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Estimation of fuel potential of faecal sludge in a water scarce city, a case study of Jaipur Urban, India

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Abstract

Non-sewer sanitation systems are widely implemented for treatment and management of faecal sludge (FS) and septage in developing nations. India became an open defecation free (ODF) country in 2019, with more than 90 million toilets at rural and urban level constructed to achieve this ODF status. Government of India also initiated a faecal sludge and septage management (FSSM) policy in 2017. This paper highlights the policy vision for the state of Rajasthan and predicts options for a safely managed sanitation system through exploring the fuel potential of faecal sludge generated in the city. The intended study is an attempt to valorize faecal sludge into a marketable product through determining the heat capacity of dried faecal sludge from different sources such as pit toilets, septic tanks etc. In the present work in urban Jaipur, which is already a water scarce city, various onsite sanitation systems were targeted to collect FS samples from different locations. It was observed that the FS generated has a high heating value of 13.96 MJ/kg, with total solids ranges from 7 to 9%. For a pragmatic resource recovery option, the experimental data observed is validated with a literature review.

Key words: ash content, biomass wastes, calorific value, faecal sludge, on-site sanitation

INTRODUCTION

Faecal sludge (FS) is partially digested slurry coming mainly from onsite systems that has not been transported through a sewer. An estimated 2.1 billion population depends on non-sewered sanitation systems, generating faecal sludge that is left untreated, leading to severe environmental contamination and health risks (Strande & Ronteltap 2014). Developing countries like India rely extensively on non-sewered sanitation systems like septic tanks, pit toilets etc. The urban population of India is 377 million as per the 2011 census, which is going to rise to 600 million by 2031. The census of 2011 also estimated that 7.90 million households defecate in the open and do not have access to safe sanitation or toilets (Ministry of Home Affairs 2014). Furthermore, as per a Central Pollution Control Board (CPCB) report, out of a total of 816 sewage treatment plants (STPs), only 522 are operational. India is generating a huge 1.7 million tonnes of faecal waste per day. Seventy eight percent of untreated sewage or FS, as per Centre for Science & Environment (CSE) 2017 is disposed of in rivers, lakes or finds its way to groundwater, one of the key causes of the high incidence of water-borne diseases, infant and child mortality rates. (Goverment of India Ministry of Urban Development 2017).

As per National Policy on FSSM, the key issues and gaps occur at every stage of the sanitation value chain, which mainly includes lack of an formal private contractors, inaccessibility, limited technology choices in treatment and disposal, lack of an integrated city-wide approach, gender-sensitive gap etc.

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Coping with fast urbanization and increasing demand and huge gaps in sanitation, it was difficult to keep pace through conventional systems. On 2 October 2014, India initiated the 'Clean India Mission' or 'Swachh Bharat Mission (SBM)'. The ultimate focus was to free India from open defecation through the largest sanitation programme on the globe, covering both urban and rural areas of the nation (Goverment of India Ministry of Urban Development 2017). With more than 90 million toilets constructed under SBM in the last five years, the key issue remained unanswered, how to deal with human excreta transported through non-sewered systems including septic tanks and pit toilets that are not properly maintained, cleaned or desludged at regular intervals. In alignment with FSSM policy and SDG6, which enforces the treatment of faecal sludge, the government and service providers are looking for sustainable and scalable treatment solutions for further valorization. (Goverment of India Ministry of Urban Development 2017).

The study also places emphasis on the second key objective of FSSM policy, suggesting and identifying the means to create a safe environment through sustainable faecal sludge and septage management in the country. This research addresses the gap related to utilizing faecal sludge as solid fuel in the future to support sustainable business models and sanitation solutions (National Institute of Urban Affairs 2017). The research serves as an initial stage of identifying the fuel potential of faecal sludge, unlatching an environmentally sound and economically beneficial substitute.

Previous studies conducted successfully analyzed FS as solid fuel. The first results were from research work done in Uganda, Senegal and Ghana in 2014 that determined the average heating value of raw FS was 17.3 MJ/kg total solids (Murray Muspratt & Nakato 2014) Another well-performed study took place in the southern state of Tamil Nadu, India, and derived a calorific value varying from 5.4 MJ/kg to 13.4 MJ.kg (Barani & Hegarty-Craver 2018).

