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RICE HUSK COMPACTION BEHAVIOUR FOR ITS USE AS BULK AND BRIQUETTE

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Abstract- Rice husk is a useful by-product of rice mill and used as bio-fuel for industrial and domestic applications. Briquetted rice fuel is being used in brick kilns at several locations. Rice husk as briquetted fuels have better physico-mechanical properties and combustion properties in comparison to lignite coal. The ignition temperature of rice husk briquettes is also lower. Briquetting of rice husk without size reduction and addition of adhesive material requires tremendous load for obtaining a briquette or consolidated mass of rice husk. Rice husk mass get compressed under the load conditions and swells as soon as the load is removed. Compaction behaviour of rich husk was studied in order to work out non-consolidating load range and consolidating load range. Bulk density immediately after compaction of rice husks was obtained as 0.503, 0.820, 1.064, 1.251 and 1.395 g/cm^3 and 0.156, 0.220, 0.285, 0.347 and 0.408 g/cm^3 after 24 hours of swelling against non-consolidating applied loads of 5, 10, 15, 20 and 25 tonnes respectively. Bulk density after compaction of rice husk were obtained as 1.510, 1.586, 1.650, 1.697, 1.743, 1.774 and 1.793 g/cm^3 and 0.465, 0.520, 0.575, 0.628, 0.679, 0.731 and 0.771 g/cm^3 after 24 hours of swelling against consolidating loads of 30, 35, 40, 45, 50, 55 and 60 tonnes, respectively.

Keywords- Rice husk, Biofuel, Briquette, Compaction behaviour; Bulk density, Swelling ratio

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Introduction

Strategies for sustainable energy development involve energy savings on the demand side [1,2], efficiency improvements in the production [3,4], and replacement of fossil fuels by various sources of renewable energy [5,6]. Large-scale renewable energy implementation plans are needed for integrating renewable sources for sustainable development influenced by energy savings and efficiency measures [7-10]. Converting present energy systems into a 100% renewable energy system is possible [11]. India and many developing countries used to spend a huge amount of foreign exchange of petroleum imports adversely affecting the economy of the countries [12]. Per capita energy consumption is considered as an index for the living standard. During March 2012, the per capita energy consumption in India was estimated to be 879 kWh. Per capita energy consumption of top five nations, namely the United States of America, Russia, France, Germany and Japan are 7031, 5113, 3868, 3811 and 3610 kilograms of oil equivalent. Based on the statistics of India, with per capita energy consumption, it is ranked at 12th positions much below the developed nations. The Indian economy is growing with real GDP growth of 7.5% over the last 10 years. This higher order of sustained economic growth is placing enormous demand on its energy resources. India is facing severe energy supply constraints at the moment. Over 70 % of the electricity generated is from coal based power plants in India. Other renewable sources of energy as wind, geothermal, solar, and hydroelectric represent a 2 percent share of the Indian fuel mix. Nuclear holds the only one percent shares. The share of coal and petroleum is expected to be about 66.8 per cent in total commercial energy produced and about 56.9 per cent in total commercial energy supply by 2021-22.

India is an agriculture based country and combustible renewable and waste constitute about one fourth of Indian energy use. Main traditional biomass sources are firewood, crop residues and dung, which are used by more than 800 million Indian households. Almost 85% of rural households are dependent on traditional biomass fuels for their cooking energy requirements. The availability of agricultural biomass is assured as a by-product of agricultural production and is on the increase in almost developing countries. The collection and disposal of these residues are becoming difficult and expensive hence left unused as waste material. The burning and decomposition of agricultural residues is becoming a great environmental concern [13]. Rice stalk, rice husk, wheat straw, sugarcane leaves and bagasse, saw dust, pigeon pea, sesbania, mustard, sorghum and maize stalk are such residues, which can be utilized as bio-fuel. Importance and relevance of biomass as a renewable resource of energy is increasing day by day with fast depletion of traditional non-renewable sources of energy such as coal and oil.

