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Performance Analysis of 4-Outlets Spray Aerator for Processing of Indigofera Leaves (*Indigofera Tinctoria Linn*) Becomes Natural Dye Substances

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Abstract

The commonly known natural dye substance processing for traditional clothes, such as batik and tenun (woven cloth) is fermentation. The fermentation process can specifically be continued with extraction to produce indigo paste. The process can be done mechanically, i.e. by stirring process, and chemically. In order to accelerate the production, manual process of aeration can be substituted with jet-spray aerator. The aerator prototype which has been developed is acrylic aerator tube with diameter of 240 mm and thickness of 5 mm. The tube was made 1 m long to provide with a sufficient space for indigo foam. Its bottom part is completed with spiral air hose having five small holes of 0.2, 0.4, and 0.6 mm diameter uniformly located along the height of solution in the tube. The aerator was designed for the 10 litters of fermentation solution of 1 kilogram indigofera leaves. Based on the mass of indigo paste produced, the optimum working condition of the aerator is achieved on 3.8 m/sec air velocity and supply pressure of 2 bar with duration of 60 minutes. The aeration test indicated operational characteristic was quite good, i.e. Oxygen Transfer Rate (OTR) of 3.6 kg/hour, Aeration Efficiency (AE) of 4.8 kg/kWh and factual Oxygen Transfer Efficiency (OTE) of 44%.

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INTRODUCTION

Natural dye substances for textile are obtained from extracts of plant parts, such as leaves and twigs. Indigo blue dye substance is usually obtained from extracts of indigofera plants (*Indigofera Tinctiora*). Due to its limitations, the use of natural indigo dye had undergone a shift and was almost entirely taken over by synthetic indigofera. With the consideration of environmental pollution caused by synthetic materials, nowadays the natural ingredients of indigo dyes are in demand even though its development encounters several obstacles, such as limited source of raw materials due to lack of serious cultivation of indigofera crops (Departemen Pertanian, 2009). Indigofera actually grows wild in nature and is easy to cultivate (Suheryanto, 2012) so that if the cultivation is planned carefully it will become a renewable natural resource in a sustainable manner.

The known method of extraction has actually been developed for a long time in Indonesia. One of them is the result of previous research on the extraction of indigofera leaves, which has been carried out by BPPI research team (Suwadji, et al., 1981) to obtain optimum parameters in the extraction process. The team used a diffusion type aerator with air supplied from a pressurized vessel with a pressure of 20 psig where an air stone attached on the tip of the air hose. Variables studied were the pH of the solution, the soaking time, and the ratio of the water mass to the indigofera material as well as the alkali type. In the study of the effect of fermentation time on the weight of the resulting precipitate, it was concluded that 12 hour fermentation gave the best result.

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In summary, the whole process used by Suwadji is preceded by a submersion / fermentation process aimed to decomposing glycoside indicants present in stems and leaves into glucose + indoxyl with a by-product of CO_2 gas. The fermentation results were then conditioned at pH 8.5 with the addition of saturated $Ba(OH)_2$. After that, the oxidation process takes place which is the process of supplying oxygen to a solution containing indoxyl. The oxidation solution is then allowed to settle within a span of 2 to 3 hours to separate the indigo suspension from the solution. In order to remove other dyestuffs and facilitate the filtration of the suspension a heating process is to be done to the solution up to 80°C. Suspension screening is done by using a special filter cloth. The last process is drying paste performed in the drying chamber, not exposed to direct sunlight for at least 1 week.

It should be noted that in the study, the team used 100 grams of leaves and branches of indigofera for each sample. The use of compressors for oxidation in the research process is still possible, but for commercial applications this will have an impact on equipment investment and operational costs are quite high. The results of the optimum parameters of the study, however are very useful to be applied in the same process in the industry as well as in related studies.

Besides of classic extraction method, another more advanced method has been developed. Pradiko H., et al. (2009) using an advanced oxidation process to separate indigo from indigo suspension solutions as well as to lower levels of pollution to the environment. The use of advanced technologies involving Ultraviolet and H_2O_2 compounds is excellent, fast and effective but is likely to be less applicable to the traditional crafters.

Similar research has also been conducted by Suheryanto (2012) who performed the fermentation process of 1 kg of indigofera in 10 liters of water with variation of time 6 to 66 hours with interval of 6 hours. The next process is done manually by stirring the fermentation solution with a dipper for 0.5 hours. The results showed that the most optimal soaking time was 36 to 48 hours. The subject of Suheryanto's research principally comes from areas in Central Java. This is confirmed by the conclusion of the results of his research where the plant variety that comes from Gunung Kidul produces the best paste.

