PULP AND PAPER FROM OIL PALM FRONDS: WAVELET NEURAL NETWORKS MODELING OF SODA-ETHANOL PULPING

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Wavelet neural networks (WNNs) were used to investigate the influence of operational variables in the soda-ethanol pulping of oil palm fronds (*viz.* NaOH concentration (10-30%), ethanol concentration (15-75%), cooking temperature (150-190 ºC), and time (60-180 min)) on the resulting pulp and paper properties (*viz.* screened yield, kappa number, tensile index, and tear index). Performance assessments demonstrated the predictive capability of WNNs, in that the experimental results of the dependent variables with error less than 6% were reproduced, while satisfactory R-squared values were obtained. It thus corroborated the good fit of the WNNs model for simulating the soda-ethanol pulping process for oil palm fronds.

Keywords: Oil palm fronds; Optimization; Pulp and paper; Soda-ethanol; Wavelet neural networks

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INTRODUCTION

The conversion of wood into pulp by mechanical, chemical, or a combination of both treatments is an essential process in the paper industry. Traditionally, wood chips are separated into individual cellulose fibers, a process called pulping, which removes the lignin-hemicelluloses protective shield and produces a fibrous substance - the wood pulp. However, there are two major issues in the paper industry that are of environmental concern. Firstly, the typical kraft pulping or sulfite process emits hazardous pollutants such as particulate matter, sulfur compounds, and nitrogen oxides during the production process, in addition to creating bad odour problems (World Bank Group 1998). Secondly, there is growing awareness of substituting wood with non-wood fibers in papermaking due to the dwindling of forest resources at an alarming rate. In response to circumventing these problems, a less polluting pulping process with recovered reagents such as organic solvents can be exploited. Meanwhile, the utilization of the alternative non-wood fiber sources, for instance, cotton stalks, leucaena, tagasaste, *Paulownia* trihybrid, canola straw, bagasse, and vine stems, in complementing the conventional wood fibers are reported (Hosseinpour *et al.* 2010; Lei *et al.* 2010; Mansouri *et al.* 2012; Rodriguez *et al.* 2008a; Zamudio *et al.* 2011) .

In the present work, the pulping of oil palm fronds by using the soda-ethanol method was studied. Ethanol, a low-boiling medium, was chosen as the pulping liquor due to its salient advantages of its environmentally friendly nature, greater ease of detoxification of the pulping effluents, less consumption of water, energy, and chemicals as compared with the traditional processes, and its versatility for all types of wood and non-wood fibre sources (Rodriguez *et al.* 2008b). Use of the oil palm fronds as nonwoody biomass feedstock for papermaking is in great favor, particularly for Malaysia, the world's second largest producer of palm oil. It is not surprisingly that Malaysia alone generated more than 77 million tonnes of biomass in 2009, where 44.84 million tonnes (dry weight basis) was found to be palm fronds (Ng *et al.* 2011). In addition to its relative abundance, cost benefits, and accessibility from the agricultural residues, the fronds fiber with an average length of 1.59 mm is longer than most of the fibrous components of the oil palm, including trunk, fruit bunch, and mesocarp, in comparison to most of the hardwood fibers (Wan Rosli *et al.* 2004). Thus, on account of its massive availability and characteristics of possessing high tensile and tear strength, the suitability and viability of fronds fiber as alternative lignocellulosic raw materials for the pulp and paper industry are promising.

With respect to maximizing the throughput and quality while simultaneously minimizing the energy and chemical consumptions, gaining insight on the optimum operating conditions for pulping processes is essentially crucial. Developing a reliable mechanistic or empirical model in determining the underlying relationship between the governing operating conditions and the dependent variables is required, which is an especially challenging task when the number of pulping experiments is usually limited. With this intention, an alternative solution by way of artificial neural networks, specifically, the wavelet neural networks (WNNs), is proposed. WNNs derive a simple empirical model for complex processes, even if the priori information on the exact mathematical description on how the process responses functionally depend on inputs is unknown beforehand. Their superiority in alleviating the inefficiencies of the popular multilayer perceptrons, which are subject to slow learning and local minima problems, has been asserted (Zhang and Benveniste 1992). Their practicability in solving a great deal of real-world situations with complex physical process has been demonstrated (Zainuddin *et al.* 2009, 2011; Zainuddin and Ong 2011a,b).

