

Research Paper

Physical properties of menstrual hygiene waste as feedstock for onsite disposal technologies

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ABSTRACT

Onsite incinerators offer a promising solution to the challenges of menstrual waste disposal, particularly in institutional settings. However, thermochemical processes are well known to depend on the nature of the feedstocks and their moisture content (MC). An analysis is presented of the physical properties of menstrual waste as potential feedstock for onsite incinerators. Waste was generated in three institutional settings – from women of wide age range and from people with different socioeconomic backgrounds such as workers and students. Over 10 separate collections, 613 discarded menstrual pads were obtained with over 93% of the waste representing commercially disposable pads and less than 7% of the waste appearing to be homemade cloth pads. A surprising finding of this study was that a significant fraction of the commercially disposed pads (23–37%) had a large wet weight (over 20 g) which was associated with MC exceeding 50 wt%. This high MC was attributed to the practice of washing the pads prior to disposal, and it was much higher than what is standard for thermal processing. These data suggest that testing protocols for menstrual waste incinerator technology performance should include an evaluation of the effects of higher MC, unfolded pads, and occasional cloth pads.

Key words | incineration, menstrual health and hygiene (MHH), moisture content, pads, sanitation

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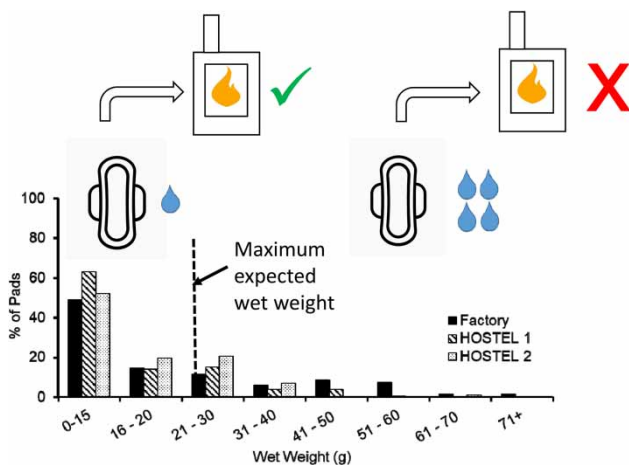
HIGHLIGHTS

- Menstrual waste consists mainly of commercially disposable pads (93% or more) and of homemade cloth pads (6–7%).
- This study found that nearly a third of commercial pad waste had a wet weight of over 20 g, which was associated with moisture content (MC) exceeding 50 wt%.
- High MC waste is attributed to the practice of washing pads prior to disposal.
- Moist waste may result in pollutant emission and incomplete processing by onsite incinerators.

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GRAPHICAL ABSTRACT



INTRODUCTION

Menstrual hygiene is an essential aspect of sanitation for women and girls, which is often neglected in sanitation program implementation in low- and middle-income countries, yet is critical for women's health and dignity as well as environmental safety (Sommer *et al.* 2013; Tilley *et al.* 2013).

A body of research has shown that the lack of access to proper menstrual hygiene management has a negative impact on women's health (Balamurugan & Bendigeri 2012; Das *et al.* 2015) and women's participation in education and the workforce (Bodat *et al.* 2013; Sommer *et al.* 2016).

Challenges related to menstrual health and hygiene (MHH) in low- and middle-income countries are related to both access to safe sanitary products and safe disposal options at the household and community levels (Elledge *et al.* 2018).

The most used menstrual products are absorbents such as sanitary pads, tissue paper (disposable, one-time use) and cloth, typically homemade (Elledge *et al.* 2018). Cloth pads are the traditional and cheaper option, while disposable sanitary pads are increasingly available, especially in urban environments, and considered as aspirational products (van Eijk *et al.* 2016). Statistical associations have been reported between the use of disposable sanitary pads and younger age, higher social class, and urban residence (Elledge *et al.* 2018); however, affordability represents a major constraint (Crofts & Fisher 2012).

Disposal of used sanitary pads is a critical element of the MHH value chain. Cloth pads are cheaper and environmentally less polluting, but cleaning is challenging since it requires access to water, privacy and drying in the sun for its disinfecting effect, as opposed to a hidden drying area utilized for a sense of shame (van Eijk *et al.* 2016). Disposable pads offer convenience of use and are considered as aspirational products for women and girls; however, they present a solid waste challenge. A woman will have an average of 459 periods over her lifetime and dispose of 125–150 kg of sanitary waste (Bharadwaj & Patkar 2004).

