Sterilisation technology for disposable diapers waste using double jacket and centrifugal speed principles

Elviliana¹, B Y R D Saputra¹, A Fahira¹ and S Suhartini²

¹Department of Agricultural Engineering, Faculty of Agricultural Technology, Universitas Brawijaya, Malang, Indonesia
²Department of Agro-industrial Technology, Faculty of Agricultural Technology, Universitas Brawijaya, Malang, Indonesia

E-mail: ssuhartini@ub.ac.id

Abstract. Globally, disposable baby diapers demand continues to grow alongside with an increase in the birth rate and child (aged 0-3) population. On average, diapers consumption is around 6-8 pieces per baby, giving approximately 6,300 diapers for the next 2.5 years. Furthermore, each diaper contains 35% of organic and 65% of inorganic materials. The presences of inorganic materials pose a detrimental effect on environment as it needs around 500-800 year to breakdown or degrade. This study was aimed to enhance the valorisation of disposable baby diapers waste by implementing sterilisation technology. The technology was based on a double jacket and centrifugal speed principles, enabling to effectively and safely sterilise the diapers waste. The comparison with the conventional technology was carried out based on the following parameters: total number of E. coli, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), turbidity, pH, temperature, and operational cost analysis. The results indicated that the proposed sterilisation technology has superior performance than conventional sterilisation technology. The findings also confirmed that the sterilised diapers waste can be further reused for making other valuable products, such as eco-friendly handy craft or souvenirs. Economically, the implementation of the proposed technology can support the creation of green creative industries, particularly in Indonesia.

1. Introduction

Disposable diapers are one of the main fractions in the overall stream of municipal solid waste (MSW) [1]. MSW generation and its management has become a big problem in most developing countries. Many of them are still applied the conventional MSW management schemes include confinement and landfilling. Not only reduces land use, such practices have been acknowledged to cause risk of toxic pollutants on the environment [2]. In 2015, approximately 5 million babies were born in Indonesia, or around 13,800 every day [3]. Disposable baby diaper represents an essential product in the parenting journey due to its many benefits, such as convenience, performance, and affordability. A study has shown that diapers consumption were around 6-8 pieces per baby, which then accumulates to approximately 6,300 diapers for 2.5 years or before they were trained using potty [4].

Super Absorbent Polymers (SAP) is one of the essential compounds in diaper, with other inorganic materials account for 65% of the total diaper components [5]. Based on these compositions, baby diapers are harder to breakdown and may take many years to degrade [6]. Thus, disposable baby diapers waste present a detrimental threat to the environment. Most of the time, their final disposal
ends up in landfills, contributing to global warming impacts due to the emissions of methane, carbon dioxide and respiratory effects [7]. Recently, many studies have reported that diapers waste can be recovered and utilised in many forms for instance: synthesised glycerol carbonate, water absorbing material in agriculture, compostable diaper and a biodegradable fraction for energy recovery [8-11].

In an attempt to reduce the disposable diaper waste, previous studies have used hydrothermal carbonization (HTC) or wet pyrolisis to treat waste biomass with a high moisture content to hydrochar [12] and valorisation via pyrolysis method for obtaining energy source [13]. Another thermal treatment such as sterilisation portrays a significant processing practice aimed at avoiding microbial growth in the sterilised object [14]. Low-temperature sterilisation has been used for many decades, especially for the objects that cannot withstand with high temperature, and hydrogen peroxide (H₂O₂) has been added as the chemical sterilant [15, 16]. It is reported that the low-temperature sterilization component, such as hydrogen peroxide, is constituting a viable alternative to provide operational cost saving [17]. To the best our knowledge, hydrogen peroxide has never been proposed to sterilize the whole disposable diapers and turned it to more economical or valuable products. Therefore, the chemical material can be explored further to gain more alternative ways to valorise untreated disposable diaper.

This study proposed a new technology designed to convert disposable diapers waste into sterilised diaper which can be used as feedstocks to make valuable products, such as handy craft or souvenirs. The aim of this study was to enhance the valorisation of disposable baby diapers waste by implementing sterilisation technology.

2. Materials and Method
   2.1. Diapers waste

Disposable baby diaper waste was freshly collected from the Brantas River, a temporary disposal site and houses of residents in Malang City. These wastes were directly used after collected to avoid any storage needed. Pre-treatment include rinse with water until no dirt was found on the surface area.

2.2. Design of sterilisation technology

The design of the proposed sterilisation technology is shown in Figure 1. This technology was based on a double jacket and centrifugal speed principles, enabling to effectively and safely sterilise the diapers waste. The sterilisation unit was based on the double jacked unit which consists of three different tubes: input tube to place the diapers waste and H₂O₂ solution, water-filled tube to place water for washing, and the oil-filled tube to provide stable temperature conditions. The rotation of the washing process was moved using centrifugal speed equipped with direction changing.