Handayani and Mualimin (2013) conducted a research of natural dye extraction from indigofera or indigofera plant as synthetic dye replacement material by acidification method and dye application on *batik* cloth. Amount of 400 grams indigofera leaves are hydrolyzed for 24 hours with acid catalyst. The results of the hydrolysis reaction are separated between the filtrate and raffinate wherein the filtrate is then oxidized using an aerator for 12 hours. The results of this study more focus on the influence of the type of acid and time range of oxidation to the indigo substances produced. No further details explanation found for aeration pressure and air velocity conditions that were supplied from an air pump.

Study conducted to the traditional crafters in Bali who prepared their own coloring material showed a slightly different process. Practically, it was found that the soaking time for fermentation can reach 2-3 days (Rai Sedana, et al, 2015). Stirring of fermentation solution was done manually for 1 hour. In the study of the effect of fermentation time on the weight of the resulting sediment, it was concluded that 12 hour fermentation gave the best result.

The aeration process is the event of dissolved oxygen in the water. Its effectiveness depends on exposed area of water surface in contact with the air. The main function of aeration is to dissolve oxygen into the water to increase the dissolved oxygen content in water and release the content of gases dissolved in water. In the dye extraction process of indigofera, the oxygen molecule binds the indoxyl pigment to form indigotin (Laitonjam and Wangkheirakpam, 2011).

On the survey of making indigo dye paste made of indigofera leaves, it was found that aeration was done by manual stirring in a concrete tub with a random size. The weight composition of the indigofera plants against water has never been weighed, only estimated. Based on the observation, all indigofera baths occupy only one-third of the tub volume. Before stirring, the leaves and twigs of indigofera are treated under fermentation about 24 hours.

After 24 hours, the leaves and twigs are removed from the water and the fermented solution is cleaned from the remains of the plant. The solution is then mixed with about 200 grams of quicklime mixed with 2 liters of water and then stirred. Stirring is done manually with a wood stick about 1.5 hours. In the early stages, the froth arises

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Figure 1. *Jet-spray* aerator instalation
1: aerator container, 2: jet-spray hose, 3. compressor, 4.pressure regulator

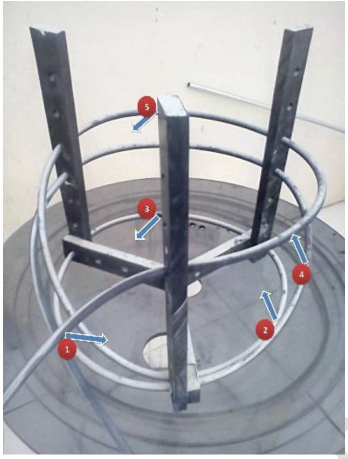

Figure 2. Pneumatic hose configuration as the *jet-spray aerator*

quickly and accumulates on the surface. The best quality dyes are obtained from the foam, but usually traditional craftsmen have never been separated from the solution. The foam is allowed to re-mix with the bottom of the solution. Stirring is stopped when the solution is saturated, unable to bind the oxygen again indicated by no longer forming the foam that appears on the surface. Stirring in large volumes in this case becomes a major obstacle when done manually because it consumes a lot of human energy.

The prior design and research on aerators is generally intended for aquaculture farming applications. There are several types of aerators that basically have the same principle, namely to seek the transfer of oxygen into the solution resulting in a reaction that binds to the dye molecule. Tucker (2006) in detail describes several types of aerators that are often used in fish ponds, where pedal-wheel aerators are the most widely used type. The components are the most easily made and have a good system efficiency. In fact, Boyd's (2008) study found that in general the pedal-wheel aerator has the highest efficiency of 3.1 lb O_2/HP-hr in average compared to those of other types.

According to Stenstrom (2010), the aerator consists of 3 types. The first type is surface aerator, using a motor that drives the propeller to spray water/fluid into the air resulting in oxygen binding. The second is a diffusion aerator, working in water/liquid by passing air through orifices or pores. The third aerator combines the two types above, such as a propeller or paddle wheel partially submerged under the liquid surface. Among the three types, the diffuser is the simplest and most efficient type of energy use (Jensen, et al., 1989).

