

FEASIBILITY STUDY ON PREPARATION OF RICE STRAW NONWOVEN COATED WITH CHITOSAN FOR REACTIVE DYE ADSORPTION

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Abstract

Rice straw is the most abundant agricultural waste material in Thailand. Therefore, this research was interested in utilizing rice straw and adding value by preparing a reactive dye bio adsorbent. The aims of this research were to prepare rice straw nonwovens by the wet-laid process, study chitosan-coated nonwovens by the dip coating method, and evaluate the reactive dye adsorption capacity of the coated nonwovens. The ratio of weight per unit area of the prepared nonwovens was controlled. The nonwovens were dipped in chitosan solutions (0.5, 1, and 1.5 wt% of chitosan) to prepare chitosan-coated nonwovens. Reactive dye adsorption capacity, chemical structure, morphology, and physical properties of the nonwovens were investigated. It was found that rice straw nonwoven coated with chitosan increased in thickness, hardness, and water resistance properties with increasing chitosan concentration. Chitosan-coated nonwoven, at 15% chitosan concentration and a contact time of 72 hours, was able to adsorb 38.40% of the reactive azo dye, C.I. Reactive Blue 194 (50 mg/L). The dye absorbency of the chitosan-coated nonwovens increased with the increase in the chitosan-coated concentration and the contact time. In addition, the chitosan-coated nonwovens could remain on rice straw cellulose nonwoven surfaces under reactive dye immersion for at least 72 hours without change. The results indicated that rice straw nonwovens coated with chitosan by the dip coating method had reactive dye adsorption abilities.

Keywords: Chitosan; Dye Adsorption; Nonwoven; Reactive Dye; Rice Straw

Introduction

Rice is an important economic crop in Thailand because it is both the staple food of the people in the country and the most exported agricultural product in the country (Center of Agricultural Information, Office of Agricultural Economics, 2019). After the

rice harvest season, there will be a lot of rice straw left over. As a result, rice straw is classified as an agricultural waste material that is abundant in Thailand. Farmers commonly use rice straw as animal feed, fertilizer, mulch, and roofing materials.

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Furthermore, it has been used as wicker, solid pressed wood as a wood substitute, and molded into various containers, but it is not yet widely used and has not been popular in the industry (Wangbon, 2008). Rice straw is a lignocellulose material that is composed of 32-47% cellulose, 19-27% hemicellulose, and 5-24% lignin (Binod *et al.*, 2010). Solvent extraction is a popular and efficient method for separating cellulose from lignocellulose materials. It is an easy process and can produce a large amount of cellulose fiber at a low cost (Pawongrat, 2015; Boonterm *et al.*, 2016; Bajpai, 2017). Johar and Ahmad (2012) isolated cellulose from rice husks with a 4% sodium hydroxide solution at 90°C for 2 hours to prepare cellulose nanocrystals from rice husks. The cellulose nanocrystals were used as a reinforcing agent in composite films made of cassava starch. Chaliewsak (2021) studied the extraction of cellulose fibers from rice straw under optimum conditions. It was extracted with a 5% sodium hydroxide solution at 90°C for 2 hours to prepare rice straw nonwoven for absorbing frying oil.

Rice straw cellulose fibers can be used in textiles, where they can be formed into nonwoven, which is a sheet of fibers that are structurally bonded together to form fabric. Rice straw fibers cannot be formed into threads and fabrics because they are short and quite rough. Therefore, rice straw fibers are suitable for textile applications as a nonwoven with more specific properties. Moreover, they can be blended with another fiber to be used as a garment (Atchariyapitak *et al.*, 2022). Yachmenev *et al.* (2002) used a needle-punched method to create a nonwoven composite of different cellulose fibers (kenaf, Jude, flax, and cotton waste) with recycled polyester and polypropylene. The resulting nonwoven had good shape stability, good tensile strength, and good bending properties. Thermal insulating properties depend on the type of cellulose fibers and the ratio of cellulose fibers to synthetic fibers. Yoon *et al.* (2013) studied the preparation of viscose rayon and carboxymethyl cellulose (CMC) nonwovens using the wet-laid method. It was found that in the synthesis, with an increasing degree of substitution, the strength of CMC nonwoven increased, but the elongation decreased. Gel blocking behavior shows the good adhesion properties of CMC nonwoven, making it suitable for use as a wound dressing material.

