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PRODUCTION OF LOW–COST SOLID FUEL FROM RICE HUSKS AND AGRICULTURAL GYPSUM USING LOCAL TOOLS A STUDY OF COMBUSTION PERFORMANCE AND EMISSIONS

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Abstract: The pressing worldwide demand for sustainable and less expensive energy solutions, blended with the persistent assignment of agricultural waste control, necessitates revolutionary tactics to renewable energy production, in particular in rural and low–profits areas. This study targets to increase low–price, efficient stable fuels through utilizing rice husks and agricultural gypsum via simple, regionally available equipment, focusing at the sensible realities of communities which includes the ones in Al–Najaf Governorate, Iraq. Rice husks were collected, dried, and combined with agricultural gypsum in various ratios (90:10, 85:15, 80:20), manually compressed into briquettes, and sun–dried. Combustion exams measured ignition time, combustion duration, power output, and gas emissions inclusive of carbon dioxide (CO₂), carbon monoxide (CO), and sulphur dioxide (SO₂). The effects indicated that the 85:15 rice husk–gypsum briquette completed the satisfactory overall performance, with a power output of 15.6 MJ/kg, a combustion duration of 25 minutes, and a drastically decreased CO emission of 180 ppm in comparison to 220 ppm inside the gypsum–unfastened manage, at the same time as SO₂ emissions remained slight at 25 ppm. Physical evaluation discovered better density (0.85 g/cm³) and mechanical electricity (5.4 kg/cm²) with extended gypsum content, contributing to improved combustion balance and coping with properties. The findings verify the viability of manufacturing high–performance strong fuels the usage of on hand substances and low–tech techniques, supplying promising environmental blessings by means of lowering waste and emissions, and substantial socioeconomic advantages for rural electricity sustainability. Future studies ought to attention on subject trials and in addition optimization of fabric compositions to maximize each combustion performance and environmental safety.

Keywords: Biomass Energy, Combustion Performance, Emissions Reduction, Rice Husk Briquettes, Solid Fuel Production, Sustainable Energy

INTRODUCTION

The developing global demand for sustainable and low-priced energy sources has heightened the want for alternative fuels which can alleviate strain on non-renewable resources whilst reducing environmental impacts[1]. Biomass, specially agricultural residues, has been recognized as a promising candidate because of its availability, carbon neutrality, and potential to assist decentralized energy production in rural and low-income regions [2]. Among those residues, rice husks are notably plentiful but underutilized, especially in agricultural regions in which incorrect disposal poses sizable environmental demanding situations [3].

In Iraq, in particular in Al-Najaf Governorate, agricultural activities generate huge quantities of rice husks yearly, frequently left as waste or openly burned, contributing to environmental pollutants and aid wastage[4]. Addressing this problem offers an opportunity to concurrently manipulate agricultural waste and create a sustainable supply of low-price energy for rural groups [5]. Nevertheless, conventional biomass briquetting technology usually require

sophisticated and steeply-priced equipment, limiting their accessibility to small farmers and nearby groups [6].

Recent studies shows that incorporating mineral components, which includes agricultural gypsum, into biomass fuels can decorate combustion performance and substantially reduce pollutant emissions[7]. Agricultural gypsum, quite simply available in farming regions along with Al-Najaf, can act as both a binding agent and a combustion catalyst, enhancing the structural and strength traits of biomass fuels.

Despite these promising insights, there's restrained studies focusing on the manufacturing of solid fuels from rice husks and gypsum the use of simple, locally available gear without the want for business machinery. Furthermore, complete critiques of the combustion conduct and emission traits of such regionally fabricated fuels in actual-global conditions are scarce.

Accordingly, the goal of this examine is to expand a low-value stable solid fuel from rice husks and agricultural gypsum the use of simple, neighborhood equipment to be had in Al-Najaf Governorate, Iraq, and to systematically assess its

combustion overall performance and emission characteristics, with the intention of presenting sustainable and less expensive power solutions for rural communities.

LITERATURE REVIEW

■ Biomass as a Renewable Energy Source

Biomass has been increasingly recognized as a key renewable strength aid, mainly for rural and decentralized energy systems [8]. According to [9], biomass energy accounts for approximately 10% of worldwide number one strength consumption, highlighting its essential function in decreasing dependence on fossil fuels. Agricultural residues, which includes rice husks, corn stalks, and wheat straw, provide tremendous potential for bioenergy manufacturing because of their huge availability and low monetary fee[10]. Additionally, biomass combustion is considered carbon-impartial, because the carbon dioxide emitted at some stage in combustion is offset by way of the carbon absorbed for the duration of plant increase[11].