In addition to using air pump as performed by Handayani and Mualimin (2013), a research of indigo extraction aided by aerator in the process of oxidation also done by Widiantara, 2009. Researcher uses mechanical aeration method with tri-angular model wheel-aerator (paddle wheel). Wheel diameter is made of 300 mm, which is fitted with 8 pedals running at 60 rpm and floated on the surface of the indigofera fermentation solution. The results showed that the time required for 1 aeration is 3 hours, quite long compared to the manual method. This is caused by the obstacles occurred when the formed indigo foam tend to harm the electric motor and poor stability of the aerator float causing the aerator shaky and upside down when working. Thus, a better and more effective aerator model is highly required.

Today the market interest of traditional and woven fabrics with natural coloring tends to increase significantly both domestic and outside the country (Puniari, 2003). On the other hand, artisans face limitations in the availability of dye which also impact on its expensive price. For that, need a breakthrough in terms of indigo pasta production process. The main obstacles identified are the scarcity of raw materials and the absence of proper technology and processing methods owned and skilled by artisans (Ministry of Agriculture, 2009). The research that has been done in this field is also still fundamental, not applicative that can be directly utilized by crafters widely.

The specific purpose of this research is to design a simple but appropriate aeration system to accommodate the needs of traditional crafters. For that reason, a device is designed on a laboratory scale to examine the operating point of the optimum

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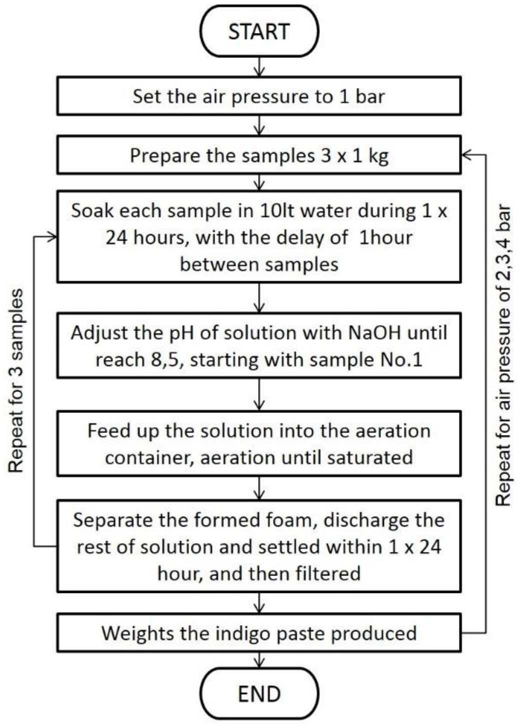

Figure 3. Experiment flowchart

aeration system for a certain amount of indigo material solution. Based on the results of the test, the prototype aerator is designed to work in accordance with the optimum conditions obtained. The expected benefit of this research is to optimize the indigo paste production process especially at the time of extraction from the base material so that it will directly affect the productivity of the crafters.

RESEARCH METHODOLOGY

This research is basically a pure experiment conducted on the developed aerator model that serves as a tool of extraction of natural indigo dye. The aerators used in this study is the results of own design, a jet type with fine spray (fine bubbles) with tubular containers, as shown in Figure 1 (Sukadana, et al., 2015a).

Aerator is designed for a capacity of 10 liters for testing 1 kg of indigofera leaves raw-material. Air is supplied from the bottom of the aerator tube using a pneumatic air tube of 4 mm in diameter. Air hose is spiral formed so that the spray hole installed along the dyed section can be distributed uniformly. The hose is retained in three positions with a triangular acrylic-based toner as shown in Figure 2. The spray hole on the pneumatic hose is positioned so that the oxygen will be mostly supplied at the bottom of the solution. Three holes are made on the bottom of the spiral path while the other two holes are made on two spirals above with the same distance distribution.

Research Variabels

In this research, the main variables to be studied are:

1. Air pressure, (P) is the measured pressure at the outlet side of the compressor tube, in psi units. This pressure is adjusted by the pressure setting available on the compressor.
2. The air velocity, (v) is the air velocity within the air intake tube into the aerator tube as measured by an anemometer, in m/s. Air velocity is regulated by using a throttle valve.
3. The indigo quantity, (m) is obtained by weighing the weight of the indigo paste deposits obtained, in grams.

Variables (1) and (2) are independent variables whereas variable (3) is a dependent variable.

