Cleaner production analysis of tofu small scale enterprise

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Abstract. Tofu has been consumed and favored by most Asians. Indonesian Central Bureau of Statistics states that the average consumption of tofu in 2017 was about 0.15 kg/person/week. On the other hand, the higher level of tofu production, the level of waste contamination, is also higher. Therefore, cleaner production is one of the practical approaches to reduce tofu industry waste. This research aims to analyze the stages of tofu production in small scale enterprises which have the greatest volume of liquid waste, assess parameters that exceed the quality standard and determine the alternative of cleaner production strategies for tofu production. This research analyzed mass balance, Activity Relationship Chart, Activity Relationship Diagram, wastewater characteristics test, and alternative selection of cleaner production strategy with the pairwise comparison. This research found out that the stages that produced the most liquid waste were the treatment and waste disposal process. The highest priority and the possible alternative of cleaner production to be implemented were waste separation at each stage, wastewater recycles, and water vapor recycles.

1. Introduction

Tofu is a food product that has long been consumed and marketed in almost all levels of Indonesian society [1]. The products are made from coagulated and molded soybean protein [2]. The protein content in tofu can be used as a substitution for animal protein [3]. The tofu industry in Indonesia is mostly classified into small scale enterprise (SSE) and spread across large and small cities. The number of tofu SMEs in Indonesia in 2015 was about 84,000 units [4].

The tofu production process requires large amounts of water for washing, soaking, blending, cooking, which is indeed proportional to the amount of waste produced. The amount of liquid waste that is not balanced with proper processing will cause severe problems to the surrounding environment. Therefore, it is necessary to make efforts to reduce the amount of waste, both liquid and solid, by processing to produce products that have economic value.

Cleaner production is a strategy to carry out the production process by installing equipment that can increase the efficiency of natural resource use and minimize waste, pollution, and environmental risks [5]. Several previous studies have stated that cleaner production is an effective approach to reduce industrial tofu waste [6]. Cleaner production can reduce the wastewater load generated by the tofu processing plant [7]. The benefits of cleaner production are to increase the yield of tofu filtrate, save fuel, and keep the environment clean [2].
This research was conducted at one of the tofu SSEs, which also had problems with liquid waste disposal. The washing and soaking process of soybeans produced liquid waste containing BOD that exceeded the quality standard. In addition, the waste from the process of separating and pressing tofu contained BOD, COD, TSS and pH which also exceeded the quality standard. Therefore, it is essential to implement cleaner production to improve the quality of work and the environment to overcome the problem of liquid waste in this SSE. Analysis by identifying the process mass balance, Activity Relation Chart (ARC), and Activity Relation Diagram (ARD), analysis of the physical-chemical characteristics of wastewater, and expert analysis to determine the alternative strategies for cleaner production using the pairwise comparison method. This research aims to identify the stages of production that most produce liquid waste in tofu SSE, what parameters that exceed the quality standard, and evaluate alternative cleaner production strategies that are most likely to be implemented according to the conditions of SSE.

2. Materials and Method

2.1 Materials and instruments
This research was conducted at tofu SSE in Krian, Sidoarjo, in June-July 2019. The tofu liquid waste test was conducted at the Surabaya Health Laboratory Center and Public Company Jasa Tirta I Malang. The data processing was conducted at the Agroindustrial Management Laboratory, Department of Agro-Industrial Technology, Faculty of Agricultural Technology, Universitas Brawijaya, Malang. Instruments used in this research were two types of questionnaires. The first questionnaire aimed to identify problems and determine alternative strategies for cleaner production with some respondents: one owner and two employees of tofu SSE and 30 people living <300 meters from the location of the tofu SSE. The second questionnaire was a pairwise comparison weighting questionnaire for one SSE owner and two environmental experts or academicians to determine priorities for strategy selection. The limitation of the problem used in this research was the analysis of the characteristics of the waste, which was carried out only in the process that produces the most liquid waste or wastewater, and the analysis was carried out from the stages of selecting soybeans to the tofu cutting process.

