and Bowman's coal, obtained from Southern Australia. The rheological properties were measured using a Haake RV-100 viscometer. The prepared coal–water slurry consisted of 23% to 50% Lochiel coal and 40% Bowman's coal. The authors found that the solid concentration affected the nature of the slurry, with 23% Newtonian showing shear-thinning at higher concentrations. Above 40%, the slurry showed viscoplastic behavior, and adding a coarser fraction to the suspension substantially reduced viscosity. No additives were used [36].

Usui et al. (1997) analyzed the sedimentation stability of a CWS using deashed coal with and without a stabilizer. Three CWMs were prepared with equal apparent viscosities, controlling coal concentration, using polymethacrylate as a dispersant and rhamsan gum as a stabilizer. The study found that very small quantities of rhamsan gum were enough to avoid sedimentation of the particles [37].

Yavuz et al. (1998) conducted research about the granulometry effect on the rheology of a lignite–water slurry. The lignite sample was divided into six: 125–90, 90–75, 75–63, 63–53, 53–45, and <45 µm. The authors used a concentration of 60% of solids. The results showed that the slurry with a particle distribution pending just for fines was not suitable, as its viscosity was very high. Thus, the authors mixed several different fractions to obtain an optimized distribution of particle sizes lower than 125 µm. The authors also investigated the sedimentation behavior of the slurries and found that with size increment, sedimentation also increases. However, above a given particle size (>35 µm), sedimentation became slower [38].

Li et al. (2002) analyzed the rheology and stability of a slurry using four different additives, such as rhamsan gums, carboxy methyl cellulose or xanthan gum. In the study, fly ashes from Matsuura Power Station in Kyushu Island (Japan) were used. Fly ashes were dispersed in deionized water at a concentration of 68 wt %. Dispersant concentration was 0.3 wt %. Results showed that the additives were effective and increased the stability of the slurry. S-194, with a concentration of 0.2%, was recommended for the preparation of a stable fly-ash–water slurry [39].

Atesok et al. (2002) investigated how coal properties affect CWS behavior using Turkish and Siberian bituminous coals with average particle sizes of 50, 36, and 19 µm. Sodium polystyrene sulphonate and sodium salt of carboxy methyl cellulose were used as dispersant and stabilizer. pH value varied from 7.05 to 7.25 for all tests, with a constant temperature of 25 ± 2 °C. pH varied according to the addition of HCl or NaOH [40].

Mishra et al. (2002) analyzed the rheology of Indian CWS using Talcher field coals. It was observed that the viscosity increases with an increment in the solids concentration. The viscosity of a CWS is higher in an acidic medium, with the highest around pH 6 and the lowest around pH 8 [41].

Dincer et al. (2003) studied the effects of different dispersants and stabilizers on the rheology of CWS. In the experiments, anionic chemicals such as polyisoprene sulphonic acid soda and sodium salt of carboxy methyl cellulose were used as dispersants and stabilizers. A Turkish bituminous coal was used with an average volatile content. It was found that polymeric anionic dispersants, such as Dynaflow, have greater effects on the viscosity and the stability [42].

Boylu et al. (2004) studied the effect of particle size distribution, volume fraction and grade on the slurries' rheology. Experiments were conducted using two Turkish lignites, from Soma and Agacli, and a Siberian bituminous coal. The samples were prepared by mixing different size fractions until the desired d50 (19, 35, 50 µm) was obtained. pH of the sample was stabilized by adding an acid or base. The measurements were taken using a shear rate of 100 rpm. The pH value and temperature were kept constant at 7.0 and 25 ± 2 °C [43].

Boylu et al. (2005) analyzed the stabilization properties using carboxy methyl cellulose. The materials chosen were brown coals from Soma and Istanbul and bituminous coal from Zonguldak. Coal particles were ground to less than 63 µm, and the mixtures prepared included 61%, 55%, and 52% coal. Stability was measured using the rod penetration test method. The effect of changing the carboxy methyl cellulose concentration upon penetration after 7 days was studied. The authors found that there was a negligible effect from changing the concentration of carboxy methyl cellulose on the stability of the coal from Soma and Istanbul, as the penetration remained the same after 7 days, and the hydrophilic nature of the lignite coals was attributed to this phenomenon. However, the authors also found that varying the concentration of carboxy methyl cellulose had a profound effect as a stabilizer on the bituminous slurry, increasing the stability, with penetration from 60% to 100% due to the hydrophobic nature of bituminous coal, and the optimum concentration of carboxy methyl cellulose was found to be 0.01% [44].