Materials and Instruments

The raw material to be used consists of the leaves and twigs of indigofera plants (*Indigofera Tinctoria Linn*) originating from Goa Gong area, Bukit Jimbaran, Bali where the land height of about 300 meters above sea level. NaOH is used to adjust the pH of fermentation solution before aeration.

The main instrument utilized for the variables measurement is a vane type anemometer of Sanfix GM 8902 to measure aeration air velocity. The anemometer has a measurement range of 0.4 up to 30 m/s with a resolution of 0.01 m/s and an accuracy of ± 3%. Weighing the mass of indigo material and paste is carried out with a digital scales TIF 9010A which has a weighing range of 0.0 up to 50.0 kg with a resolution of 2 grams and an accuracy of ± 0.5%. Measurement of Dissolve Oxygen (DO) is done using DO 5510 Oxigen Meter connected to RS232 connector to PC to data logger interface SW-U801-WIN software version 120921.

Experiment Setup and the Procedure

Experiments were carried out with variations of aerated air velocities regulated using air hole diameters of 0.2, 0.4 and 0.6 mm. For each variation of air hole diameter, experiment performed with variations of air pressure of 1 to 4 bar (14 to 58 psig) with increment of 1 bar. Each data point is tested with 3 samples so that the total data taken is 36 record. For each data retrieval, it is planned to use leaves and twigs of indigofera

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Table 1. Callibration data of anemometer Sanfix GW8902

Pressure (bar)	**Measurement (m/s)** Sanfix	Krisbow	Luthron	**mean** (m/s)	**Std Error** (-)
1	1,67	1,75	1,70	1,71	0,0233
2	1,96	2,04	2,00	2,00	0,0231
3	2,50	2,62	2,52	2,55	0,0371
4	2,94	3,03	3,00	2,99	0,0265
5	3,45	3,54	3,50	3,50	0,0260

Table 2. Variation of aeration air velocity at various pressure

Spray no.	**diameter**	**Pressure (bar)** 1	2	3	4
1	0.2 mm	1.66	1.96	2.50	2.94
2	0.4 mm	2.76	3.80	4.74	5.42
3	0.6 mm	8.12	9.34	10.28	11.34

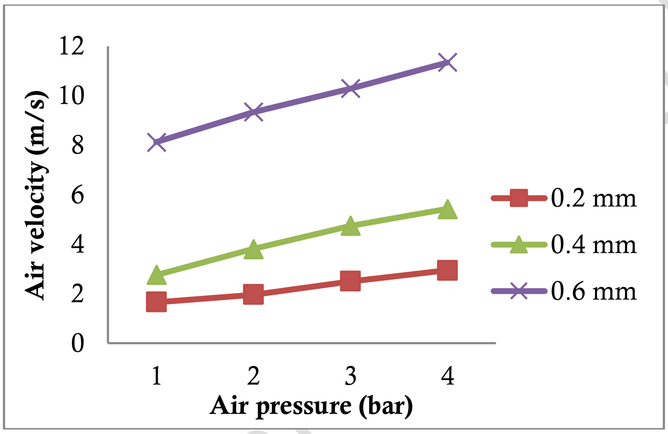

Figure 4. Effect of spray diameter change and air pressure on the air velocity

weighing of 1 kg so that the whole experiment require 10 kgs raw material of the leaves and twigs of indigofera plant.

Implementation and experimental steps are carried out as set out in the research of Suwadji et al. (1981) with optimal parameters as suggested in the results of their study. The experiment procedure is shown in Figure 3.

Data Analysis

The results of the experiments were the dependent variables of the aerated paste mass which directly showed the best results as the effect of both variations of pressure variables and aeration air velocities. Thus, the analysis is performed graphically as the comparison of results on each variation of air pressure and velocity.

RESULT AND DISCUSSION

Variation of Aeration Velocity

Air velocity is an important factor in binding of indigotin pigments based on the momentum of the resulting oxygen molecules. At the same spray hole diameter, the change in working pressure will affect the air velocity. Measurements were made with a calibrated vane anemometer using a comparator of two similar anemometers namely Krisbow KW06-564 and Luthron LM-81AM. The results are listed in Table 1 where Standard Error is calculated by Descriptive Statistic method and air velocity measurement is only performed on sprayer 1 with 0.2 mm hole. The calibration results show a small measurement error so that the anemometer used is concluded to be accurate.

