

RESEARCH AND ANALYSIS OF ABSORBENT HYGIENE PRODUCT (AHP) RECYCLING

Anita Gerina-Ancane, Agrita Eiduka

¹Riga Technical University, Latvia

anita.gerina-ancane@rtu.lv, agrita.eiduka@rtu.lv

Abstract. The paper presents different Absorbent Hygiene Product (AHP) recycling methods and the analysis of products obtained from recycled AHPs. The paper gives view of two different AHP waste recycling methods with different recycling products (plastic pellets, pellets), describes the technological methods step by step, shows plusses and minuses of the methods. On the basis of two existing recycling methods, experimentally a new AHP recycling method is developed using the pyrolysis method, which gives recycling products as gas and pellets. As for the economical field, from the experiment with the pyrolysis recycling method it seems that this method is self-contained. The most popular technology in the world processes AHPs and reclaims valuable plastic and fiber. The next technology reviewed in this paper changes used diapers into fuel resources in a safely managed process. Its final outcome is energy pellets with calorific value $20853 \text{ kJ}\cdot\text{kg}^{-1}$, which is a fuel for biomass boilers. The energy from the biomass boiler can be supplied to in-house and/or neighboring facilities. One more technology is created to convert AHP into coal and gas by the pyrolysis process. Calorific values for them respectively are $15950\text{-}18080 \text{ kJ}\cdot\text{kg}^{-1}$ (coal) and $34400 \text{ kJ}\cdot\text{kg}^{-1}$ (gas). The energetic balance should be done in the future re-research to understand, what kind of product obtained from AHP is the most effective and useful. The maximal use or reuse of human waste let to decrease the amount of waste on the landfills, and help protect the nature.

Keywords: absorbent hygiene products (AHPs) waste, recycling method, pyrolysis, recycling products.

Introduction

Every day tons of feminine hygiene and disposable nappy/diaper/diaper waste are generated at home, in public places, at work, in maternity hospitals and at care homes. Diapers include polymer and pulp. All these products after use are called as Absorbent Hygiene Product (AHP) waste. After using these wastes are landfilled. Worldwide AHPs waste grows million tons per day. Worldwide, disposable absorbent products and nappies represent about 4 % of solid waste and about 2 % of all waste sent to landfill [1]. A child uses, on average, 4.6 nappies/diapers per day or around 33 per week (weight of average used nappy/diaper at 230 g, adult 320 g), 6 kg of disposable nappy/diaper waste is generated each week per child and it gives many millions tons per year in every country.

Some modern cloth diaper companies are presenting environmentally-friendly solutions of reducing disposable diaper waste – production of cloth and re-usable diapers. Other diaper companies produce disposable biodegradable diapers that contain materials that are less harmful to the environment. In some cases, companies are combining both cloth and eco-friendly disposable components to make what is referred to as a “hybrid” diaper. Absorbency layer is made primarily from biodegradable and compostable materials. This type of absorbency layer can be used and thrown away just like a disposable diaper, except that it is designed to decompose much faster [2].

But still, these kinds of diapers are not popular, because more easily it is to throw out one and replace it by a new one than regular wash reusable diapers or hybrid diapers. Superabsorbent disposable diapers hold more moisture and wick moisture better than cloth or other disposable diapers. Superabsorbent disposable diapers are better than cloth diapers in preventing leakage because they hold more urine [3]

Worldwide this is a big problem, where to put all waste. To solve this problem a law is adopted – waste strategy is zero biodegradable waste to landfill by 2020 [2; 4]. Recycling methods are different, but not so many, because only some countries are thinking about AHPs waste utilization. It is a field, where scientists can work to search better and effective recycling methods, also to make optimization of the exciting waste recycling methods.

Predictions of how our waste will increase in the near future took into account the growing industrialization of developing countries, population growth and attempts to limit the flow of plastic debris into the oceans and land-fill based on waste-management activities on the land [5]. One part of such kind of activities is recycling of the waste and this paper describes the products obtained from recycled AHPs by different recycling methods.

