Pyrolysis-Based Resource Recovery from Sanitary Napkins: a Sustainable Waste Management Approach

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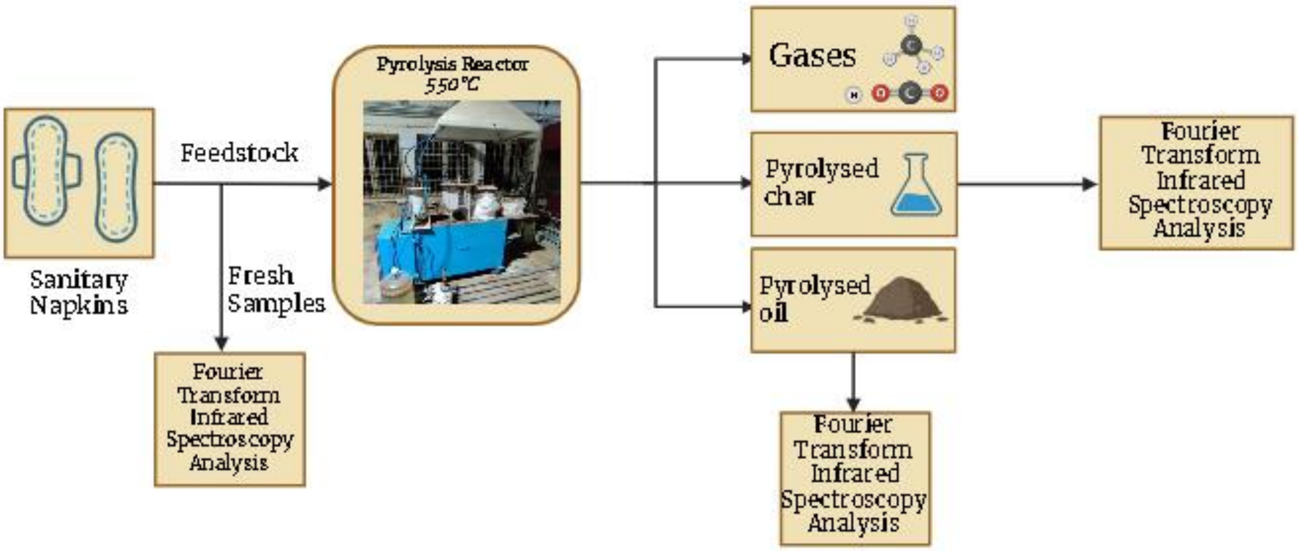
GRAPHICAL ABSTRACT



ABSTRACT

Sanitary napkins, an indispensable component of feminine hygiene, pose a serious environmental challenge due to their non-biodegradable nature. The market growth of sanitary napkins in India can be attributed to the rising demand for high-quality sanitary napkins made from eco-friendly raw materials, which aligns with societal and medical advancements in menstrual health awareness. The improper disposal of used sanitary napkins leads to the accumulation of waste in landfills, which depletes resources and pollutes the environment. To mitigate the detrimental effects of sanitary napkin waste, implementation of pyrolysis experiments at various temperatures and orientations of the napkins are focused along with Fourier Transform Infrared Spectroscopy (FTIR) to examine both the composition of fresh napkins and the characteristics of the pyro-oil and pyro-char obtained as products from the pyrolysis process. The findings of this research contribute to the development of sustainable waste management strategies for sanitary napkins, enabling resource recovery and reducing the environmental footprint associated with their disposal. The recovered resources can find applications in agriculture, energy generation, and chemical industries, leading to a more circular and resource-efficient approach to sanitary napkin waste management.

Keywords: Circular economy, Pyrolysis, Resource recovery, Sanitary pads, Waste management

Highlights

- Analysis of the environmental impacts associated with sanitary napkin waste disposal.
- Characterization of sanitary napkin waste, including the composition and properties of different components.
- Investigation into the pyrolysis process as a solution for sanitary napkin waste management and resource recovery.
- Analysis of the liquid and solid fractions derived from the pyrolysis process, including their chemical compositionand properties