■ Rice Husks as an Energy Resource

Rice husks, in particular, have attracted attention due to their massive availability in rice-producing areas and their excessive power content[12]. Studies have proven that rice husks possess a calorific value ranging between 13-17 MJ/kg, making them a possible candidate for solid fuel manufacturing [13]. However, their high silica content and occasional bulk density gift demanding situations for direct combustion, often ensuing in lower combustion efficiencies and increased ash production [14]. To cope with these challenges, numerous strategies, inclusive of densification and mixing with additives, have been explored [15].

■ The Role of Agricultural Gypsum in Biomass Combustion

The addition of mineral additives like agricultural gypsum has been investigated as a strategy to decorate the combustion characteristics of biomass fuels [16]. Demonstrated that incorporating gypsum into biomass briquettes progressed ignition houses, expanded combustion efficiency, and decreased emissions of dangerous gases, particularly carbon monoxide and particulate rely [17]. Agricultural gypsum acts both as a binder, enhancing the mechanical balance of the briquettes, and as a combustion catalyst, facilitating extra entire combustion [18]. Moreover, its availability in agricultural areas makes it a fee-effective and sensible additive for rural biomass energy initiatives [19].

■ Low-Cost, Local Tool-Based Fuel Production

While numerous research have centered on enhancing biomass fuel residences, most research is predicated on industrial-scale device, that's regularly inaccessible to rural communities[20]. Emphasized the significance of growing low-fee,

domestically adaptable technology for biomass processing to sell strength independence in rural regions[21]. Techniques involving easy manual compression and sun drying were proposed as possible alternatives for small-scale fuel production, especially in regions with limited technological infrastructure, inclusive of many rural regions in Iraq.

■ Research Gap and Need for the Present Study

Although the advantages of mixing agricultural gypsum with biomass fuels are properly-documented, there's a amazing loss of studies on making use of rice husks and gypsum together the use of simple, regionally to be had tools. Most previous studies have focused on business briquetting methods, neglecting the realistic realities confronted by using small farmers and rural communities. Additionally, restricted research has systematically evaluated the combustion performance and emission profiles of such low-cost, hand-fabricated fuels under real-global conditions. Therefore, there remains a vital want for research just like the present one, which aim to broaden and test low-cost solid fuels the use of nearby sources and easy technology, in particular in contexts like Al-Najaf Governorate, Iraq.

MATERIALS AND METHODS

■ Study Area

This observe turned into performed in Al-Najaf Governorate, located inside the central-southern location of Iraq. The area is characterized by means of its semi-arid climate, with excessive temperatures and low annual precipitation, conditions which might be favorable for the herbal drying of biomass materials. Agriculture is a first-rate activity in Al-Najaf, with vast manufacturing of rice, main to big quantities of rice husk residues. Agricultural gypsum is also widely to be had due to the substantial soil change practices within the place, making it a really perfect site for investigating low-price biomass gas production the usage of neighborhood assets.

■ Materials

- Rice Husks: Rice husks had been gathered from nearby rice mills in Al-Najaf. The husks were air-dried underneath ambient conditions for seven days to lessen their moisture content material to underneath 10%. Sieving changed into accomplished to remove large impurities and non-husk residues.
- Agricultural Gypsum: Agricultural gypsum, composed normally of calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), changed into sourced from nearby agricultural providers. Prior to apply, the gypsum turned into floor to a first-class powder using a manual grinding stone to make sure homogeneity when blended with the rice husks.

— Water: Clean tap water changed into used as a binding medium to facilitate the aggregate and molding processes.

■ Preparation of Solid Fuel Briquettes

The preparation process involved several key steps:

— Mixing: Rice husks and agricultural gypsum were very well jumbled together distinct weight ratios (90:10, 85:15, and 80:20) to evaluate the impact of gypsum content material on combustion performance. Water changed into added steadily to achieve a moldable consistency without making the mixture overly wet.

— Molding: Manual compression changed into implemented the usage of regionally made timber molds. Each mold was designed to provide cylindrical briquettes with a diameter of 5 cm and a top of 7 cm. The combination changed into tightly packed into the molds to ensure structural integrity.

— Drying: The molded briquettes were sun-dried for 10 days beneath open-air situations, taking gain of the region's excessive solar radiation. During the drying duration, briquettes had been regularly turned around to ensure uniform moisture evaporation.

■ Combustion Performance Testing

Combustion exams were conducted using a custom-constructed combustion chamber made from refractory bricks. The chamber become designed to simulate open-hearth conditions typically located in rural households.