The lack of disposal solutions leads to negative health outcomes, e.g. infrequent pad changes during school (Singh & Bhardwaj 2017) as well as environmental issues. Where solid waste management is not available, disposal practices for sanitary pads include throwing them in the open where they can contaminate water bodies, burning (in an open pit), burying them (whether waste is compostable or not), or flushing in the toilet, where they cause clogging and impair the biological degradation of human waste in sanitation systems (Path 2017).

In addition to the lack of sanitation infrastructure, menstruation is associated with stigma and taboos such as the perception of impure or shameful processes leading to restrictions of women's activities during menstruation

and secrecy around menstrual fluid management (Sommer *et al.* 2013; Garg & Anand 2015). Importantly, cultural beliefs and taboos, in addition to convenience and information, contribute to the selection of disposal method (e.g. bury or burn) and to practices such as washing pads before disposal (Ali & Rizvi 2010; Sommer *et al.* 2013).

Onsite incineration is an option for managing the disposal of menstrual waste to achieve both pathogen and volume reduction, thus alleviating the environmental problems associated with improper disposal. Small-scale incinerators placed within a toilet facility may provide an effective and discrete way of disposing menstrual absorbents, align with decentralized waste treatment practices, and are well suited for institutional settings such as schools and worksites (Elledge *et al.* 2018).

Concerns in regard to the adoption of incineration are related to negative health and environmental impacts associated with the release of pollutants and toxic emissions as well as incomplete waste processing (Sommer *et al.* 2013); in the past decade, poor design and insufficient operation and maintenance have resulted in negative experiences for people (Tilley *et al.* 2013).

The Government of India has promoted the adoption of incineration for menstrual waste as part of its Swatch Bharat (Clean India) mission (2018). In India, menstrual waste volume is significantly high, with an estimated 121 million women disposing of 113,000 tons of menstrual hygiene waste (12.3 billion pads) annually (Path 2017). A number of programs implemented to increase access to sanitary pads have been successful in achieving widespread adoption recently, with an estimated 98% urban women using them (Dixit *et al.* 2016) and 64% of women in low-income areas gaining access to such pads (Garikipati & Boudot 2017). It is estimated that over 50 suppliers on the Indian market sell sanitary pad incinerators in institutional settings, with the majority being electric incinerators processing batch sizes as small as 10 pads (Bill & Melinda Gates Foundation 2021). The Government of India has classified sanitary pads as solid waste (SWM 2016), with associated emission thresholds for incineration, and since 2016 has stipulated the manufacturers of sanitary napkins to, among other things, provide wrappers for used sanitary napkins. However, lack of oversight and enforcement of

regulations remains a concern for menstrual waste incineration (Elledge *et al.* 2018).

To our knowledge, there are no published reports on the performance of menstrual waste incinerators on the Indian market nor is there any information that includes the details of operation with actual menstrual waste.

Thermochemical processes such as incineration are well known to depend on the nature of the feedstock and its moisture content (MC). A very low MC is advantageous to incineration, and, to give some examples, the maximum MC allowed for thermal processes including incineration has been reported to be <15% (Burguete *et al.* 2016; Eke *et al.* 2019), while municipal solid waste thermal processes operate at no more than 20–25% moisture (Dong *et al.* 2016). In general, a higher MC can result in higher pollution and incomplete treatment (Youcai *et al.* 2004).

In order to enable the evaluation of menstrual pad incinerators based on realistic feedstock characteristics, this paper characterizes the physical properties of menstrual waste in the context of feedstocks for incineration. We collected and characterized menstrual waste from women's bathrooms from three institutional sites in India, and this paper reports our findings on the nature of the waste and its physical parameters: wet weight and MC.

MATERIAL AND METHODS

Site characteristics and study population

Menstrual waste was collected from three sites in the city of Coimbatore, India, between September 2019 and March 2020. All sites were communal women's toilet facilities: a private textile factory and two student residence halls in an educational institute, Hostel 1 and Hostel 2. The collection of pads was carried out by the caretakers (custodian or janitor) of each facility. The caretakers received an orientation about the purpose of the project prior to the beginning of the study and wore personal protective equipment (masks and gloves).