1. INTRODUCTION

Synthetic disposable napkins follow a four-layered polymeric structure with the top sheet being a fluid-permeable surface that tends to percolate the menstrual fluid down to the core, hence keeping the top layer dry [1][2]. This is achieved by using a porous non-woven thermoplastic fiber, either polypropylene or polyethylene that has wet mechanical sustainability. A blend of cellulosic pulp and super absorbent polymers (SAP) polymerized primarily by acrylic acid or acrylamide, present in the third layer, are the ones that help in absorbing fluid up to 30 times its weight. Superabsorbent polymers (SAPs) are cross-linked hydrophilic macromolecular networks with a high absorption and liquid-holding capacity. SAPs are insoluble in water and consist of three-dimensional networks of cross-linked polymer chains that maintain the structure while retaining water. The degree of cross-linking, hydrophilic functional groups (OH, $-SO_3H$, $-NH_2$), and porosity affect the amount of water that SAP can absorb. SAPs are frequently used in the sanitary napkin's absorbent core. SAPs can hold onto enormous amounts of fluids, keeping users dry for an extended period of time, by producing a gel that prevents the liquid from seeping back onto the sanitary napkin's surface. The two main types of SAPs available today are those made synthetically using petrochemicals and those made naturally using polysaccharides and polypeptides. Cross-linked and partly neutralized sodium polyacrylates are the SAPs that are most often accessible and employed in the industry nowadays because of their superior price-to-efficiency ratio. Today's market offers two main categories of SAPs: synthetic petrochemical-based and natural polysaccharide- and polypeptide-based. cross-linked and partly neutralized sodium polyacrylates are the SAPs that are often accessible and are employed in the industry. However, this kind of SAP is not biodegradable and has a relatively high molecular weight. As it is non-biodegradable, it serves as a breeding ground for a large range of viruses and bacteria [3].

According to the literature, Polyethylene, and Polypropylene, which have a bulk density of 0.01 to 0.1, are the raw materials used in the top sheet of sanitary napkins. The cellulosic pulp in the inner cotton has a bulk density of 0.08 to 0.3,and the inner absorbent is a mixture of SAP and cellulose. Polypropylene or Polyurethanes are typically used for back sheets of napkins. Polyolefins are used as adhesives whereas sticker strips are made of plastic to ensure that they stay in the desired position to effectively absorb menstrual flow and prevent leaks [4][5][6][7]. Phthalates, also known as phthalic acid esters (PAES), are diesters derived from 1,2-benzene dicarboxylicc acid (phthalic acid). They have been utilized as plasticizers to enhance the softness and flexibility of materials, increase their plasticity, lower viscosity, and reduce friction during the manufacturing process. Phthalates have been incorporated into various plastics since the 1930s, and DEHP (a significant phthalate commonly found in sanitary pads) alone accounts for one-fifth of all plasticizers ever created. Volatile organic compounds, also known as VOCs, are compounds that have a low water solubility and high vapor pressure, which are released in the form of gas from certain solids or liquids. In sanitary pads, VOCs are added as fragrances, adsorbents, moisture barriers, adhesives, and binders. VOCs may also be unintentionally present in the raw material or packaging material [8]. The table below (Table 1) illustrates the composition of phthalates and Volatile organic compounds (VOCs) in three different brands of sanitary napkins.

Table 1. The percentage composition of VOCs and phthalates per Sanitary napkin

	Compounds (In percentage composition per pad)	**Sample 1**	**Sample 2**	**Organic Samples**
Phthalates	Di-isobutyl phthalate (DIBP)	7.87	22.28	3.35
	Dibutyl phthalate (DBP)	4.3	32.93	ND
	Di-isononyl phthalate (DINP)	ND	0.20	ND
	Di-isodecyl phthalate (DIDP)	ND	0.80	90.07
	2,2-Dimethoxypropane (DMP)	0.3	0.20	ND
	Bis(2-ethylhexyl) phthalate (DEHP)	38.58	12.85	1.16
	3,4-Dihydropyran (DHP)	5.82	7.42	ND
	Benzyl butyl phthalate (BBP)	28.50	3.61	1.02
	Di-n-octyl phthalate (DNOP)	ND	3.21	ND
Volatile organic compounds (VOCs)	Acetone	52.88	80.32	5.04
	o-xylene	1.69	0.46	2.58
	m-Xylene	2.20	1.39	3.54
	Dichloromethane	4.23	0.11	2.72
	N-Hexane	3.05	3.84	2.17
	Chloroform	0.67	1.28	1.08
	Tetrahydrofuran	0.50	0.23	0.27
	Benzene	0.16	0.11	0.13
	Toluene	1.52	0.46	1.22
	Cyclohexane	26.94	2.44	34.60
Reference: [8]				