Materials and methods

1. AHPs waste treatment technology

In the United States of America, the United Kingdom and Canada Company Knowaste Ltd. has been researching and developing the waste treatment technology for processing Absorbent Hygiene Products since the 1990's. The waste is shredded, separated and using advanced thermal treatment technology, the waste material is sterilized by gamma stars. At this stage the super absorbent polymers are collapsed, rendered inert and the moisture is released utilizing the Knowaste Ltd. patented formula and process. Knowaste Ltd. has many patents of their recycling process [6-9].

There follows further sorting and separation of plastics and fibres, and removal of contaminants. The plastics continue through granulation and multiple-washing stages before being pelletized to be used, in the new products such as plastic components or as an ingredient in composite materials replacing concrete and steel. The fibres are washed, dried and processed for use in pet litter, concrete and tarmac additive, brick manufacture and insulation materials. 100 % of the product can be recycled with the remaining solids and liquids sent to the sewer/treatment.



Fig. 1. **Fibres obtained from recycled AHPs (left) and plastic pellets obtained from recycled AHPs (right)**

The Knowaste Ltd waste treatment technology costs are very high, because the AHPs waste sterilization process is very complicated, and the process is not self-contained [10].

The most popular technology in the world processes AHPs and reclaims valuable plastic. Designed for comfort and protection, AHPs consist of several materials – fibres to absorb moisture, super absorbent polymers to retain moisture and plastic membranes and tabs to keep the user dry and secure. The technology is created to make full use of this waste and deal effectively with contaminants [11].

Plastic pellets and fibres (see Fig. 1) are recycled into products such as: plastic components for product manufacturing; plastic recycling bins; composite materials replacing steel, wood and concrete; roof tiles; seed trays; pet litter and bedding; cardboard industrial tubing; blow moulded protective packaging; fillers in the construction and road building sector.

Pelletizing reclaimed plastic is the final step in most recycling processes. Converting post-consumer plastic into pellets allows for easier distribution and remanufacturing, and ultimately benefits the speed and effectiveness of reintroducing recycled plastic into industrial manufacturing. After sorting, separating, and drying the reclaimed material, the flake stock is ready to be extruded into pellets.

2. AHPs SFD recycling system

In Japan Company Super Faiths Inc. made the SFD system. The SFD system changes used diapers into fuel resources in a safely managed process. Its final outcome (pellet) will be a fuel for biomass boilers [12]. The energy from the biomass boiler can be supplied to in-house and/or neighboring facilities.

Used diapers sealed in a plastic bag can be thrown into the SFD machine by anyone with no special skill. Diapers go through shredding, fermentation and drying process automatically. Outcome fluffy fuel chips are bacteria-free. Effective catalyst is used to deodorize the material. It is designed

not to emit the exhaust air [13]. The above process is conducted in one tank, so to avoid in-house virus infection.

Fluffy chips from the SFD system are formed into pellets by the above forming machine. Outcome pellets can be used as energy source to biomass boiler and stove (see Fig 2.).

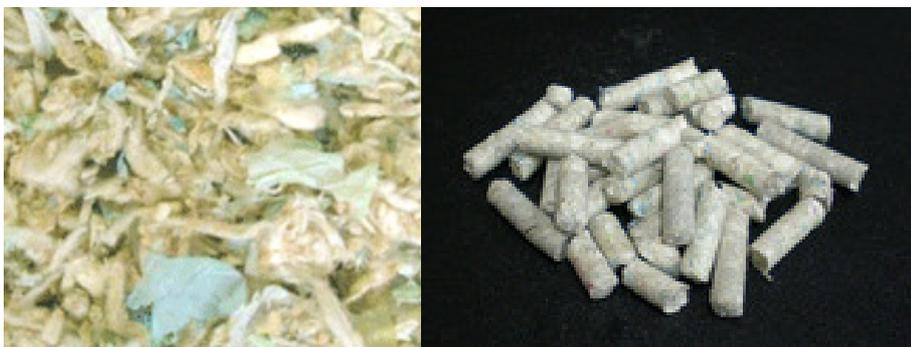


Fig. 2. Fluffy biomass chips obtained from recycled AHP and energy pellets obtained from recycled AHP [7]

The SFD machine capacity is very low [10]. Also the recycling process is not effective and not self-contained. The price of the SFD machine is very high. After the recycling process the recycling product – pellets is obtained. These pellets have very good heat capacity ($Q = 20853 \text{ kJ}\cdot\text{kg}^{-1}$) compared with wood pellets ($Q = 17100 \text{ kJ}\cdot\text{kg}^{-1}$). The SFD recycling system machine does not need a sterilization process, because the temperature of pyrolysis is very high (Table 1).