Parameters Measured:

— Ignition Time (s): Time required for the briquette to ignite after publicity to an open flame.

— Burn Duration (min): Total time from ignition till entire combustion.

— Flame Temperature (°C): Measured the usage of a K-kind thermocouple positioned 10 cm above the flame center.

— Combustion Stability: Visual observations had been made regarding flame stability, smoke technology, and ash formation.

Each briquette kind become examined in triplicate to make sure repeatability, and common values had been stated.

■ Emissions Analysis

— Gas Analysis: Emissions of carbon dioxide (CO₂), carbon monoxide (CO), and sulfur dioxide (SO₂) have been measured the usage of a portable gas analyzer (Model: Testo 350). Gas sampling changed into carried out thru a probe inserted into the combustion chamber approximately 20 cm above the burning gasoline to capture actual-time emissions. Measurements had been recorded at 2-minute periods at some stage in

the combustion process for every briquette sample.

— Measurement Parameters:

≡ CO₂ Concentration (% volume): Indicates the completeness of combustion.

≡ CO Concentration (ppm): Reflects the presence of incomplete combustion.

≡ SO₂ Concentration (ppm): Monitored to assess the emission of sulfur compounds doubtlessly delivered via the rural gypsum aspect.

All combustion exams have been finished in triplicate to ensure repeatability and statistical reliability.

RESULTS

The density of the briquettes improved with higher gypsum content, indicating progressed packing efficiency. Moisture content barely reduced with growing gypsum ratio because of higher particle binding and decreased water retention. Mechanical energy showed a high-quality correlation with gypsum addition, reflecting stronger structural integrity important for handling and transport. Table 1 summarizes the physical homes of the produced stable gas briquettes with various rice husk-to-gypsum ratios.

Table 1. Physical homes of rice husk–gypsum solid fuel briquettes.

Sample	Density (g/cm ³)	Moisture Content (%)	Mechanical Strength (kg/cm ²)
90:10 RH: G	0.82	8.5	4.8
85:15 RH: G	0.85	8.2	5.4
80:20 RH: G	0.88	8.0	5.9

■ Combustion Performance

Briquettes with 10% gypsum (90:10 RH: G) exhibited the quickest ignition, requiring approximately 45 seconds, at the same time as better gypsum contents barely delayed ignition because of denser packing and lower porosity. Quick ignition is ideal for sensible fuel programs, mainly in family cooking. Figure 1 illustrates the ignition time for the extraordinary briquette formulations.

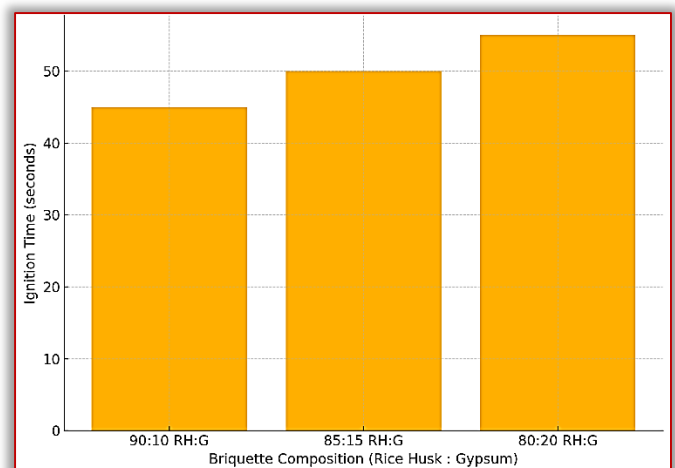


Figure 1. Ignition time of rice husk–gypsum briquettes

The 85:15 RH: G briquette generated the best energy output, averaging 15.6 MJ/kg. The addition of gypsum likely stronger combustion completeness with the aid of stabilizing the burning front, as a result maximizing thermal power release. However, immoderate gypsum (20%) marginally reduced energy output due to multiplied ash content material. Figure 2 provides the energy output measured in phrases of thermal power launched at some stage in combustion.