India is the second largest rice grower in the world after China with 152.6 million tonnes of annual production. Rice is a major food grain for southern and many northern states in India, and for at least 15 other countries in the world. The term rice husk refers to the by -product produced in the milling of paddy and forms 16-25% by weight of the paddy processed. The huge amount of rice husk is produced by the rice producing countries, which are burnt for either heating or dumped as a waste. India alone produces around 24 million tonnes of rice husk per year. Farm income can be increased both directly and indirectly if economically profitable means of utilizing rice husk generated are utilized in industry. Rice husk can be used successfully as a fuel in brick kilns and furnaces if briquetted and in rice mills for parboiling with or without briquetting. Rice husk as such is used for preparing poultry beds. The use of rice husk-fired boilers for the steam generation has already been applied at a large number of locations throughout the country [14]. Major non-energy applications of rice husk include animal feed, filling of low-lying land, particle board/chemical manufacture and poultry bed etc.

The calorific value of rice husk ranges 3000 to 3500 kcal /kg. Rice husk, if utilized as fuel, this can replace about 10 million tonnes of coal or about 5 million tonnes of oil. The husk price varied from Rs. 300 to Rs. 800/tonne and is higher in industrialized states/regions. Countries in which rice husk is being utilized on a large scale include China, Philippines, Thailand, Japan, Italy, Brazil and Korea etc. Rice husk briquetting machines have been designed and commercialized in Japan, Switzerland, Thailand, USA and China etc. The values of bulk density of rice husk range from 0.083 to 0.125 kg/ m³ [15]. Its transportation and storage as a bulk is a problem. Briquetting is a good technological option to increase bulk density of rice husk several folds [16,17]. Brick kilns can be a major beneficiary of the rice husk briquette. There is potential of installing more than 100 briquetting plants of 500 kg/hour briquetting capacity with coal saving potential of 16000 million tonnes annually. Briquetting is a way to convert loose biomass residues into high density solid blocks that can be used as a fuel. Rice husk briquettes can replace fossil fuels or wood for cooking and industrial processes. The rice husk briquettes have been investigated by many researchers on different aspects [18-22]. Under high load conditions, rice husk and other biomass get consolidated and can be conveniently used as fuel. Under low load conditions, rice husk density gets increased but it remains loose. Transportation cost of compacted be it solidified or lose will be minimized significantly. The present study is undertaken to study the compaction behaviour of the rice husk to increase the bulk density of non-consolidated rice husk and consolidated rice husk mass as a briquette.

MaterialsandMethods

The bulk of paddy husk was collected from the nearest rice mill during the month of May, the extreme summer month for studying compaction behaviour. The bulk density of paddy husk was worked out as 0.0889 g/cm³ and its moisture content as 10.1%. For compressing paddy husk at different loads an arrangement of a cylinder of thick G.I. pipe and piston of steel rod was made. The internal diameter of the cylinder was 62.5 mm and the length of the cylinder was 250 mm. The diameter of the rigid piston was 60 mm and length 38.6 mm, which was attached with a connecting rod of 50 mm diameter, and length of 350-mm. Upper end of the piston had the arrangement of fastening plates for fixing with moving arm of Universal Testing Machine (UTM) with the help of two nuts and bolts. Cylinder and piston head had a clearance of 2.25 mm. About 68.223 g rice husk was filled in the cylinder and placed on the fixed platform of UTM. Bulk density of rice husk was increased by applying 5 to 60 tonnes loads at an interval of 5 tonnes. The load was maintained for a period of one minute for stabilizing the rice husk bulk and briquettes. The bulk density of briquettes was measured immediately after compaction and after 24 hours. Swelling ratio (ϕ) which is the ratio of corresponding lengths of compacted rice husk mass or briquette to the swelled rice husk mass or briquettes was calculated as below.

$$\varphi = \frac{\rho_s}{\rho_c} = \frac{l_c}{l_s} \quad [1]$$

Where,

φ = swelling ratio

ρ_c = bulk density of rice husk immediately after compaction, g/cm³

ρ_s = bulk density of rice husk after 24 hours of swelling, g/cm³

l_c = length of rice husk mass or briquette immediately after compaction, cm

l_s = length of rice husk mass or briquette after 24 hours of swelling, cm

Result and Discussions

Compaction before Consolidation

When the compaction load is applied on rice husk filled in the cylindrical mould through a piston, the rice husk starts getting compacted by shrinking and reducing the large pore spaces between rice husks, thus increasing the bulk density of compacted rice husk. As soon as, the load is removed the compacted husk starts swelling thereby reducing the bulk density of compacted mass. At higher loads rice husks also start breaking into smaller pieces and filling the larger voids with fine pieces of husk. At a load of 30 tonnes, the rice husk starts consolidating as wood, but, still swell losing the acquired bulk density immediately after compaction. Variation of average bulk density and average swelling ratios under different loads are presented in [Table-1] and shown in [Fig-1].

