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An Approach for the Assessment of Water Use in Batik Production Processes

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Abstract. Batik production processes use large quantities of water that are currently not evaluated. The Indonesian government has set the direct water use standard in the batik production process, but a method for assessing this water use indicator is needed. In this paper, we report work on developing an approach for assessing water used in the batik production process as an integral part of the batik fabric design process. The input parameters used in the approach are available in the design process, while the output parameter is the total direct water used in the production process of batik fabric made using a batik design. Three batik fabrics with different designs were selected as a case study. The production process model of the three designs was developed and implemented in a discrete event simulation software package. To validate the simulation results, data related to water use in batik production from batik factories were obtained using an online survey. The output of the proposed approach can be used as data for water use analysis to carry out process improvement in batik production processes.

Keywords: Water use assessment, Batik production process, Product design.

1 Introduction

Batik production is a wet textile process. Over 47,000 manufacturers undertake batik production in Indonesia, spread across 101 industrial centers [1]. Although most are small and medium sized enterprises, they make a significant contribution to Indonesia's economic development [2]. However, the batik industry uses large quantities of water that currently are not evaluated [3]. In response, the Indonesian government proposed green industry standards for the batik industry in 2019. These include two indicators of water use: direct water use and wastewater reuse ratio [4]. The unit used for the indicator of direct water use in the production process is liters of water per square meter of fabric per color ($l/m^2/color$). Therefore, the mechanism used to assess the direct water used in batik production must consider the fabric design.

The literature on sustainable water use highlights several methods for assessing water used in manufacturing processes [5]. The goal of these methods is to identify potential improvements for stakeholders and decision-makers [6]. However, current methods support neither the operational assessment of direct water use in batik production nor the evaluation of alternative scenarios to reduce water use considering product design, and production order and planning issues such as production volumes. This paper reports research on developing an approach to assess water used in batik production that is specific to each batik fabric design based on operating conditions at the design stage. The remainder of this paper proceeds as follows. Section 2 provides a literature review concerning the characteristics of batik production processes and previous research on water use in the textile processing industries. The proposed approach, which is evaluated through a single case study, is introduced in section 3, while section 4 presents a discussion of the results. The conclusion is provided in section 5.

2 Literature Review

2.1 Characteristic of Batik Production Processes

The batik production process produces colored and patterned fabric called "batik fabric". The design and manufacture of this fabric is both an art and a craft, and part of an ancient tradition [7]. Batik fabrics are made with the wax-resist dyeing technique which forms pattern motifs by applying wax and dyes to the fabric [8]. A batik design is characterized by its color, composition, and pattern. Batik patterns have hundreds of variations and unique features [9] and can be applied to various types of fabric. However, cotton fabric is more commonly used [10]. The main auxiliary materials used in the batik production process are wax and dyes. Batik wax is made of ingredients including residues of pine-gum distillation, resin from Shorea Javanica, paraffin, micro wax, animal fat such as Kendal which is fat from cows, coconut oil, beeswax, and lancing wax [11]. Based on the tools used for applying hot wax, batik fabrics are divided into three types: written, stamped, and combination. As regards dyes, two types of dye are used: synthetic and natural. Most batik manufacturers prefer synthetic dyes because natural dyes do not have as much color variation and have longer processing times [8]. Data from several studies suggest that the most widely used synthetic dyes in the batik production process are Remazol, Naphthol, Indigo Soluble, Direct, and Reactive [2, 12]. Other auxiliary materials for producing batik fabrics are soda ash (sodium carbonate), water glass (sodium silicate), sulphur, and chlorine.

Batik production consists of three main processes (dyeing, waxing, and dewaxing) and three additional processes (fabric preparation, bleaching, and finishing). Dyeing is a process in which color is transferred to the fabric to add permanent and long-lasting color. The dyeing process can be carried out with various dyeing techniques such as dipping, smocking, dabbing, spraying, and painting. More than one color can be applied to the fabric in each dyeing process, depending on the color combination in the product design. Waxing is a process in which hot wax is applied to fabric to prevent dye from penetrating, and so color change in, areas of fabric which are covered by wax. Dewaxing is the process for removing wax from the fabric by dipping it in a vat of boiling water that melts the wax. The rinsing process is carried out in the process of dyeing and dewaxing. This process is also done in fabric preparation, bleaching, and finishing processes. The batik production process can be started from either the dyeing or waxing process. In addition, the dyeing, waxing, and dewaxing processes can be repeated several times to form a finished batik design [13]. The source of water used by most Indonesian batik manufacturers is groundwater. Water is used in every stage of the batik production process except waxing. Most water used in the batik production processes is discharged to rivers as wastewater, while water absorbed by the fabric evaporates in the drying process. Visually, wastewater produced in the batik production process has color and is highly polluting due to synthetic dyes and other chemical materials [14].