2.2 Methods
The followings were the steps of data processing:
1. Technical analysis
   Technical analysis was carried out by identifying the stages of production to determine the process flow diagram as a tool for understanding the flow of materials, mass balance, and sources of waste generation. Analysis of the production process and mass balance was carried out at each stage of the process by observing each input, treatment, and output [8]. Then ARC and ARD were made to determine the activity relationship map to identify alternatives to optimize the production process.
   a. Mass balance
      The steps of mass balance were determined as the basis of calculation and the development of the process diagram. If a chemical reaction occurred, the solution was based on the elements and used mole units. If no chemical reaction occurred, the answer was based on the compound and used units of mass [9].
   b. ARC and ARD
      The procedure to make an activity relationship map was to identify all work facilities that would be laid out and their sequences. The stages were carried out by (1) conducting interviews or surveys on employees of each department and authorized management, (2) determining the criteria for the relationship between departments to be placed based on the closeness of the relationship and their respective reasons, (3) compiling the results of the relationship assessment between departments, and (4) determining departmental plans following the results of the relationship assessment [10].
2. Wastewater characteristics test
The wastewater characteristic test was carried out by analyzing the liquid waste content and comparing it with existing quality standards. This process occurred by taking a sample of liquid waste at the stage that produced the most liquid waste. Identification was made physically, and the treatment for each test was different, they were color, turbidity, and odor were observed directly without tools. The temperature identified directly at the SSE used a digital thermometer with a measurement range of \(-50^\circ C \sim 110^\circ C\) with an accuracy of 0.1°C. The pH of the waste was identified directly at the SSE using pH paper. COD was tested based IK / KIM method 32/05/18 and carried out by the Surabaya Health Laboratory Center. TSS was tested based on SNI 06-6989.3 2004 method and carried out by the Surabaya Health Laboratory Center. BOD was tested based on the APHA 5210 13-1998 method and carried out by the Public Service Company Tirta I Malang.

3. Problem identification
Problem identification was carried out based on the results of the mass balance, ARC, ARD, and the effects of waste testing. The aim was to identify problems that require alternative cleaner production strategies. The identification of this problem was made by using Ishikawa diagrams for the impact or effect of trouble with various causes.

4. Cleaner production strategy identification
This process was based on identifying the problems by the questionnaire results of the surrounding community, expert opinion, and literature. This research aimed to find alternatives to increase production efficiency, prevent and reduce waste from input materials.

5. Selection of alternative solutions with pairwise comparison
Pairwise comparison was part of the Analytical Hierarchy Process (AHP) method. The choice of alternative solutions was based on weakness, convenience, the possibility of application, and suitability with industrial conditions and seen from the impact on the environment. The weighting and selection of alternatives were carried out by the owner of tofu SSE to provide a subjective assessment. Stages of calculation were: (1) defined the problem and determine the desired solution, (2) developed a hierarchical and alternative structure, (3) constructed a pairwise comparison matrix, (4) summed the element values of each column from the importance of the previous criteria matrix element, (5) summarized the value of each column from the matrix, divided each column value by the corresponding column total and added up the costs of each row and divided by the number of elements, (6) added up each row and then calculated the priority value of the criteria by dividing each number of rows by the number of criteria, (7) calculated of consistency index (Equation 1), and (8) calculated of consistency ratio (Equation 2). The value of the consistency ratio (CR) should be smaller or equal to 0.1 (10%); it meant that it had the right consistency [11].

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CI = (\lambda_{\text{max}} - n)/(n - 1) \quad (1)
\]

\[
CR = CI/IR \quad (2)
\]

6. Cleaner production alternative strategy recommendations
The results of alternative weighting could be used as recommendations for alternative strategies for cleaner production. This recommendation was expected to be applied in the future and could have a positive impact by the principle of cleaner production, namely increasing the efficiency of natural resource use and minimizing waste, pollution, and environmental risks.