Gu et al. (2008) studied the effect of coal blending on a CWS using three different samples from Daliuta, Linhuan, and Yongcheng. The maximum size of the coal was 300 µm, and 75% of the particles were smaller than 74 µm. The dispersant used was a naphthalene sulphuric acid formaldehyde condensate. Linhuan and Yongcheng coal was mixed with Daliuta with a weight percentage of 10–40%. It was observed that the addition of coal with a high grade can improve the slurryability of LGC [45].

Senapati et al. (2008) analyzed the rheological behavior of a CWS using a natural additive. Two samples with different ash contents were obtained from the Talcher coal field in Orissa, India. CWS was prepared with a concentration ranging between 55% and 63.7%. Additives varied from 0.4–1.2% by weight. The static stability was measured using a rod penetration test. The authors found that the CWS in the presence of natural additives exhibited Bingham plastic behavior. The static stability CWS was achieved 3 to 4 weeks after employing the additive [46].

Das et al. (2009) prepared a highly concentrated CWS using three Indian LGCs with different ash contents. The properties of the slurry were investigated using saponin as a dispersant. Saponins were found to stabilize the slurry. Authors claim that saponin can be replaced by a synthetic compound, such as sodium dodecyl sulphate [47].

Xiong et al. (2009) reported the effect of the granulometry, solvent type and ratio, temperature and shear time on Shengli lignite–solvent slurries. Three solvents were used: a hydrogenated recycled solvent obtained from a liquefaction pilot plant, quartic-hydrogenated products of heavy oil from the Anqing Oilfield and tetralin. The results showed changes from pseudoplastic to Newtonian behavior with the increment of the temperature [48].

Zhou et al. (2010) applied the Herschel–Bulkley model to analyze the rheological properties of a concentrated CWS. The slurry was dispersed with lignin-based dispersant. Two slurries were prepared with a coal concentration of 64% and a dispersant dosage of 0.7% and 1.5%. The authors found that when the dispersant dosage was 0.7%, the slurry showed shear-thinning characteristics, and at a 1.5% dosage, it showed shear-thickening characteristics. Factors affecting rheological properties, such as solid load and the dispersant content, were also studied. Results showed that the slurry tends toward pseudoplastic characteristics with the increment in solids concentration, but tends toward dilatant flow characteristics with an increase in dispersant dosage [49].

Lu et al. (2010) analyzed the effects of size distribution on the flow in the pipeline. Authors observed three distinct patterns for different size distributions and velocities. Particle size distribution affects flow significantly. Lighter fine- and medium-size particles tend to be lifted up by the turbulent dispersive action of the fluid. In this way, a uniform and suspended flow is achieved, whereas coarser and heavier particles can also be lifted. However, it is difficult for these particles to become fully suspended, even with high flow velocities [50].

Bentz et al. (2012) studied the influence of several variables (fly ash size distribution and ratio) at each one of the four levels on the yield stress and viscosity of the blend. From the experiments, the authors concluded that both particle density and surface area are critical parameters influencing the rheological properties of the slurry [51].

Buranasrisak and Narasingha (2012) studied the effects of size distribution on the rheology behavior of a CWS. A sub-bituminous coal of Indonesian origin was used to prepare the samples. The samples were classified into six particle size ranges. Naphthalene sulphonate formaldehyde and Na-carboxy methylcellulose were used as dispersant and stabilizer, respectively. Viscosities were measured using an MV-2000 series II Cannon Rotary Viscometer at different solid loadings ranging from 60% to 65% by weight. The different packing characteristics of the coal samples were defined by making monomodal, bimodal and multimodal distributions at different coarse-to-fine ratios. The authors observed that maximum coal loading was possible when the coal–water slurry was made from a bimodal particle size distribution [52].

Chakravarthy et al. (2014) carried out research using a coal sample of Indian origin. The characterization studies were done prior to the rheological study to determine the ash content, particle size distribution, morphology and coal–water mixture pH values. pH decreased with the increment in solids concentration. After the characterization studies, rheological data were generated for the coal sample to determine the coal–water slurry flow behavior [53]. The same group of researchers continued to develop this area of knowledge, presenting several works in the same and following years [54–56]. The research presented during the years 2014 to 2018 was predominantly concerning the stability of the mixtures and about the handling of these materials.