2.2 Water Use in the Textile Processing Industries

A large and growing body of literature has investigated water use in the textile processing industry because it not only uses a large amount of water but also is one of the main producers of industrial wastewater in many countries [15]. Hussain and Wahab [16] categorized research on water uses in the textile industry into wastewater treatment and reuse, production equipment, process and chemical innovations, and advanced water analysis and saving tools. A considerable amount of literature has been published on wastewater treatment and reuse in textile processes, including the batik production process [13]. These studies propose several possible treatment processes for wastewater including physical, oxidation, and biological methods [17]. Further work reports methods for managing water use in textile processing through innovations; however, capital investment is identified as a central barrier for applying these methods [16].

Meanwhile, methods used for analyzing water use in textile processes are life cycle assessment (LCA) and water footprint assessment [16]. LCA focuses on identifying potential environmental impacts due to water use, while the water footprint assessment method is used to quantify the volume of water needed to produce a product [18, 19]. In the water footprint assessment method, a product's water footprint is divided into three components: green water, blue water, and grey water footprints. The green water footprint is the volume of rainwater consumed during the production process [20]. In the Indonesian batik industry this is not considered unless rainwater is used as a water source. The blue water footprint is the amount of surface and ground water used in the production of the product and disposed of as wastewater. Finally, the grey water footprint is the theoretical volume of water required to dilute a critical pollutant load to meet water quality standards [19]. The total water footprint of a product includes its direct and indirect water footprints [19]. The direct water footprint is the volume of water consumed or polluted when producing a product, while the indirect water footprint refers to water consumed to produce raw materials and energy for the production process, sometimes referred to as virtual water [19, 20]. However, the grey and indirect blue water footprints were out of scope in this research.

The water footprint method has been applied to a number of textile applications. For example, Chico et al. [21] calculated the total water footprint of a pair of jeans based on the types of textiles and production methods. Zhang et al. [22] used it to evaluate the total water footprint of three kinds of zipper. Handayani et al. [10] examined the total water footprint of a natural-colored batik fabric. Other authors investigated the total water footprint in the ready-made garment (RMG) production in Bangladesh [23]. In addition, Wang et al. [24] introduced a methodology of water footprint assessment for the Chinese textile manufacturing sector. They calculated the blue water footprint by summing the volume of freshwater appropriated in all processes. In contrast, Lévová and Hauschild [25] developed a method to calculate an impact score for water use based on LCA. In quantifying the amount of water used in the production process, this method considers the negative effects of removing the water from the water source, changing water quality, and causing a time delay between extraction and discharge. This model was applied in the textile industry to select the production site and the type of chemicals and was also employed in a study by Nursanti et al. [26] to assess the impact of water use in a batik factory. However, these studies did not consider the use of water in the production process and the characteristics of the production process system in detail based on operating conditions. These studies also did not evaluate different what-if scenarios for reducing water use that considers product design, production order and production planning, such as production volumes. Adjusting production orders and production plans are practiced to reduce water use [22].

3 Proposed Approach

3.1 Research methodology

An inductive methodology was used to identify requirements (Section 3.2) for the proposed approach. These informed the development of a conceptual model (Section 3.3) of the production process for the three batik designs that were selected as case studies. The WITNESS discrete event simulation system was used to implement the conceptual model (Section 3.4) and enable the quantification and visualization of direct water use. For validation, outputs of the approach were compared with data on water use in batik production from factories in Central Java, Indonesia, obtained with an online survey.