The tendency of the change of the spray airflow velocity is shown in Table 2 and illustrated in Figure 4. For 0.2 mm spray holes, it appears that the increase in velocity due to the addition of air pressure from 1 to 4 bar is gradually not very high compared to the two subsequent pressure conditions. This can be caused by the narrowness of the spray hole which does not allow the significant increase of the air mass flow rate at the time when air pressure increases. For larger spray holes, there

Table 3. Variations of froth volume and mass of indigo paste on the pressure changes

Sample	Pressure (bar)	Spray1		Spray2		Spray3	
		Vf(dm^3)	m (gr)	Vf(dm^3)	m (gr)	Vf(dm^3)	m (gr)
A	1	7,36	6,0	14,73	10,0	15,71	6,0
B	2	8,84	12,7	22,09	26,7	19,63	23,3
C	3	12,27	8,0	24,54	14,3	24,54	19,7
D	4	18,65	6,7	24,54	11,3	25,53	17,3

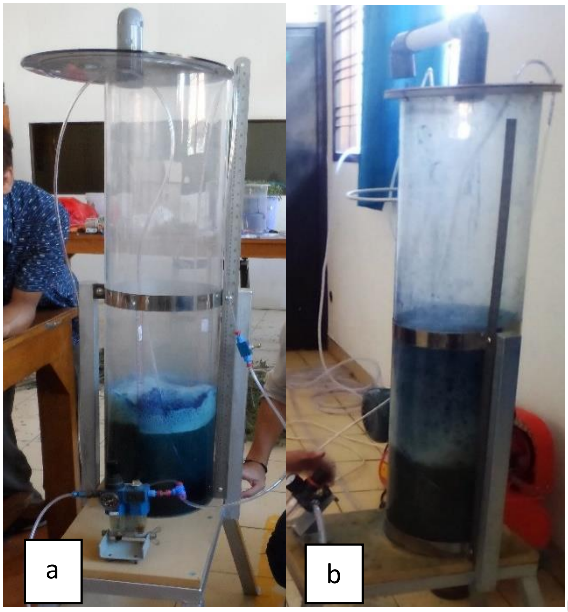

Figure 5. Comparison of aeration character at the low pressure (a) and high pressure (b) within the first 5 minutes of process respectively.

appears to be an significant increase in mass flow rate to maintain the desired air pressure, due to enlargement of the air passage.

Setting of the pressure and velocity variables in this case subsequently, indirectly affects the mass of oxygen molecules that react with indoxyl in the indigofera solution. At the same pressure, the larger the spray hole and the higher the air velocity the more oxygen mass will be generated. On the other hand, for the same amount of mass of solution, there will be an equilibrium of reaction between the oxygen molecules and the indoxyl particles that are capable to bond, so that the increase in air pressure and spray hole enlargement will have a point where the resulting indigo paste will be maximum.

Aeration Characteristic on Various Air Pressure

The process of molecular oxygen bonding with indoxyl pigments at low pressure regions i.e. 1 and 2 bars occurs relatively slow. In the first five minutes, the froth formed over the aerated solution is not too much and lasts until the end of the process (Figure 5a). At 1 and 2 bar pressure, the most formed foam occupies only up to 50 cm, half the height of the container. The process was discontinued within 60 minutes, as the observations indicated the solution had saturated, no new formation of foaming was found.

On the higher pressure, i.e. 3 and 4 bar when the aeration process begins, the formation of foam occurs relatively fast at the beginning and gradually decreases to near the end of the experiment which lasts about 40 minutes (Figure 5b). As the supply air pressure increases from the compressor, the aeration process time also decreases. This is due to the increasing momentum of the oxygen particle collision on the indigotin particles leading to acceleration of the binding process subsequently. On this higher pressure experiments the process is stopped after 40 minutes because the observations show no more additional froth formed.

Result of Indigofera Extraction

Extract of indigofera obtained from the aeration process consisted of two major parts, namely indigo particles bonded in froth and indigotin deposits at the bottom of the solution. The foam formed is then collected with a container to acquire natural drying within 1 day. Table 3 lists the volumes of froth measurements and total paste mass weights obtained at each variation of aeration pressure and the respective aeration velocity. The higher the pressure and the working speed of the aerator, the greater the volume of froth obtained, but this does not mean the higher the mass of indigo paste produced. Note that the volume of froth is calculated based on the maximum height of foam in the aeration tube which can be achieved during the aeration process.