Reactive dye is a synthetic dye that can permanently bind to the molecules of the dyed material. It can occur by the reaction between the hydroxyl groups or other ionized groups of cellulose molecules in the base solution with the triacyl group or vinyl sulfone of the reactive dye and then being held together by covalent bonds. After the dyeing

process, the wastewater must be treated before being discharged into the environment. Dyeing wastewater treatment can be done in several ways: filtration, chemical coagulation, chemical precipitation, biological decomposition, adsorption, etc. An interesting dyeing wastewater treatment method is to use absorbents produced from agricultural waste, which can effectively absorb dye and treat wastewater from dyeing. Moreover, raw materials can be obtained easily and cheaply (Suwattanamala *et al.*, 2021; Umpuch *et al.*, 2021; Amalina *et al.*, 2022; Bilal *et al.*, 2022).

Dye-absorbing materials from rice straws have been studied in a variety of ways to improve dye absorbency. Bishnoi and Bishnoi (2016) studied the application of residual biomass of rice straw from lignocellulolytic enzyme production to remove methylene blue from dye waste instead of expensive methods. Four factors affecting color change were studied. The factors that affected the decolorization of methylene blue dye were pH, dye content, sorbent content, and temperature. It was found that all factors affected the decolorization of methylene blue dye. The optimal temperature is degrees Celsius, adsorbent dose 1%, and dye concentration of 200 mg/L. Lutfi Firdaus *et al.* (2017) studied a simple method for the removal of synthetic dyes by using adsorbents. Two types of adsorbents from biomass were studied: rice straw and palm leaf core. The adsorbents were used to adsorb naphthol AS-G dye. The effects of solution pH, amount of the adsorbents, and contact time were studied. The dye removal took 60 minutes at a pH range of 4 to 8. The highest dye adsorption capacities of activated carbon, rice straw, and palm leaf core were 55.86 mg/g and 69.44 mg/g, respectively. Carbon from biomass was a good technique for treating wastewater from the textile industry, which can remove up to 95% of dyes and also reduce other pollutants such as COD, nitrates, and phosphates. Prilinita and Oktrianto (2018) studied the use of rice straw as a biosorbent in wastewater treatment in the batik industry. Methylene blue was used in the dye adsorption test. Investigate how to improve the adsorption efficiency of rice straw with 1 mM HNO₃ and 0.75 mM NaOH, as well as the appropriate amount of adsorbent. It was found that the optimum adsorbent was 1.67 g/L and could adsorb 95.27% of 4 ppm methylene blue and 30.59% of 4 ppm of wastewater from the batik industry.

In addition to the use of agricultural waste as a dye absorbent. Chitosan, a naturally extracted substance, is also used to increase the dye absorption efficiency of the dye adsorbent. Karim *et al.* (2014) studied the preparation of cellulose nanocrystal (CNCs) porous membranes with chitosan as the matrix. CNCs were prepared by acid hydrolysis of