Table 1

SFD system machine specification

Model	SFD-600	SFD-1200	SFD-2000
Daily process volume	max 150kg	max 300 kg	max 600 kg
Size of the machine	Width 3200mm	Width 4015 mm	Width 4856 mm
	Depth 2000mm	Depth 2400 mm	Depth 1696 mm
	Height 2406mm	Height 2947 mm	Height 3670 mm
Additional specification	Deodorizer (built-in)	Deodorizer (separated)	Deodorizer (separated)
	Blower (built-in)	Blower (separated)	Blower (separated)
	Exhaust pipe (optional)	Exhaust pipe (optional)	Exhaust pipe (optional)
Consumed electricity	220 kWh per day	57 kWh per day	86 kWh per day
Consumed gas	-	28 kg per day (LPG)	50 kg per day (LPG)

The use of diaper fuel is environmentally friendly, it reduces CO_2 by using biomass chips instead of fossil fuel. Stable quality, because the chips are made from apparent material (diapers). Safe material – no hazardous materials are included. Diapers are made based on burning after use. High calorie solid fuel, because diapers include polymer and pulp. Also compact. In the form of pellets, they are easy to handle and space saving. By mixing recycled plastics and adjusting the volume, the calorific level can be controlled [14].

3. AHPs waste recycling with pyrolysis method

Researching the Knowaste Ltd. and Super Faiths Inc. AHPs waste recycling methods, the idea arose to use the pyrolysis/gasification method for the recycling process [15]. Pyrolysis is a type of thermolysis, and it is most commonly observed in organic materials exposed to high temperatures. It is one of the processes involved in charring wood, starting at 200-300 °C [10]. The similar principle is used in the special technology, which created to transfer AHP into coal and gas. The advantage of such a system compared to the existing methods – little requirements for sterility of raw materials, getting recycling products with added-value (carbon, fuel gas and tar/light fraction condensable hydrocarbons) and the efficiency of utilization of waste without creating unnecessary waste products. For that the experimental pyrolysis system was built (see Fig. 3-4).

The experimental pyrolysis system consists of three main parts – the reactor, part of the liquid fraction of the quality control and condenser. The reactor function is performed by a hermetic metal

container, in which AHPs (medical and sanitary wastes) are placed. The reactor has a high temperature (300-450 °C) and oxygen-free environment. In this environment, organic fibres and plastics evaporate (gasification and pyrolysis), vapor comes into the part of the liquid fraction of the quality control. Part of the liquid fraction of the quality control function is performed with a catalyst filled metal container. This part function is to maintain a specific temperature of the environment through which the gas/vapor flows. Depending on this temperature, heavy hydrocarbon fractions condense and are returned to the reactor for recycling. Fractions of light hydrocarbons and resulting of organic fibres gasification gases at the specified temperature are the part of the liquid fraction of the quality control liquid fraction that in vapor form goes to the condenser where it is condensed into liquid. Reactor heater power is 3000 W (see Fig. 5).



Fig. 3. Used nappies for experiment



Fig. 4. Experimental pyrolysis system

The first one is coal, obtained from recycled AHP by the pyrolysis method, shown in Fig. 6. on the left side. Coal mass is formed by simple granulating process into coal pellets, because pellets are more comfortable for use. Coal pellets are shown in Fig. 6, on the right side.