Since sanitary napkins can take several years to decompose, using them poses a grave threat to the environment. In addition, every sanitary napkin leaves behind 2 g of plastic that cannot biodegrade. A lack of appropriate and safe disposal mechanisms may lead to unhygienic menstrual hygiene management (MHM). Sanitary waste in India is classified underSolid Waste Rules, rather than biomedical waste. As a result of this classification, most of the sanitary waste ends up in landfills. Furthermore, the new guidelines to address the issue released in 2018 suggested local incineration as a viable method to divert this waste from going into landfills. Here, it is important to note that most low-cost incinerators (both at urban and local levels) do not conform to stated guidelines, thereby not incinerating the sanitary waste at the required high temperatures. This in turn increases the risk of these chemicals being released into the environment due to incomplete burning. Some studies indicate the incineration of household waste as a source of VOCs being released into

the environment [9]. Handling soiled sanitary napkins has become a massive challenge for the solid waste management sector due to their biohazard and disease transmission potential. Menstrual waste is difficult to dispose of properly since people typically dispose of it in trash cans, toilets, or general waste containers, where it eventually ends up in landfills, sewers, or is burned outside [10][11]. Dioxin, which can cause pollution and other negative environmental effects, can be produced when napkins are burned [12]. An estimated 121 million women in India dispose of 113,000 tons of menstrual hygiene waste annually. Dueto the presence of blood and endometrial tissues, substantial emissions are produced when sanitary napkins containing menstrual fluid are burned in an incinerator [13]. Considering the demerits of incineration, it is crucial to explore sustainable and safe waste management options that minimize health risks and environmental impacts. To address Health hazards associated with conventional waste management strategies, Integrated Solid Waste Management (ISWM) proposes a waste management hierarchy and technologies that depend on the quantity and characteristics of total waste generated [14]. In promoting menstrual health and hygiene, synthetic sanitary napkins can be substituted with biodegradable napkins made withorganic cotton like bamboo or banana fiber. This reduces a large amount of toxic release of gases like dioxins, furans and phthalates. As part of an innovative circular strategy, the first step toward menstrual waste management should be mechanicalsegregation and chemical/thermal treatment. The circular economy can be brought by research on the potential of recycling and recovering resources from sanitary waste, with a focus on waste-based cellulose utilization.
Co-gasification is an environmentally friendly method of chemical recycling that effectively processes plastic and biomass waste simultaneously. This technology enables the treatment of various waste types together, resulting in the production of producer gas. However, the impact of having both plastic and moisture present simultaneously in the feedstock has yet to be identified [15]. Methods such as pyrolysis, which are already utilized for extracting energy from municipal solid waste, can also be employed for the same purpose when it comes to sanitary napkin waste. A high volatile matter content favors waste-to-energy production or thermochemical processes, such as gasification and pyrolysis. Methods such as gasification and pyrolysis are energy-intensive because they are designed to potentially reduce the volume of waste by converting it into syngas or oils after thermochemical conversion treatment. For instance, syngas is a product of waste gasification which can be used for gas engines, turbines, and power generation [16].

The potential for resource extraction from waste generated by sanitary napkins has been limited due to its hazardous nature and the lack of efficient methods to separate its constituent materials. However, considering the high carbon content and the minimal value of these products, there is a significant opportunity for energy recovery through their conversion into alternative fuel sources. Additionally, by employing disinfection and sterilization processes, harmful microorganisms and odors in the waste can be effectively eliminated, allowing for the recovery of its cellulose and plastic components. These approaches offer the potential to reduce the environmental and health impact associated with sanitary napkin disposal while establishing a new value chain for this waste material.

So far, there has been little research reported on the pyrolysis of sanitary napkins, and existing literature is limited tomostly studies performed on the pyrolysis of baby diapers. It was determined that waste oil and pyro-char could be treated quite well using the present pyrolysis methods, which also have a number of benefits. In this study, pyrolysis of different brands of sanitary napkins in the presence of catalysts such as HY Zeolite and HY Plas 103 was studied in a pilot scale reactor with a feed capacity of 1kg/batch. The yield of oil, pyro-char, and gas was estimated in three trials with two different feeding methods. The presence of different functional groups was analyzed.

2. MATERIALS AND METHODS

2.1 Materials

To investigate the composition of commercially available disposable sanitary napkins, five different brands were purchased and subjected to analysis. Each part of the napkin, including the top sheet layer, inner cotton, absorbent layer, back sheet, and sticker strips were separated and collected as samples for laboratory testing. These observations facilitated the characterization of sanitary napkins, ranging from the identification of functional groups to proximate and ultimate analysis.// The analysis included five brands of napkins found in the market, including one organic variant. The napkins were divided into five sections, and each section was individually analyzed, enabling a comprehensive understanding of their composition.

