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Production of Indigenous and Enriched Khyber Pakhtunkhwa Coal Briquettes: Combustion and Disintegration Strength Analysis

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Abstract

Khyber Pakhtun Khwa province of Pakistan has considerable amounts of low ranked coal. However, due to the absence of any centrally administered power generation system there is a need to explore indigenous methods for effectively using this valuable energy resource. In the present study an indigenous coal briquetting technology has been developed and evaluated in terms of combustion characteristics such as moisture content, volatile matter, ash, fixed carbon and calorific value of the resulting coal briquette and disintegration strength using polyvinyl acetate (PVA) in combination with calcium carbonate (sample no 3 with highest disintegration strength value of 2059N). Comparison of test samples with the commercially available coal briquettes revealed improved combustion characteristics for the PVA bonded (sample no 1 and 5) coal briquettes having higher fixed carbon content and calorific value, lower ash contents as well as lower initial ignition time.

Keywords: Coal Briquettes; Disintegration strength analysis; Volatile matter; Ash content; Fixed carbon; Calorific value.

Introduction

The developing countries including Pakistan are currently facing huge energy crisis due to ever-increasing cost of imported fuels. One option to contain the present energy crisis is to harness the power of indigenous coal reserves, which are poorly developed but abundantly available in Pakistan. The past two decades have seen the importance of coal being recognised as an alternative source of energy in comparison to the petroleum products. This is mainly triggered by the diminishing oil reserves as well as international and maritime security issues. The use of indigenous coal offers an inexpensive and locally available alternative. An estimated 2.87 million tonnes of coal reserves (equivalent to 700 million tonnes of crude oil) are currently available in the world [1]. However, the handling and burning of raw coal for domestic, semi-commercial and commercial applications poses a challenging problem mainly due to its high ignition temperature, varying coal quality, higher ash, micron-size particle emission and smoke generation. In addition to the above factors and with existing coal profile, coal is prone to disintegration during the course of its mining, transportation, handling and on exposure to weather. The amount of disintegrated coal and/or flakes form a considerable percentage of the mined coal in comparison to the lumped coal and are sold at considerably low rates. The conversion of flaked coal into briquettes upgrades the value and is often sold at higher prices than that for the lumped coal.

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In the absence of any centrally administered large scale power generation system for coal reserves in Pakistan, especially in Khyber Pakhtun Khwa (KPK) province, there is a need to develop methods that can effectively utilise the indigenous coal reserves to uplift the local domestic and small scale industrial economy. Many solutions exist in this regards such as coal gasification, liquefaction and briquet0ting, which all have their own advantages and disadvantages. Due to the lack of any local, technical and/or practical knowhow about coal gasification and liquefaction, the proposed method of coal briquetting technology is aimed at effectively utilizing the indigenous coal reserves and to develop and implement it for the local market. This is in line with the current trend where the use of coal briquettes and improved performance stoves are encouraged in the developing world especially in countries where coal is found in abundance in comparison to other fuel sources [2]. The improved briquetting technology is mainly focused on offsetting the pollution and health impacts that result due to the inefficient burning of low quality raw coal. Firewood and charcoal use in Pakistan has led to extensive deforestation. The country has rich resources of low ranked indigenous coal which can be utilized in the form of coal briquettes to heat the residential, commercial, and industrial processes [3]. Glen (2003) also highlighted the social acceptance of coal briquettes in the Pakistani domestic market and suggested that coal briquettes can easily replace the traditional wood burning in the urban areas of Punjab and KPK provinces [3]. However, the acceptance of coal briquetting technology in the industrial sector was welcomed with hesitation indicating its slow adoption in these areas.

Burring characteristics of coal briquettes such as ignition temperature, steady state burning, smoke and ash content along with non-burning characteristics such as mechanical strength, moisture content and moisture resistance will all have an effect in the adoption of this technology by the domestic and industrial market. To address some of these issues Altun *et al.*, (2004) has looked into the burning characteristics of coal briquettes from a combustion kinetics point of view and suggested that the coal briquettes ignition and the efficiency and effectiveness of combustion reaction was considerably dependent on the binder type, amount of binder agent and water addition [4]. Mechanical disintegration strength of the prepared coal briquettes affects its storage and transportation to the intended markets and hence Blesa *et al.*, (2003) looked into the mechanical characteristics of the heat cured coal briquettes made from molasses and suggested that curing brings a uniform morphology in the resulting structures and hence give good disintegration strength for normal use [5]. Ellison and Stanmore (1981) have referred to the production of high mechanical strength coal briquettes by mechanical compression without the addition of any binder [6]. Yildirim and Ozbayogh (1997) and Rubio *et al.*, (1999) have looked into using different binders for coal briquettes production [7, 8].