METHODOLOGY

Site description

Jaipur city, with a population of 3.1 million people, is the capital city of the state of Rajasthan, which is spread across 484.6 km^2. The city is located in the semi-arid zone of India, characterized by low rainfall, high temperature and mild winter. Jaipur's mean temperature varies from 36 °C–18 °C in winters in January to 40 °C in summers in June. The average rainfall of Jaipur is around 600 mm/annum compared to the national average of 1,170 mm/annum (Gurjar 2015). In the last decade, the water table in Jaipur city has gone down almost 25 metres and all 13 zones of Jaipur city are dark zones (over exploited) as per the Central Ground Water Board report. For drinking water supply, the city is presently depending on the distant Bisalpur dam (120 km away) along with tank service and tubewells to fill the demand gap from 3.1 million users. The city serves 91 well-defined municipal wards. Sanitation coverage is also not so encouraging in Jaipur city, as per census 2011, as shown in Figure 1.

According to the Rajasthan Urban Infrastructure Development Programme (RUIDP) 2011 report, the existing treatment capacity of STPs is only 235MLD out of 378MLD of wastewater generated.

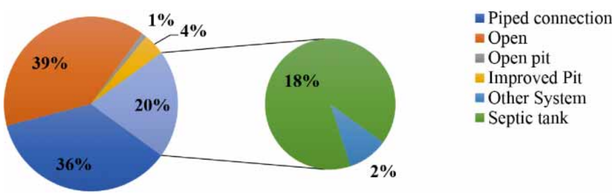

Figure 1 | Sanitation coverage in Jaipur city as per census 2011.

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About 36% of the population have piped or underground sewerage connections; 25% rely on on-site sanitation systems and 39% still practice open defecation (Government of Rajasthan 2017).

SAMPLING

Faecal sludge samples were collected from different locations in Jaipur city from vacuum trucks serving residential areas, hotels, hostels and peri-urban areas. Samples were collected on separate days by selecting random desludging trucks of 2 m^3–3 m^3 capacity, in 1-L plastic containers at the time of desludging, and transported to the laboratory for further analysis (Strande & Ronteltap 2014). Information regarding the source of FS was gained by interview from the truck driver at the time of collection, as recorded in Table 1. Faecal sludge samples were collected in the months of February to March 2019 during the winter season. At the time of collection, the average temperature of the city was 15° C with atmospheric humidity of approximately 49% (Gurjar 2015).

Table 1 | Breakdown of FS samples collected from urban Jaipur

Sample name	Location	Area	FS present in vacuum truck	Inclusion of grey-water
S1	Manasoravar	Residential	Septic tank	No
S2	Vaishali Nagar	Residential	Mix[a]	Yes
S3	Bagru	Industrial	Public toilet	No
S4	Hostel STP	Hostel	STP	No
S5	Sanganer	Residential	Pit latrine	Yes
S6	Gandhi Nagar	Residential	Mix[a]	No
S7	Sanganer	Industrial	Septic	No

[a]The FS collected through vacuum truck were not from specific source like pit latrine, septic tank instead it was uncertain and collected from different systems.

The collected FS samples were prepared within 72 hours for drying and determining the calorific value and other characteristics. Another sample was collected from Manipal University Jaipur (MUJ), Hostel STP after dewatering at the outlet, and tested for the same properties. In order to utilize FS as solid fuel, initial drying is required and then it is analyzed for calorific value under two drying conditions: solar dry and oven dry.

To dry the samples, they were placed in an oven for 8–10 hours at 50 °C, whereas the samples for solar drying were placed to dry in solar heat for 36–48 hours. Two duplicate samples of each type were prepared for analysis and the average value was considered.

Some of the samples were also tested after mixing small quantities of organic waste, cow dung (CD). All the samples prepared were proportioned through volume batching. The samples were mixed in various proportions like SL: CD; FS: CD, as shown in Table 2.