2.2Pyrolysis of sanitary napkins

Pyrolysis is a chemical reaction of breaking down these long chains into small units. The pyrolysis process is conducted at a temperature greater than 450℃, in the absence of air and the reaction time ranges between 60-90 minutes. Pyrolysis involves the anaerobic thermal decomposition of wastes to form liquids, char, and gas depending on the operating parameters such as temperature, heating rate and material type which attempt to reduce the amount of waste by converting it into useful products [17]. Long carbon chains in sanitary napkins are thermally broken down into useful fractions that can be used as fuels or sources of chemicals during pyrolysis. The so-called "char," a carbonaceous byproduct typical of the heat degradation of some polymers, and the inorganic waste components are typically combined to create the solid product. The variability of the solid product makes it typically difficult to valorize. The gaseous fraction, on the other hand, typically complies with the requirements for gaseous fuel. The pyrolysis unit consists of two heaters along with two thermocouplesto measure the temperature of both the top and bottom parts. The Schematic representation of the pyrolysis unit and mobile pyrolysis unit developed in IIT Madras is illustrated in Figure 1.

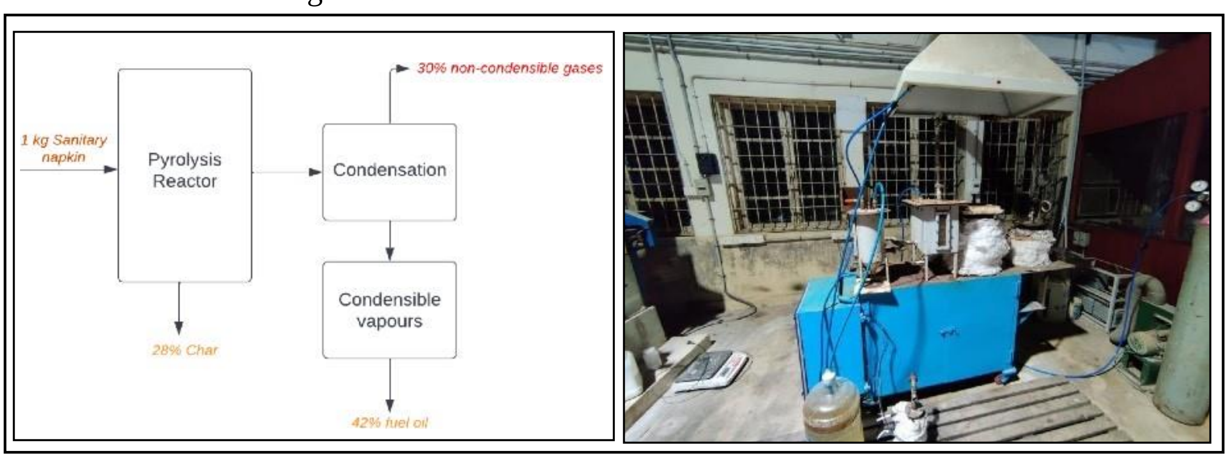


Fig.1. Schematic representation of pyrolysis reactor (A) and Mobile pyrolysis unit in IIT Madras (B)

2.3Pyrolysis experiments

One kilogram of Sanitary napkin was fed to the reactor in the presence of zeolite catalyst, is heated up to a temperature of 550°C. Gases obtained are condensed by the condenser and come out as oil. The remaining char left inside the chamber is pyro-char. The type of feeding method and the pyrolysis products are depicted in Figure 2.

Fig.2. Fresh rolled pads as feed (A), obtained Oil and Pyro-char (B)

2.4 Characterization of plastic wastes and pyrolysis products

The FTIR Spectrophotometer was used to examine the characteristics of the oil and char derived from discarded sanitary napkins, investigating their physical, chemical, and thermal attributes. This analysis aimed to identify specific functional groups present in the napkins, pyrolysis oil, and resulting char by studying their respective IR spectra.The composition and functional groups of various components in five different samples of commercial sanitary napkins and one sample of an organic pad were examined. FTIR spectra of fresh sanitary napkins and pyrolysis fractions were recorded in the range of 4000–400 cm^{-1} with IRAffinity-1 spectrometer with DLaTGS- KBr detector.

3. RESULTS AND DISCUSSION

3.1. Characterization of napkin waste

Fourier transform infrared spectroscopy (FTIR) was used to analyze the types of chemical bonds and functional groups present in the materials used to manufacture napkins. It identifies the chemical bonds of a molecule by producing an infrared absorption spectrum [18]. Infrared radiation is absorbed by specific functional groups as peaks or bands at a specific wavelength, wavenumber, or region. The vibrational and rotational levels of the atoms have an impact on the region of infrared light that is absorbed. Therefore, the presence of functional groups in a sanitary napkin and the kind of vibration of compounds can be determined by looking at the peaks or bands on an FTIR spectrum [1].