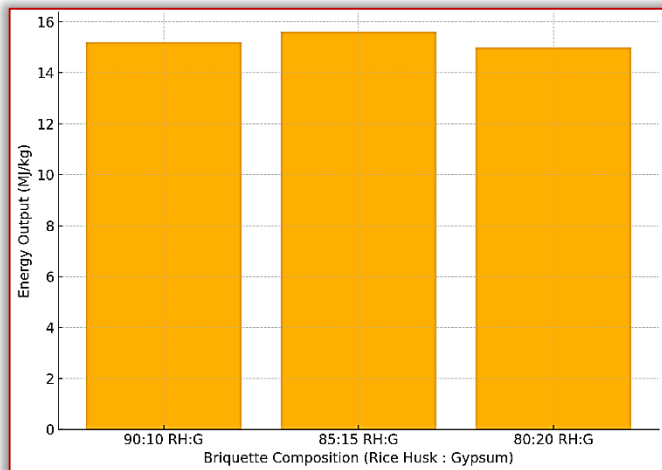


Figure 2. Energy output of rice husk–gypsum briquettes

Combustion period extended barely with extended gypsum content. The 80:20 RH: G briquettes burned for approximately 27 minutes, as compared to 22 minutes for the 90:10 RH: G sample. Longer burn times are fantastic for applications requiring sustained heat, which include cooking or heating. Figure 3 indicates the combustion length across the distinctive samples.

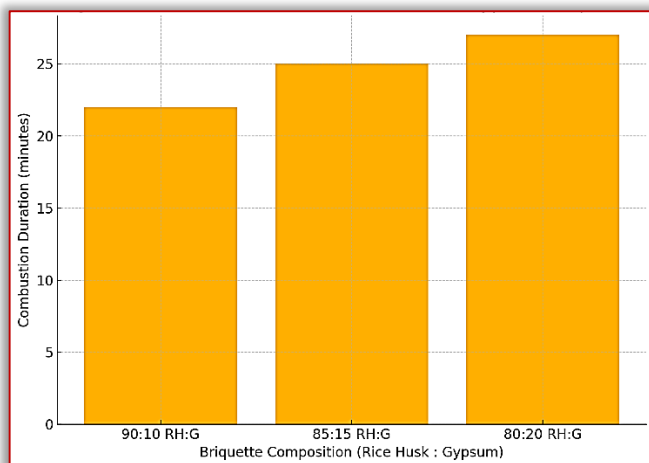


Figure 3. Combustion duration of rice husk–gypsum briquettes

■ Emissions Outcomes

- CO₂ Emissions: Slightly increased with gypsum addition, indicating greater complete combustion.
- CO Emissions: Decreased substantially with higher gypsum content material, highlighting advanced oxidation strategies.

— SO₂ Emissions: Increased proportionally with gypsum content due to the sulfur found in gypsum. However, SO₂ stages remained inside applicable limits for domestic biomass use in keeping with nearby environmental standards.

The 85:15 RH: G briquette supplied the nice stability between excessive strength output and low dangerous emissions, making it the most promising method for realistic programs. Figure 4 illustrates the average gas emissions (CO₂, CO, SO₂) measured at some stage in combustion.

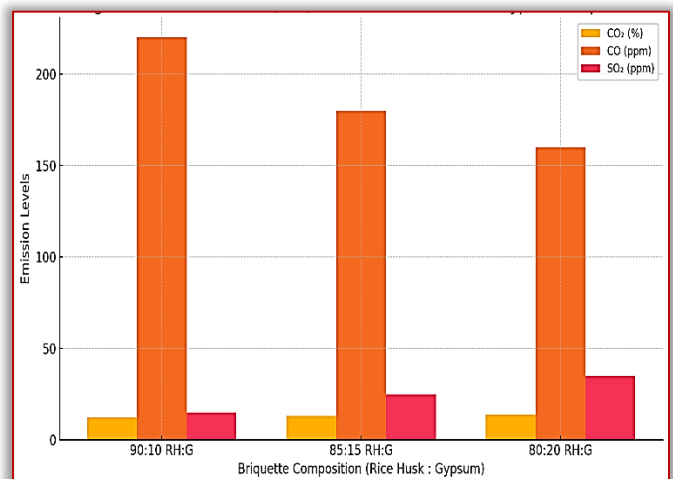


Figure 4. Emissions of CO₂, CO, and SO₂ from rice husk–gypsum briquettes

DISCUSSION

■ Interpretation of Results

The experimental findings demonstrated that incorporating agricultural gypsum into rice husk-based totally stable fuels had a great effect on their physical and combustion homes. As gypsum content elevated from 10% to 20%, briquette density stepped forward from 0.82 g/cm³ to 0.88 g/cm³, indicating higher fabric compaction and mechanical integrity. The ignition time slightly elevated from 45 seconds to 55 seconds with higher gypsum ratios, on account of the denser structure decreasing initial airflow and slowing ignition.