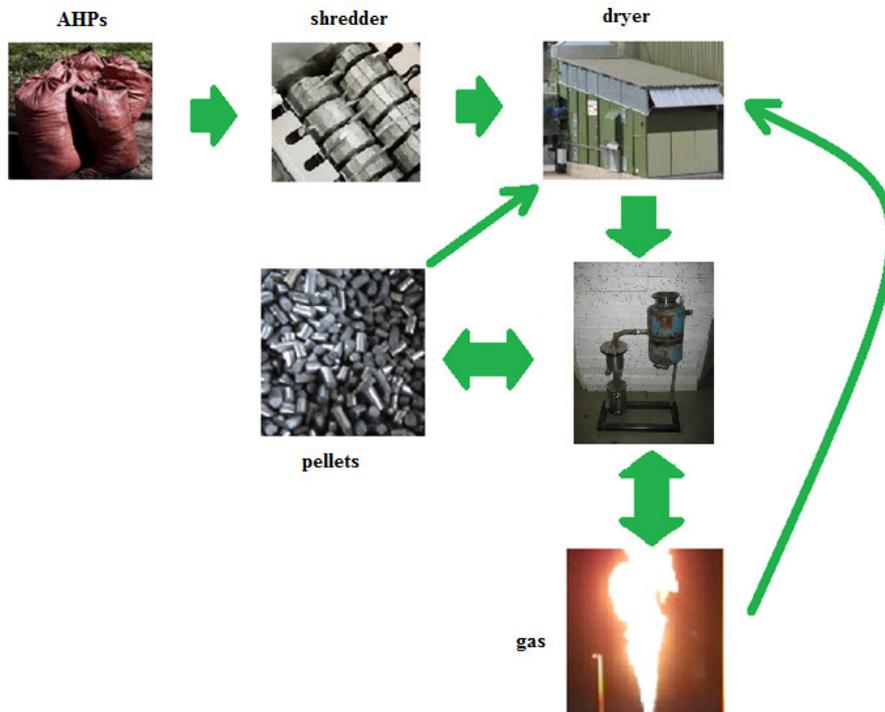


Fig. 5. AHPs pyrolysis recycling method

The coal obtained from recycled AHP by the pyrolysis method is tested in certificated laboratory. Experimentally the calorific values of the coal are found – Q , humidity in the tested material before

burning M_{ad} and ashes – A_{ad} , left after the burning process. The calorific values show that pellets can be used as an energy source to biomass boilers, stoves and neighbouring energy sources.

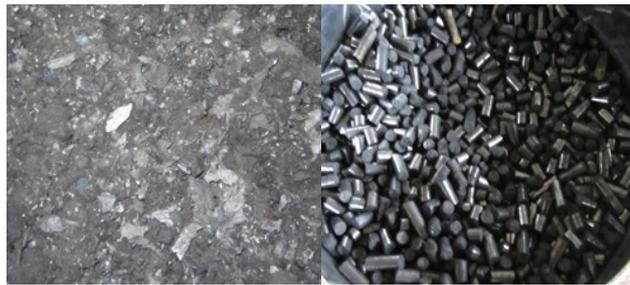


Fig. 6. Coal obtained from recycled AHP (left) and coal pellets obtained from recycled AHP

Another kind of product obtained from AHP is gas. Spectrum analysis is made to characterize the structure of the gas. The spectrum analysis shows only average data of gas consistence, because many of elements have very close positions.



Fig. 7. Spectrum analysis of the gas, graph (left) and consistence of the gas obtained from AHP (right)

Gas spectrum graphical analysis is shown above in Fig. 7, on the left. Consistence of the gas obtained from AHP by the pyrolysis method is shown below in Fig. 7, on the right.

This kind of gas differs from natural gas with low methane consistence – just approximately 16.1 %; higher amount of other hydrocarbons and higher amount of carbon dioxide – nearly 15.4 %. Attention should be taken to carbon monoxide (CO) in the gas consistence about 12.2 %.

CO does not occur naturally in the atmosphere. It is also the result of oxygen-starved combustion in improperly ventilated fuel-burning appliances such as oil and gas furnaces, gas water heaters, gas ovens, gas or kerosene space heaters, fire places and wood stoves. CO is generated by any gasoline engine that does not use a catalytic converter and it is the most common type of fatal poisoning in many countries [16]. Calorific value of the gas obtained from recycled AHP is numerically calculated using the equations below, according to [11].