Table 2. FTIR analysis of fresh napkins

Samples	Component	Raw Material	Functional groups							
			Alkanes	**Alcohols**	**Silicon Compounds**	**Ethers**	**Phosphorus**	**Halogens**	**Amine Salts**	**References**
Sample1	Top sheet	Cellulosefiber	√				√			[19]
	Inner absorbent	Diethyaminoethyl cellulose	√	√	√		√		√	[20]
	Inner cotton/ Cell ulose	Cellulose fiber/ KAYOCEL		√						[8]
	Backsheet	Polyethylene	√				√			[21]
	Plastic strip	Cellulosefiber	√	√	√	√	√	√		-
Sample2	Top sheet	PE+silicate	√		√		√			-
	Inner absorbent	Cellulose	√	√	√	√	√	√		[22]
	Inner cotton/ cellulose	Cellulose	√	√	√	√	√	√		[8]
	Back sheet	HDPE 8%	√		√		√	√		[23]
	Sticker	Cellulosefiber	√	√	√		√			-
Sample3	Top sheet	HDPE	√				√			[23]
	Inner absorbent	Cellulose	√	√	√	√	√		√	[22]
	Inner cotton/ cellulose	Cellulose fiber	√	√	√	√	√		√	[8]

	Back sheet	Synthetic wax vinyl polymer/ polyethylene	√							[24]
	Sticker	Diethylaminoethyl cellulose ion exchange material		√	√	√	√	√		[20]
Sample 4	Top sheet	Polyester Urethane Foam/ Isonicotonic acid/ benzene phosphinic acid			√			√		[25]
	Inner absorbent	Cellulose fiber	√	√	√	√	√			[22]
	Inner cotton/cellulose	Cellulose fiber		√	√	√	√		√	[8]
	Back sheet	Polypropylene homopolymer	√							[25]
	Sticker	Polyester Urethane Foam/ Isonicotonic acid/ benzene phosphinic acid			√	√		√		[25]

Sample 5 Organic pads	Top Sheet	Mineral and cellulose filled compound/ polymeric coating	✓	✓	✓		✓			[26]
	Inner absorbent	Cellulose fiber compound/polysaccharide/carbohydrate	✓	✓	✓	✓	✓		✓	[27]
	Back sheet	Cellulose fiber compound	✓	✓	✓	✓	✓		✓	[28]
	Plastic strip	Ethoxylated tertiary/ Distearyl pentaerythritol disphosphite	✓		✓	✓	✓			-

A usual disposable sanitary pad consists of 48% cellulosic fluff, 36% PE, PP, and PET, 7% adhesives, 6% superabsorbent, and about 3% release paper. From FTIR studies which are shown in Table 2, the Inner absorbent layer of all five samples of Sanitary napkins is found to be different forms of cellulose fibres along with Low-density polyethylene resins. This layer is made up of fluff cellulose and superabsorbent polymer grains, which are covered in cellulose or polypropylene nonwoven. The majority of sanitary pads adhere to a similar fundamental design: a cellulose-based absorbent core with superabsorbent gel particles layered between a fluid-permeable surface and moisture-impermeable backing. According to the recent examinations of commercially available sanitary pads, Super absorbent polymers (SAP) are widely used to improve fluid absorption levels and the overall pad contains a variety of polymers and volatile organic solvents such as Styrene and Chloroethane. A polymer derived from acrylic acid monomer and sodium hydroxide is blended with cellulose having a high fluid retention capacity. Cellulose, with a large number of hydroxyl groups, is highly absorbable due to its hydrophilic nature. Therefore, it is believed that the incorporation of this material is intended to improve both the tactile and the absorption aspects. For all types of absorbent pads, the top sheet commonly consists of a thin layer of perforated polypropylene and/or polyethylene nonwoven and this layer is in direct contact with the skin. The main function of this layer is to transfer fluids and faeces quickly to the layer beneath; thus, a high-wicking ability is desirable. Mostly, emollient or lotion is applied onto the top sheet material to grant protection from irritation and skin softness. The top layer consists of traces of Isonicotinic acid as well as Benzene phosphinic acid. The presence of silicates is found along with polyethylene which increases the absorbency of the napkin and provides a drier, more comfortable surface for use which can be consideredas an additional absorbing material. Cellulose Fibers in the top sheet are soft and gentle on the skin, which makes them a popular choice for use in products that come into contact with sensitive areas of the body. The back sheet is typically made ofa water-proof polyethylene or polypropylene film laminated with polypropylene nonwoven along with adhesives to fix on thecloth. This layer prevents fluid from leaking. Synthetic wax vinyl polymers confirm the presence of hot melt adhesives in napkins. Diethylaminomethyl cellulose ion exchange material has a high binding capacity and is found in stickers of sanitary napkins. Through this analysis, even traces of chlorine content were not detected so there is no need for scrubbing. Both the literature review and Fourier Transform Infrared (FTIR) analysis indicate that organic pads are composed of cellulose cotton. These pads have a similar structure to other disposable pads, but the top and bottom sheets are made exclusively from organic cotton. The inner absorbent layers of organic pads consist of biodegradable materials such as bamboo or banana fibers. One key advantage of organic pads is that they are chemical-free, which helps to prevent the release of toxins during use. This makes them a more environmentally friendly and potentially safer option for menstrual hygiene.