3. Results and Discussion

3.1 Mass balance
The mass balance used in this study was mass balance without chemical reactions. Calculation of the mass balance without chemical reaction is done by calculating the total flow and flow of components that enter and leave the system. The amount of incoming material will be the same as the amount of output material (no material is lost) [12]. There were two types of data used in this mass balance analysis, namely primary and secondary data. Preliminary data were obtained directly from the volume of the production process, and secondary data comes from literature. The tofu SSE produces 150 kg of
soybeans/day and produces 71.6 kg of solid waste consisting of 60 kg of tofu pulp and 11.6 kg of the soybean skin, 637.3 L of liquid waste, and 147 kilograms of tofu. However, 63 L of liquid waste in the whey stage was not disposed of but was left to sit overnight as a medium for clumping tofu for the next production. The flow chart for the mass balance of the production process can be seen in Figure 1.

![Flow chart for the mass balance of the production process in tofu SSE.](image)

**Figure 1.** The flow chart for the mass balance of the production process in tofu SSE.

### 3.2. ARC and ARD

#### 3.2.1 The flow of fuel and raw material before repaired

The flow of fuel and raw material before repair can be seen in Figure 2. The advantages of fuel and raw material before repair were easy receiving and shipping process, and employees were not directly exposed to the heat and dust of the furnace. The weakness was it has a random flow, and the flow of material from one station to another was less efficient.

![Diagram showing the flow of fuel and raw material before repaired in tofu SSE.](image)

**Figure 2.** The flow of fuel and raw material before repaired in tofu SSE.
3.2.2 ARC
ARC was based on levels of interest between production stations. The firewood storage was essential to be close to the furnace or immersion station, to minimize the distances of transport and reduce the scatter of materials. Soaking and washing stations were crucial to be close together because they used the same equipment. The results of the ARC analysis that have been obtained are used as a reference for the ARD [10]. ARC in tofu SSE can be seen in Figure 3.

3.2.3 ARD
ARD was formed from the identification of the ARC map to explain the relationship of material flow and the location of each station in the production process. Stations with high values were located side by side, and stations with low values were kept out. Besides, it was also adapted to several considerations such as building area, ease of receiving, and shipping to minimize handling costs [13]. ARD of tofu SSE can be seen in Figure 4.

3.2.4 The flow of fuel and raw material after repaired

The flow of fuel and raw material after repair can be seen in Figure 5. The advantages of fuel and raw material after repair were the easy installations of water faucets and steam pipes. Adjacent frying stations made the installation of air circulation easier. The storage and packaging station were located outside to expedite the receiving and shipping process. The weakness was that the storage of raw material located beside the washing station would affect the dry soybean supply, and the furnace that was close to the entrance was dangerous for workers who passed it.
3.3 Characteristics of liquid waste

The identification of waste characteristics was carried out at two production stations that produced the most number of wastewater, namely, soaking-washing and separation-pressing. Some parameters exceeded the existing quality standards. The results of testing liquid waste in tofu SSE were compared with the standards of wastewater for tofu production, according to the regulation of the Minister of Environment in Indonesia Number 5 in 2014. It can be seen in Table 1. From the test results, it was known that the BOD value in soybean soaking-washing wastewater and the BOD, COD, TSS, pH values in the tofu separation-pressing wastewater exceeded the standards. This result suggested that the use of acidic whey caused total wastewater to become sour, and it was dangerous for the biota environment. Overall, tofu wastewater contained protein 40% - 60%, carbohydrates 25%-50%, fat 10%, and other suspended solids. The more organic-inorganic content of a substance, the BOD-COD level would also increase [14]. Meanwhile, the high of TSS caused by tofu sludge that had been removed during the separating process so it could pollute the waters.

### Table 1. A test result of wastewater and quality standard of wastewater of tofu production.

| Parameter          | Quality Standard | Separating and Pressing | Soaking and washing |
|--------------------|------------------|-------------------------|---------------------|
| BOD (mg/L)         | 150              | 9936                    | 4671                |
| COD (mg/L)         | 300              | 2886                    | 135.7               |
| TSS (mg/L)         | 200              | 425                     | 54                  |
| pH                 | 6-9              | 5                       | 7                   |
| The highest quantity of wastewater (m/ton) | 20 | 0.008 | 0.030 |
| Temperature (°C)   | -                | 39.2                    | 30.1                |
| Colour             | -                | Greenish-yellow         | Greenish-yellow     |
| Turbidity          | -                | Yellowish-white         | Yellowish-white     |
| Odor               | -                | A little turbid         | A little turbid     |