non-dried cellulose residue (sludge) with 63.5% sulfuric acid for 105 min at 45°C. Chitosan (75.5%DD and viscosity, 20-300 cps) was dissolved in 2 wt% acetic acid to form a chitosan solution of 1 wt%. Forming membranes using the 9:1 ratio of CNCs: chitosan solution. The thickness of membranes was 250-270 μm , a pore size of 13-10 nm, and then studied the dye adsorption. The membrane successfully removed positively charged dyes like Victoria Blue 2B, Methyl Violet 2B, and Rhodamine 6G at 98%, 84%, and 70%, respectively. Electrostatic attraction between negatively charged CNC and positively charged dye. Khan *et al.* (2016) studied preparations of chitosan/copper oxide (CS/CuO) composite spheres to use as adsorbent material. CuO nanomaterials were mixed in a chitosan solution, then the mixture was added to an NH_4OH solution to obtain composite spheres. The adsorption of indigo carmine, congo red, and methyl orange from water was studied. The composite spheres were found to have the best adsorption capacity of methyl orange and were also antibacterial by inhibiting the growth of *Pseudomonas aeruginosa*. Doondani *et al.* (2022) studied the dye adsorption preparation from cotton straw biochar coated with chitosan, using oxalic acid as a crosslinking agent. The adsorption efficiency of the azo-dye Reactive Red 21 was studied. The adsorbent could adsorb a dye of 125 mg/g at pH 5.0 within 90 minutes of contact time. Therefore, the adsorbent presented adsorption behavior as a super-sorbent material. Huo *et al.* (2021) studied the preparation of cellulose nanofiber/chitosan (CNF/CS) composite film for the effective removal of anionic dyes. The composite film had low swelling and acid-proof properties, so it can prevent degradation in the adsorption process. The increased cation charge of the CNF/CS composite film improved the adsorption capacity of anionic dyes. It could absorb up to 655.23 mg/g of methyl orange and had good recyclability. Furthermore, chitosan can also enhance the adsorption efficiency of metal ions on cellulose fiber. Ahmad *et al.* (2016) studied the coating of filter paper, a cellulose microfiber, with chitosan to enhance the surface efficiency of metal ion uptake. Then the chitosan-coated filter paper was coated with Ag nanoparticles in an AgNO_3 solution. Ag nanoparticles attached to the cellulose microfibrils were used as dip catalysts for the hydrolysis of nitrophenol (2-NP) and 4-nitrophenol (4-NP) by NaBH_4 .

This research is interested in increasing the value and utility of rice straw, which is an agricultural waste material that is readily available, cheap, and abundant in Thailand. It focuses on a simple and efficient process for rice straw fiber

preparation and nonwoven fabrication using sodium hydroxide, which is cheap and saves time and energy in the extraction method. Then, to increase the dye absorption efficiency with chitosan for use as reactive dye absorbent sheets in the community-level textile industry, which can be easily produced in the community and is inexpensive. Therefore, the aims of this study were to prepare rice straw nonwovens by the wet-laid process, study chitosan-coated nonwovens by the dip coating method, and evaluate the reactive dye adsorption capacity of the coated nonwovens. In addition, this process can be further applied to dye nonwoven or paper from wastewater. To use the excess color from dyeing fabrics in the community or industry to further develop products from nonwoven or paper. It involves the disposal of industrial waste and reduces the generation of new waste from the cellulose dyeing process as well.

Materials and Methods

Materials

The rice straw used in this study was Thai Pathumthani Fragrant Rice from Pathum Thani, Thailand. Sodium hydroxide of the analytical quality grade was purchased from Fisher Chemicals Company. Chitosan (degree of deacetylation: 91.4%, viscosity: 300 cps) was purchased from Sinudom Agriculture Products Ltd. Acetic acid was purchased from PFO FOOD Co.,Ltd. The reactive dye was C.I. Reactive Blue 194 (B194) from KCB TEXTILE Co., Ltd.

Rice Straw Nonwoven Preparation

Rice straw cellulose fibers were extracted with a sodium hydroxide solution at the optimum condition from the previous study, i.e., extracted with a 5% sodium hydroxide solution at 90°C for 2 hours (Chaliewsak, 2021). The rice straw cellulose fibers were formed into nonwovens with a controlled weight per area. The weight of nonwoven in this study was 10 grams per $8 \times 10 \text{ in}^2$ (208 grams per square meter (g/m^2 , gsm)). The nonwoven rice straw was made by a wet-laid method in which rice straw fibers (wet stage) were spread on the frame, and then water injection was used to help spread the fibers and make them uniform. After that, the obtained nonwoven was dried at 60°C for 4 hours to allow the nonwoven to dry and maintain its shape. Hydrogen bonds are formed between the cellulose fibers for the strength of rice straw nonwovens.