1. To find the molar mass M_x of a compound.

The chemical formula is used to determine the number of each type of atoms present in the compound. The atomic weight (from the periodic table) of each element is multiplied by the number of atoms of that element present in the compound and added all together.

2. Using molar volume equation (1), the amount of substance is found, where V_0 is approximately equal to $22.4 \cdot 10^{-3} \text{ m}^3 \cdot \text{mol}^{-1}$.

$$n_x = \frac{V_x}{V_0} \quad (1)$$

3. Using molar mass equation (2) the mass m_x of compounds is found:

$$m_x = n_x \cdot M_x. \quad (2)$$

4. Gas net heating values q_x [3] are multiplied by a mass of the compounds and the calorific value Q_x of the compound is found:

$$Q_x = q_x \cdot m_x. \quad (3)$$

5. And summing the calorific values of the compounds the gas calorific value Q_{gas} is found:

$$Q_{gas} = \sum Q_{x_i}, \quad (4)$$

where Q_{gas} – approximately equals to 34400 kJ·kg⁻¹.

Table 2 shown below approximately describes the calorific values of the most common energy sources – wooden pellets, natural gas, coal, and calorific values of products obtained from recycled AHPs – AHP energy pellets, AHP pyrolysis coal and AHP pyrolysis gas. Comparison of all calorific values shows that AHP energy pellets, AHP pyrolysis coal and AHP pyrolysis gas are close to the most common energy sources, it means, they are useful to replace them.

Table 2

Characteristics of different energy sources: wooden pellets, natural gas, coal, AHP energy pellets, AHP pyrolysis coal and AHP pyrolysis gas

Parameters	Wooden pellets [13]	Natural gas [3]	Coal [2]	AHP energy pellets [14]	AHP pyrolysis coal	AHP pyrolysis gas	
Diameter, mm	4-10	-	-	4-15	Powder/4-10	-	
Humidity, %	about 10.0	-	4.5-12.0	< 10.0	4.0	0.2-0.4	
Calorific value	kcal·kg ⁻¹	about 4100	11703	5135	5000	3809-4318	8216
	kJ·kg ⁻¹	about 17100	47141	about 21500	20853	15950-18080	34400
	MWh·t ⁻¹	about 4.80	13.50	5.97	5.80	4.43-5.02	9.56
Ashes, %	0.5-6.0	-	1.0-40.0 and more	No data	48.8	-	

Results

Recycling AHPs (diapers/nappies, incontinence pads and pants, feminine hygiene products) the methods are different with different recycling products. Choosing one of them, it is important to understand the recycling process power and technical possibilities, because using the Knowaste LLC waste treatment technology the sterilization process is very specific and not used for every country.

The pyrolysis recycling method is technically a simple method, not expensive and the recycling products are with high added-value. Processing power can range from small to very large. The self-contained recycling process gives all possibilities for developing and optimizing AHPs waste recycling in the future.

The waste of Absorbent Hygiene Products, like used disposable nappies/diapers, adult incontinence pads and pants, and feminine hygiene products, can be recycled by different methods. The paper describes the products obtained from recycled AHPs and the use of these products. It is very important to nature for future to minimize the waste coming to the landfill. Recycling this part of human waste it is possible to minimize municipal solid waste about 2 %. The energetic balance should be done in the future research to understand, what kind of product obtained from AHP is the most effective and useful. The paper shows how many different products it is possible to get from used AHPs. The maximal use or reuse of human waste let to decrease the amount of waste on the landfills, and help protect the nature.

Conclusions

1. Absorbent Hygiene Products can be recycled into fibres and plastic pellets or energy pellets, or coal pellets and gas.

2. Pyrolysis AHPs recycling method gives gas with calorific value $34400 \text{ kJ}\cdot\text{kg}^{-1}$ and coat pellets with calorific value $15950\text{-}18080 \text{ kJ}\cdot\text{kg}^{-1}$.
3. Pyrolysis AHPs recycling method is self-contained as other used recycling methods with low costs.

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