The sample of indigo paste already obtained is shown in Figure 6. The precipitate at the bottom of the aerated liquor after being collected was filtered again and then allowed to dry naturally for 1 day indoors. The mass of the paste which determines the extraction results is a combined of

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Figure 6. Sample of indigo paste produced from aeration experiments

non-extended drying foam with the filtered precipitate.

The paste shown in Figure 6 appears to have the upper portion (frothy portion) which is lighter in blue color and the dark blue color of the sediment part. To facilitate the mass measurement, the two parts are mixed homogeneously in plastic containers.

Effect of Air Pressure and Velocity on the Mass of Indigo Paste Obtained

Figure 7 shows a bar chat of the indigo paste mass attainment at each pressure change for each spray diameter. Considering the mass obtained, the setting of 1 bar air pressure is less feasible implemented even for each spray variation owing to its very low yield. The mass of the obtained paste increases significantly from pressure of 2 bar but tends to decrease if aeration air pressure is increased continuously (Sukadana, et al 2015b).

It indicates that most results are obtained at 2 bar pressure using spray no. 2 (0.4 mm, air velocity of 3.8 m/s) with a 60 minute aeration duration. At this point obtained the mass of the most pastes of 26 gr from processing 1 kg of indigofera raw material. According to chemical reactions, the process of binding of indigotin molecules by oxygen molecules takes place following a certain mole equilibrium (Chanayat et al., 2002), so the excessive supply of oxygen volume from free air will not have a significant effect on the mass of indigo paste produced. This leads to the optimum pressure point to be considered where the most of the indigo paste is formed.

Mechanically, the process of binding of indigotin by oxygen is also influenced by the collision force (momentum) between molecules (Jensen, et al., 1989). Theoretically, the stronger the momentum the easier the bonds between indoxyl molecules break down to form indigotin molecules due to being bound to oxygen molecules. Momentum in this case is strongly influenced by mass and air velocity into the solution.

With the use of aerator under optimal conditions i.e. the no. 2 spray operated at 2 bar air pressure, the indigo paste produced from 1000 g indigofera is 20 gr in average, thus the tool yield is 2.0%. When compared with the result of similar research using different type of aerator (Chanayat, dkk.2002) that get maximum rendemen of 0.5%, then in this case can be concluded that the performance of the tool developed is reasonably good.

Aerator Performance in Supplying Oxygen

Further investigation on aerator performance can be assessed in terms of its effectiveness of producing soluble oxygen and bonded to the molecules contained in the fluid. Measurement of Dissolve Oxygen (DO) quantities

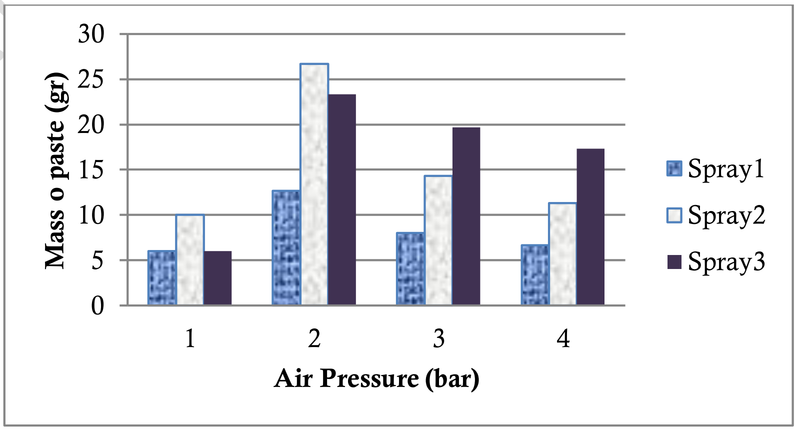

Figure 7. Graph of mass variation of indigo paste obtained at each variation of air pressure and velocity.

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Table 4. Summary of DO measurement on fresh water.

No	Pressure Bar	Temp °C	DO, average mg/L
1	1	28.2	7.45
2	2	26.9	7.77
3	3	25.4	7.92
4	4	23.9	8.23

Table 5. Summary of DO measurement on indigofera solution.