Chitosan coating preparation

Chitosan coating process were adapted from Kamal *et al.* (2016). Chitosan coating solutions

were prepared by dissolving various chitosan concentrations of 0.5, 1, and 1.5 wt% in an acetic acid aqueous solution (2% v/v) and then stirring for complete dissolution. Nonwovens were dipped in chitosan solutions for 1 minute at a ratio of 50 ml per 120 cm². The excess chitosan solution was wiped from the nonwoven. The coated nonwovens were dried at room temperature for 48 hours.

Percentage change in weight and thickness of the coated nonwovens

The percent change in weight and thickness of the nonwoven after chitosan coating was calculated. They were obtained from the change in value after nonwoven coating per weight or thickness before nonwoven coating in percentage, as shown in equations 1 and 2.

$$W_c = \frac{(W_1 - W_0)}{W_0} \times 100 \quad (1)$$

Where: W_c = weight change (%)
 W_0 = weight before coating (g)
 W_1 = weight after coating (g)

$$T_c = \frac{(T_1 - T_0)}{T_0} \times 100 \quad (2)$$

Where: T_c = thickness change (%)
 T_0 = thickness before coating (mm)
 T_1 = thickness after coating (mm)

Fourier Transform Infrared (FTIR) Spectroscopy

The chemical structure and functional group of the nonwovens were analyzed by Fourier transform infrared spectrometer of PERKIN ELMER Spectrum One using ATR mode in the wavenumber range of 4000-400 cm⁻¹.

Scanning Electron Microscope (SEM)

The surface morphology of the nonwovens was examined by scanning electron microscopy, using a JEOL scanning electron microscope model JSM 6400 LV. The samples were prepared by drying at 60°C for 24 hours before being gold coated by a sputter-coater. An electric potential of 5 kV and a spot size of 20 were used for analysis. For this research, magnifications of 100x and 500x were used.

Water contact angle (WCA) analysis

The surface wettability of the chitosan-coated nonwovens was examined by water contact angle (WCA) analysis. The WCA analysis was applied to follow ASTM D 7334 - 08 surface wettability of coatings, substrates, and pigments by advancing contact angle measurement. The water was dropped

onto the surface of the specimens at a distance of 3 mm. The drop was captured by the video device, and the WCA value was measured by the Image J. program.

Dye adsorption study

The reactive dye used in this research was C.I. Reactive Blue 194 (B194). The reactive dyed water was prepared by preparing a stock solution of B194 at a concentration of 1,000 mg/L. After that, the stock solution was diluted with distilled water to achieve a concentration of 50 mg/L.

The test specimens were prepared with a dimension of 1×3.5 cm² and were immersed in 100 ml of the dyed water (50 mg/L) (Kamal *et al.*, 2016) at contact times of 0.25, 0.5, 1, 1.5, 2, 12, 24, 48, and 72 hours. The dyed water of all contact times was collected and analyzed for dye adsorption capacity using a UV-Vis spectrophotometer. After that, the specimens were collected and air-dried to study coating stability.

UV-Vis spectrophotometry

The light absorbance of the dye after dye absorbance testing was analyzed by a UV-Vis spectrophotometer, METTLER TOLEDO. The absorption wavelength for the reactive dye in this study was 590 nm (Manikandan *et al.*, 2017).

Results and Discussion

Physical characteristics of the nonwovens

Physical characteristics of rice straw nonwoven were shown in Table 1. The problem of losing large amounts of weight, decreased strength, and low homogeneity of the wet-laid, prepared nonwoven in its fiber-dry state because the dry fibers were dispersed in water before forming. There is a loss of strength from breaking bonds and forming new ones (Chaliwisa, 2021). In this research, nonwovens were prepared by a wet-laid method in the wet fiber state. The ratio of fiber weight to the area of nonwoven was controlled by calculating the weight per standard forming frame size, weight per given area, and the fiber weight loss was less than that of the dry fiber preparation. The prepared nonwoven weighs 10.39% (229.98±27.31 gsm) more than the specified weight (208 gsm) with a thickness of 1.68±0.44 mm and fiber diameter of 6.43±1.29 µm.