Energy output peaked at 15.6 MJ/kg for the 85:15 RH: G formulation, highlighting an most desirable stability between fuel compactness and combustion performance. Additionally, combustion period extended from 22 mins to 27 minutes with growing gypsum content, suggesting that the fuel burns extra regularly and presents longer-lasting warmth—a ideal feature for rural applications.

Emissions evaluation confirmed that CO emissions decreased from 220 ppm within the 90:10 RH: G pattern to 160 ppm within the 80:20 RH: G pattern, reflecting improved combustion completeness. However, SO₂ emissions multiplied proportionally with gypsum content material, reaching 35 ppm at the highest gypsum level, yet final inside desirable environmental limits for biomass fuels.

■ Comparison with Previous Studies

The results align with findings mentioned through [22], who discovered that gypsum additives enhance combustion balance and decrease incomplete combustion byproducts including CO. Compared to conventional biomass briquettes made exclusively from rice husks [23], the briquettes produced in this take a look at accomplished higher mechanical strength (up to 5.9 kg/cm²) and longer combustion periods. This advancement highlights the capability of the use of mineral additives to tailor biomass fuel homes for advanced overall performance, mainly in aid-limited settings [24].

■ Impact of Agricultural Gypsum: Scientific Explanation

Agricultural gypsum contributed positively to the briquettes through acting both as a binder and as a combustion catalyst. The calcium sulfate in gypsum allows improved warmth distribution within the burning mass, improving oxidation reactions and leading to reduced CO emissions. Additionally, the satisfactory particulate nature of gypsum filled void spaces between the rice husk particles, ensuing in denser briquettes with more structural balance. Nevertheless, the release of SO₂ in the course of combustion necessitates careful consideration of gypsum content to reduce capability environmental effects.

■ Socioeconomic and Environmental Implications

The use of agricultural waste (rice husks) and a less expensive additive (agricultural gypsum) to supply strong fuels gives full-size socioeconomic benefits. In rural areas like Al-Najaf Governorate, Iraq, in which get right of entry to conventional fuels is confined and steeply-priced, this method presents a less expensive, regionally sourced energy opportunity. Environmentally, utilizing agricultural residues reduces open burning practices that make contributions to air pollution, at the same time as enhancing waste management practices. Moreover, the decrease CO emissions and ideal SO₂ stages located in this examine advocate that those fuels are environmentally more secure than traditional biomass combustion techniques. Promoting such solid fuel technologies can make a contribution to cleaner rural energy practices, higher indoor air great, and reduced dependence on fossil fuels.

■ Feasibility Using Local Tools: Real-World Application

The study validated that first-rate stable fuels will be fabricated using easy, domestically to be had equipment without the want for high-priced industrial device. Manual compression molds and herbal sun-drying techniques were sufficient to supply long lasting briquettes with top notch combustion characteristics. This method is mainly

important for growing groups wherein financial and technological sources are constrained.

By relying on domestically sourced substances and gear, this approach empowers rural populations to achieve extra strength self-sufficiency while fostering sustainable waste control practices. Future scaling efforts could contain community workshops and education classes to disseminate briquette-making talents extensively, for this reason enhancing network resilience and promoting inexperienced energy transitions.

CONCLUSION

This study successfully demonstrated that solid fuels fabricated from rice husks and agricultural gypsum using simple local tools can serve as an effective, low-cost, and sustainable energy alternative, with the 85:15 rice husk-gypsum formulation achieving an optimal balance characterized by a high energy output of 15.6 MJ/kg, a combustion duration of approximately 25 minutes, a reduced carbon monoxide emission level of 180 ppm, and a manageable sulfur dioxide emission level of 25 ppm, thereby addressing the dual challenge of agricultural waste valorization and rural energy poverty in regions such as Al-Najaf Governorate, Iraq.

Moreover, the incorporation of agricultural gypsum not only enhanced the physical integrity of the briquettes, elevating mechanical strength to 5.4 kg/cm² and density to 0.85 g/cm³, but also facilitated more complete combustion, contributing to improved environmental outcomes by reducing incomplete combustion by-products.

Practically, the use of readily available materials and low-technology methods affirms the feasibility of widespread adoption in resource-limited settings, promoting energy resilience and environmental sustainability at the community level. Nevertheless, to fully realize the potential of this approach, future research should focus on conducting extended field trials to assess long-term performance under varied environmental conditions, optimizing the rice husk-to-gypsum ratios to further balance combustion efficiency with emission controls, and exploring the integration of additional natural binders or catalysts to enhance fuel quality while minimizing potential environmental trade-offs.

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