At the time of sample collection and after interviewing the truck owner, it was observed that apart from FS collection the same trucks were also utilized for pumping marble slurry in some areas of the

Table 2 | Proportions of FS sample when blended with organic wastes via the volumetric method

Sample name	Volume proportion mixed
FS (raw)	1
FS:CD	5:1
SL:CD (stabilized sludge)	1:1

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city. Therefore, sometimes this results in mixing of both FS and marble slurry. Samples collected from Gandhi Nagar (residential area) also show the presence of marble slurry in significant amounts, and this was clearly visible. Marble slurry results from furnishing marble in industries and is therefore inorganic in nature (Andriessen & Ward 2019).

Sample analysis

The moisture content of collected samples was initially in the range of 95% $\pm$ 5% wt. Collected faecal sludge samples were subjected to series of experiments, for example Chemical Oxygen Demand (COD) was calculated through the open reflux method according to ***APHA-5220 B***, total solids (TS) as per ***APHA 2540 B***, water content, calorific value according to ***ASTM D5856***, and ash content by weighing after complete combustion was conducted (APHA 2012).

To determine the calorific value, a bomb calorimeter was used, which was calibrated using benzoic acid of a known higher calorific value (HCV) and the HCV of FS was determined using Equation (1):

$$HCV = \frac{(weight\ of\ water - water\ equivalent) * \Delta T}{weight\ of\ sample\ (g)}\ (cal/g) \tag{1}$$

RESULTS AND DISCUSSION

The total solids and chemical oxygen demand of collected samples vary from location to location as shown in Table 3. It was noted that in sample S6, total solids calculated was 30%, due to the presence of inorganic matter (marble) mixed with FS in the truck at the time of collection of FS. It was also observed that the variation in value of COD does not affect the calorific value of the samples.

Table 3 | Primary results of total solids and chemical oxygen demand in different samples collected

Sample	Type of system	TS (%)	COD (mg/L)
S1	Septic tank	8	4,224
S2	Mix – septic tank/pit latrine/bore pit	5.7	4,268
S3	Public toilet	2.3	1,024
S4	Hostel-STP	25	640
S5	Pit latrine	4.8	4,268
S6	Mix – septic tank/pit latrine/bore pit	30	796.8
S7[a]	Septic tank	5.6	4,212

[a]The TS and COD results determined for sample S7 are of raw faecal sludge only.

Determination of heating value through experimentation

As indicated in Table 4, the average calorific values of raw FS dried in oven at 50 °C were in range of 12 MJ/kg to 14.40 MJ/kg. On the other hand, calorific values of FS dried in solar heat were in range of 11 MJ/kg–13 MJ/kg.

The calorific value of sample S3 turned out to be exceptionally low due to the presence of excessive water content in it (98.2%) and negligible useful organic matter. As shown in Table 4 sample S6 contains a large amount of inorganic matter (marble slurry), therefore leading to a decrease in calorific value by approximately 8 MJs.

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Table 4 | Results of calorific value of raw FS under two drying conditions in MJ/kg

Sample	Type of system	Oven dry (MJ/kg)	Solar dry (MJ/kg)
S1	Septic tank	12.71	11.68
S2	Mix	12.96	10.66
S3	Public toilet	0.244	–
S4	Hostel-STP	8.03	7.79
S5	Pit latrine	13.40	12.99
S6	Mix	4.6	3.5

The variation in calorific value under two drying conditions can be distinctly seen in Figures 2 and 3. After complete combustion of raw FS samples, weights of ash were taken using a weighing machine and this accounted for 30% ± 10% of weight.