Table 1. The physical characteristics of rice straw nonwoven

Controlled (gsm)	Prepared (gsm)	Thickness (mm)
208	229.98±27.31	1.68±0.44

The prepared rice straw nonwoven was depicted in Figure 1 by its physical structure (Figure 1(a)) and morphologies (Figure 1(b)). The prepared nonwoven had a disordered distribution of cellulose fibers. The rice straw nonwoven was formed by the wet-laid method, in which the wet fiber was spread by hand on the sieve to form the nonwoven. High-pressure water was used to help spread the fibers evenly. There is no direction of fiber orientation in the forming of nonwoven like the use of machines, which can determine the orientation of the fibers to be balanced in the transverse direction (TD) and machine direction (MD). Furthermore, the obtained rice straw nonwovens have a higher fiber density as the fiber weight per area increases compared with other ratios of fiber weight to area of nonwovens. It can be observed that the space between the fibers decreases with increasing fiber content because the air permeability of the nonwoven decreases compared with other ratios of fiber weight to area of nonwovens, which is consistent with my previous study (Chaliewsak, 2021).

Percentage change in weight and thickness of coated nonwovens were shown in Table 2. When chitosan coating is applied to nonwovens, the nonwovens gain weight as the concentration of chitosan coating increases. Due to the increase in chitosan concentration, the viscosity of the coating increased. The coating can adhere better to the nonwoven surface. Therefore, the weight of the nonwoven increased with the concentration and viscosity of the chitosan coating. The thickness of the nonwoven increased with the concentration of the chitosan coating as well as the effect of nonwoven weight. This results in a thicker chitosan film layer on the nonwoven surface. Coating the nonwoven with chitosan makes the nonwoven stronger. The surface is shiny and has increased hydrophobic properties. In addition, the nonwoven coating process controlled the dipping time because of the acid-resistant properties of cellulose fibers. The nonwoven was degraded when immersed in a highly acidic chitosan solution. Therefore, the thickness of the nonwoven was controlled by the process and the time of dipping the nonwoven in the coating solution.

Morphologies of the surface and the cross-section of nonwovens are shown in Table 3. It was discovered that increasing the concentration of chitosan in the coating allowed it to coat the nonwoven's surface more thoroughly as the viscosity of the solution increases. This allows for greater adhesion to the cellulose fibers in the nonwoven structure. As the chitosan concentration increased, so did the thickness of the coating layer. The dip coating method for chitosan coating on nonwovens allows the chitosan coating to be applied

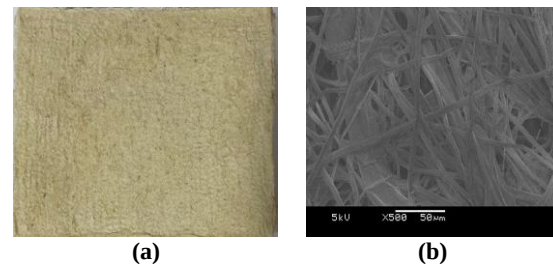


Figure 1. The prepared rice straw nonwoven (a) physical structure and (b) morphologies with SEM images (500x)

Table 2. The percentage change in weight and thickness of coated nonwovens

sample	weight change (%)	Thickness change (%)
CS 0.5%	2.43±1.21	17.53±1.17
CS 1%	8.48±1.23	21.63±1.39
CS 1.5%	15.57±0.69	25.24±1.10

Table 3. The morphologies of the surface and the cross-section of nonwovens with SEM images (50x and 100x)

Surface (100x)	Cross section (50x)
Nonwoven	Nonwoven
CS 0.5%	CS 0.5%
CS 1%	CS 1%
CS 1.5%	CS 1.5%