3.2 Requirement definition

The purpose of the proposed approach was to assess direct water used in batik production, based on operating conditions, at the design stage. This allows water to be incorporated into the design assessment process and provides opportunities for identifying process improvements. Using the approach, experiments with alternative production scenarios can be carried out to explore how they affect water use. The input parameters used in this approach were the information available during the design process of a batik pattern and its production process, including the type of batik, production process flow, techniques used in each process, and the dye used in each dye application process. Three batik fabrics with different designs were selected as case studies, as shown in Fig. 1. The first design is a written batik fabric [27], the second is stamped [28], and the third is a combination fabric [29]. The first design was a traditional one, the second modern and the third a combination of the two. Data to support the model, including water used in each process and the size of each batik fabric, was gathered from a previous study by Nursanti et al. [26]. Each piece of batik fabric was 2.75 meters long and 1.15 meters wide. The volume of water used in the dye application and color fixation was assumed to be the same for all types of dyes and dye application techniques and used to process one piece of fabric. This assumption was made due to data availability. In addition, the number of pieces of equipment used in each process was assumed to be one except for the rinsing process in the dyeing and dewaxing processes which use two water tubs.


(a) (b) (c)

Fig. 1. (a) First batik design; (b) Second batik design; (c) Third batik design

3.3 Conceptual Model

The conceptual model presents the batik production processes as described in the literature review; the production process of batik fabric varies depending on the pattern made. The process flow for each dyeing process also varies depending on the technique and dye used. In addition, the model shows in detail the processes in batik production that use water. The conceptual model is shown in Fig. 2. There are three production process flows in the model: one for each of the three batik designs. Waxing, dyeing, and dewaxing processes are carried out several times. The bleaching process is carried out to produce the second batik design. In processes that use water, water was added and discharged each operation. The volume of water for wetting, rinsing, bleaching, and wax removal is the capacity of equipment used, which can be used to process more than one piece of fabric. The number of fabrics processed or the batch size in each operation varies. The water used in each operation is discharged if it is concentrated due to dyes, waxes, and other substances that dissolve.

3.4 Implementation

The model of the batik production was implemented in the Witness discrete event simulation package. The production flow for each design was defined by the routing through the different processes. The routing of the different fabrics as they proceed through the various processes was controlled by the input/output logic at each production stage. The model was run until all pieces of fabric were processed into the final products. It was run 100 times for each case study with different production volumes and batch sizes. Together with the production process flow of the case study, the production volume and batch size were defined and set up each time the model was run. The production volumes used ranged from five to one hundred pieces of fabric. One of a range of batch sizes (10, 20, 30, 40, and 50 pieces of fabric), which is the number of pieces of fabric processed per operation at the workstation for wet, rinse, bleach, and remove wax, was used in each simulation. The volume of water for each process used was from Nursanti et al. [23].

