RESEARCH PAPER

Solid fuel production using Municipal Dewatered Sewage Sludge

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Abstract

This study focuses on the production of solid alternative fuel using municipal dewatered sewage sludge, sawmill dust, and fly ash as waste-derived raw materials. The research addresses two major issues: the increasing demand for sustainable energy sources and the environmental difficulty of disposing sewage sludge generated from sewage treatment plants. Sewage sludge contains high moisture, pathogens, heavy metals, and organic matter, making its direct disposal problematic. Therefore, the study proposes converting sludge into granulated solid fuel by blending it with sawmill dust and fly ash. Three fuel mixtures were prepared with different proportions of sewage sludge, sawmill dust, and fly ash. The prepared granules were tested for moisture content, ash content, volatile matter, carbon, hydrogen, sulphur, chlorine, and calorific value. The results showed that increasing sawmill dust content improved the fuel quality because sawmill dust has high volatile matter and a higher calorific value. Among the prepared mixtures, Mix III showed the best performance, with the lowest moisture content of 34.80%, lower ash content of 21.70%, higher volatile matter of 64.10%, and the highest calorific value of 14,431 kJ/kg. The study concludes that sewage sludge-based granulated fuel can be used as a supplementary fuel in cement and energy industries.

Keywords: Organic waste, Fossil fuel, Energy, Sewage sludge, Calorific value, etc.
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1. Introduction

The increasing demand for energy and the continuous depletion of fossil fuel [1] reserves have created a strong need for sustainable and waste-derived fuel alternatives. Conventional fossil fuels such as coal, diesel, and natural gas are associated with high greenhouse gas emissions, environmental degradation, and long-term energy insecurity [2]; [3]. At the same time, large quantities of organic and industrial wastes are generated from municipal wastewater treatment plants, sawmills, and thermal power stations. Municipal sewage sludge is one of the most challenging wastes because it contains high moisture, organic matter, pathogens, heavy metals, and ash-forming components, making direct disposal environmentally unsafe. However, sewage sludge also contains combustible organic matter and can be converted into useful energy when properly processed [4] reported that organic sludge blended with sawdust can be developed as refuse-derived fuel with environmental and economic benefits. Similarly, sewage sludge has been recognised as a potential renewable energy resource when converted into solid fuel, pellets, briquettes, or co-firing material [5]. Therefore, the conversion of municipal dewatered sewage sludge into solid fuel provides a practical solution for both waste management and energy recovery.

Sawmill dust and fly ash are important supporting materials in sludge-based fuel production. Sawmill dust is a biomass residue with high volatile matter and good calorific value, which improves ignition, combustion behaviour, and overall heating value of the fuel. In contrast, sewage sludge generally has high moisture and ash content, which reduces its direct calorific efficiency. Therefore, blending sewage sludge with sawmill dust helps balance the fuel properties. [6] found that co-palletisation of sewage sludge and biomass improves pellet density, hardness, and combustion behaviour, making the product more suitable for handling and thermal use. [7] also demonstrated that alternative granulated fuels prepared from sewage sludge and wood waste can achieve useful calorific values depending on mixture composition. Fly ash, although it has almost no calorific value, can act as a stabilising additive due to its mineral and alkaline nature. In the present study, fly ash is used with sewage sludge and sawmill dust to develop granulated solid fuel with improved physical and fuel characteristics.

The present research paper focuses on producing solid fuel from municipal dewatered sewage sludge by combining it with sawmill dust and fly ash in different proportions. The main purpose is to evaluate whether these waste materials can be converted into a useful alternative fuel for cement plants and energy industries. The study analyses important fuel parameters such as moisture content, ash content, volatile matter, carbon, hydrogen, sulphur, chlorine, and calorific value. According to the experimental results of the present work, the increase in sawmill dust percentage improves the calorific value and volatile matter content of the granulated fuel, while reduction in sewage sludge percentage decreases moisture and ash content. Among the prepared mixtures, the best fuel performance was obtained in Mix III, containing 30% sewage sludge, 60% sawmill dust, and 10% fly ash, with a calorific value of 14,431 kJ/kg. These findings are consistent with previous studies showing that sawdust addition enhances the energy quality of sludge-based fuels [4]; [5]. Thus, the study supports a circular economy approach by converting municipal and industrial wastes into a value-added solid fuel.