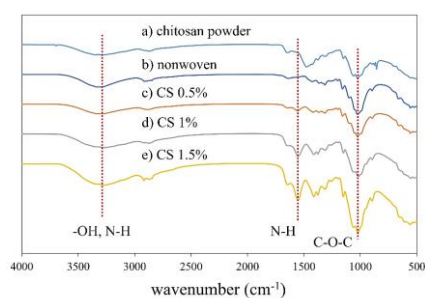


Figure 2. The FTIR spectra of chitosan powder, uncoated nonwoven and nonwovens coated with chitosan 0.5, 1, and 1.5%

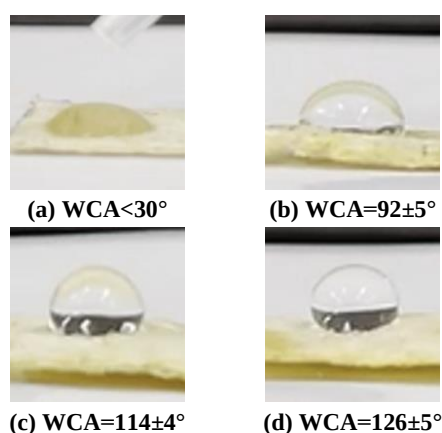


Figure 3. The water contact angle of (a) uncoated nonwoven and nonwovens coated with chitosan (b) 0.5%, (c) 1%, and (d) 1.5%

only on the nonwoven's surface. There is no penetration of the chitosan coating into the nonwoven interior. The dip-coating method of the chitosan coating is therefore suitable for coating the outer surface of the nonwoven. There is very little penetration of the coating into the nonwoven. Therefore, the nonwoven retains its unique characteristics and does not become a high-strength composite material.

FTIR spectra of nonwovens coated with chitosan

The FTIR spectra of chitosan powder, uncoated nonwoven and nonwovens coated with chitosan were shown in Figure 2. It was found that chitosan-coated nonwovens showed chitosan chemical characteristics as N-H (1567 cm^{-1}), -OH, N-H ($3000\text{--}3500\text{ cm}^{-1}$) and chitosan saccharide structure (800 cm^{-1} , 1200 cm^{-1}). With an increase in the concentration of the chitosan coating, the peak intensity of the functional groups characterizing the chemistry of chitosan increases accordingly. In addition, the ether C-O-C group ($1020\text{--}1035\text{ cm}^{-1}$) had an increasing peak intensity with increasing

concentrations of chitosan coating (El-Hefian *et al.*, 2012a and Ma *et al.*, 2021). While the uncoated and chitosan-coated nonwovens continued to exhibit the peak intensity of functional groups characterizing the chemistry of cellulose, i.e. -OH ($3400\text{--}3200\text{ cm}^{-1}$), -CH_n ($2970\text{--}2860\text{ cm}^{-1}$), C-H ($1431\text{--}1315\text{ cm}^{-1}$), C-O-C (1160 cm^{-1}) and C-O (1060 cm^{-1}) (Yang *et al.*, 2007; He *et al.*, 2008). It shows that the chitosan coating with different concentrations of chitosan by the dip coating method can show the chemical characteristics of chitosan at different concentrations and that the chitosan coating with different concentrations by this method did not cause a change in the chemical structure of rice straw cellulose.

Effect of chitosan concentration on water contact angle of the nonwovens

Water contact angle of the nonwovens was shown in Figure 3. The water-resistance ability of chitosan-coated nonwovens was classified as a material with hydrophobic properties ($\text{WCA } 150^\circ > \theta \geq 90^\circ$) based on the water resistance test of chitosan-coated nonwovens measured by WCA. The uncoated nonwoven was classified as super hydrophilic material ($\text{WCA } \theta < 30^\circ$) (Peethan *et al.*, 2019 and Kaewsaneha *et al.*, 2022). The hydrophobic properties of the coated nonwoven surface increased with increasing chitosan concentration, consistent with the low water solubility of chitosan, which can be soluble in water only in acidic solutions at $\text{pH} < 6.5$. Because the structure of chitosan has amino groups (-NH_2) and hydroxyl groups (-OH), when dissolved in an acid solution, the amino groups receive protons (H^+) and form a positive charge (-NH_3^+). Therefore, chitosan can dissolve in an acid solution. While water is a very weak electrolyte, it can donate very few protons. So chitosan is less soluble in water. (Philippova *et al.*, 2012; El-Hefian *et al.*, 2012b; Aranaz *et al.*, 2021).