Coal briquettes can be made in a variety of different ways by adjusting the shape, filler, binder and coal composition. A variation in all these factors affect the calorific value, initial ignition temperature, ash content, moisture, storage and transportation of the resulting coal Briquettes [9-10]. The problem of briquetting is not always about how to make the best possible briquettes in a certain locality but the quality of coal flakes and the binder prices influences the production of satisfactory grade for the intended use [11]. No such study has been carried out to look into these factors for the indigenous KPK coal reserves and hence it was the principal purpose of this research to investigate the effects of different binders on the strength, dryness and burning characteristics of the resulting coal briquettes.

Materials and Methods

Coal Briquettes used in the present study were locally prepared in the Clean Energy Engineering Laboratory of the Department of Chemical Engineering at the University of Engineering and Technology Peshawar, Pakistan. The major experimental tasks involved in this research are given in (Fig. 1).

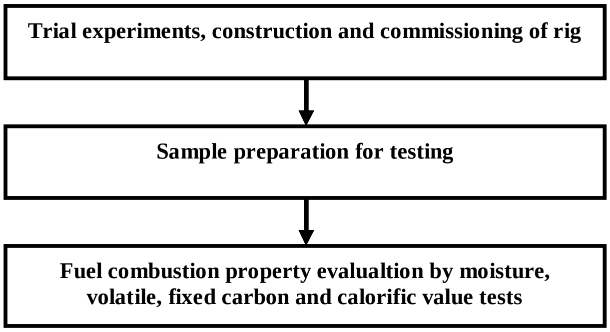

Figure 1. **Overview of the experimental tasks.**

In the initial trial experiments different coals were analysed for their moisture, volatile matter, ash, calorific value and fixed carbon contents. Although several coal deposits exist in the KPK province but based on the initial trial experiments only three were selected for the coal briquetting experiments reported here. The preliminary selection was based on the amount of fixed carbon content, ash, moisture, volatile matter and calorific value as well as their proximity to the project site. Coal sourced from Dera Adam Khel was labelled as Coal-1, from Doaba as Coal-2 and that from Hangu was labelled as Coal-3. The particle size of coal in this study was limited to anything passing through a 600 micron sieve. The initial tests performed were to find out the moisture level, volatile matter, ash content, fixed carbon and calorific value of the three different types of coal as given in (Table 1).

Table 1. **Measured moisture content, volatile matter, ash content, fixed carbon, and calorific values of raw coal samples**

Coal Sample	Moisture level / %	Volatile matter / %	Ash content / %	Fixed carbon content / %	Calorific value / Joules
Dera Adam Khel, Coal-1	1.10	10.66	19.2	69.04	29840
Doaba, Coal-2	1.28	15.16	20.4	63.16	22468
Hangu, Coal-3	1.40	12.20	21.3	65.10	25984

A = Coal-1 with 1000 ml PVA; B = Coal-1 with 1000 ml PVA and 250gm $CaCO_3$; C = Coal-1 with 1000 ml PVA and 500gm $CaCO_3$; D = Coal-2 with 1000 ml PVA and 250gm $CaCO_3$; E = Coal-3 with 1000 ml PVA; F = Available coal briquettes in market (PTC); G = Available coal briquettes in market (Phoenix)

After selecting the coal types, next step involved the mechanical construction of a compression test rig to make the different composition coal briquettes for onward combustion analysis to optimise the optimum composition. A cylindrical shaped pattern was selected based on the ease of briquettes production, storage, use and mechanical strength to make the coal briquettes as shown in (Fig. 2). The dimensions of the coal briquette pressing cylinder are shown in (Fig. 3).