Table-1 *Variation of bulk density and density ratio after compaction.*

Load, Tonne	ρ_c, g/cm³	ρ_c/ρ_b	ρ_s , g/cm³	ρ_s/ρ_b	$\varphi=\rho_s/\rho_c$	$1/\varphi=\rho_c/\rho_s$
0	0.089	-	0.089	-	1.000	1.000
5	0.503	5.648	0.156	1.754	0.310	3.220
10	0.820	9.214	0.220	2.476	0.268	3.721
15	1.064	11.953	0.285	3.200	0.267	3.736
20	1.251	14.058	0.347	3.901	0.277	3.604
25	1.395	15.675	0.408	4.580	0.292	3.422
30	1.510	16.966	0.465	5.225	0.307	3.247
35	1.586	17.820	0.520	5.843	0.327	3.050
40	1.650	18.539	0.575	6.461	0.348	2.869
45	1.697	19.067	0.628	7.056	0.370	2.702
50	1.743	19.584	0.679	7.629	0.389	2.567
55	1.774	19.934	0.731	8.213	0.412	2.426
60	1.793	20.146	0.771	8.663	0.430	2.325

Note : ϕ is swelling ratio, ρ_c is bulk density of rice husk immediately after compaction, g/cm³, ρ_s is bulk density of rice husk after compaction 24 hours, g/cm³ and ρ_b is bulk density of rice husk, g/cm3

It can be seen from [Table-1] and [Fig-1] that bulk density increases continuously with an increase in loads. Increase in bulk density after load application and swelling are presented in [Fig-2]. The rice husk could not be consolidated upto the load level 25 tonnes hence termed as non-consolidating load. There was a tremendous increase in rice husk bulk density after compaction even before the consolidation. The bulk density obtained at applied loads of 5, 10, 15, 20 and 25 tonnes were 0.503, 0.820, 1.064, 1.251 and 1.395 g/cm³, respectively. The bulk density increased 5.648, 9.214, 11.953, 14.058 and 15.675 times compared to the loose husk bulk density immediately after application of 5, 10, 15, 20 and 25 tonnes of load, respectively [Fig-2]. Bulk density of rice husk increased significantly upto 25 tonne load but, the rice husk remained loose. The rice husk density can be increased to the tune of 4.6 times yet to retain the characteristic of bulk husk. This property of the compaction behaviour of rice husk in non-consolidating range of applied loads of 5-25 tonnes will be useful in minimizing the cost of transportation significantly. Variation of bulk density immediately after compaction and swelling was best explained by the following equations [Equ-1 and Equ-2].