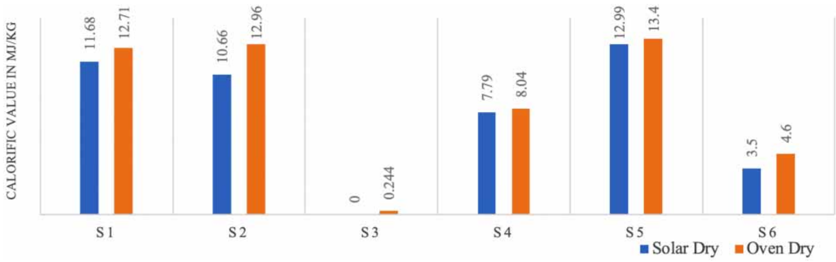

Figure 2 | Experimental results of calorific value of raw samples under solar and oven drying conditions in MJ/kg.

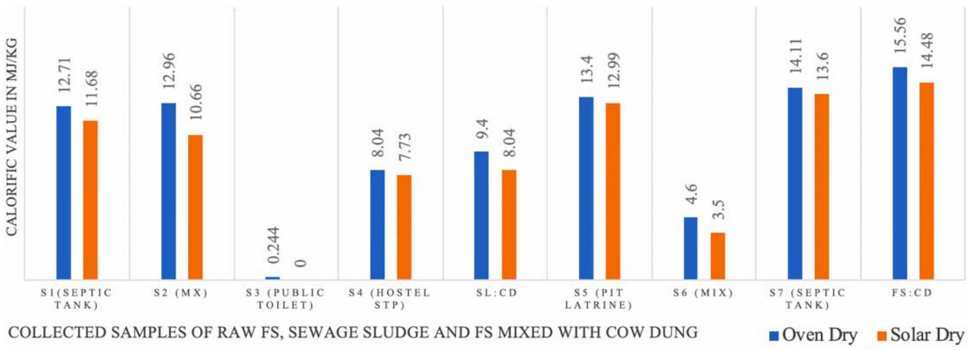

Figure 3 | Variation in calorific values corresponding to different drying and mixing conditions in MJ/kg.

Sample S4, which is digested sewage sludge taken from the outlet of Hostel-STP, was stabilized and centrifuged at the time of collection. The determined calorific value of the initial sample was 8.03 MJ/kg. The main reason for the lower calorific value is the stabilization of the sludge, which reduces the degradable organic fraction. Furthermore, the same sample, S4, was mixed with cow dung (CD) in equal proportion (1:1) and it was observed that sample S4 has an increment in calorific value by 1 MJ/kg, resulting in an overall calorific value of 9.40 MJ/kg. Whereas S3 sample was collected from a public toilet with a high water content of 98.2%, with suspended solid particles with a COD of 1,024 mg/l, due to the greater liquid to solid ratio the calorific value is very low.

From the observed result, another experiment was performed with FS mixed with cow dung, which is presented in Table 5 with several mix designs.

As a result, a significant increase in calorific value of nearly 2.0 MJ/kg was observed, as shown in Figure 4. When organic wastes like cow dung, husk, sawdust and so on are added to FS for increasing

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Table 5 | Results of increased Calorific Value of FS when blend with cow dung in MJ/kg

Sample	Oven Dry (MJ/kg)	Solar Dry (MJ/kg)
FS(raw)	14.11	13.60
FS: CD	15.56	14.48
SL (raw)	8.03	7.79
SL: CD	9.40	8.04

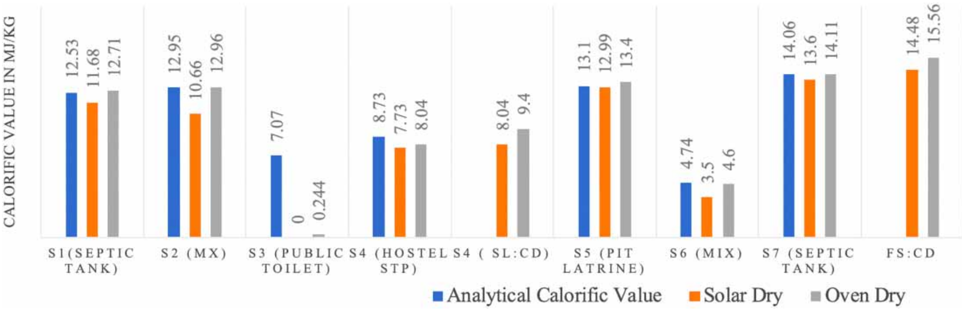

Figure 4 | Comparison of experimental and analytical calorific value of faecal sludge.

the calorific value it was also observed that the quantity of ash content was increased from 30% to 40% ± 5% of weight.