2. Literature Review

[4] studied organic sludge and sawdust-derived fuel and reported that blending sludge with lignocellulosic waste can improve fuel characteristics, especially calorific value and combustion suitability. [8] investigated solid fuel production from sewage sludge using steam explosion and showed that sludge can be converted into useful fuel when moisture and dewaterability are properly controlled. [9] examined thermally dried sewage sludge as an alternative fuel in Portland cement clinker production and concluded that sludge ash can be incorporated into clinker, reducing separate ash disposal. Aranda-Usón et al. (2013) reviewed alternative fuels and raw materials in the cement industry and highlighted sewage sludge, biomass, and industrial waste as sustainable options for reducing fossil fuel dependency. [6] studied co-palletization of sewage sludge and biomass and found that biomass addition improves pellet density, hardness, and handling quality, which directly supports sludge-based granulated fuel production.

[10] evaluated the calorific value of faecal sludge from Uganda, Ghana, and Senegal and showed that sludge-based residues can function as solid fuels when properly dried and processed. Xiao et al. (2015) analyzed municipal sewage sludge and wood sawdust pellet fuels and focused on combustion efficiency, energy recovery, and secondary pollutant generation. [11] investigated sewage sludge biochar as a solid fuel and noted that although energy recovery is possible, high pollutant and ash contents must be carefully managed. [12] examined co-palletization of sewage sludge with agricultural wastes and reported calorific values in the range of approximately 8.6–14.58 MJ/kg, showing similarity with sludge-biomass fuel blends. [13] evaluated combustion of sewage sludge-based biofuels in grate furnaces and found that sludge-derived fuels can be considered for thermal systems, but emissions and ash deposition behavior require attention.

[14] studied combustion melting characteristics of sewage sludge solid fuel and reported a higher heating value of about 14.94 MJ/kg, which is close to the best mix value in the present study. [15] reviewed biomass co-combustion with fossil fuels and explained that biomass-based fuels can support coal substitution when fuel properties and combustion systems are properly matched. [16] discussed environmental and economic benefits of using alternative fuels, including sewage sludge, in cement-related applications. [17] studied co-incineration of sewage sludge and biomass pellets and highlighted energy recovery along with pollutant-emission considerations. [7] produced alternative fuels based on sewage sludge, rubber waste, wood waste, and sawdust, showing that reducing sludge share and increasing high-calorific waste improves fuel quality. [5] transformed sewage sludge and *Pinus* sawdust into solid fuel and

confirmed that sawdust improves carbon, hydrogen, volatile matter, and calorific value, while sewage sludge contributes higher ash, Sulphur, and nitrogen content. These findings are directly aligned with the present study, where Mix III with higher sawmill dust content achieved the best calorific value of 14,431 kJ/kg.

3. Materials And Methods

The materials and methods section describe the experimental approach adopted for producing granulated solid fuel using municipal dewatered sewage sludge, sawmill dust, and fly ash. In this study, sewage sludge was collected from the digester unit of a municipal wastewater treatment plant, sawmill dust was obtained from a sawmill facility, and fly ash was collected from a coal-based thermal power plant. These three waste materials were selected because sludge contains combustible organic matter, sawmill dust improves calorific value, and fly ash supports stabilisation of the fuel blend. The materials were mixed in different proportions to prepare three fuel mixtures. The blended materials were processed using a laboratory mixer and granulator to form cylindrical pellets. The prepared granulated fuels were then tested for important fuel properties such as moisture content, ash content, volatile matter, carbon, hydrogen, sulphur, chlorine, and calorific value to evaluate their suitability as alternative solid fuel.

Three primary input materials were employed in the preparation of experimental fuel blends: domestically sourced digested sewage sludge, sawmill-derived waste in the form of sawdust, and fly ash obtained from a thermal power generation facility.

Representative sewage sludge samples were collected from the digester unit of a municipal wastewater treatment plant. Sampling procedures were conducted in accordance with the Bureau of Indian Standards specification IS 3025 (*Methods of Sampling and Test for Water and Wastewater*), with composite samples obtained at defined intervals via filter press extraction to ensure representativeness of the bulk material. The sewage sludge to be tested is shown in Figure 1

Figure 1. Sewage sludge

Sawmill waste was sourced directly from an operational sawmill facility. Whilst sawmill operations generate a variety of residual materials - including bark, shavings, off-cuts, wood chips, and sawdust - the present study focused exclusively on sawdust as the selected waste fraction. This selection was informed by the technical consideration that the utilisation of sawdust as a sole combustion feedstock necessitates specialised boiler design, making its incorporation into composite fuel blends a more practically feasible approach. The Saw dust collected are shown in Fig 2.