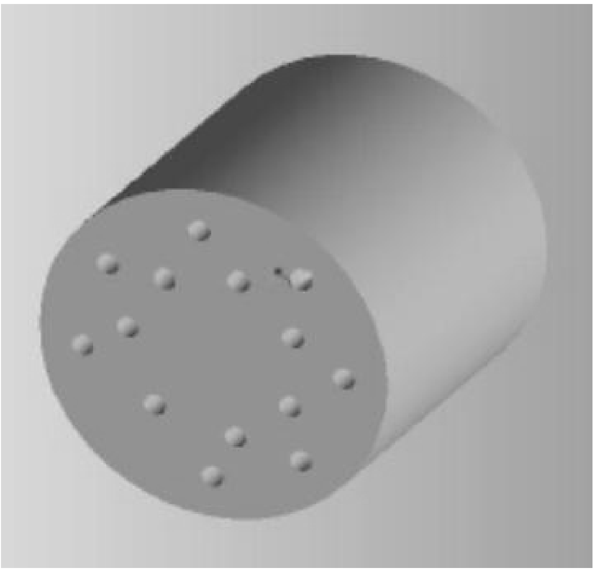

Figure 2. **Cylindrical coal briquettes designed for this study.**

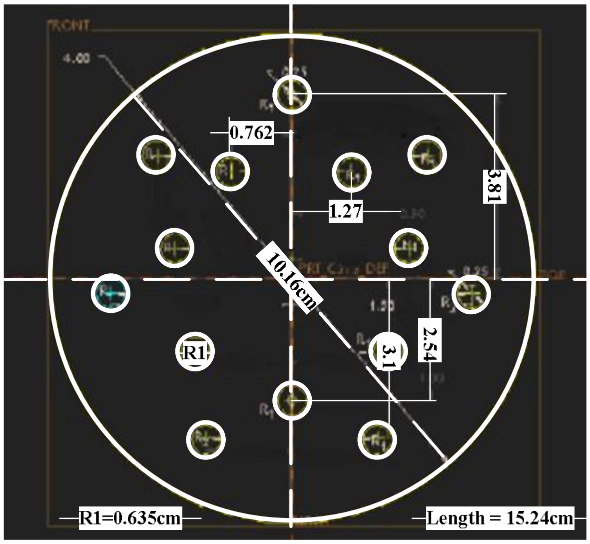

Figure 3. **Mechanical layout of the coal briquetting cylinder.**

The actual design of the coal briquetting press was simple and consisted of an iron metal frame upon which a 4 inch diameter and 6 inch length cylinder was welded. The cylinder had removable top and bottom circular plates with 14, 0.25 inch diameter holes that were provided to linearly move on the circular bars inside the cylinder during coal briquettes compression and removal cycles as is shown in (Fig. 4 & Fig. 5).

Figure 4. **Coal Briquetting press machine showing the compression and jack removal mechanisms.**

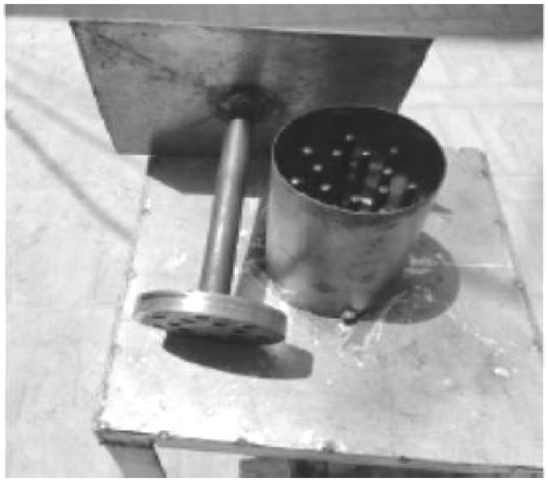

Figure 5. **Top view of the compression cylinder with top circular steel plate with holes to slide inside the cylinder under the influence of sufficient load.**

The presence of holes in the resulting briquettes also aided in the ease of combustion and drying due to the circulation of air in the holed structure. To make a briquette, the bottom plate was in-placed and coal, filler and binder mixture was poured into the 10.16cm cylinder to make up the desired height which in this case was limited to 15.24cm in the horizontal plane. Once filled, the perforated top steel plate was moved downward by the application of an appropriate load (20 kg concrete block). Once compressed for at-least 10 minutes, the cylindrical shaped contents were removed from the cylinder by moving the bottom perforated plate by means of an ordinary car jack which ensured the slow and integrated removal of the resulting coal briquette. The labelled coal briquettes were then placed in sunlight to dry for at-least 10 hours (Fig. 6). After drying the coal briquettes were ready for different combustion tests.