Analysis of heating value

Barani & Hegarty-Craver (2018) performed the ultimate analysis to find out the elemental composition of FS from varying sources like bore pits, latrines and septic tanks, using the elemental composition and from the measured calorific values of the sample depicted in Table 2. The presented study calculated the amount of C, H, O, S composition in a sample having a calorific value of 13.60 MJ/kg due to limited resource conditions. The determination of elemental composition is carried out using an empirical method such as Dulong's formula; the elemental composition of dried samples and calorific content was determined using Equation (2) (Fakkaew 2015). The determined calorific values are indicated in Table 6.

$$HCV = \frac{1}{100}\left\{ 8080C + 34500\left(H - \frac{O}{8}\right) + 2240S\right\} kcal/kg \quad (2)$$

Table 6 | Results of calorific value in MJ/kg using Dulong's formula

Sample	C (%)	H (%)	O (%)	S (%)	Calorific value in kcal/kg	Calorific value in MJ/kg
S1	26	3.6	8.9	1.6	12,530.35	12.53
S2	28.9	3.0	7.0	1.2	12,950.00	12.95
S3	1.46	0.1	0.08	0.9	707.84	7.07
S4	20	3.5	17.8	1.3	8,723.61	8.73
S5	29.5	3.7	13	1.5	13,108.78	13.10
S6	10.6	3.1	19	1.2	4,742.50	4.74
S7	33.6	3.8	16	1.2	14,069.78	14.06

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Implementation

To determine the optimum value, it's useful to compare the ash content of FS pellets dried under different conditions collected from various sources, to provide a normalized energy yield of FS as shown in Figure 5. Based on the data in Figure 6, it was observed that FS dried under solar drying has an average ash content of 33.51% per gram whereas oven dried FS has an average ash content of 29.51% per gram. The reason for the higher ash content in the solar dried sample is the presence of inorganic components as in-bound moisture within the FS, which requires a high temperature for removal.

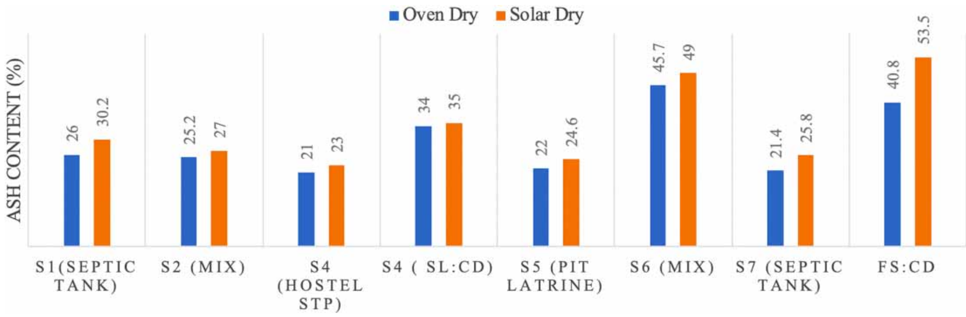

Figure 5 | Percentage of ash after complete combustion per gram of sample.

Trials with different drying methods for FS helped to estimate the calorific value of dried FS samples per unit dried weight as presented in Figures 6 and 7, which is helpful in analysing the calorific value of FS per unit dry weight to evaluate the solid fuel potential.