No	Pressure Bar	Temp °C	DO, average mg/L
1	1	28.0	9.06
2	2	26.3	13.15
3	3	24.8	14.26
4	4	23.9	14.51

is intended to determine the extent to which the aerator is able to provide additional Oxygen molecules into the liquid for use in indigotin binding reactions during aeration. The instrument used is DO 5510 Oxigen Meter which is connected with data interconnect through RS232 connection. Prior to measurement, calibration of the device is made by zeroing the O_2 composite pointer at the time the probe is not connected. Then the probe is connected, after 5 minutes the O_2 composition is confirmed to show a 20.8% or 20.9% oxygen content in the air. The height setting or elevation of the measurement location is adjusted to the experimental location of 100 m above sea level, which is checked using the Altimeter software (Sukadana, et al., 2016).

Measurements were first performed on the source of water to be used to soak the leaves of indigofera, under unaerated conditions. The results show a content of 6.1 mg/L. This measurement is intended to determine the oxygen content or the amount of dissolved oxygen in freshwater at first without any intervention of the aeration process. Thus, performance of the aerator being used can be known to which extent able to supply dissolved oxygen into the fluid.

Next step, DO measurements were made on 20 liters of fresh water in the main aeration container to which an air spray from the aerator is applied. Air pressure is varied from 1 to 4 bar with increment of 1 bar within 15 minutes for each pressure variation. The DO meter probe is immersed at a depth of 10 cm below the surface of the fluid.

Test results in fresh water are summarized in table 4 and presented in graphical form as shown in Figure 8.

The test results in Table 4 above show an average increase of 3% DO on every 1 bar of air pressure increase. Checking the velocity of the airflow at an increase in pressure of 1 bar indicates an increase in air velocity by an average of 30%. For the same air hose cross section, this also correlates with an increase in air mass flow rate of 30% for each increase of aeration air pressure. If it is assumed that the oxygen content in air is 30%, then the increase in oxygen content supplied is about 9% each increase of 1 bar of aeration air pressure. It can be concluded that the aerator is able to increase the oxygen solubility in fresh water by 30% of the oxygen mass supplied for each increase of 1 bar of air aeration pressure.

The DO_{FW} graph of figure 8 illustrates the DO measurements of freshwater obtained by aeration at air pressure varying from 1 to 4 bar with increment of 1 bar, as indicated by the graph P. The measurement results show that the DO increase occurs gradually, regularly and continuous increase in aeration air pressure. This corresponds to a similar type of aerator test results described by Mueller et al. (2002) where in clean fresh water the performance of the aerator is prominently influenced by the aerator immersion depth and the amount of oxygen supply mass from pressurized air sources. For the constant water depth as in this case, the oxygen mass supplied becomes the most dominant parameter. It has also been noted that the rise in pressure correlates with the increase in the oxygen masses in the aerator supplied air. So it is normal that in the process of aeration of fresh water increased of DO will be occurred though the changes is not too noticeable.

In the DO measurement of the indigofera solution, there appears to be differences in aerator performance characteristics in terms of oxygen dissolve. The results are summarized in the following table 5 and are also presented graphically in Figure 8 with a graph labeled as $DO_{indigofera}$.

Data summary in Table 5 indicates a drastic increase in DO on the pressure increase from 1 bar to 2 bar. The average DO increase is 45% of initial DO only for a 1 bar increase in air pressure. This is due to the reaction of the binding of O_2 molecules with indoxyl molecules to form indigotin (Chanayath, et al, 2002). The binding of these molecules takes place in a certain mass or mole

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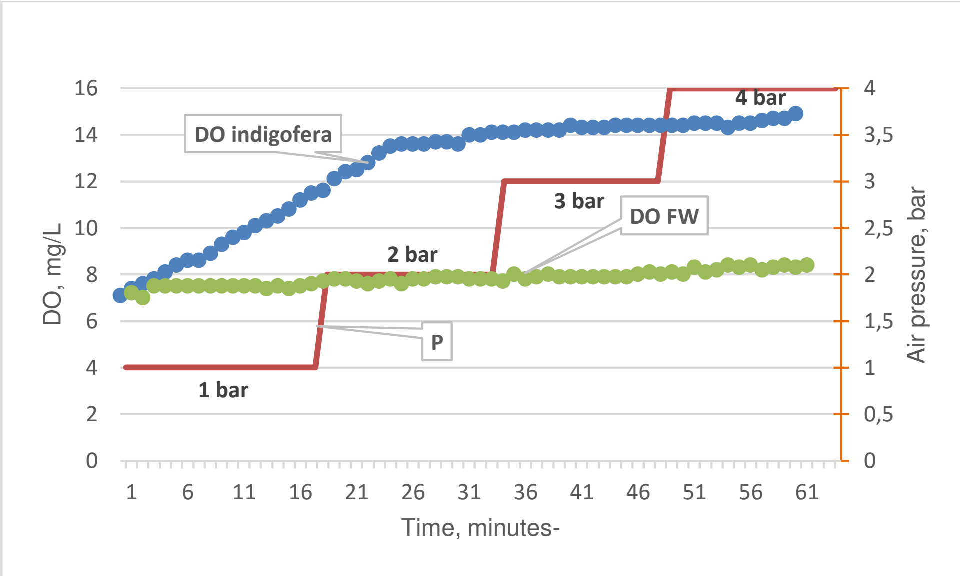