Rao et al. (2019) presented a comparative study on the rheology of two CWS with sodium tripolyphosphate as a dispersing agent [57] in consonance with the research conducted by Routray et al. (2019), where the effect of mixing natural and synthetic surfactant and particle size distribution for stabilized high-concentrated CWS was presented [58]. More recently, a study presented by Singh et al. (2020) computationally analyzed the disposal of CWS with high solid concentrations through a pipeline, demonstrating the interest of the subject in this transition to a coal-free energy production [59]. It is in this context that several research works have evolved, such as those presented by Loureiro et al. (2018), where the development and rheological characterization of an industrial liquid fuel consisting of charcoal dispersed in water was presented, demonstrating a new path for this research field of searching for alternatives to the use of coal [60].

5. CWS Rheology

The definition of rheology can be presented as the study of the flow of matter, primarily in a liquid state, but also as soft solids or even solids that, in response to the application of a force, present a plastic flow rather than deforming elastically [61].

The rheological properties of particle suspensions are of great importance in several industrial applications, including the pipeline transportation of slurries [62], and can be used to determine the relationship between the flow rate and pressure drops. Rheological parameters can also be used to determine the power required to agitate the slurry in the tank and to determine the wear rate and life of the pipeline. The rheology of a slurry depends on several parameters, such as the particles' shape and size distribution, solid concentration, and fluid properties [63,64]. By suitably manipulating the particle size distribution, if other parameters are kept the same, it is possible to obtain a stabilized slurry suspension. This information is important to predict the requirements for pumping the slurry. The presence of solids affects the performance of the pump, and inner surfaces wear more due to the presence of solid particles [64].

Historically, the rheology of suspensions has been investigated mostly through experimentation on equalized particulate suspensions. Correlations have been derived, on the basis of the above data, to predict the Newtonian viscosity of a suspension [65]. Furthermore, the particles of different materials will differ in various properties, such as density and shape. Thus, the actual flow pattern that exists in a slurry pipeline will differ from material to material. Moreover, the behavior of a slurry is generally non-Newtonian at the concentrations that are commercially used [66]. It is essential to obtain a good understanding of the methods of characterizing rheological properties and extrapolating these characteristics to commercial slurries [67].

In the absence of any suitable correlations for predicting the rheological parameters of non-Newtonian slurries containing large-sized particles with a wide particle size distribution, viscometric tests are unavoidable. For slurries containing large particles in a low-viscosity carrier liquid, viscometric measurements are difficult because large particles tend to settle during measurements, thereby affecting the homogeneity of the suspension. The geometric interference of particles with the walls of the viscometer also places a limit on the largest size particles that can be accommodated during tests. To overcome these problems, large/heavy particles may have to be removed from the original sample before rheometric tests can be performed with the remaining fine particulate slurries. However, presently, the effect of removing large particles is not fully understood [68].

CWSs are non-Newtonian fluids with a viscosity function that decreases with the increment of the shear rate. Pseudoplastic fluids exhibit a shear-thinning behavior without yield stress. Dilatant fluids, on the contrary, exhibit shear-thickening behavior. Expensive additives, dispersants, and stabilizers have been used to improve the rheology and the static stability for transportation, storage, and combustion [69].

The rheology of a coal suspension depends on the existing interparticle attractive forces [70], which in turn depend on the chemical structure of the surface, which is specific to a particular coal, and the total surface area [71]. Porosity is inherent to a specific coal and affects reagents adsorption but may contribute to interparticle attraction. Interparticle forces can be modified by the presence of surface-active chemicals, inorganic electrolytes, pH, and polyelectrolytes [72].

6. Conclusions

CWS technology has the potential to allow us to increase our coal consumption while displacing conventional oil-derived fuels. Therefore, in certain areas, the conversion of existing oil- and gas-fired units could be beneficial, as could the installation of new facilities, especially in locations far from coal production points, which would benefit from CWS long-distance pipeline transportation capacity.

CWM consists of ground coal particles in suspension in a liquid. This liquid can be oil, water, or others, and contain small amounts of additives to improve the stability, homogeneity, and dispersibility of the slurry. The main purpose of CWM is to make solid coal behave like a liquid that can be transported, stored, and burned in the same way that heavy fuel oil is.

Further research is still needed to fully understand the complete possibilities of CWS as an alternative form of fuel, as well as the possibility of using the logistic and transportation advantages afforded by the use of CWS. It is important that there be a thorough analysis of the legal and normative restrictions of many countries, namely European countries, where the use of coal recently started to have its outcome scheduled for the next years.

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