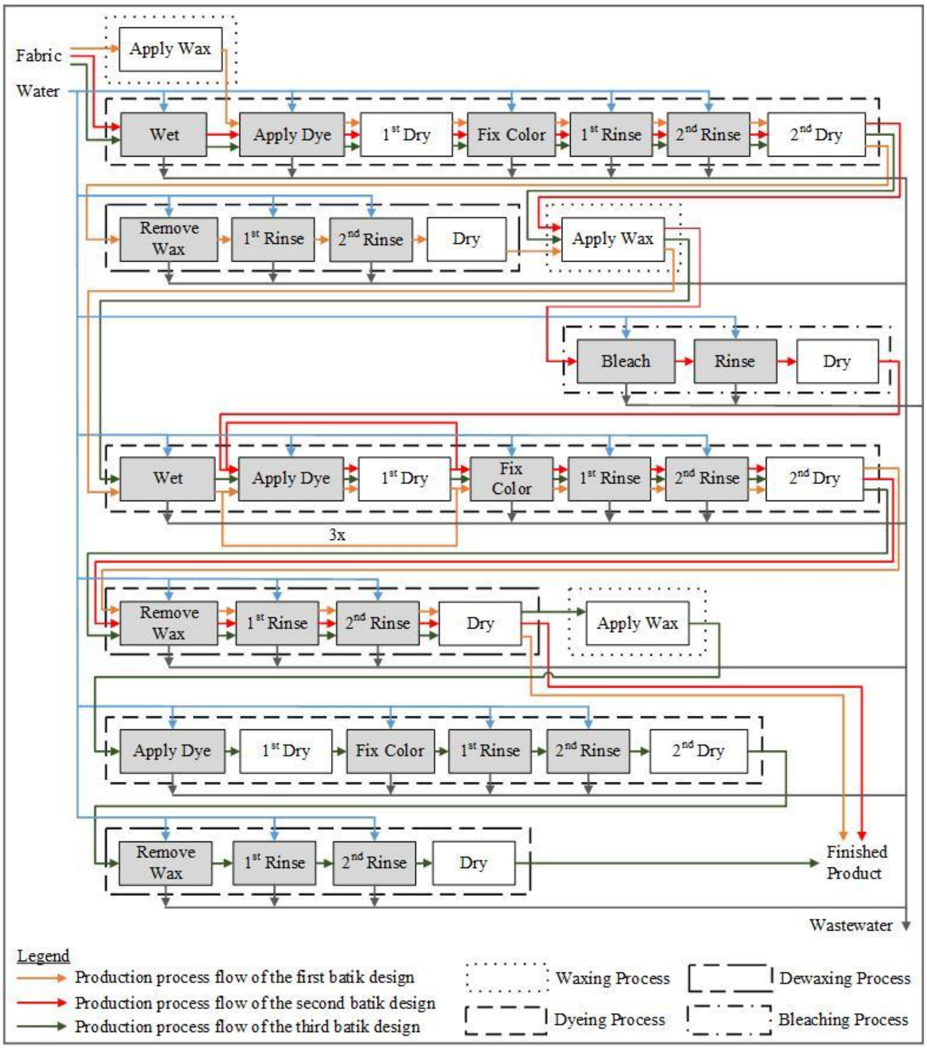
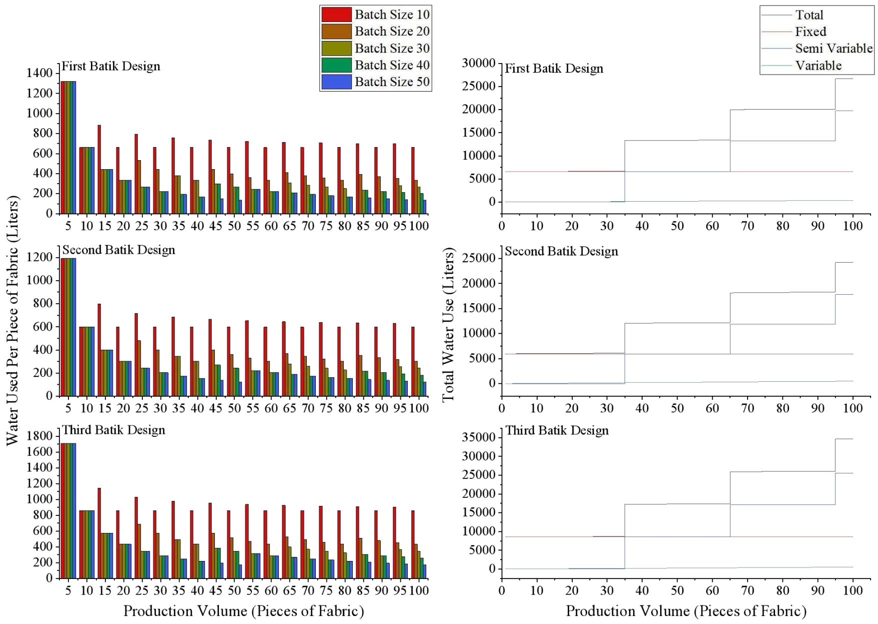


Fig. 2. Conceptual model

The simulation results for all three batik designs are shown in Fig. 3. Fig. 3 (a) presents water use to produce one piece of batik fabric for each specified production volume and batch size per operation. It can be seen that water used to produce a piece of batik fabric decreases if the production volume increases and the production volume exceeds the number of pieces of fabric processed per operation at each workstation. In addition, the total water used graphs that are presented in Fig. 3 (b) indicate that there are fixed, semi-variable, and variable water uses. Fixed water usage is the volume of water used for a given operation regardless of production volume. Semi-variable water use is fixed for a given production volume but increases when that production volume is exceeded. In contrast, the variable water use is water that fluctuates with production volume. The total water use from this assessment can be used as input data to analyze the water use of a batik design.