Source: Quality Standard (Regulation of the Minister of Environment in Indonesia Number 5 of 2014), BOD (Water Quality Laboratory of Public Company Jasa Tirta I Malang), COD and TSS (Surabaya Health Laboratory)

3.4 Ishikawa diagram

[Figure 6. Ishikawa Diagram of Tofu SSE.]
Identification of cause and effect was obtained from the results of literature, interview with respondents from tofu SSE owners, and questionnaires from the surrounding community. Based on the results of the questionnaire, 83% of the local community agreed with wastewater treatment before it flowed into the river, and 70% agreed with the use of wastewater to increase the value. Besides, 66% agreed with the need for process modification, 83% agree with the need for engine modification, and 56% also agreed with the need for material standardization in the hope of minimizing the amount of waste. It could be concluded that the leading cause of not achieving cleaner production was from an environmental perspective. Meanwhile, according to SSE, the leading cause of not achieving cleaner production was due to human resources. The Ishikawa diagram of tofu SSE can be seen in Figure 6.

3.5 Cleaner production alternatives
The alternatives were determined based on the Ishikawa diagram and would be selected based on the pairwise comparison results that were weighted by the SSE owner and academicians by considering costs, availability of land, and human resources. These alternatives include processing and utilizing waste, improving good housekeeping, improving process control, modifying processes, changing technology, and standardizing raw materials. In general, one alternative would affect other alternatives.

a) Changes the facility layout
Several layout changes could reduce the distance between facilities, reduced spillage of materials, the efficiency of water and steam pipes, and the efficiency of receiving and shipping. A good layout produced a comfortable, safe, efficient, structured environment, and improves results [15].

b) Changes in material composition
Composition changes occurred when the addition of ingredients to facilitate the clumping process of tofu by reducing the amount of excess whey, which caused a low pH of the waste. It was recommended to use another type of lump in the form of a tofu rock (Glucono Delta Lactone) [16].

c) The use of dry soybean peeler
The dry soybean peeler machine had an average capacity of 50 kg/hour with a stripping and splitting efficiency of up to 85%. Meanwhile, manual peeling of soybean skin required a long time and massive amounts of water both during immersion and washing. Therefore, it was recommended to use a dry soybean peeler so that it could reduce the amount of water used [17].

d) The use of vacuum boiler machine
Boiling twice was considered less efficient because it required more energy and time. It was recommended to use a vacuum boiler because water evaporated at a lower temperature due to its lower boiling point in a vacuum condition so that the energy and time required would be more efficient [18].

e) The use of molding machine
The molding process was recommended to use a machine so that the operation could run efficiently and had a more symmetrical shape. Besides, the use of this machine could also save time and effort so that the level of productivity could increase with a fixed number of workers [19].

f) Waste separation at each stage
Every process had different wastewater characteristics so that the treatment process was also different. Wastes that required fair treatment were more comfortable to reuse, and only massive demolitions required further treatment. This action would reduce the total waste treatment burden and costs [20]. So, it was advisable to make several storage ponds to facilitate the further treatment of wastewater.

g) Wastewater recycles
The wastewater from soaking, washing, separating, and pressing could be treated and reused. It was considered a large amount of wastewater produced. The easiest way was phytoremediation using water plants. It was recommended to utilize water plants such as water hyacinth, which could remove, move, stabilize, and destroy pollutants, both organic and inorganic compounds, because of their ability to assimilate. Also, water hyacinth was a plant that was easily got and cheap [21].
h) Water vapor recycle

Various ways were often used to get clean water; one of them was the distillation process. Distillation involved evaporation and condensation processes. In the condensation process, the saturated vapor would change the phase to water. The amount of water needed was huge, which was around 769.3 L/day, and the amount of water vapor disappeared at about 150 L/day. It was recommended to make a steam catchment channel equipped with plastic nets so that water vapor could be condensed into water and collected for reuse [22].