The plastic element can substitute concrete and steel in composite materials, while the recovered fiber serves multiple purposes such as pet litter, concrete and tarmac additives, brick production, and insulation materials. This recycling process significantly reduces carbon emissions by 71% compared to landfill or incineration. The superabsorbent material's adsorption properties make it suitable for anti-flooding barriers and gardening. Additionally, the plastics can be utilized in making pallets, benches, and various products, while the pulp materials can be repurposed into recycled paper, biofuel, cat litter, and anti-flooding solutions [29]. Polyacrylamide cationic (PSA) has the capacity to retain approximately 100–1000 grams of water per gram of polymer, making it an excellent option for agricultural purposes, for safeguarding forests at risk of desertification, and for absorbing bodily fluids [30].

3.2 Pyrolysis product yield

Three trials of pyrolysis were conducted with different brands of fresh napkins. Each trial with fresh sanitarynapkins was recorded and yield of oil and pyro-char were noted. Microwave pyrolysis of baby diapers generated products which composed of 43 wt.% of liquid oil, 29 wt.% gases and 28 wt.% yield of char product [31]. During trial 1, as mentioned in Table 4, pyrolysis was performed using 265 g of shredded napkins in the presence of HY Zeolite. The pyrolysis process yielded only 5 grams of bio-oil and 60 grams of char at an operating temperature of 550°C. It was observed that the char obtained was not fully burned and contained remnants of cellulose in the form of chunks.

Table 4. Trials of Sanitary napkin pyrolysis

	Initial weight	Catalyst	Temperature cutoff	Final pyro-char	Final pyro-oil	Final gas
TRIAL-1 Shredded napkins	265 g	14 g HY Zeolite	550 °C	60 g	5 g	200 g
TRIAL-2 Shredded napkins	250 g	13 g of HY Plas103	600°C	54 g	1-2 g	195 g
TRIAL-3 Rolled napkins	300 g	15 g of HY Plas103	450°C	70 g	104 g	76 g

In trial 2, pyrolysis was conducted with 250 g of shredded napkins with HY Plas 103 which could obtain only 2 grams of bio-oil and 54 g of char at a higher operating temperature of 600° C. The char obtained was not completely burned and contained chunks of cellulose. The final trial of pyrolysis proved to be successful by altering the orientation of 300 grams of pads into a rolled form and subjecting them to a temperature of approximately 450°C. This process yielded a pyro-oil quantity of 104 grams and a pyro-char quantity of 70 grams. This observation highlights that the cellulose cotton content in the pads does not readily burn and requires a higher temperature for complete combustion. It recommends using this type of loading pattern during sanitary napkin pyrolysis. The main gases produced after pyrolysis include hydrogen, carbon dioxide, carbon monoxide, methane, ethane and butadiene, with smaller amounts of propane, propene, n-butane, and other hydrocarbons. The exact composition of these gases can vary depending on factors such as the type of plastic being pyrolyzed and the conditions of the pyrolysis.

3.3. Characterization of pyrolysis oil

The second generation of biofuels referred to as pyrolysis oil (Py-oil) or bio-oil exhibits remarkable carbon fixation from biomass and is used for producing fuels and other value-added products. The pathway from the pyrolysis of sanitary napkin waste to the production of various value-added products is depicted in Figure 3.