(a)

(b)

Fig. 3. (a) Water use per piece of fabric; (b) Total water use if the batch size per operation is 30 pieces of fabric (The fabric size is 2,75 meters long and 1,15 meters wide)

4 Discussion

Fig. 4 presents the water used to produce one square meter of batik fabric based on the simulation and survey results. Since the size of the fabric used in batik factories varies, the unit of fabric used to present the data in the figure was the square meter. The data obtained from the survey was the average water use per day, the average production volume per day, and the type of batik produced in several batik factories. However, the batik patterns and the number of batik designs made in these factories were unknown. Thus, in calculating water use per square meter of fabric, all batik fabric made in a batik factory were considered to have the same production process. The batik production process varies depending on the design of the pattern, as shown in this paper.

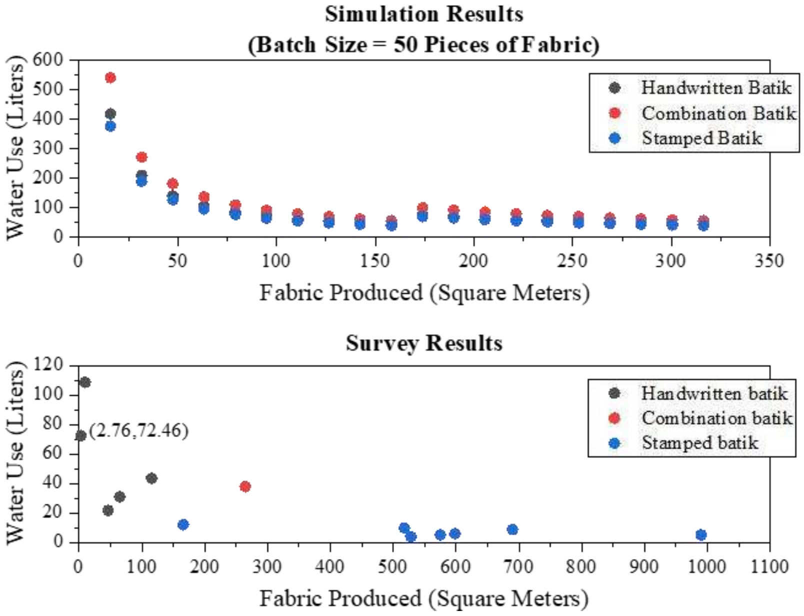


Fig. 4. Water use per square meter of fabric based on simulation results and survey results

According to the survey results, water used in the production of written batik fabric is high because the production volume is low. However, as in the simulation results, the water used to produce written batik fabric is greater than the water used for the stamped batik fabric production process. In addition, if the fabric produced about 270 square meters, the water used to make combination batik fabric in the simulation results is close to the value of water used in the production process of combination batik fabric in the survey results. The water use per square meter in the simulation results is higher because the production equipment used in batik factories varies such as the size of the tubs, and the batch size per operation at each workstation also varies.

5 Conclusions

An approach for evaluating water use in batik production processes based on information available in the process of designing a batik pattern and its production process has been proposed in this paper. The data determined when designing a batik pattern and its production process are the batik production processes carried out and the sequence of the processes, the technique used in each process, and the type of dye used in each dye application process. Production volumes are determined later in production planning. In addition, to calculate water consumption in the production process, historical data is needed, such as the number of products processed, and the volume of water used per operation at each workstation. The output of this approach is the total direct water used to produce batik fabric made using a batik design. Two limitations of the research are (i) only three production processes of batik designs were used as a case study, and (ii) limited water use data was obtained from batik factories. However, this study's findings provide much room for further progress in determining the strategies to improve water sustainability in the batik production process. Results from the proposed approach can be used as data for water use analysis of each batik design produced in a batik factory so that process improvement can be carried out. In addition, the proposed approach can facilitate the evaluation of water use based on green industry standards for the batik industry since the batik production process is not generalized. In future work, other factors related to water used in batik production will be considered in the approach. The approach also will be applied to assess water use in batik production processes in several batik companies.

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