3.6 Pairwise comparison

Eight alternative cleaner production strategies could be applied to tofu SSE. Priority and alternative ranking could be seen in Table 2. From the table, it could be seen that the alternatives F, G, and H were three alternatives with the highest-ranking value. It meant that the separation of waste at each stage, wastewater recycles, and water vapor recycle were the chosen alternatives to be implemented in the future. Through the calculation of consistency based on Equations 1 and 2, the \( \lambda_{\text{max}} \) value was obtained at 8.46, CI value 0.07, and CR value 0.05. Because the CR value was ≤ 0.1, the calculation results were stated to be consistent, so that the alternative selection was considered valid.

The implementation of the three alternatives was related to each other. First, the wastewater from each disposal process was separated, then wastewater treatment was carried out according to the characteristics of the waste. Waste that required light handling could be processed smoothly and quickly. In this case, it was water vapor recycle, filtering, deposition, and reuse of soybean washing water. The second washing water could be reused for the first washing of the next production process, while the first washing water could be filtered and deposited first. Based on the level of ease implementation, washing wastewater recycles the easiest. Then followed by water vapor recycle, waste separation at each stage, and wastewater recycles of tofu clumping. It was because processing wastewater with high COD and BOD content was more complicated and required a relatively long time. In conventional processing systems, the time required was around 10-90 days and required a large area of land [23].

| Alternatives                          | Priority (weight) | Rank |
|---------------------------------------|------------------|------|
| A (Changes to the facility layout)    | 0.02             | 5    |
| B (Changes in material composition)   | 0.03             | 4    |
| C (The use of dry soybean peeler)     | 0.12             | 2    |
| D (The use of vacuum boiler machine)  | 0.06             | 3    |
| E (The use of molding machine)        | 0.06             | 3    |
| F (Waste separation at each stage)    | 0.24             | 1    |
| G (Wastewater recycle)                | 0.24             | 1    |
| H (Water vapor recycle)               | 0.24             | 1    |

4. Conclusions

The stages of making tofu include sorting, weighing, soaking, washing, blending, boiling, clumping, separating, pressing, and cutting. The steps that produced the most wastewater were in the soaking-washing (449.5 L) and separation-pressing (187.8 L) processes. At the soaking-washing stage, the BOD value exceeded the quality standard, while in the separating-pressing stage, BOD, COD, TSS, and pH values exceeded the quality standard. There were three of the eight alternatives with the highest priority value and the most feasible to be applied, namely: waste separation at each stage, wastewater recycles, and water vapor recycles. It was to facilitate the treatment and reuse of wastewater in a considerable amount considering that the need for clean water for the production process of the tofu SSE was also significant.
References

[1] Salim E 2013 Kiat cerdas wirausaha aneka olahan kedelai (Entrepreneurial smart tips for various processed soybeans) Lily Publisher [In Indonesian]

[2] Djayanti S 2015 Kajian Penerapan produksi bersih di industri tahu di Desa Jimbaran, Bandungan, Jawa Tengah (Study on the application of clean production in tofu industry in Jimbaran Village, Bandungan, Central Java) Jurnal Riset Teknologi Pencegahan Pencemaran Industri 6 2 75-80. [In Indonesian]

[3] Kartika Ela S, Pratiwi R D, Pujirahayu A, Alhidayat F, Sholihah M 2009 Pemanfaatan limbah padat industri tahu menjadi soya bean nugget sebagai upaya pemberdayaan perempuan (Utilization of tofu industry solid waste to become soya bean nugget as an effort to women empowerment) DIPA UNS [In Indonesia]

[4] Faisal M, Machdar I, Maulana F, Daimon H 2016 Waste management option and renewable energy from tofu processing waste in Banda Aceh International Conference of Chemical Engineering on Science and Applications

[5] Purvi S, Patel, Yamini S, Maulik A R 2015 Cleaner production tool technology change: a better economical option Int. J. Curr. Res. 7 11 22451-22454.