![Figure 1. Design of sterilisation unit based on double jacket and centrifugal speed principles](image-url)
2.3. Experimental set-up
The conventional sterilisation method was conducted by washing the disposable diapers waste in flowing water with the addition of chemical bleach (sodium hypochlorite) and disinfection liquid. In the proposed sterilisation technology, the process was carried out under the different temperature of 60°C and 100°C, with the same amount of H₂O₂ added. The procedures were as follows: about 5 kg of diapers waste were placed in the input tube. A 5 L water was added, followed by the addition of 500 mL of H₂O₂. The temperature for sterilisation was set up via temperature control button. The first washing process was in the rotation of back and forth for 30 minutes. Then, the next washing process was carried out by changing the direction of rotation for 15 minutes. The diapers samples were taken out. The wastewater resulted from both conventional method and the proposed sterilisation technology was analysed include pH, temperature, turbidity, chemical oxygen demand (COD), biological oxygen demand (BOD) and the number of E. coli.

2.4. Analysis
The culture of E. coli bacteria was counted according to swab method. BOD determination was analysed using SNI 6898.72-2009. COD was measured according to APHA 5220 [18]. The physical parameters analysed include pH, temperature and turbidity. pH was measured using a digital pH meter, calibrated in buffers at pH 7. Turbidity is measured by Lovibond TB300IR. Operational cost analysis was also carried out to compare the conventional method with the proposed technology.

3. Results and Discussion
3.1. E. coli analysis test result
This study showed that after sterilisation in both conventional and proposed technology, no E. coli was found in the wastewater effluent (Table 1), meeting the standard value of E. coli presents in wastewater effluent (Table 2). This may be due to the addition of chemical sterilant such as chemical bleach and H₂O₂, which contributed to a great reduction of E. coli. A study reported that H₂O₂ is able to slow the bacterial growth and subsequent biofilm formation, with the cellulose production was found to be stimulated by H₂O₂, a factor which may impede the bacterial establishment [19]. Sodium hypochlorite used in the conventional method is determined as highly cytotoxic substances that have harmful effects on the environment [20]. E. coli and “coliform” bacteria are considered as part of the normal microbiome of the human intestinal tract. When confined in the gut, these bacteria are generally treated harmless, however, a number of pathogen such as E. coli can cause disease in humans and animals [21].

| Sample                        | Total of Bacteria (CFU/cm²) |
|-------------------------------|------------------------------|
| Diapers waste before sterilize| ~                            |
| Conventional method           | 0                            |
| H₂O₂ with 60 °C               | 0                            |
| H₂O₂ with 100 °C              | 0                            |

| Parameter                  | Quality Standard¹ |
|----------------------------|-------------------|
| MPN-Coli Bacteria/100 mL   | 1000              |

¹East Java Governor Regulation Number 72 in 2013

3.2. Chemical and physical test results
Table 3 shown that the chemical and physical test results of wastewater effluent from the conventional and the proposed sterilisation technology. COD value of wastewater from the conventional method
was 180 mg/L, exceeded the standard quality value of 100 mg/L. This may possibly due to the use of chemical bleach that causes a decrease in dissolved oxygen [22], which can harm the aquatic life and affect water quality.

However, when using the proposed sterilisation technology with the addition of H₂O₂ operating at temperature of 60 °C and 100 °C, both resulted wastewater with COD values below that of the standard quality. This indicated that the wastewater effluent was safe to be discharged to the environment [23]. The addition of H₂O₂ may greatly contribute to reduce the COD content in the resulted wastewater.

In terms of BOD content, all treatments resulted wastewater with a low BOD content, as seen in Table 3. When using H₂O₂ either heated at temperature of 60 °C and 100 °C, the BOD values were lower than that of the conventional method. This was due to the ability of H₂O₂ to oxidise organic matter causing a BOD reduction, as well as H₂O₂ can break down into H₂O and O₂ considered as ecologically harmless due to no toxic by-products is generated [24]. The presence of suspended solids in water body or wastewater causes turbidity [25]. A high turbidity value from the wastewater effluent of conventional sterilisation technology indicating a high suspended solid remained, which potentially blocked sunlight entering the water body [26]. However, the proposed sterilisation technology was able to reduce turbidity value by 75.69 % (H₂O₂ at 60 °C) and by 84.40 % (H₂O₂ at 100 °C), respectively. This result indicates that increasing the sterilisation temperature causing an increase in turbidity removal efficiency. In terms of pH values, despite all treatments gave higher pH values, the conventional sterilisation method still producing the wastewater effluent with the highest pH value, which may potentially inhibit the fish growth [27].