Inspired by its excellent performance at the heart of a variety of scientific and engineering problems, the attempt in exploiting the predictive capability of WNNs to ascertain those determining operational conditions that act upon the variation of pulp and paper qualities has been put forward in this study. The two main focuses are: (i) To examine the influence of the operational variables of the pulping of oil palm fronds with alkaline soda-ethanol (*viz.* cooking temperature and time, ethanol (EtOH) and sodium hydroxide (NaOH) concentration) on properties of the resulting pulps (*viz.* screened yield and kappa number) and paper sheets (tensile index and tear index) based on WNNs, and (ii) to obtain the optimum pulping conditions for the soda-ethanol pulping process.

EXPERIMENTAL

Materials

Samples of the processed oil palm fronds for this research purpose were kindly supplied by a local palm oil mill in Perak, Malaysia. The palm fronds were chopped by means of a cleaver into small sizes of about 4 cm (length) x 2 cm (width) with variable thickness, 5 to 10 mm. Subsequently, the chopped chips were washed and air dried to an average moisture content of 12.5% and stored in polyethylene bags before the pulping process.

Pulping and Sheet Making

All pulping experiments were carried out in a 4-liter stationary stainless steel digester (NAC Autoclave Co. Ltd., Japan) fitted with a computer-controller thermo-couple. The four pulping variables investigated were: Sodium hydroxide (NaOH), *A*; Ethanol (EtOH), *Et*; and temperature, *T*, and time, *t*, with variable ranges of 10 to 30%, 15 to 75%, 150 to 190ºC, and 60 to 180 min, respectively. The amount of NaOH was expressed as a percentage based on oven dried fiber, whilst ethanol was given as the volume percentage (v/v) with respect to cooking liquor. The conditions of liquor-to-material ratio and time to maximum temperature were maintained at 6:1 and 90 min, respectively, throughout the experiment. At the completion of the cook, the pulps were mechanically disintegrated in a three-bladed mixer for 1 min at a pulp consistency of 2% and subsequently screened on a flat-plate screen with 0.15 mm slits. Screened yield were measured on an oven-dry weight basis. The properties of the pulps and 60 g/m^2 handsheets were characterized according to the following TAPPI methods: kappa number, TAPPI T 236 om-85; freeness, T 227 om-94; tensile index, T 494 om-01; and tear index, T 414 om-98. The handsheets were conditioned for at least 24 hours, at 23 ºC, and 50% RH prior to testing.

Experimental Design

The two-level full factorial design which consisted of 27 experiments was used to determine the effects of four pulping variables (*viz.* NaOH concentration, EtOH concentration, temperature, and time) on the pulp and paper properties. The total number of experiments performed was determined by the expression 2^k+2k+n_0, where the terms 2^k denotes the cubic points, $2k$ is the axial points, n_0 represents the number of repetition on the central points, and k is the number of pulping variables.

Wavelet Neural Networks Modeling

WNNs, as one of the facets of the neural networks research field, had been introduced by Zhang and Benveniste, with the eye-catching uniqueness of preserving the universal approximator property and achieving the same quality of approximation with a network of reduced size (Zhang and Benveniste 1992). WNNs are a three-layered neural networks model, with one input layer, one hidden layer, and one output layer. They differ from the other neural networks models in their adoption of wavelet functions in the network architecture, which eventually leads to a more compact network topology and a faster learning rate than others. Variability in pulp and paper properties is defined as a function of the operational variables of the pulping process by WNNs, where the dependent response variables are formulated by WNNs as,

$$Y_e = \sum_{i=1}^{m} w_i \, |a_i|^{-1/2} \, \psi\left(\frac{x - b_i}{a_i}\right) \tag{1}$$

where Y_e is the predicted value for the dependent response variables (*viz.* screened yield, kappa number, tensile index, and tear index), m is the number of hidden nodes in the hidden layer of WNNs, ψ is the wavelet activation function, x represents the input values of NaOH concentration (A), ethanol concentration (Et), temperature (T), and time (t), whereas a_i and b_i denote the dilation and translation vectors, respectively. w_i is the connecting weight vectors between the hidden layer and the output layer, which will be optimized during the learning phase, in which the trained knowledge of the developed model is stored.