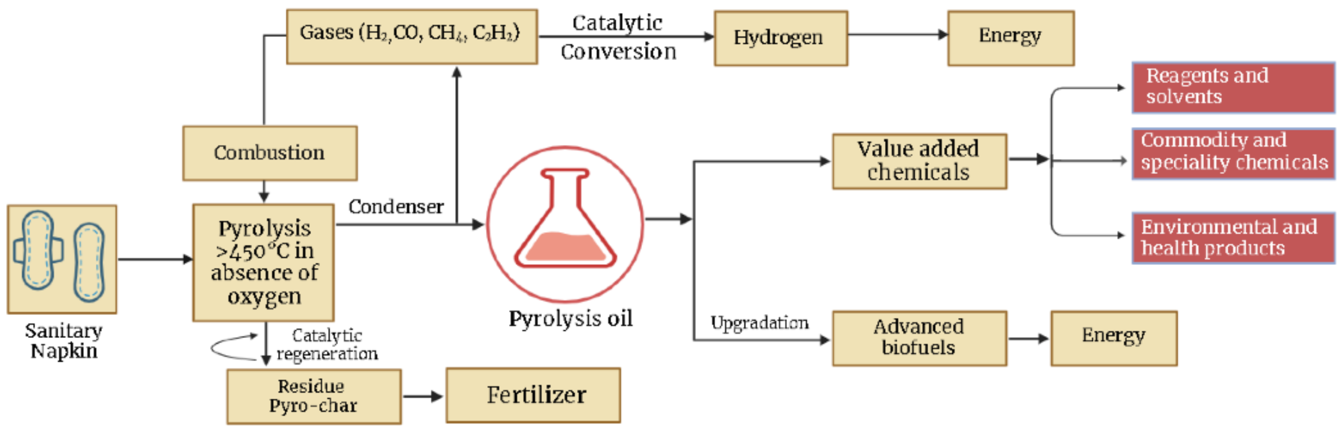


Fig.3. Pathway of pyrolysis of Sanitary napkin

Py-oil is a complex mixture of polar and non-polar compounds with a range of molecular weights (MW) and the feedstocks and processing conditions have an impact on its composition [32]. The goal of the detailed characterization of Py-oils is to deliver high-quality data and findings that make it easier to solve problems for practical applications. In a comparison of the volatile matter between the two fractions (Plastic and Cellulose), the exterior fraction (Plastic) is more combustible (due to a higher volatile fraction). Hence, it is more suitable for energy recovery. Considering up to 90% of a napkin is composed of plastic, there is a huge potential in deriving pyrolysis oil, which can be replaced with furnace oil if refined further, can be replaced with diesel. The liquid oil contains aliphatic hydrocarbons including alkanes and alkenes, which have the potential to be used as fuel and chemical additives [31]. Pyrolysis oil from plastic has a similar calorific value to that of Biodiesel and Furnace oil which is around 10,000 kcal/kg. It has a density of about 0.7477 g/cc is comparable with n-octane which has a density of 0.703 g/cc and kerosene with a density of 0.82 g/cc.

The composition and functional groups of the oil obtained from the pyrolysis of sanitary napkins were analyzed. These properties were then compared to the properties of various commercially available fuel oils, indicating the potential forsubstituting pyrolyzed oil as an alternative fuel source. The pyrolysis trial conducted using freshly rolled sanitary padsyielded the highest yield, allowing for a detailed characterization of the oil and char produced in that trial. The oil sample wascharacterized using FTIR for functional group composition analysis, which is illustrated in supplementary materials figures S1 and S2 respectively, proving that a reactive polyamide substance is present in the pyrolysis oil along with a major portion of alkane groups.

3.4. Characterization of pyrolysis char

Pyro-char is a type of environmental black carbon, a common sorbent made of carbonaceous materials found in soil and sediment. It is a significant soil supplement used to increase soil fertility and store carbon. The physical and chemical characteristics of pyro-char vary depending on the type of biomass used, the pyrolysis settings, and the pre-and post-treatment. Despite this, they all share functional groups that bind cations and porous structures that have a big impact on important soil qualities [33].

FTIR Spectrum of obtained pyro-char, which is illustrated in supplementary materials Figure S3, reveals the presence of functional groups like (R)3-POH, NH_2^+, and Ph-CH_3 which are classified in Figure S4. Phosphorus compounds like Phosphines can be used in agriculture as a fumigant to reduce pests and insects. Phosphorus-oxygen double bond combinations with alkyl or aryl make up phosphine oxides. These substances are thermally stable and do not begin to break down until 450 °C [1]. Amines are one of the main forces shaping the composition of the bacterial community. Polyamides lower soil pH and stimulate ammonification and nitrification processes along with respiratory activity. The pyrolysis conditions determine the chemical makeup of the solid byproducts. When the char's pore structure and surface area are suitable, it can be employed in the manufacture of active carbon.