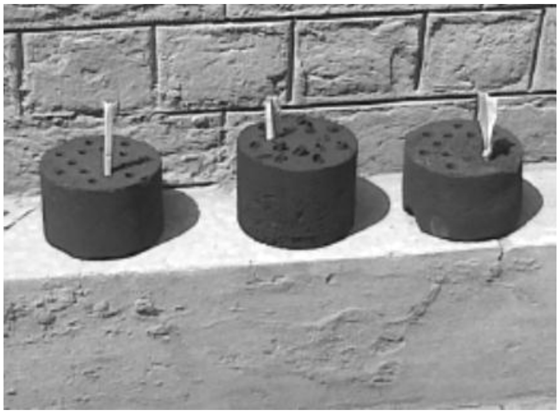

Figure 6. **Cylindrical coal briquettes drying in the sunlight.**

Moisture content in this study was reported by heating the weighted quantity of coal sample in a laboratory scale muffle furnace (Japanese model FM-38) at 105°C for one hour Volatile matter was reported by heating the moisture free sample in a covered crucible at 950°C for 7 minutes Ash content was reported by burning a known quantity of sample in the muffle furnace until a constant weight of the burned content was achieved. Fixed carbon value was found by difference from the moisture, volatile and ash content values. Calorific value reported in this work was determined by using a bomb calorimeter (Shimadzu model CA-4PJ). The coal briquettes used in this work were made by mixing the coal samples (Table 1) with Poly Vinyl Acetate (PVA) and $CaCO_3$ in varying compositions. The contents were well mixed in a laboratory scaled ribbon mixer. Furthermore, the vertical axis disintegration strength of the coal briquettes was measured by the universal testing machine (Testometric model-M500-100KN) which gave the maximum disintegration load values in newton (N).

Results and Discussion

The compositions of coal briquettes made with varying binder type are shown in (Table 2). The sole addition of Poly Vinyl Acetate (PVA) as binder in coal-1 resulted in somewhat less disintegration strength in comparison to other samples but gave high calorific value, high fixed carbon content, less ash and volatile matter (sample no 1 and 5 in Table 2). The amount of moisture in all the investigated samples was nearly the same and stayed below 2% (Table 2). The values reported in this work showed good reproducibility with 5% deviation on either side of the mean value obtained by five repeat measurements. The use of PVA and calcium carbonate ($CaCO_3$) as binding material resulted in showing an improved disintegration strength for the resulting coal briquettes but at the cost of reduced calorific value, fixed carbon, and high ash and volatile matter as shown in the case of sample no 2, 3, and 4 in (Table 2).

The combustion characterisation values of moisture content, volatile matter, ash content and fixed carbon values, shown in Table 2, are graphically compared and shown in (Fig. 7), which shows the comparison of test samples 1, 2, 3, 4 and 5 with the commercially available samples 6 and 7. The test samples of coal briquettes showed a clear advantage of giving high calorific value, high fixed carbon, and low ash content at a marginal disadvantage of reduction in disintegration strength in comparison to the commercially available coal briquettes.

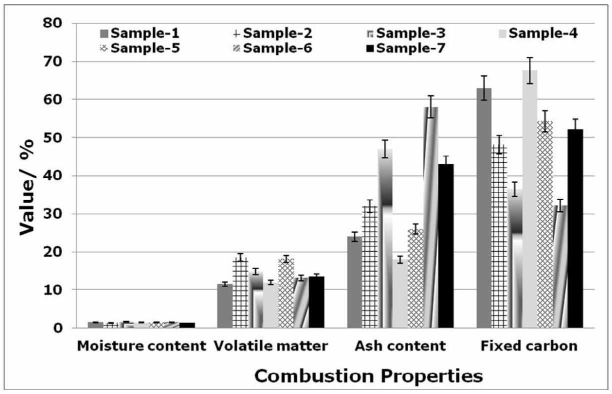

Figure 7. **Measured combustion properties of samples used in this study (sample numbers correspond to the compositions given in Table 2.**

The initial ignition times shown in (Fig. 8) for all test and commercially available briquette samples were obtained by burning a unit quantity of fuel in laboratory furnace at 800°C and noting the time when the combustion reaction first started.