Effect of chitosan concentration on dye absorption property

The reactive dye adsorption capacity of the nonwovens coated with different concentrations of chitosan coatings was shown in Figure 4. The dye adsorption capacity at different contact times was shown in Figure 4(a). It was found that the absorbance at 590 nm of the colored water decreased when it was adsorbed on nonwovens coated with a higher concentration of chitosan at the same contact time. Because the positive charge of chitosan on the surface of the nonwoven binds to the negative charge of the reactive dye as the amount of chitosan on the surface increases, this makes the reactive dye more absorbent Huo *et al.* (2021).

Therefore, the dyed water had a lighter color. When testing the absorbance of the colored water, the values decreased.

In addition, the absorbance value at 590 nm of the colored water decreased when adsorbed with nonwoven coated with the same concentration of chitosan. However, the nonwovens had contact with the dyed water for a longer period. Because the contact time of the nonwovens with the dyed water increases, the positive charge of chitosan on the surface of the nonwoven fabric increases the binding time of the negative charge of the reactive dye. This makes the reactive dye more absorbent. As a result, colored water appears lighter. When testing the absorbance of the dyed water, the values decreased.

The dye removal capacity at different contact times is shown in Figure 4(b) and %dye removal of uncoated nonwoven and nonwovens coated with chitosan 0.5, 1, and 1.5% at contact times 0-72 hours were shown in Table 4. At 72 hours of contact time, 1.5% chitosan-coated nonwoven had the highest dye absorption percentage, 38.40%, followed by 1%, 0.5% chitosan-coated nonwoven, and uncoated nonwoven (34.24%, 27.97%, and 10.99%, respectively). The dye absorption percentage was calculated from the absorbance value. It was found that the dye adsorption capacity of nonwovens depends on the concentration of chitosan and the time of contact with dyed water.

In addition, uncoated nonwovens were slightly able to absorb dyes, with the reactive dye adsorption capacity of nonwovens tending to increase with contact time, and the fiber weight per area of nonwoven increasing. Because the dye penetrates into the nonwoven by using the gaps between the nonwoven fibers through the capillary effect, this is consistent with the research of Xu *et al.* (2015). Surface treatment by plasma grooving and silica nanoparticles can self-absorb water and oil with the capillary force generated by the microgaps and microgrooves on the double helix rope and the diffusion of dye water into the nonwoven. In addition, the reactive dye in the dye water and excess dye in the synthetic wastewater will be chemically adsorbed to the nonwoven cellulose.

The comparison of the physical characteristics of the coated nonwovens after absorption of dye for 0, 24, and 72 hours is shown in Table 5. It was found that the colors of nonwovens coated with high concentrations of chitosan had more reactive staining than nonwovens coated with low concentrations of chitosan at the same contact time and the colors of the nonwoven coated with the same concentration of chitosan at longer contact times