Determination of WNNs network topology, such as choice of activation function, type of learning algorithm, number of hidden nodes, and initialization for dilation and translation vectors, has to be done judiciously, as the prediction accuracy may be drastically jeopardized when WNNs are improperly designed. To pursue this issue, WNNs with four input nodes and one output node, a pseudo-inverse learning algorithm and a random initialization approach were configured in this work. The number of hidden nodes, *m*, was chosen according to the number of training samples, while the technique of early stopping was adopted to prevent over-fitting. Normalization of the input variables, *i.e*., the independent variables and the targeted response variables (the dependent variables) was carried out for comparability purpose. Since only a small number of pulping experiments was performed, the technique of leave-one-out cross validation was employed in order to yield an unbiased estimator for the WNNs generalization capability. For brevity, further discussion of the network architecture and learning strategy of the WNNs is provided elsewhere (Zainuddin and Ong 2011a,b). The parameters in Equation (1) and training of WNNs were simulated using the Neural Network (NNET) toolbox in the Matlab version R2010a software package (MathWorks 2010a).

RESULTS AND DISCUSSION

Table 1 shows the operating conditions and the obtained experimental values of the pulp and paper properties from the 27 experimental trials. The operating conditions were determined based on the two-level factorial design, where the operational variables were in the ranges of: 10 to 30% (NaOH), 15 to 75% (EtOH), 150 to 190 ºC (temperature), and 60 to 180 min (cooking time). The experimental data of Table 1 were used in conjunction with the NNET toolbox in Matlab version R2010a in order to develop the WNNs forecasting model, in which each dependent response variable was characterized by the summation of the weighted contribution of each independent pulping variable through the WNNs. The modeling for the pulping process was performed separately for each dependent variable. Initially, the pulping variables in Table 1 were fed into the WNNs with the screened yield as the predefined target output. Once trained, the developed forecasting model was stored as a single set of weights generated during the learning phase. The established model then can be used to predict the variations in the screened yield as a function of the pulping variables. Subsequently, by using the same input variables, similar simulations were carried out to predict the changes in the properties of kappa number, tensile index, and tear index.

Table 2 presents the actual obtained experimental values for the pulp and paper properties and the predicted values given by the established WNNs models using Equation (1). As shown in this table, the feasibility of the WNNs in modeling the multivariate heterogeneous pulping process and their reactions to different experimental conditions was promising, from which the successful nonlinear mapping between the dependent and independent variables which established by the WNNs was confirmed. It can be observed that the response values predicted by the WNNs only departed marginally from their experimental counterparts, specifically, by less than 4% for screened yield, less than 5% for kappa number, less than 6% for tensile index and less than 3% for tear index, which corroborated the accurate estimations of the WNNs.

Table 1. Pulping Variables and Experimental Values of the Pulp and Paper Properties of Oil Palm Fronds

No	Pulping Variables				Experimental Values for the Pulp and Paper Qualities Response			
	NaOH (%)	EtOH (%)	Temperature (ºC)	Time (min)	Screened Yield (%)	Kappa Number	Tensile Index (N m/g)	Tear Index (mN m^2/g)
1	10	45	170	120	28.25	102.0	28.59	2.83
2	20	45	170	120	28.12	32.6	62.99	4.13
3	25	60	180	90	24.51	23.3	46.5	3.84
4	25	60	160	150	22.52	24.9	64.74	4.18
5	15	30	180	150	32.92	59.6	46.06	3.55
6	15	60	180	90	31.71	57.5	44.88	3.38
7	30	45	170	120	25.91	25.4	51.26	3.64
8	20	45	170	180	29.45	30.9	51.29	3.95
9	25	30	180	150	24.07	25.4	56.88	3.56
10	20	45	170	60	28.75	39.5	56.12	4.13
11	15	60	160	150	28.98	58.7	39.52	3.35
12	15	30	160	150	31.50	72.7	33.53	2.96
13	25	30	180	90	25.60	28.1	60.59	4.65
14	20	45	170	120	29.54	31.7	57.1	4.23
15	25	30	160	90	25.65	34.6	59.82	4.45
16	15	60	180	150	32.10	53.0	49.6	3.56
17	15	30	160	90	29.03	75.1	33.14	3.01
18	20	45	190	120	26.84	31.6	59.1	4.23
19	25	60	160	90	25.99	28.5	47.06	3.73
20	15	60	160	90	30.54	62.5	35.28	3.06
21	25	60	180	150	23.24	20.2	48.4	3.45
22	20	15	170	120	26.57	47.0	54.27	3.65
23	20	75	170	120	28.01	32.0	50.52	3.5
24	20	45	170	120	27.86	32.5	58.4	3.95
25	20	45	150	120	27.15	48.8	50.32	3.9
26	25	30	160	150	25.67	31.0	64.69	4.68
27	15	30	180	90	31.66	63.3	41.83	3.56