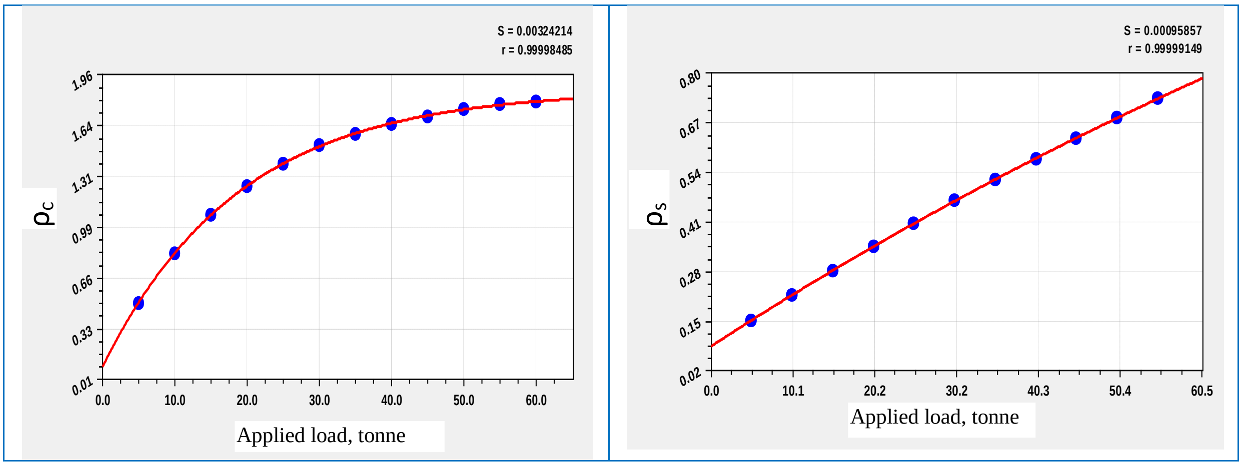

Fig-1 Variation of bulk density against applied loads

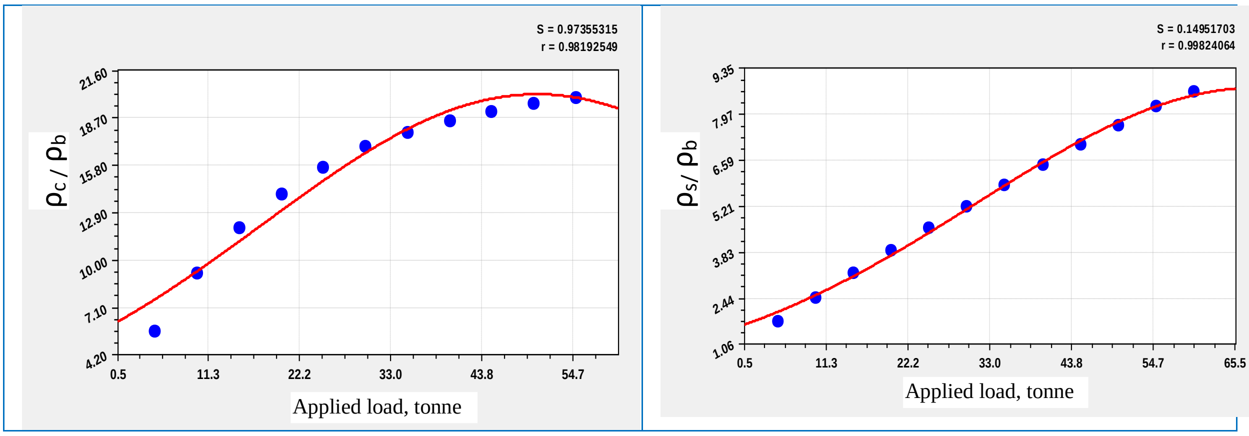

Fig-2 Increase in bulk density of rice husk after compaction and swelling.

$$\rho_c = 1.7774142(1.0500785 - e^{-0.05302851L}) \quad [2]$$

$$\rho_s = 2.2630140(1.039083 - e^{-0.00605170L}) \quad [3]$$

The variation of bulk density immediately after compaction follows a non-linear trend but after swelling it looks like linearly varying yet explained well with [Eq-3].

Compaction till Consolidation

For studying the compaction, behavior of rice husk for consolidation the load was further increased beyond 25 tonnes. The rice husk starts consolidating at a load of 30 tonnes and thereafter. The loads applied in this range were 30, 35, 40, 45, 50, 55 and 60 tonnes. It can be seen from [Table-1] and [Fig-1] that the immediately after the compaction, the obtained bulk densities of briquettes were 1.510, 1.586, 1.650, 1.697, 1.743, 1.774 and 1.793 g/cm^3 with the corresponding increase in bulk density of 16.966, 17.820, 18.539, 19.067, 19.584, 19.934 and 20.146 times compared to the bulk density of loose rice husk against the applied consolidating loads of 30, 35, 40, 45, 50, 55 and 60 tonnes, respectively. Bulk densities of a briquette after swelling were observed to be 0.465, 0.520, 0.575, 0.628, 0.679, 0.731 and 0.771 g/cm^3 indicating 5.225, 5.843, 6.461, 7.056, 7.629, 8.213 and 8.663 times increase compared with the loose rice husk density against the consolidating load of 30, 35, 40, 45, 50, 55 and 60 tonnes respectively [Fig-2].