4. CONCLUSIONS

Innovative disposal methods for napkins, including biodegradation, pyrolysis, and composting, have potential. Though still in their infancy, these techniques have a number of drawbacks. The pyrolysis of sanitary napkins yields 42% oil, 28% pyro-char and it shows many advantages over other thermal methods like incineration, but it requires optimization for the system with different feedstock such as pyrolysis temperature, heating power, temperature, and particle size [29]. Pyrolysis may be viewed as a temporary solution that does not address the need for sustainable, long-term waste management practices. The method's greater total expenses are one of its downsides. This shows that initiatives are only financially viable if they have access to large amounts of napkins that can be converted into biofuel. It's crucial to remember that this procedure needs a continuous fuel supply; if the facility can't get enough napkins, it won't be able to work at its full potential for processing. Despite this, considering the process's advantages and disadvantages, in terms of the economy and the environment are contrasted with one another, it is difficult to say that pyrolysis and other processes that are analogous to it are the processes of the future. They provide remedies to so many different problems that it is well worth the effort to overcome the challenges posed. This is because there are many benefits to using sanitary napkins in this way that exceeds the drawbacks. Since sanitary pads have high contents of cellulose cotton fluff blended with sodium acrylate, it’s advised to recycle the cellulose. The recycled cellulose from waste sanitary napkins is completely contaminant-free and since the superabsorbent polymer is deactivated the cellulose content in it is biodegradable.

It would be worthwhile to carry on researching further aspects of using recovered cellulose to structure a new sanitary napkin by blending the new recycled cotton with biodegradable materials like banana fiber and other cellulose-rich wastes to produce bioplastics that can be used for single-use plastic applications in order to explore the full potential of this process.

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SUPPLEMENTARY MATERIALS

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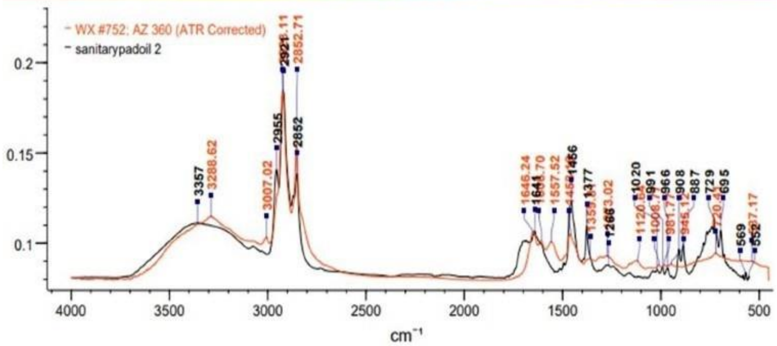

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Fig.S1. FTIR Composition of pyrolyzed oil

Classification	Group
Solvent Impu	Hexane
Alkanes	$R(CH_2)_4$-C
Alkanes	$R(CH_2)_4$-OR
Alkanes	R-CH_3
Solvent Impu	Cyclohexane
Alkanes	R-CH_2-R
Polyethers-P	Polyethylene glycol (aı
Solvent Impu	Nujol
Alkenes	RCH=CHR cis
Polyethers-P	Polyethylene glycol (cı

Fig.S2. Functional group of pyrolyzed oil

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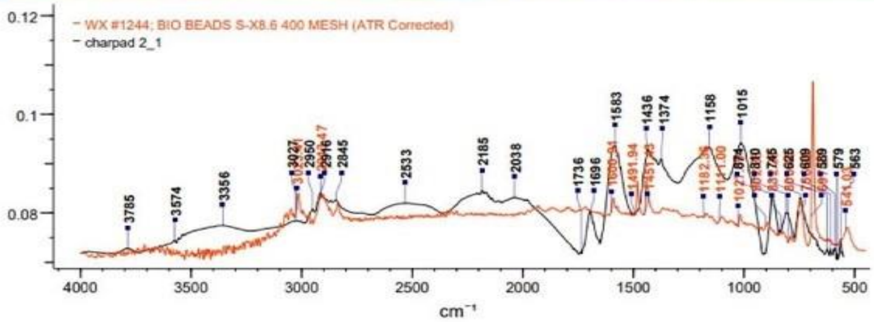

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Fig S3. FTIR Composition of pyro-char

Classification	Group
Phosphorus	$(R)_2P\text{-}OH$
Sulfur Comp	R-SOOH
Alkanes	Cyclohexyl
Sulfur Comp	$R\text{-}SO_3^- H_3O^+$
Alkanes	$Ph\text{-}CH_3$
Polyamides-I	Poly (vinyl pyrrolidone
Silicon Comp	$R\text{-}SiF_3$
Amine Salts	NH_2^+
Phosphorus	$(R)_3P{=}O$
Sulfur Comp	S-H

Fig S4. Functional group of pyro-char