Vanishingly small values of mean squared error (MSE) were obtained (from 1.1392e-04 to 0.0964), and for the most part, the reactions of each dependent variables to various impacts were described precisely.

The superiority of WNNs was presumably attributed to the following: (a) the local support wavelet activation functions in the hidden layer pave the way for faster convergence and better generalization performance of WNNs; (b) data normalization ensures that all variables are in the same order of magnitude for a fair comparison so as they are not more significant than in reality; (c) the leave-one-out method is particularly vital due to data scarcity, as it allows sufficient training for WNNs; and (d) the ability of the WNNs to change its network structure adaptively based on external and internal information that flows through the network during the learning phase.

Table 2. Values of the Dependent Variables as Predicted by the Wavelet Neural Networks

No	Dependent Variables							
	Screened Yield (%)		Kappa Number		Tensile Index (N m/g)		Tear Index (mN m^2/g)	
	Exp.	Pred.	Exp.	Pred.	Exp.	Pred.	Exp.	Pred.
1	28.25	28.25	102.0	102.0	28.59	28.59	2.83	2.83
2	28.12	28.12	32.6	32.6	62.99	62.99	4.13	4.13
3	24.51	24.51	23.3	23.3	46.5	46.50	3.84	3.84
4	22.52	22.52	24.9	24.9	64.74	64.74	4.18	4.18
5	32.92	32.92	59.6	59.6	46.06	46.06	3.55	3.55
6	31.71	31.71	57.5	57.5	44.88	44.88	3.38	3.38
7	25.91	26.69(3.01)	25.4	25.4	51.26	51.26	3.64	3.56(2.20)
8	29.45	29.45	30.9	30.9	51.29	51.29	3.95	3.95
9	24.07	24.07	25.4	25.4	56.88	56.88	3.56	3.56
10	28.75	28.94(0.66)	39.5	39.5	56.12	56.12	4.13	4.13
11	28.98	28.98	58.7	58.7	39.52	41.76(5.67)	3.35	3.35
12	31.50	31.50	72.7	72.7	33.53	33.53	2.96	2.96
13	25.60	25.60	28.1	28.1	60.59	60.59	4.65	4.65
14	29.54	29.54	31.7	32.74(3.28)	57.1	57.1	4.23	4.23
15	25.65	25.65	34.6	32.91(4.88)	59.82	59.82	4.45	4.45
16	32.10	32.10	53.0	53.0	49.6	49.6	3.56	3.60(1.12)
17	29.03	29.03	75.1	75.1	33.14	33.14	3.01	3.01
18	26.84	26.84	31.6	31.6	59.1	59.1	4.23	4.23
19	25.99	25.99	28.5	28.5	47.06	47.06	3.73	3.73
20	30.54	30.54	62.5	62.5	35.28	35.28	3.06	3.06
21	23.24	23.24	20.2	20.2	48.4	48.4	3.45	3.45
22	26.57	26.57	47.0	47.0	54.27	54.27	3.65	3.65
23	28.01	28.01	32.0	32.0	50.52	50.52	3.5	3.5
24	27.86	27.86	32.5	32.5	58.4	58.4	3.95	3.95
25	27.15	27.15	48.8	48.8	50.32	50.32	3.9	3.9
26	25.67	25.67	31.0	31.0	64.69	64.69	4.68	4.68
27	31.66	31.66	63.3	63.3	41.83	41.95(0.29)	3.56	3.56
MSE	0.0123		0.0761		0.0964		1.1392e-04	
R^2	0.9921		0.9637		0.9647		0.9642	

Note: Exp. refers to the actual experimental values and pred. refers to the predicted values. The percentage of difference error is given in the bracket, which is calculated by: |Exp-Pred|/Exp x 100%.