Figure 2. Sawmill dust

Fly ash samples were collected from a coal-fired thermal power plant, where the materials arise as a particulate residue of the combustion process. The fly ash collected are shown in Fig. 3

Figure 3. Fly Ash

Fuel blends were subsequently prepared by combining the three input materials in systematically varied proportions, as detailed in Table 1, with the objective of identifying compositional ratios yielding optimal fuel performance characteristics. Blending was carried out using a laboratory-scale mixer in accordance with the prescribed proportions. The resulting homogenised mixtures were then processed through a laboratory granulator to produce cylindrical solid fuel pellets with lengths ranging from 10 to 50 mm and diameters of 6 mm.

Characterisation of both the raw input materials and the prepared fuel blends was conducted in accordance with applicable ISO standards, supplemented where appropriate by procedures specified within the Indian Standards for Standardisation framework. The full suite of analytical tests performed, together with the fuel properties thereby determined, is presented in Table 2.

4. Results And Discussion

The individual waste characterisation results are presented in Tables 3, 4, and 5. Sewage sludge exhibited the highest moisture content of the three materials, measured at 78%, alongside an ash content of 34.50% and volatile matter of 49.50%. Sawmill dust recorded a moisture content of 10%, ash content of 0.50%, and volatile matter of 75%. Fly ash, by contrast, was almost entirely dry, with a moisture content of just 0.2%, a very high ash content of 95%, and a negligible volatile matter fraction of 0.01%. The elevated moisture content of sewage sludge is a critical concern, as it directly reduces the calorific value of any fuel derived from it – a relationship well established in the literature [18]; [19] Conversely, the high volatile matter fraction of sawmill dust is a favourable characteristic, as volatile-rich materials contain greater quantities of combustible substances that promote efficient ignition and sustained combustion [20]; [21]. Sulfur content in sewage sludge was measured at 1.08%, while values below 1% were recorded for both sawmill dust and fly ash. Chlorine content across all three materials was low, ranging from 0.0% to 0.05%. The elevated sulfur concentrations are a known cause of corrosion in combustion installations and associated equipment, and the value recorded for sewage sludge warrants attention in any thermal application [22]; [23]. The calorific value of sewage sludge was the lowest at 11 MJ/kg, attributable primarily to its high moisture content, while sawmill dust achieved the highest calorific value of 18.10 MJ/kg.

Table 1. Fuel mixture sets in different proportions

Percentage % of wastes	Mixture		
	I	II	III
Sewage Sludge	60%	40%	30%
Sawmill Dust	20%	45%	60%
Fly Ash	20%	15%	10%

Figure 6. Typical Solid fuel in granulated form

Table 3. Results of tests on sewage sludge properties

Sewage Sludge		
Parameter	Unit	Value
Water content W	%	78
Ash content A	%	34.50
Volatile matter content V	%	49.50
Carbon content C	%	35.50
Hydrogen content H	%	4.05
Sulfur content S	%	1.08
Chlorine content CI	%	0.05
Calorific value Qi	kJ/kg	11,050

Table 4. Results of tests on the properties of sawmill dust

Sawmill dust		
Parameter	Unit	Value
Water content W	%	10
Ash content A	%	0.5
Volatile matter content V	%	75.0
Carbon content C	%	45.0
Hydrogen content H	%	6.1
Sulfur content S	%	0.05
Chlorine content CI	%	0.04
Calorific value Qi	kJ/kg	18,108

Table 5. Results of testing the properties of fly ash

Fly ash		
Parameter	Unit	Value
Water content W	%	0.2
Ash content A	%	95
Volatile matter content V	%	0.01
Carbon content C	%	1.20
Hydrogen content H	%	0.5
Sulfur content S	%	0.56
Chlorine content CI	%	0.05
Calorific value Qi	kJ/kg	0.00

The properties of the pelletised composite fuels produced from the three waste materials in varying proportions are summarised in table 6. Moisture content in the granulated fuel ranged from 34.80 % to 49.60%, with the higher values corresponding to mixes containing a greater proportion of sewage sludge. As the fraction of sewage sludge decreased across the mix

Table 6: Parameters of granulated fuel

Parameter	**Unit**	**Granulated Fuel**		
		Mix 1	**Mix II**	**Mix III**
Water content W	%	49.60	39.45	34.80
Ash content A	%	41.40	29.65	21.70
Volatile matter content V	%	48.20	57.55	64.10
Carbon content C	%	28.20	34.05	38.10
Hydrogen content H	%	4.26	4.75	5.13
Sulfur content S	%	0.97	0.67	0.51
Chlorine content CI	%	0.32	0.23	0.18
Calorific value Qi	kJ/kg	11,842	13,279	**14,431**

designs I through III, a consistent reduction in moisture content was observed. Ash content across the three mixes was a minimum of 21.70%, which exceeds the 6.4% ash content reported for eco-pea coal [24]; however, this is a characteristic feature of sludge-based composite fuels and must be managed in any combustion system. Volatile matter was high throughout, ranging from 48.20% to 64.10%, with higher values again corresponding to mixes with a lower sludge fraction and greater sawmill dust content. This elevated volatile fraction contributes positively to the calorific value of the fuel.