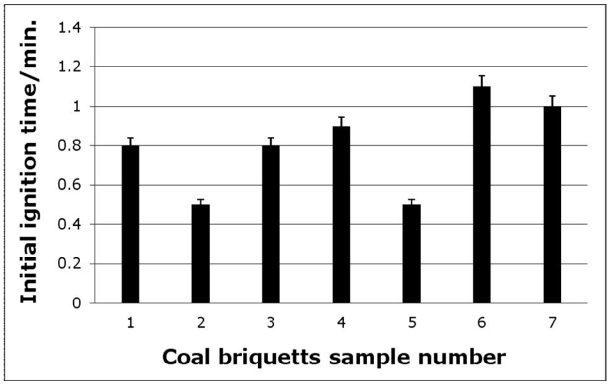

Figure 8. **Initial ignition time in minutes. The sample numbers correspond to the compositions given in Table 2.**

Table 2. **Measured combustion characteristics of coal briquetts samples used in this study**

Sample number	Sample name	Measured values					
		Moisture %	Volatile matter %	Ash %	Fixed carbon (% by difference)	Calorific value, Joule/g	Disintegration strength, Newton / N
1	**A**	1.53	11.55	24	63	30463	1471
2	**B**	1.30	18.58	32	48.12	23268	1765
3	**C**	1.7	14.85	47	36.45	22251	2059
4	**D**	1.44	12.0	18	67.6	25893	1667
5	**E**	1.51	18.13	26	54.3	28354	1569
6	**F**	1.51	13.15	58	32.12	16232	1863
7	**G**	1.41	13.50	43	52.15	24523	1667

A = Coal-1 with 1000 ml PVA; B = Coal-1 with 1000 ml PVA and 250gm $CaCO_3$; C = Coal-1 with 1000 ml PVA and 500gm $CaCO_3$; D = Coal-2 with 1000 ml PVA and 250gm $CaCO_3$; E = Coal-3 with 1000 ml PVA; F = Available coal briquettes in market (PTC); G = Available coal briquettes in market (Phoenix)

The measurements of initial ignition time for all the investigated samples varied in the range of 0.5 to 1.1 min for a fixed ignition temperature of 800°C. The initial ignition time for the commercially available samples 6 and 7 was slightly higher as compared to others mainly due to the existence of less volatile matter. The low initial ignition time for all samples reported in this work can be attributed to the presence of low moisture content in all samples. Since water (i.e. moisture) has high heat capacity thus the ignition of coal briquettes is delayed until all the moisture is nearly driven off from the coal briquette after which the volatile matter drive off to the atmosphere to make high enough concentration for initial ignition. Samples 1, 4, 6 and 7 had the least percentage of volatile matter while samples 2, 3, and 5 had the highest value and thus this would have contributed to their quicker initial ignition.

The comparison of calorific values showed that samples 1 and 5 had the highest magnitude followed by sample 4 as compared to commercially available sample 6 and 7 that lagged behind in this respect and were only better than test sample 3. The increased calorific value of the test samples can be attributed to the presence of high fixed carbon content in the test samples except for that in sample 3 where the addition of an increased amount of $CaCO_3$ led to a decrease in fixed carbon content. The measured calorific values of all samples are shown in (Fig. 9). The decrease in calorific value of samples 3, 6 and 7 is justified due to the presence of less fixed carbon content in comparison to other samples as shown in Fig. 9 and in Table 2, which also show the amount of ash content left after complete combustion. The ash content represents the minerals that form a non-combustible residue after carbon, oxygen, sulphur and moisture has been driven off during the combustion reaction. In addition to other factors the amount of ash content in a sample has an effect on the resulting calorific value, which can be observed Table 2 for the different test samples.

The disintegration strength comparison among all the samples revealed marginal weaknesses of test samples 1, 2, 4 and 5 in comparison to the commercially available samples 6 and 7. Sample 3 was an exception which gave the highest value of vertical axis disintegration strength possibly due to the presence of high $CaCO_3$ content which would have fused in the presence of moisture and applied stress to give cementation strength to the resulting coal briquette. However, this came at the expense of decreased fixed carbon presence and low calorific value. All the disintegration strength values varied marginally between 2059 and 1471 N, as shown in (Fig. 10), and did not show any significant disadvantage for normal combustion testing use in this work.