Site 1: The private textile factory site is a shared toilet for live-in and day workers. According to the warden, the number of users ranges between 20 and 50 women

between 18 and 50 years of age. The facility has five toilet stalls, with a dedicated lidded bin for menstrual waste disposal. After an accumulation period of 2–3 weeks, the five bins were collected by the caretaker by placing the waste in one larger disposal bag and delivered to the investigators for analysis. Five separate collections were used for this study, yielding a total of 304 pads.

Site 2: Hostel 1 is a multistorey building housing approximately 900 female students, estimated to be between 23 and 30 years of age. Each floor contains a toilet facility with 25 individual toilet stalls. Each stall has a dedicated lidded bin for menstrual waste (Figure 1(a)). Caretakers empty the waste bins daily. Standard disposal operations involve the caretaker collecting the contents of all individual bins from one floor into one large disposal bag. In order to preserve the contents of each bin and prevent clumping of the pads, black garbage liner bags were provided to the caretakers the day before collection and placed in each bin. Black liners containing at least one pad were delivered to the investigators (Figure 1(b)). Four separate collections were carried out at this site for one or more floors for a total of 47 bags.

Site 3: Hostel 2 is a multistorey building housing approximately 350 female students, estimated to be between 23 and 30 years of age. Each floor contains a toilet facility with 10 individual toilet stalls. One waste bin is shared between two toilet stalls. The janitors empty the individual waste bins daily into one large disposal bag per floor, similar to hostel 1. Black garbage liners for the bins were provided to the caretakers the day before collection. After 1 day, liners containing at least one pad were

delivered to the investigators. One collection was carried out at this site for a total of 24 bags.

Menstrual waste physical analysis

Analysis began the same day menstrual waste was received from the caretakers. Metal tongs were used to sort the waste into individual pads. For each pad, its type was recorded as either commercially disposable cellulose or homemade cloth (Figure 1(c)). Commercial pads were further analyzed for disposal shape and assigned one of the following categories: unfolded, rolled up/crumbled, or stuck together. Pads that were stuck together due to exposed adhesive liners were recorded as such and not analyzed further. Additional information collected from commercial pads included the presence of wings and additional coatings, as determined by a different color of the substrate material. Cloth pads were homemade and nonuniform in size; therefore, we recorded the length, width, and layers of cloth of the pad.

In a fume hood, an analytical balance was used to record the wet weight for all individual pads received. A subset of approximately 15–18 pads from each collection was further evaluated for MC analysis. Pads were assigned to three weight categories based on wet weight: low (5–20 g), medium (21–40 g), and heavy (>41 g). The pads for MC measurements were randomly selected in quantities proportional to their number in each of the three weight categories.

MC was calculated using the conventional formula $\% MC = (W_{\text{wet}} - W_{\text{dry}}/W_{\text{wet}}) * 100$, where W_{wet} is the wet



Figure 1 | (a) Photograph of a bathroom stall with individual waste bins. (b) Waste bin bag liner as received. (c) Disposed of homemade cloth pad. (d) Individually labeled commercial pads in a dry oven for moisture measurement.

weight and W_{dry} is the dry weight. Pads were placed inside a vented hot air oven whose temperature did not exceed 100 °C (typically 55–70 °C) (Figure 1(d)). The drying temperature is lower than the standard value of 105 °C because of the limited temperature control capability of the oven. By drying at 55–70 °C, we ensured that no temperature swings exceeded 105 °C, which would cause mass loss to volatilization, and thus, we obtained an accurate dry weight value at the cost of longer drying times. The weight of the pads was recorded over multiple days until it did not change more than 4% from prior measurement, thereby providing the dry weight value. After the completion of analytical characterization, all specimens were discarded as biohazardous waste.

Ethics

PSG IMSR's Institute Human Ethics Committee (IHEC) reviewed and approved the study as exempted (2018/

Appr/Exe/017). Duke University IRB determined the study to be non-human subject research.