The calorific values of the pelletised fuel ranged from 11.84 MJ/kg to 14.43 MJ/kg. Notably, the best-performing mix achieved a calorific value of 14.43 MJ/kg, which approaches the range reported for lignite (15–21 MJ/kg) [25] and supports the potential use of this fuel in co-firing applications alongside hard coal (24–28 MJ/kg) [26]; [27]. Sulfur and chlorine levels in all pelletised mixes were present only in trace quantities, indicating that the fuel is unlikely to cause significant corrosion or generate harmful emissions in thermal conversion systems.

Taken together, these results demonstrate that the granulated composite fuel possesses characteristics suitable for use as an alternative or supplementary fuel in co-firing with coal, offering a pathway to reducing dependence on fossil fuels.

5. Discussion

The results clearly indicate that the quality of granulated solid fuel depends strongly on the proportion of sewage sludge, sawmill dust, and fly ash used in the mixture. Sewage sludge alone showed high moisture content of 78%, ash content of 34.50%, and a calorific value of 11,050 kJ/kg, which limits its direct fuel application. In contrast, sawmill dust showed better fuel characteristics, including only 10% moisture, 75% volatile matter, and a calorific value of 18,108 kJ/kg. Fly ash had almost no fuel value, but its alkaline and stabilising nature helps improve the physical quality of the blended fuel. Among the three granulated mixtures, Mix I showed the highest moisture content of 49.60% and lowest calorific value of 11,842 kJ/kg due to its higher sewage sludge proportion. Mix III, containing 30% sewage sludge, 60% sawmill dust, and 10% fly ash, performed best with 34.80% moisture, 64.10% volatile matter, and 14,431 kJ/kg calorific value. This confirms that increasing sawmill dust improves combustion potential. The low sulphur and chlorine levels also suggest reduced corrosion and emission risks during thermal use.

6. Conclusion

The study concludes that municipal dewatered sewage sludge can be effectively converted into granulated solid fuel when blended with sawmill dust and fly ash in suitable proportions. The research demonstrates a practical waste-to-energy approach that reduces the environmental burden of sewage sludge disposal while producing a usable alternative fuel. The experimental results show that sawmill dust plays a major role in improving the calorific value and volatile matter content of the fuel, whereas fly ash supports stabilisation of the mixture. Among all tested combinations, Mix III was found to be the most suitable composition because it achieved the highest calorific value of 14,431 kJ/kg, lowest moisture content of 34.80%, and comparatively lower ash content of 21.70%. These values indicate that the prepared granulated fuel has potential for co-firing applications in cement plants and energy generation units. The fuel may help reduce fossil fuel dependency and support circular economy practices by converting waste materials into useful energy resources. However, further research is required on combustion behaviour, emission analysis, long-term storage stability, and large-scale industrial application before commercial adoption.

7. Future Scope

Future research should focus on integrating a Life Cycle Assessment (LCA) framework with municipal dewatered sewage sludge-based solid fuel production. The complete process should be evaluated from sludge collection, drying, pelletising, end-use combustion, and landfill avoidance. Each stage should be mapped with its emission sources and possible reduction benefits. Although emissions may occur during transportation, drying, and pelletising, considerable carbon reduction can be achieved by avoiding landfill methane emissions and replacing fossil fuels. Net reductions of about 350–800 kg CO_2-eq per tonne of dry sludge solids may be possible depending on the process efficiency.

The future scope also includes assessing the carbon credit generation potential of sludge-to-solid-fuel projects. Credits can be estimated under three layers:
Scope 1, through methane and nitrous oxide avoidance;
Scope 2, through grid electricity or thermal energy displacement; and
Scope 3, through fossil fuel replacement in cement and energy industries. Suitable carbon credit methodologies such as CDM AMS-III.F, ACM0022, AMS-I.C/I.D, Verra VCS VM0025, Gold Standard, and India's CCTS framework should be studied. Overall, integrating carbon credit assessment with technical and economic analysis can make sludge-based solid fuel a sustainable waste-to-energy and climate-mitigation solution.

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