The output surfaces for dependent variables, which were interpolated from the trained WNNs models, are shown in Fig. 1, in order to investigate the influences of the pulping conditions on the resulting pulp and paper properties. The response surfaces were expressed as a function of two variables at a time, while the other pulping variables were fixed at central level, in such a way that main effects and the two-variable interaction effects of those factors with the response variables can be analyzed.

Screened Yield

The surface plot of screened yield as a function of ethanol and NaOH concentration at a constant temperature of 170 ºC and 120 min reaction time is portrayed in Fig. 1(a).

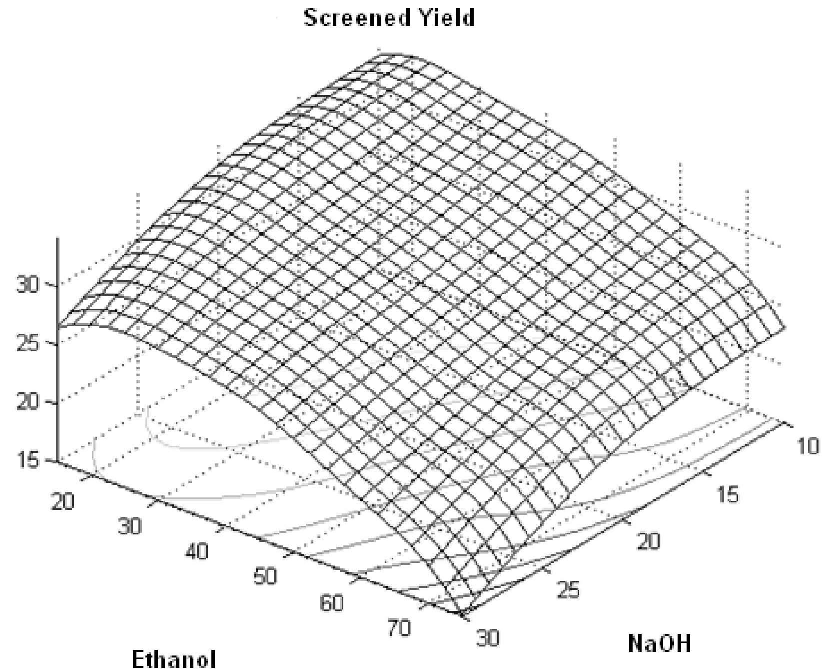

Fig. 1(a). Screened yield as a function of ethanol and NaOH concentration at constant temperature, T (170 ºC) and time, t (120 min)

As can be observed in this figure, the screened yield exhibits strong dependence on the alkaline concentration. Increasing the alkaline concentration reduced pulp yield drastically due to alkaline hydrolysis of the glycosidic linkages. These effects are more significant in the region with more severe pulping conditions, where pulp production is unfavored by a high level of NaOH concentration, since it might promote cellulose degradation, resulting in further losses in screened yield, as shown in Fig. 1(a).

It is interesting to note that the high level of ethanol (starting at *ca.* 45%) reflects an antagonistic effect on yield. This is in contrast with most reports that show the positive effects of increase of ethanol, which was believed to be due to suppression of degradation reactions of carbohydrates and prevention of lignin condensation reactions (Shatalov and Pereira 2002). In soda-ethanol pulping, removal of lignin relies on the chemical breakdown of the lignin macromolecule before it is dissolved, with cleavages of the α–ether linkages and β–aryl ether bonds being primarily responsible for this breakdown (Gierer 1982; Mcdonough 1993; Sarkanen 1991). The effects observed in this study could be related to the solubilization of lignin. Once it is broken into very small molecules, lignin is being solubilize by ethanol, and the amount presumably increases with solvent concentration. The recent work of Xu *et al.* (2007) which shows that below an ethanol dosage of 42%, large amounts of lignin will precipitate on the pulp, adds credence to the effects observed in this study. Apart from lignin, polysaccharides are also continuously removed during the pulping process, the amount varying depending on the stage. In the beginning of the process, lignin is mostly removed, and polysaccharides in much lesser quantities. However, towards the end of the stage, delignification becomes very difficult, and the chemical attack is now directed at the cellulose. Consequently, the screened yield progressively decreases. Hence, to obtain a substantial amount of pulp yield, it is preferred to operate the pulping process at mild to moderate conditions (*i.e.*, *A* within 10% to 20%, and *Et* within 15% to 45%).