RESULTS AND DISCUSSION

A total of 613 discarded menstrual pads were collected over multiple collections from three institutional sites, a factory and two residence halls from an institution of higher education (Hostels 1 and 2). Two types of menstrual waste were observed: commercially disposable cellulose pads and homemade cloth pads. The overwhelming majority ($\geq 93\%$) of the pads collected from the three sites were commercially disposable pads, and of these, a large majority had wings or some type of cellulose coating as detected by different colored pad material. Homemade cloth pads were found in waste in two of the three sites, namely, the factory and Hostel 1. Results over multiple collections at the same sites were consistent over time. Table 1 summarizes the

Table 1 | Descriptive statistics of waste collection and its weight and moisture properties

Parameter	Collection sites			Total number
	Factory	Hostel 1	Hostel 2	
Collected pads	304	207	102	613
Collections	5	4	1	10
Commercial pads	284	194	102	580
Cloth pads	20	13	0	33
Commercial pads (%)	93	94	100	95
Featuring wings, coatings	244	192	99	535
<i>Commercial pads in waste</i>				
Unfolded	220	127	7	354
Rolled up/crumpled	8	73	95	176
Stuck together	22	7	0	29
Individually weighed pads	268	187	102	557
Wet weight median (g)	13.9	14.1	15.8	15.2
Wet weight minimum/maximum (g)	6.8/89.2	5.7/52.8	6.8/63.8	5.7/89.2
Pads with wet weight >20 g (%)	37	23	28	31
<i>Moisture analysis of commercial pads</i>				
Pads analyzed for moisture	44	64	17	125
Dry weight median (g)	8.5	7.6	8.9	7.8
Dry weight minimum/maximum (g)	4.8/11.7	4.7/13.7	5.4/14.1	4.7/14.1

results of the physical analysis of the disposable commercial pads for all collections.

Properties of commercial pads

There was a difference in the manner of disposal across sites, with the pads at the factory site being largely disposed of as unfolded, while at the hostels, we observed a mix of unfolded and rolled up, often wrapped by a piece of newspaper. We note that India being a country with a washing culture, bathrooms do not feature toilet paper, which is commonly used as a wrapper prior to disposal in other geographies. Unfolded pads are likely to stick to each other and form clumps that may be problematic for incineration, cause them to stick to surfaces, or be improperly positioned inside the incinerator.

The number of clustered pads was higher at the factory site than at the hostels due, in part, to both the manner of collection and the adoption of liner bags for the menstrual waste bins at the hostels.

The wet weight of the pads had a similar median value consistent across sites (median wet weight between 13.9 and 15.8 g); however, the range was very broad, from 5.7 to 89 g. The dry weight of the pads had median values 7.6–8.9 g and ranged between 4.7 and 14.1 g, consistent with typical ranges for different commercial pad sizes.

Commercial pads are designed to absorb typically 5 ml and, in some models, up to 10 ml of liquid (Fraser *et al.* 2001). Given that blood density is slightly more than water (1.06 g/ml), we estimate that blood adds 5–10 g to the dry weight of pads. Using the largest dry weight measured, for pad, of 14 g, we estimate 14 g (pad) + 5 g (blood) ~ 20 g as the maximum weight of used pads (dashed line in Figure 2), being aware that in some cases we may observe 14 + 10 = 24 g.

Figure 2 shows the wet weight distribution of the pads, indicating that approximately half of the collected waste was below 15 g, with the majority below the expected maximum weight of 20 g. However, a long distribution tail of wet weights higher than 20 g was recorded for all three sites, particularly at the factory site, where as many as 37% of the pads were heavier than 20 g. Weights are plotted against measured MC in Figure 3. The data show that, consistently across the three sites, heavier wet pads feature very high MCs reaching 80–90%. The dotted line at 50% MC

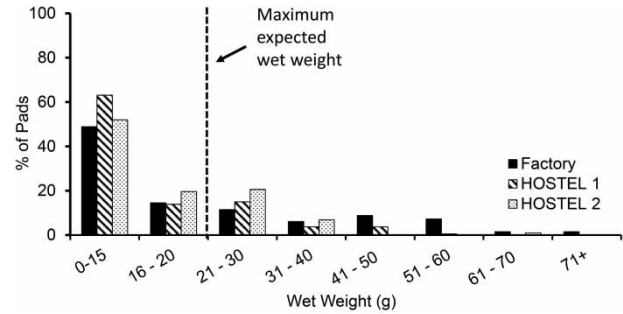


Figure 2 | Wet weight distribution of commercial pads shown as a percentage of the total number of pads from each site.