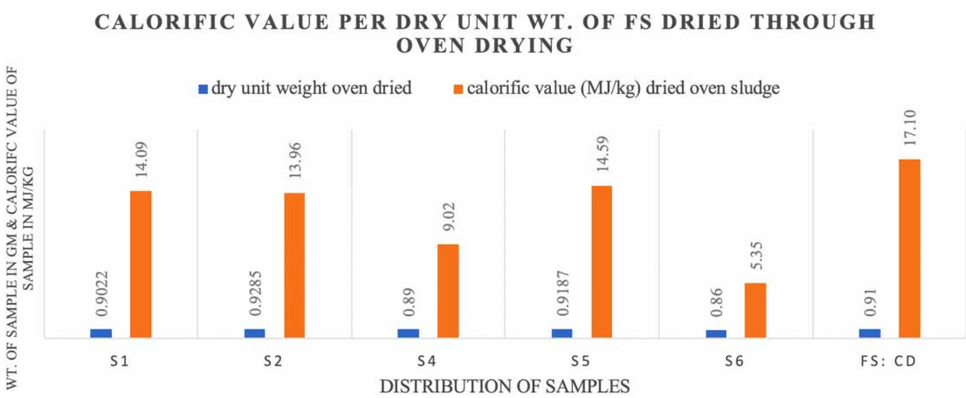

Figure 6 | Energy content per unit dry weight of FS samples through oven drying.

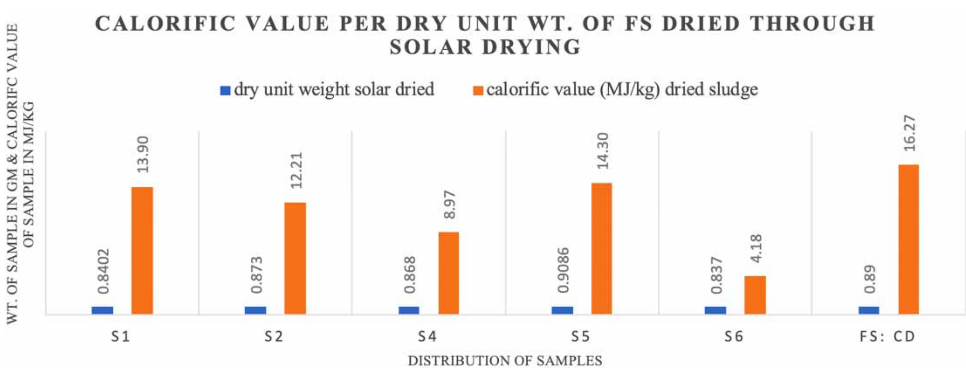

Figure 7 | Energy content per unit dry weight of FS samples through solar drying.

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As per the data observed from Figures 6 and 7, the effects of moisture content on the energy content of the FS under solar drying and oven drying show energy contents of 14.59 and 14.30 MJ/kg could be obtained, when the moisture contents were varied at 8% and 10%, respectively. Also, on mixing cow dung in FS, as mentioned in Table 2, a high energy content of 17.10 and 16.27 MJ/kg was observed.

Financial and operational feasibility of FS briquetting

Murray Muspratt & Nakato (2014) investigated the environmental and financial viability of FS as solid fuel where 500 m^3 FS were dried to 27%, 60% and 85% dry solids and summarised the value fuel cost/saving for Ghana, Uganda and Senegal, which came out to be 28, 807 and 1,397 USD/day. As per data shown in Figures 6 and 7, a sludge having a moisture content varying from 8 to 10% could be utilised for briquetting. The feasibility of FS briquettes being accepted in the market greatly depends upon the fuel value, which is similar to biomass-based briquettes available in the market. A comparison of a dried FS briquette and a biomass briquette is presented in Table 7.

Table 7 | Comparison of fuel value of dried FS briquette and biomass briquette

Name of biofuel	Calorific value of hard coal in kWh/kg	Moisture content (in %)	Rate/kg (INR)	Remarks
FS Briquette	3.91976	9.78	4.10	Based on analysis
Biomass	4.7	10	5.2	Zaybaan (2012)

On critically analysing the operation of the plant, it could be identified that for a particle size less than 25 mm a crushing machine or shredding machine is not required. Along with this, due to the presence of in-bound moisture content, FS briquetting is suitable at 10% of moisture content, having an energy content of 3.91 kWh.

Dry FS is suitable for industrial application and is a fair replacement for conventional fuels like charcoal, wood etc. This study has investigated useful insights for the elemental composition of FS, ash content and future application of faecal sludge as solid fuel. Along with that is the variation in FS calorific value when mixed with other organic waste such as cow dung, which could be implemented at pilot or industrial scale.