Kappa Number

The influence of NaOH and ethanol on kappa number is presented in Fig. 1(b), at a constant temperature of 170 ºC and 120 min reaction time.

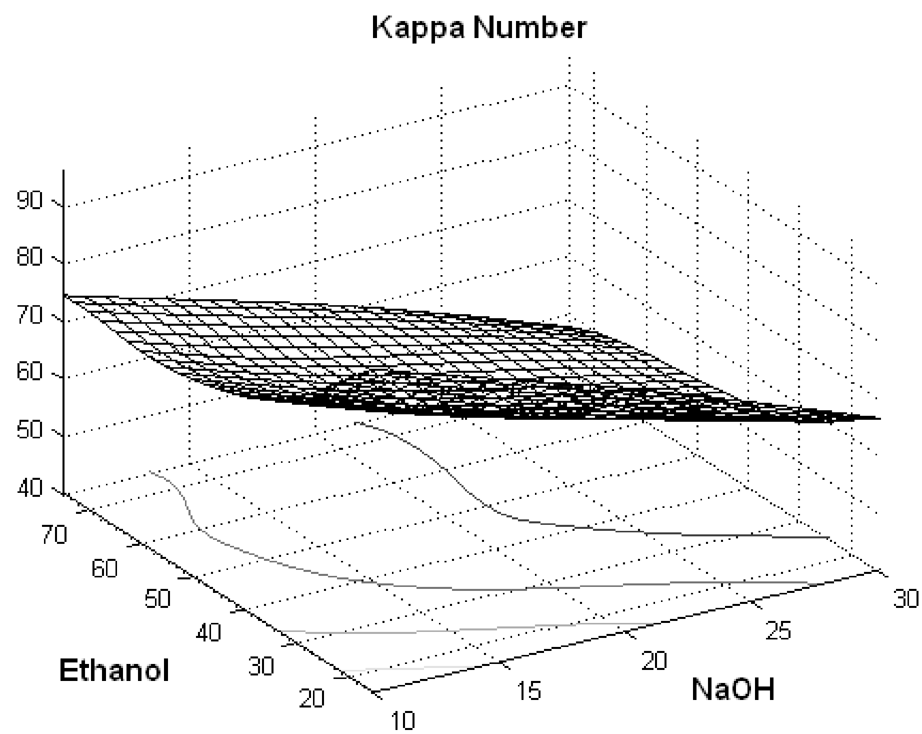

Fig. 1(b). Kappa number as a function of ethanol and NaOH concentration at constant temperature, T (170 ºC) and time, t (120 min)

As evident from this figure, both parameters are effective in reducing the kappa number, particularly in the region with mild to moderate pulping conditions. However, the decremental trend is less pronounced for any further increase in these variables. For example, in the region of high *Et* (>50%), the contour lines are more or less parallel to the ethanol axis. This suggests that the delignification process has become completed or decelerated in this region, where any changes in the ethanol dosage at fixed alkaline charge will merely cause insignificant change on kappa number.

Moreover, an almost flat response surface was obtained in the regions with severe treatment, indicating the insensitivity of the kappa number at those particular conditions. In this case, to improve the lignin removal towards obtaining a satisfying kappa number, pulping with a moderate alkali and ethanol levels is more favored (*i.e.*, *A* within 15% to 25%, and *Et* within 40% to 50%). It is presumably a matter of condensation and redeposition of lignin on the fibers, as reported by Kleinert (1974).

Tensile Index

Fig. 1(c) graphically displays the effects of NaOH and ethanol on the tensile index, at the constant temperature of 170 ºC and 120 min reaction time.