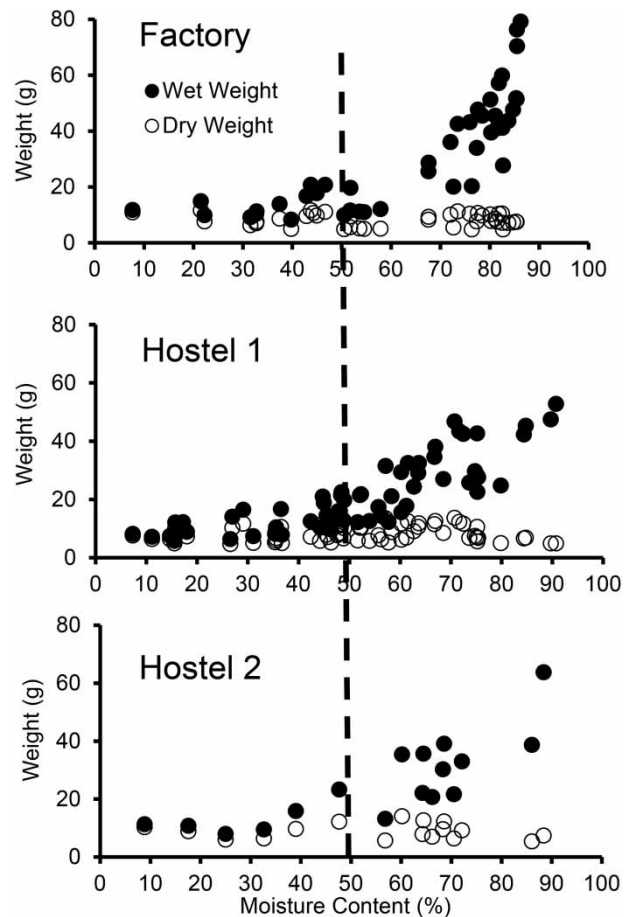


Figure 3 | MC results: wet and dry weights are reported by site. The dashed line represents 50% moisture, the expected upper limit for moisture for used menstrual pads.

corresponds to an 8 g dry pad receiving 8 ml of blood. This is expected to be an upper limit for MC for two reasons: (1) the typical volume of blood for pad rarely exceeds 5 ml and (2) in this study, drying of the pad can occur during

the time between disposal and collection (time lag = 1 day for hostels, 1–2 weeks for the factory site). Yet, the measured moisture values are too high to be consistent with moisture from menstrual blood alone. While we did not conduct chemical analysis on the liquid, we note that since India has a washing culture, a tap with water per personal wash is available in each of the toilets included in this study. Thus, we infer that wet heavy pads derive from the practice of washing them prior to disposal (Ali & Rizvi 2010; Sommer *et al.* 2013). This practice is associated with the concept that menstrual blood is impure and the belief that others should not see it, and also possibly with a lack of awareness on proper disposal practices (Garg & Anand 2015).

While MC was not measured for all pads (wet weight was measured), all pads in Figure 3 whose wet weight exceeded 20 g had a MC exceeding 50% (dotted line). Thereby, a significant portion of disposed pads (23, 28 and 37%) with wet weight above 20 g were estimated to have a MC ranging from 50 to 90%. Such high moisture levels could be problematic for thermal processing because they significantly exceed the optimal 15–25% feedstock moisture (Dong *et al.* 2016; Eke *et al.* 2019).

Properties of cloth pads

Out of the 613 pads collected in this study, 33 were homemade cloth pads. We note that since the cloth pads are reusable, the low fraction of disposed cloth pads does not represent an indication of how prevalent their use is. It is, however, an indication that the menstrual pad incinerator should be evaluated for its ability to process feedstock that contains a percentage of cloth material that has been reused multiple times.

Figure 4(a) illustrates the distribution of wet weight of cloth pads. Higher weights were observed particularly at the factory site, where cloth as long as 88 cm and as wide as 38 cm was folded in layers to serve as a pad (for reference, the length and width of a typical commercial pad product is 25 cm length \times 7.2 cm width). The MC of the homemade cloth was, however, narrower than that observed for the commercial pads and ranged between 16 and 40%. Also, the MC was not associated with wet weight, with some of the heavy pads consisting of a larger quantity of material. A possible explanation for the difference in MC between cloth and commercial pads is the fact that commercial cellulose pads are designed to absorb liquid and, therefore, when washed, retain a large amount of liquid, while cloth pads can dry more easily after disposal.

Comparison with prior studies

Prior studies of menstrual waste are based on surveys, and only a few of them address specific questions on disposal practices that are relevant to our physical assessment results.

A key finding of this study is that a significant fraction of the commercial pads (23–37%) was associated with a high MC consistent with washing prior to disposal.