Table 3. The chemical and physical characteristics of wastewater after sterilisation process

| Parameters          | Conventional method | Proposed sterilisation technology | Standard value* |
|---------------------|---------------------|-----------------------------------|-----------------|
| COD (mg/L)          | 180                 | 40                               | 40              | 100              |
| BOD (mg/L)          | 6.36                | 2.34                             | 5.20            | 30               |
| pH                  | 9.41                | 8.62                             | 8.47            | -                |
| Turbidity (NTU)     | 43.2                | 10.5                             | 6.74            | -                |
| Temperature (°C)    | 24                  | 46                               | 87              | -                |

*Indonesia Ministry of Environment and Forestry Regulation Number 68 in 2016

3.3. Operational cost analysis

The economic analysis, in particular the operational cost analysis, was carried out based on the data collected from two small and medium-sized enterprises (SMEs) in Malang City. The average data obtained from these SMEs was used in the calculation to compare the economic value of applying the conventional and the proposed sterilisation technology (Table 4). For the conventional method, the chemical sterilants added were detergent and bleaching. In this method, for 1 diaper waste needed 7 L of water, 23 g of detergent and 180 mL of bleach was needed, giving the total cost of IDR 3,671. However, if using antibacterial soap for sterilisation, 1 diaper waste required 7 L of water, 175 mL antibacterial soap and hot water with the total cost of IDR 26,810. This indicated that using different chemicals sterilant may change the operational cost of sterilisation process, and the cost of chemicals have a big portion in the total cost of the conventional method.

In the proposed sterilisation technology, however, there was a significant reduction of input materials needed, include water or chemicals. For example, for treatment of H₂O₂ and detergent,1 diaper waste needed 0.667 L of water, 50 mL of H₂O₂, and 23 g of detergent, with the total cost of IDR 1,102. If the sterilisation process was only combined with fabric softener, the operational cost was greatly reduced to IDR 619.76, from the use of 0.667 L of water, 0.4 mL of fabric softener and 50 mL of H₂O₂. There was a slight decrease in the operational cost (IDR 602) when the sterilisation process only added H₂O₂ to treat the diaper waste, as it required 0.667 L of water and 50 mL of H₂O₂.
Table 4. Comparison of economic analysis of sterilization processing technology

| Technology                | Chemical used          | Total cost (in IDR) |
|---------------------------|------------------------|---------------------|
| Conventional              | Detergent and Bleach   | 3,761               |
|                           | Antibacterial Soap     | 26,810              |
| Proposed sterilisation    | $H_2O_2$ and Detergent | 1,102               |
| technology                | $H_2O_2$ and Fabric Softener | 619.76          |
|                           | $H_2O_2$               | 602                 |

4. Conclusions
The findings confirmed that compared with the conventional method, the proposed technology for sterilisation of baby diapers waste has potential to tackle the baby diapers waste problem. This process can greatly reduce the content of COD and BOD to below the standard requirement for wastewater effluent. No *E. coli* was evident in the wastewater produced. The sterilisation technology proposed offered an eco-friendly way in treating diapers waste and converted the waste into valuable products. In terms of economic perspective based on the product components, applying the sterilisation technology based on double jacket and centrifugal speed has lower operational cost compared to that of the conventional method. However, a more detail study is required to investigate the impact of wastewater resulted in the environment.

Acknowledgments
The authors express their gratitude for the support from Ministry of Research and Higher Education of Indonesia through the Student Scientific Competition Grant for Research Scheme (PKM-PE) in 2018.