CONCLUSIONS

In the light of observations and experimentation, the following are the assembled outcomes:

1. The difference in results of calorific value for faecal sludge and sludge samples from STP is mainly due to digestion/stabilization at treatment plants, which reduces the degradable organic matter and leads to a decrease in calorific value.
2. Calorific value results obtained for samples in oven drying condition were greater than the calorific value of samples obtained through solar drying, because in oven drying there is less in-bound moisture present after complete drying.
3. As per the finding from the conducted study, FS with 8–10% of moisture content should be considered for briquetting.
4. Quality of construction of septic tank or bore pits also has a major impact on the FS composition, as unlined and poorly constructed tanks contain inorganic materials like clay or sand. In experimentation it was observed that clay or sand bound with FS lower the calorific value but increase the ash content after complete combustion.

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5. Considering sustainability in mixing organic waste with FS to attain a higher energy value, different mix compositions could be tried out as per the availability in local areas. Also, for better understanding of the thermal behaviour of faecal sludge, a TGA study is recommended for selection of a drying technique.
6. Further selecting a drying method could result in enhancing the dry unit weight of FS briquettes, which would increase the energy content of the FS, establishing it as a sustainable bio-fuel for thermal plants, brick furnaces, chemical industries plant etc.

This study addresses methods of recovering energy resources in solid form to prevent environmental degradation, cross-contamination, and other health risks. It also suggests that energy recovery models a key strategy towards maintaining the financial sustainability of faecal sludge treatment plants and is a promising step towards a circular economy.

REFERENCES

Andriessen, N. & Ward, B. J. 2019 To Char or Not to Char? Review of Technologies to Produce Solid Fuels for Resource Recovery From Faecal Sludge. *Water, Sanitation and Hygiene for Development* 9 (2), 210–224.

APHA 2012 *Standard Methods for Examination of Water and Wastewater*. American Public Health Association, Washington, DC.

Barani, V. & Hegarty-Craver, M. 2018 *Characterization of Fecal Sludge as Biomass Feedstock in the Southern Indian State of Tamil Nadu*. Gates Open Research, London, UK.

Fakkaew, T. K. 2015 Hydrochar production by hydrothermal carbonization of faecal sludge. *Journal of Water, Sanitation and Hygiene for Development* 5, 439–447.

Goverment of India Ministry of Urban Development 2017 *National Policy on Faecal Sludge and Septage Management (FSSM)*. Ministry of Urban Development, New Delhi, India.

Government of Rajasthan 2017 *Draft Policy on Faecal Sludge and Septage Management (FSSM)*. Government of Rajasthan, Jaipur, India.

Gurjar, R. D. 2015 Geographical characterstics of Jaipur city. In: *Assessment of Impact of Urbanization on Micro Climate in Jaipur Urban Complex Based on Satellite Derived Parameters* (Gurjar, R. D., ed.). Shodhganga, Jaipur, India.

Ministry of Home Affairs 2014 *Office of the Registrar General & Census Commissioner, India. Retrieved From Ministry of Home Affairs*. Government of India, New Delhi, India, http://purimunicipality.nic.in/SBM/SBM_Guideline.pdf.

Murray Muspratt, A. & Nakato, T. 2014 Fuel Potential of Faecal Sludge: Calorific Value Results From Uganda, Ghana and Senegal. *Water, Sanitation and Hygiene for Development* 4 (2), 223–230.

National Institute of Urban Affairs 2017 *Urban Rajasthan- Status and Opportunities in Septage*. Sanitation Capacity Building Platform, New Delhi, India.

Strande, L. & Ronteltap, M. 2014 *Faecal Sludge Management: Systems Approach for Implementation and Operation*. IWA Publishing, London, UK.

Zaybaan 2012 *Radeindustrial Corporation. (Biomass Briquetting Machine)*. Available from: https://pushpaprakash.com/biomass-briquettes-business-india/ (assessed 25 March 2020).