Prior literature that investigated reproductive tract health included questions about the pad material type and the frequency of personal washing. Within the studies that included details on menstrual hygiene material, the topic of pad washing emerged in the context of cloth pads and their reuse (Omidvar & Begum 2010; Das *et al.* 2015), while separate studies addressed the topic of pad disposal, with no mention made on washing (Wagh *et al.* 2018). Combining

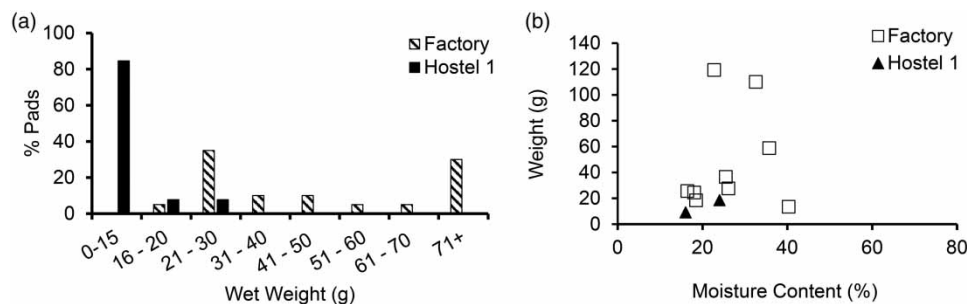


Figure 4 | Analysis of homemade pad properties. (a) Distribution of wet weight (factory: 20 pads; Hostel 1: 13 pads). No cloth pads were collected from Hostel 2. (b) MC was measured for a range of wet weights.

questions on both washing and disposing, a study in Pakistan reported that as many as 60% of the respondents washed and discarded cloth pads; however, there was no explicit question about the washing of disposable pads (Ali & Rizvi 2010). We identified one publication (Kumar & Srivastava 2011) that, while reporting on social restrictions and taboos around menstruation, found that the majority of girls from residential areas in a city in India used disposable pads and that 25% of them washed such sanitary napkins after using them and then disposed them. This observation of washing sanitary napkins prior to disposal is consistent with the high MC in waste that we measured.

Another finding of our work is that a large portion of the pads are disposed of unfolded and, therefore, not wrapped in any paper or plastic. This result is not reflected in prior literature, because the question whether pads are wrapped prior to disposal was not directly asked. In Nayak *et al.* (2017), 98% of the respondents described the material selected to wrap pads (either paper or plastic), and only 1% of the surveyed women did not respond to the question. In Dipali *et al.* (2009), the questionnaire asked about the material the pad was disposed in, not whether it was wrapped; thus, no information on unfolded pads was captured. This difference between our findings and prior reports on this matter highlights the complementarity of physical assessments and surveys in the study of behavior and practices.

CONCLUSIONS

We investigated the physical properties of menstrual waste as feedstock for incinerators that represent an attractive solution to the challenges of menstrual waste disposal, particularly in institutional settings.

Menstrual waste was generated by women of different ages (18–50 years) and different education/income (workers vs. college students), yet consistent outcomes were observed across the two groups. The use of commercial cellulose pads was prevalent at all sites (>93%), in agreement with recent reports (Dixit *et al.* 2016; Garikipati & Boudot 2017). In two out of three sites, 6–7% of the waste consisted of homemade cloth pads, suggesting that a menstrual pad incinerator technology will encounter multiple types of feedstock. The commercial pads were disposed both unfolded or folded, indicating that the

incinerator configuration should be robust with respect pad insertion and positioning inside the unit; folded pads were not wrapped in manufacturer-provided wrappers, despite country regulations and standard use instructions.

A major finding of this study was that a significant fraction of the commercial disposed pads (23–37%) had a large wet weight (over 20 g), which was associated with MCs exceeding 50%. This MC is much higher than ideal for thermal processing (<25%) and can be quite problematic for typical incinerators, leading to incomplete combustion and increased hazardous air emissions. We infer that the MC is due to the practice of washing pads before disposal, a practice that has been reported in washing cultures. While this study on menstrual waste in India is limited to three sites, hundreds of pads were collected in repeated collections over periods of months, and the results were consistent across collections. These findings suggest that further research is needed to fill the knowledge gap on practices in menstrual disposal and that testing protocols of disposal technologies should include an evaluation of the effects of high MC, unfolded pads, and occasional cloth pads on waste processing performance.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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