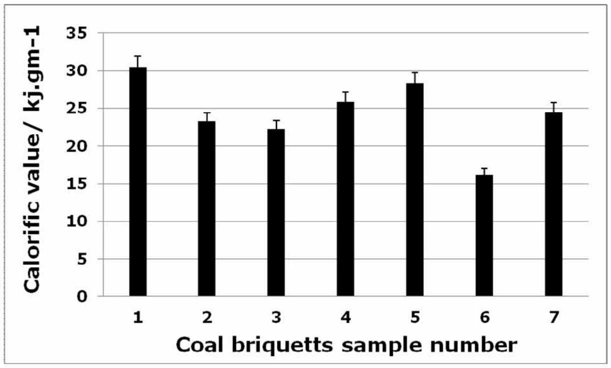

Figure 9. **Caloric values of different coal briquette samples. The sample numbers correspond to the compositions given in Table 2.**

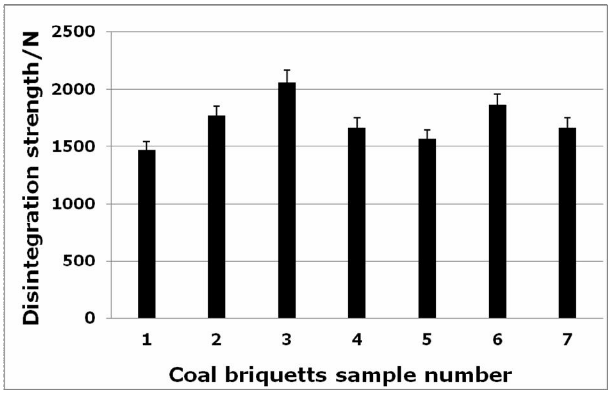

Figure 10. **Disintegration strength of different coal briquette samples. The sample numbers correspond to the compositions given in Table 2.**

The results obtained from this research work suggested that a simple coal briquetting technique can be devised that can make coal briquettes from the locally available cheap sources of disintegrated low ranked coal, polyvinyl acetate (PVA) and calcium carbonate. A comparison of combustion characteristics among all the samples revealed that the sole use of PVA as a binding agent resulted in disintegration strength that was only marginally inferior to the other combinations of binders. The loss of marginal disintegration strength was found to be insignificant for the normal conditions of use. The briquettes samples that contained PVA (1 and 5) as a binding agent showed considerable amount of fixed carbon, volatile matter and had less ash. All this resulted in giving these samples a high calorific value in comparison to other samples. The increase in calorific value of samples 1 and 5 briquettes can also be attributed to the presence of PVA binder which is combustible and would have aided in the overall calorific value. This is also evident from comparing the calorific values of raw coal in Table 1 with that of the coal briquettes test samples with PVA binder in Table 2. The presence of high ash and less volatile and fixed carbon content in other samples resulted in decreased caloric value and difficulty in attaining a low ignition time for combustion. Analysis of three different types of local coals revealed that Dera Adam Khel coal (designated as coal-1 in Table 1) contained the least amount of volatile matter among all but had the highest proportion of fixed carbon and hence gave the highest calorific value during bomb calorimeter testing. Next in rank was Hangu coal (coal-3 in Table 1) which had a volatile matter content of 12.2% and the fixed carbon content of 65.1 giving the second highest calorific value. Doaba coal (coal-2 in Table 1) had the highest volatile matter content but had the least fixed carbon content and thus gave the lowest calorific values.

Conclusion

Based on the findings given in this work it can be concluded that, in the absence of any large scale coal utilization plants for power production, the low ranked KPK coal can be effectively utilised by devising the simple indigenous technology for coal briquetting. Coal samples tested in this work showed that the use of PVA as a binding material can help elevate the calorific value of the resulting briquettes by aiding in combustion (sample no 1 and 5). The use of $CaCO_3$ in any combination with PVA resulted in low calorific value due to an increase in the non-combustible content of the resulting briquettes; however, its presence in one sample resulted in increasing the vertical axis disintegration strength. The entire test briquettes used in this work had considerably low moisture content and thus had low initial ignition time. All test briquettes made in this work had an acceptable level of disintegration strength for normal use. The use of $CaCO_3$ in combination with PVA gave the highest disintegration strength of 2059N. In line with other findings, the coal sample with high volatile matter attained the least initial ignition time, the one with high fixed carbon and less ash content gave the high calorific value. Based on the findings reported in this work, it is proposed to use this technique for producing low cost coal briquettes that have low initial ignition time, low ash and high calorific value for the ease of utilisation in the domestic and small scale industry. This work forms a first step in a series of efforts towards devising and assessing the indigenous coal briquetting technology in the KPK region.

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