[6] Widodo L 2017 Potensi penerapan konsep produksi bersih pada industri keramik di Probolinggo (Potential application of clean production concepts in the ceramics industry in Probolinggo) Jurnal Teknologi Lingkungan 18 2 192-199. [In Indonesia]

[7] Rahayu S S, Budiyono, Puranto 2017 Integration of cleaner production and waste water treatment on tofu small industry for biogas production using AnSBR Reactor ICUENIS 1-4

[8] Septifani R, Panji D, I Jannah 2018 Green productivity analysis at tofu production (Case study of UD gudange tahu takwa Kediri) IOP Conference Series: Earth and Environmental Science 131

[9] Wuryanti S 2016 Neraca massa dan energi (Mass and energy balance) Politeknik Negeri Bandung [In Indonesia]

[10] Safitiril M D, Ilmi Z, Kadafi M A 2017 Analisis perancangan tata letak fasilitas produksi menggunakan metode ARC (Analysis of production facility layout design using ARC method) Jurnal Manajemen 9 1 38-47 [In Indonesian]

[11] Septifani R, Imam S, BN Rodhiyah 2019 Risk mitigation strategy of rice seed supply chains using Fuzzy-FMEA and Fuzzy-AHP (Case study: PT. XYZ) IOP Conference Series: Earth and Environmental Science 230

[12] Oktavian R, Saptadi D 2017 Aplikasi spreadsheet untuk perhitungan teknik kimia sederhana (Spreadsheet application for simple chemical engineering calculations) UB Press [In Indonesia]

[13] Rosyidi M R 2018 Analisa tata letak fasilitas produksi dengan metode ARC, ARD dan AAD di PT.XYZ (Analysis of production facility layout using ARC, ARD and AAD methods at PT. XYZ) Jurnal Teknik Waktu 16 1 82-95 [In Indonesian]

[14] Pradana T D, Suharto, Apriyansyah 2018 Pengolahan limbah cair tahu untuk menurunkan kadar TSS dan BOD (Tofu liquid waste treatment to reduce TSS and BOD Levels) Jurnal Vokasi Kesehatan 4 2 56-62. [In Indonesian]

[15] Rastogi M K 2010 Production and operation management Laxmi Publication

[16] Prasetyo A 2017 Analisis tingkat kematangan rantai pasokan produk tahu (Maturity level analysis of tofu product supply chain) Indocamp Jakarta [In Indonesian]

[17] Suhendra, Setiawan B 2010 Model efisiensi mesin pengupas dan pembelah biji kedelai tipe piringan menggunakan program powersim (Efficiency model of disc-type soybean peeling and splitting machine using powersim program) Positron 2 2 25-32 [In Indonesian]

[18] Pan Z, Atungulu G G Infrared heating for food and agricultural processing CRC Press Boca Raton

[19] Wicaksana D, Poernomo H, Bisono F 2017 Rancang bangun mesin pencetak tahu takwa dan stik tahu menggunakan sistem eletropneumatik (Design of tofu and tofu stick printing machine using electropneumatik system) Proceedings Conference on Design Manufacture Engineering and its Application 1 1 212-218 [In Indonesian]
[20] Septifani R, Retno A, R N Akbar 2020 Green productivity analysis of tempeh chips production IOP Conference Series: Earth and Environmental Science 475

[21] Harahap S 2014 Penggunaan reator biofilter bermedia zeolit-arang atif dan tumbuhan air dalam pengolahan limbah cair industri tahu untuk menurunkan tingkat pencemaran lingkungan (Use of zeolite-active charcoal reator biofilter and water plants in tofu industrial liquid waste treatment to reduce environmental pollution levels) IJAS 4 2 31-41. [In Indonesian]

[22] Catrawedarma 2008 Pengaruh massa air baku terhadap performansi sistem destilasi (Effect of mass of raw water on performance of distillation system) Jurnal Ilmiah Teknik Mesin CAKRAM 2 2 117-123 [In Indonesian]

[23] Yulastri, Hazmi A, Desmiarti R 2013 Aplikasi plasma dengan metoda dielectric barrier discharge (DBD) untuk pengolahan limbah cair kelapa sawit (Application of plasma with Dielectric Barrier Discharge (DBD) method for oil palm liquid waste treatment) Jurnal Nasional Teknik Elektro 2 2 46 – 50 [In Indonesia]