Figure 8. Comparison of DO measurement results on freshwater and indigofera solution

equilibrium thus triggering an increasing number of oxygen molecules that react to the indigofera solution that containing indican.

The trend of $DO_{indigofera}$ graph in Figure 8 which shows a significant increase in oxygen content at pressures up to 2 bar indicates the optimum pressure region for the most binding of O2-indoxyl molecules. This corresponds to the test results of the effect of increased pressure and velocity on Section 3.4 which leads to the operating pressure producing the most indigo paste is on 2 bar. If the pressure is increased steadily, there is an increase in oxygen binding, but not significantly as seen in the tendency of the $DO_{indigofera}$ curve above the pressure of 2 bar, as shown in Fig. 8. From the trend of curve gradient becomes flatter as the aeration pressure increases, it is predicted that the aerator will no longer works effectively at high pressure.

Apparently the effectiveness of aerator performance is better on the desired operating conditions, ie when handling indigofera solution that has a viscosity and of course the number of TDS (Total Dissolve Solids) higher than fresh water. The two DO charts in Fig. 8 indicate that the average DO differences occurred under operating conditions are 75% higher than that of the aerators used for handling freshwater. This is in accordance with the original purpose of design and manufacture of a special aerator tool for the application of indigo paste extraction from indigofera leaves, provided that the condition only applies to the same operating pressure region and higher than 2 bar.

In addition, to know the factual performance of its application, the operational parameters of the aerator also need to be studied further. According to Mueller, et al. (2002) main parameters of aeration process using aerators include Standard Oxygen Transfer Rate (SOTR), Standard Aeration Efficiency (SAE) and Standard Oxygen Transfer Efficiency (SOTE). The SOTR parameter shows the ability of the aerator to transfer a certain amount of oxygen mass per unit time. SAE represents the rate of oxygen transfer per unit of input power while SOTR indicates the portion of oxygen supplied to the aeration tank that is completely transferred or dissolved in the liquid. These three parameters were also measured in this study as additional subject of study.

The test results indicate that the design characteristics of Standard Oxygen Transfer Rate (SOTR) of 2 kg/hour, Standard Aeration Efficiency (SAE) of 2.07 kg/kWh and Standard Oxygen Transfer Efficiency (SOTE) of 25%. Operational characteristics lead to higher performance of 3.6 kg / hour, 4.8 kg / kWh and 44% for OTR, AE and OTE factual (Sukadana, IBP, et al., 2016), respectively. The results of this test indicate that the SAE aerator has been quite high when compared with similar aerator research results mentioned in Mueller et al. (2002) where for the type of jet spray, the highest SAE was found in the range of 1.6 to 2.2. Thus, the aerator designed in this study has

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shown a satisfactory performance. SOTE values obtained under standard conditions of only 25% indicates a less significant aeration process when performed on fresh water or clean water. SOTE of 44% on operational conditions is quite satisfactory, but still needs to be improved to close to 50 - 60% to deal with a tool that provides an efficient aeration process.

CONCLUSION

From the results of experiment that has been done, some conclusions can be taken are as follows.

The maximum yield produced by the aerator developed is 2.0% indicating the ratio of the resulting mass of indigo paste to each 1 kilogram of fermented leaves and twigs of indigofera. Testing of performance showed that the aerator optimal condition was found at aeration air velocity of 3.8 m/s and pressure of 2 bar, with aeration duration of 60 min.

In testing of operational characteristics, the developed aerator has been able to increase the oxygen solubility in freshwater by 30% of the oxygen mass supplied for increment of 1 bar aeration pressure. The average difference of DO obtained under operating conditions are 75% higher than when aerator is used for freshwater handling.

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