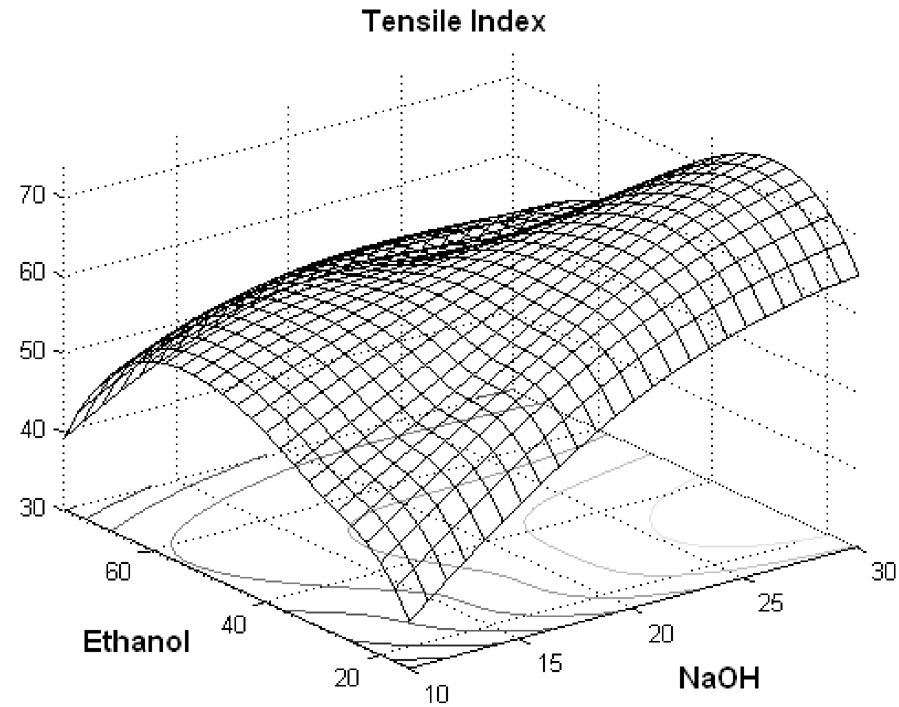

Fig. 1(c). Tensile index as a function of ethanol and NaOH concentration at constant temperature, T (170 ºC) and time, t (120 min)

As can be seen in this figure, the variation in tensile index is markedly dependent on both of these governing parameters. In the region of low alkali charge and low ethanol level (for example, *A* = 10% and *Et* = 15%), an increase of either of these two factors has a positive effect, as highlighted by a steep rise in tensile strength. The delignification process has opened new sites for hydrogen inter-bonding between the fibers, resulting in an increase of tensile strength. Due to the effects of interaction between the NaOH and ethanol, a continuing increase in these two factors enhanced the fiber bonding to a greater extent, albeit at a reduced rate (as the space between the contour lines became larger), which peaks at moderate ethanol and alkaline levels (*i.e.*, *A*≈45% and *Et*≈19%). The interaction effects of NaOH and ethanol is further evident when a simultaneous increase in both of these two parameters is accompanied by a decline in tensile index. This is most probably due to the decrease in fiber strength resulting from cellulose degradation, which occurs at high NaOH and ethanol levels that corresponds to the lowest point of screened yield in Fig. 1(a). This observation is intriguing with a view to preserving fiber quality properties for papermaking, which suggests the necessity of maintaining the operating ranges in moderate pulping conditions (*i.e.*, *A* within 15% to 20%, and *Et* within 35% to 50%) , in order to increase the tensile strength while achieving an adequate amount of pulp yield (≈28%).

Tear Index

The surface plot of tear index with respect to alkali charge and ethanol dosage, at a constant time of 120 min and temperature of 170 ºC is given in Fig. 1(d).