Increase in the bulk density of rice husk compared to bulk density of loose rice husk was well explained with the following relationships.

$$\frac{\rho_c}{\rho_b} = 20.131455\, e^{-\frac{1}{2}\left(\frac{L-50.326378}{32.529068}\right)^2} \quad [4]$$

$$\frac{\rho_s}{\rho_b} = 8.7784716\, e^{-\frac{1}{2}\left(\frac{L-68.64355}{37.278515}\right)^2} \quad [5]$$

Where,

ρ_b = bulk density of rice husk, g/cm^3

Increase in bulk density with non-consolidating loads tend to be linear but the best explained with [Eq-5].

Swelling Ratio (ϕ)

Variation of swelling ratio calculated by [Eq-1] against applied loads is shown in [Fig-3]. It can be seen from [Table-1] and [Fig-3] that the swelling ratio increased with decrease in load application. It is mainly due to less swelling immediately after compaction of rice husk compared to the swelling after 24 hours. Swelling ratio upto non consolidating load range were observed to be 3.220, 3.721, 3.736, 3.604 and 3.422 against applied load of 5, 10, 15, 20 and 25 tonnes respectively and 3.247, 3.0500, 2.869, 2.702, 2.567, 2.426 and 2.325 against applied consolidating loads of 30, 35, 40, 45, 50, 55 and 60 tonnes respectively. Inverse of swelling ratio upto non consolidating load ranges were observed to be 0.310, 0.268, 0.267, 0.277 and 0.292 against applied load of 5, 10, 15, 20 and 25 tonnes, respectively, and 0.307, 0.327, 0.348, 0.370, 0.389, 0.412 and 0.430 against applied consolidating loads of 30, 35, 40, 45, 50, 55 and 60 tonnes, respectively. Swelling ratio was observed to be 0.430 against maximum load of 60 tonnes, reported similar density ratio of 0.45 in his study on briquetting [23]. The swelling ratio and inverse of swelling ratio were well explained with following relationships.

$$\frac{\rho_s}{\rho_c} = e^{-3.2776267 + \frac{6.0600701}{L} + 0.56574255 \ln L} \quad [6]$$

$$\frac{\rho_c}{\rho_s} = e^{3.1322867 - \frac{5.6589659}{L} - 0.52756206 \ln L} \quad [7]$$

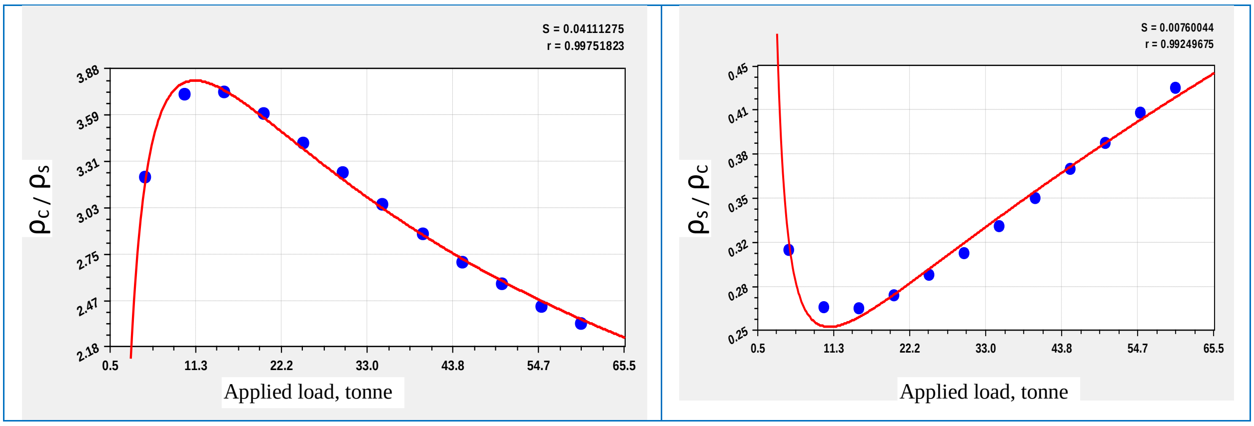

Fig-3 Variation of swelling ratios with applied loads.