References
[1] Colon J, Ruggieri L, Sanchez A, Gonzalez A, Puig I 2010 Possibilities of composting disposable diapers with municipal solid waste *Waste Manage. Res.* **29** 3 249-259.
[2] Espinosa-Valdemar R M, Sotelo-Navarro P X, Quecholac-Pina X, García-Rivera M A, Beltran-Villavicencio M, Ojeda-Benitez S, Vazquez-Morillas A 2014 Biological recycling of used baby diapers in a small-scale composting system *Resour. Conserv. Recycl.* **84** 153-157.
[3] Nations U 2015 Department of Economic and Social Affairs Population Division.
[4] Khoo S C, Phang X Y, Ng C M, Lim K L, Lam S S, Ma N L 2019 Recent technologies for treatment and recycling of used disposable baby diapers *Process Saf. Environ. Prot.* **123** 116-129.
[5] Sanchez-Orozco R, Timoteo-Cruz B, Torres-Blancas T, Urena-Nunez F 2017 Valorization of superabsorbent polymers from used disposable diapers as soil moisture conditioner *Int. J. Res. – Granthaalayah* **5** 4 105-117.
[6] Rahat S H, Sarkar A T, Rafie S A A, Hossain S 2014 Prospects of diaper disposal and its environmental impacts on populated urban area like Dhaka city University of Engineering and Technology Dhaka.
[7] Wambui K E, Joseph M, Makindi S 2015 Soiled diapers disposal practices among caregivers in poor and middle income urban settings *Int. J. Sci. Res. Pub.** 5** 10 1-10.
[8] Wang S, Wang J, Sun P, Xu L, Okoye P U, Li S, Zhang L, Guo A, Zhang J, Zhang A 2019 Disposable baby diapers waste derived catalyst for synthesizing glycerol carbonate by transesterification of glycerol with dimethyl carbonater *J. Clean. Prod.* **211** 330-341.
[9] Al-Jabari M, Ghyadah R A, Alokely R 2019 Recovery of hydrogel from baby diaper wastes and its application for enhancing soil irrigation management *J. Environ. Manage.* **239** 255-261.
[10] Colon J, Mestre-Montserrat M, Puig-Ventosa I, Sanchez A 2013 Performance of compostable baby used diapers in the composting process with the organic fraction of municipal solid waste *Waste Manage.* **33** 1097-1103.
[11] Torrijos M, Sousbie P, Rouez M, Lemunier M, Lessard Y, Galtier L, Simao A, Steyer J P 2014 Treatment of the biodegradable fraction of used disposable diapers by co-digestion with waste activated sludge *Waste Manage.* 34 669-675.

[12] Budyk Y, Fullana A 2019 Hydrothermal carbonization of disposable diapers *J. Env. Chem. Eng.* 7 103341.

[13] Lam S S, Mahari W A W, Ma N L, Azwar E, Kwon E E, Peng W, Chong C T, Liu Z, Park Y -K 2019 Microwave pyrolysis valorization of used baby diaper *Chemosphere* 230 294-302.

[14] Hradecky J, Kludskà E, Belkova B, Wagner M, Hajslová J 2017 Ohmic heating: A promising technology to reduce furan formation in sterilized vegetable and vegetable/meat baby foods *Innov. Food Sci. Emerg. Technol.* 43 1-6.

[15] Schneider P M 2013 New technologies in sterilization and disinfection *Am. J. Infect. Control* 41 5 S81-S86.

[16] Wallace C A 2016 New development in disinfection and sterilization *Am. J. Infect. Control* 44 e23-e27.

[17] McEvoy B, Rowan N J 2019 Terminal sterilization of medical devices using vaporized hydrogen peroxide: a review of current methods and emerging opportunities *J. App. Microb.* 127 1403-1420.

[18] APHA 5220 2012 Standard methods for the examination of water and waste water 22nd edition American Public Health Association.

[19] Adamus-Bialek W, Vollmerhausen T L, Janik K 2019 Hydrogen peroxide stimulates uropathogenic *Escherichia coli* strains to cellulose production *Microb. Pathogen.* 126 287-291.

[20] Salazar-Mercado S A, Torres-Leon C A, Rojas-Suáres J 2019 Cytotoxic evaluation of sodium hypochlorite, using *Pisum sativum* L as effective bioindicator *Ecotox. Env. Safe.* 173 71-76.

[21] Bettelheim K A, Goldwater P N 2015 *Escherichia coli* and sudden infant death syndrome *Front. Immunol.* 6 343 1-7.

[22] Kulkarni S J 2016 A review on research and studies on dissolved oxygen and its affecting parameters *Int. J. Res. Rev.* 3 8 18-22.

[23] Ministry of Environment and Forestry 2016 Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor 2016 tentang Baku Mutu Air Limbah Plastik (Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 2016 about Plastic Waste Water Quality Standards) [In Indonesian]

[24] Tofant A, Vučemilo M, Pavičić Z, Milić D 2006 The hydrogen peroxide, as a potentially useful slurry disinfectant *Livestock Sci.* 102 3 243-247.

[25] Tan C W A, Thishalini A, Goh E G, Edlic S 2017 Studies on turbidity in relation to suspended solid, velocity, temperature, pH, conductivity, colour and time *ARPN J. Eng. Appl. Sci.* 12 19 5626-5635.

[26] Foundriest Environmental Inc 2014 Turbidity, total suspended solids and water clarity. Accessed from http://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/ on 13 March 2019.

[27] Njoku I, Obialo M B, Oguchukwu O 2007 Effect on pH on the growth performance of *Heterobranchus bidorsalis* X *Clarias gariepinus* hybrid juveniles *Anim. Res. Int.* 4 1 639-642.