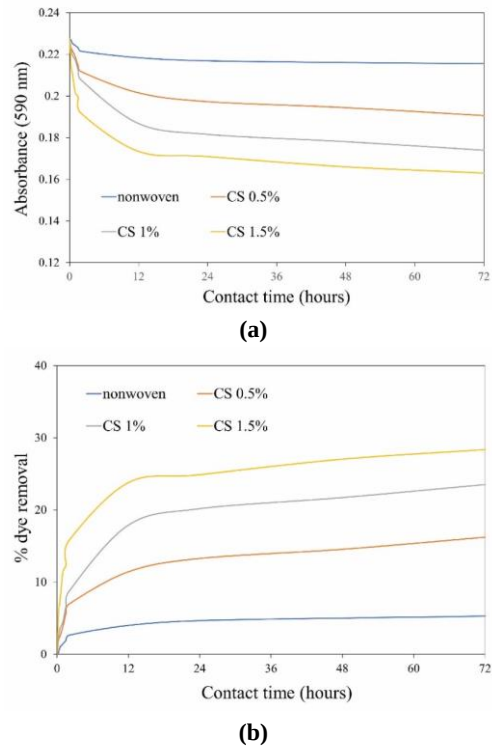


Figure 4. The reactive dye adsorption capacity of the nonwovens a) light absorbance of the dye after dye adsorption study and b) %dye removal of uncoated nonwoven and nonwovens coated with chitosan 0.5, 1, and 1.5% at contact time 0-72 hours

Table 4. The % dye removal of uncoated nonwoven and nonwovens coated with chitosan 0.5, 1, and 1.5% at contact time 0-72 hours

Contact time (hours)	% dye removal			
	Non woven	CS 0.5%	CS 1%	CS 1.5%
0.25	0.26	0.94	2.34	3.85
0.5	1.25	1.81	4.95	5.67
1	1.81	4.12	7.22	8.73
1.5	2.42	6.12	11.79	12.92
2	3.21	7.90	13.95	16.59
12	6.12	16.29	25.62	28.04
24	8.96	21.66	29.86	33.52
48	9.64	26.53	32.69	35.53
72	10.99	27.97	34.24	38.40

had more reactive pigmentation at shorter contact times. It indicates that the color adhesion of the nonwoven depends on the concentration of the chitosan coating and the time of contact with the dye. It can also be used to dye nonwoven fabrics or paper with wastewater.

Table 5. The comparison of the nonwovens after absorption of dye for 0, 24 and 72 hours

0 hrs	24 hrs	72hrs
nonwoven	nonwoven	nonwoven
CS 0.5%	CS 0.5%	CS 0.5%
CS 1%	CS 1%	CS 1%
CS 1.5%	CS 1.5%	CS 1.5%

Table 6. The morphologies of the surface of nonwovens after absorption of dye for 24 hours with SEM images (100x and 500x)

100x	500x
nonwoven	nonwoven
CS 0.5%	CS 0.5%
CS 1%	CS 1%
CS 1.5%	CS 1.5%

Stability of chitosan coating nonwovens for dye absorption

Morphologies of the surface of nonwovens after absorption of dye for 24 hours were shown in Table 6. It was found that after 24 hours of immersion in reactive dyed water, the chitosan coating remained on the nonwoven surface. In particular, the chitosan coating at a concentration of 1.5% still exhibited the same coating characteristics on the nonwoven surface as before immersion in paint water. Table 4 shows that the nonwoven coated with chitosan coating remained unchanged after immersion be strong with no swelling of the fibers. Fiber swelling occurs in nonwoven fabrics that do not have a chitosan coating, and there is deformation. This indicates that nonwovens coated with chitosan have a durability of at least 72 hours.

Conclusions

The chitosan coating increased the thickness and hardness of the rice straw cellulose nonwovens, and improved their water-repellent properties from superhydrophilic to hydrophobic. The dip coating method was suitable for the outer coating of nonwovens. The chitosan solution could not penetrate inside the nonwovens. The nonwoven coated with 15% chitosan and a contact time of 72 hours showed the best reactive dye adsorption behavior with a dye removal value of 38.40%. As the chitosan concentration increased, the positive charge on the nonwoven surface increased. They were better able to absorb ionic dyes, and a longer contact time gave the dye more time to absorb on the nonwoven. Therefore, the factors affecting the dye adsorption efficiency in this research were the amount of chitosan on the nonwoven surface and the contact time. In addition, the chitosan coating could remain on the nonwoven in the dye testing solution for at least 72 hours without any change.

According to the different staining effects of the nonwoven coated with different concentrations of chitosan, dye wastewater can also be used to dye nonwoven or paper. The excess color from fabric dyeing will be used to further create products from nonwoven or paper. It involves the disposal of industrial waste and reduces the generation of new waste from the cellulose dyeing process as well.

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