Swelling has a peak initially at 10 tonnes of load and decreases thereafter. Inversing the swelling ratio the peak is reversed [Fig-3]. [Fig-3] provides understanding how the swelling ratio decreases with load application and at what level of load desired swelling ratio can be retained.

Conclusion

Use and recycling of agri-bio-waste and agri-by product are being advocated strongly due to sustainability point of view, high disposal cost, increasing cost of conventional energy and environmental concerns. Developing countries are spending huge amount of hard earned foreign currency for procurement of petroleum products for meeting their growing energy demands annually. Cow dung cake, pigeon pea stalk, sesbania stalk, mustard stalk, sorghum stalk and maize stalk, bagasse, coconut fiber and shells, sawdust and rice husk are being used as domestic fuel by Indian rural masses to meet their daily energy demand since long. Their present use has become more important from sustainability point of view and disposal point of view as well. Storage of agri-bio-wastes and agri-by-products is tedious due to low density, large space requirement and other associated problems. Increasing costs of traditional energy sources are forcing rural peoples to use agri-bio-waste and by-products as domestic fuels more intensively. Low density and huge volumes are major concerns due to increasing labor cost. Rural domestic kitchens and domestic stoves are not properly designed to burn agri-bio-waste or by-products efficiently with minimum associated health risks. Smoke is a real problem. Government's efforts to provide liquified petroleum gas in rural area are pursuing rural masses to avoid use of agri-bio-wastes and agri-by-products as domestic fuels. India is second largest producer of rice in the world and produces huge quantity of rice husk. Increased production of rice husk and limited use of it as fuel in domestic areas is a big concern. The rice husk needs to be changed into efficient fuels in term of calorific values, storage and transportability. The simplest way is compaction. The bulk density of loose rice husk ranges between 0.083 to 0.125 g/cm^3 which is quite low and a constraint for its transportation, handling and storage. Compaction of rice husk can increase its bulk density several folds minimizing associated problems of low bulk density. Application of load on loose rice husk increases bulk density, but as soon as the load is removed it has a tendency to swell. The swelling of the compacted rice husk decreases with an increase in applied loads. Application of high load will lead to a consolidation of rice husk and consolidated husk is known as briquette when intended to be used as fuel. Consolidated rice husk briquettes could be used in domestic stoves as well as for commercial application. Compaction behavior study is necessary to know the consolidating and non-consolidating load ranges and corresponding husk densities. The compaction behavior of rice husk was studied by applying loads on loose rice husk filled in a cylindrical mould over a UTM in order to work out consolidation and non-consolidation load range and acquired a bulk density due to compaction. Rice husk was collected from a nearby rice mill. Rice husk was sun dried and stored in a polyethylene bags. At a load of 30 tonnes and above rice husk starts consolidating without any heat treatment and addition of any binding materials in it. Density of rice husk after compaction ranged 0.503 to 1.315 g/cm^3 in non-consolidating load range of 5 to 25 tonnes and 1.510 to 1.793 g/cm^3 in consolidating load range of 30 to 60 tonnes. The increase in density ranged 5.648 to 15.675 times in non-consolidating load range and 16.966 to 20.146 times in consolidating load range. Density after 24 hours of load relaxation ranged 0.156 to 0.408 g/cm^3 in non-consolidating load range and 0.408 to 0.771 g/cm^3 in consolidating load range. The corresponding increase in bulk densities was 1.754 to 4.580 times and 5.225 to 8.663 times compared to the loose rice husk density. Similarly, swelling ratio ranged from 3.220 to 3.736 and 2.325 to 3.2473 in non-consolidating and consolidating load application ranges, respectively. Increasing bulk density of rice husk by applying loads and transforming husks into briquettes for its use as fuel for commercial and domestic applications will decrease the cost of packaging, transportation and storage.

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Conflict of Interest: None declared

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