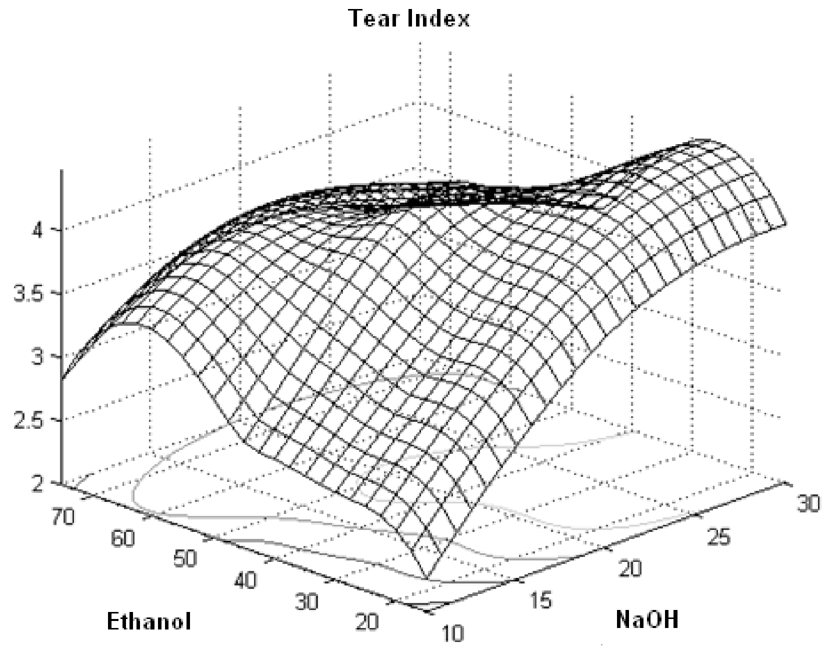

Fig. 1(d). Tear index a function of ethanol and NaOH concentration at constant temperature, *T* (170 ºC) and time, *t* (120 min)

Evidently, the surface plot indicates that an increase of both the NaOH and ethanol leads to an augmentation of the tear index, with the effects appearing to be more significant at mild to moderate pulping conditions. In the region of lower NaOH concentration, an increase in either NaOH or ethanol is accompanied by an increase in tear index. However, when the tear index culminates at approximately 20% NaOH and 50% ethanol level, it starts falling gradually afterwards.

To understand this behavior, one has to look at the parameters that govern tear strength, which is a function of both fiber strength and bonding (Seth and Page 1988; Page and Macleod 1992) and subsequently is influenced by the degree of delignification. As lignin is removed, more bonds are formed and consequently stronger paper is produced as can be seen under mild pulping conditions of low alkali charge and ethanol concentration. However at higher alkali charge and ethanol concentration, not only is lignin removed, but also the cellulose component is being degraded, resulting in fiber damage that contributes to poorer tear strength. Thus, the use of a pulping regime with intermediate alkali charge and moderate ethanol dosage is more favorable for tear strength (*i.e.*, *A* within 15% to 20%, and *Et* within 35% to 50%).

Optimization of the Pulping Process

As can be inferred from previous sections, the pulping conditions to maximize pulp yield, tensile strength, and tear index, while minimizing the kappa number simultaneously, are fairly different. In order to obtain the optimum values for the pulp and paper properties, a compromise of the pulping variables is all that is needed. In this present work, by specifying the desired values or ranges of the pulp and paper properties beforehand (as listed in Table 3), the proper pulping conditions were calculated based on the obtained WNNs. The amount of desired pulp yield is fixed at maximum of 32.92%, which is chosen based on the results in Table 1. Similarly, the ranges for the desired kappa number, tensile index, and tear index are determined according to Table 1. One of the optimal pulping conditions predicted by WNNs is A, 18.15%; Et, 38.12%; T, 165.23 ºC; and t, 167.71 min, which conforms to the attained observations in Fig. 1.

Table 3. The Specified Desired Values of Response for the Optimization of the Pulping Process

Variables	Target	Minimum	Maximum
NaOH (%)	In the range of	10	30
EtOH (%)	In the range of	15	75
Temperature (ºC)	In the range of	150	190
Time (min)	In the range of	60	180
Screened Yield	Maximum	-	32.92
Kappa Number	In the range of	20	60
Tear Index	In the range of	30	60
Tensile Index	In the range of	3	5

CONCLUSIONS

The feasibility of using wavelet neural networks (WNNs) in forecasting the pulp and paper properties precisely in the soda-ethanol pulping of oil palm fronds was demonstrated in this study. The established WNNs models using the experimental data were able to predict the variation of pulp and paper qualities accurately, as the WNNs delivered a good fit of the experimental values, with error less than 6%, while achieving a satisfactory regression values R^2 concurrently. In addition, from the utilization of WNNs in optimizing the operating conditions, it has been shown that maximum pulp yield (32.92%) with high tear strength, high tensile index, and low kappa number can be obtained at the optimized conditions of: NaOH concentration 18.15%; EtOH dosage 38.12%, temperature 165.23 ºC and cooking time 167.71 min. The obtained results have thus indicated a new promising alternative approach by ways of WNNs, especially its ability to derive a simple empirical model without knowing the underlying relationship between the operational variables with the pulp and paper qualities.

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