J Indian Acad Wood Sci (June 2016) 13(1):44–47
DOI 10.1007/s13196-016-0164-8

ORIGINAL ARTICLE

The relationship of pulp yield with ethanol pulping concentrations on Acacia hybrid

Kang Chiang Liew[1] · **Eunice Wan Ni Chong**[1]

Received: 4 December 2015 / Accepted: 24 March 2016 / Published online: 31 March 2016

Abstract This study aimed at determining the total yield, screened yield, rejected yield, Kappa number and viscosity of organosolv Acacia hybrid pulp. Acacia hybrid wood chips of uniform size were used to undergo pulping in a digester with five different ethanol concentrations, 50, 60, 70, 80 and 90 % (v/v) with 1 M of sodium hydroxide as catalyst and water. All chips were digested at 185 °C, duration of 3 h cooking time and pressure 1.1–1.2 MPa. It was observed that increasing of ethanol concentration has led to increment in pulp yield and degree of delignification.

Keywords Organosolv pulping · Ethanol · Sodium hydroxide · Acacia hybrid · Pulp yield

Introduction

Pulping is one of the most essential processes to form paper. It is a process which involves mechanical, semi-chemical or chemical treatment of breaking down lignin bonds within the wood structure to form fibrous mass, also known as pulp. This process is also known as delignification in some researches. Chemical pulping is among the most promising methods since it is able to produce higher yield and stronger pulp compared to those using semi-chemical and mechanical treatment. Statistic revealed that the world chemical pulps are mostly produced by the Kraft pulping process (Sridach 2010). However, the pressure appeared to the environmental regulations on emissions of sulphur dioxide, suspended solids and wastewater pollution (UNEP 1997). These environmental disadvantages have brought forth a more environmental friendlier pulping process referred as organosolv pulping.

Pulp and paper industry has emphasised on pulp yield production due to its benefit in generating profit to the industry. Besides that, high pulp yield production is required in order to fulfil the demand of the consumers. Pulp yield can be affected by many factors including wood species, wood anatomy, pulping chemistry, mill digester systems, cooking temperature, chip size, chip quality, Kappa number and many other sub-factors (MacLeod 2007). In order to increase pulp yield, research has been continued to improvise the method of pulping especially in the area of pulping chemistry and Kappa number relationship using different species of hardwood and softwood. This study has emphasised in the usage of different concentrations of ethanol as organic solvent in the pulping process to evaluate on the yield of pulp produced using Acacia hybrid as the raw material.

Materials and methods

Raw material

The raw material used in this study was Acacia hybrid wood chips. These chips were generated from 30 to 50 cm diameter breast height trees harvested from Sabah Forestry Development Authority (SAFODA) plot in Kinarut, Sabah. Logs were debarked, sawed, chipped and screened to uniform dimension of 20 mm × 20 mm × 5 mm.

✉ Kang Chiang Liew
liewkc@ums.edu.my

[1] Faculty of Science and Natural Resources (Forestry Complex), Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia

Ethanol pulping

The ethanol pulping process of oven dried Acacia hybrid wood chips was carried out in a 15 L rotary batch digester at five concentrations of ethanol [50, 60, 70, 80and 90 % (v/v)], water and 1 M NaOH as catalyst. Each of the five different concentrations of ethanol pulping was replicated 3 times using 1 kg of wood chips each with the ratio of liquor to wood chips at 10:1. The digesting process was 120 min to maximum temperature (185 °C) including pre-heating stage and remained constant for 60 min at maximum temperature. Maximum pressure ranged from 1.1 to 1.2 MPa. The cooked chips were then disintegrated in a hydropulper to generate pulp and screened according to TAPPI T 275.

Yield determination

The pulp was measured for its total yield, screened yield and rejected yield.

Results and discussion

Referring to Fig. 1, there is a close relationship between ethanol concentration and total unscreened yield as $r^2 = 93.57$ %, followed by Fig. 2 which displayed the relationship between ethanol concentration and screened yield as $r^2 = 94.61$ % and Fig. 3 which displayed that the ethanol concentrations were positively correlated with rejected yield as $r^2 = 91.48$ %. This shows that increasing ethanol concentration may have strong tendency to affect pulp yield from 50 to 90 % of ethanol concentration as the yield keep increasing as the ethanol concentration was increased. It was obvious that the results of total unscreened yield, screened yield and rejected yield were strongly dependent on ethanol concentrations. The strong relationship between two variables is able to help us to predict the resulted yield of a particular ethanol concentration in the future.

Based on Table 1, the average total yield increased gradually from 45.25 to 49.43 %. Meanwhile, as ethanol increased from 50 to 60 %, the average screened yield increased by 2.71 % followed by 1.42 % from 60 to 70 % of ethanol concentration, 6.91 % from 70 to 80 % of ethanol concentration and finally, 3.44 % from 80 to 90 % of ethanol concentration. On the other hand, rejected yield decreased from 6.89 to 5.24 %. This signified that pulping in higher concentration of ethanol is able to increase screened yield and at the same time, reduce yield loss. Nevertheless, further statistical analysis (One-way ANOVA) was used to observe the effect of each ethanol concentration towards the pulp yield. Significant difference at $p \leq 0.05$ was observed in average screened yield when compared between the ethanol concentrations. Besides that, the average rejected yield and total unscreened yield

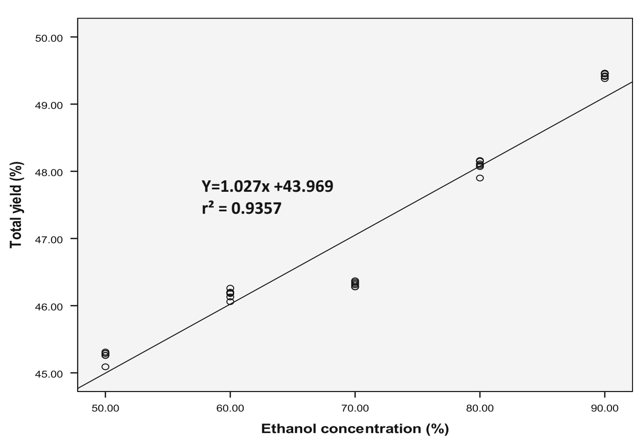

Fig. 1 Relationship between different ethanol concentrations and total unscreened yield

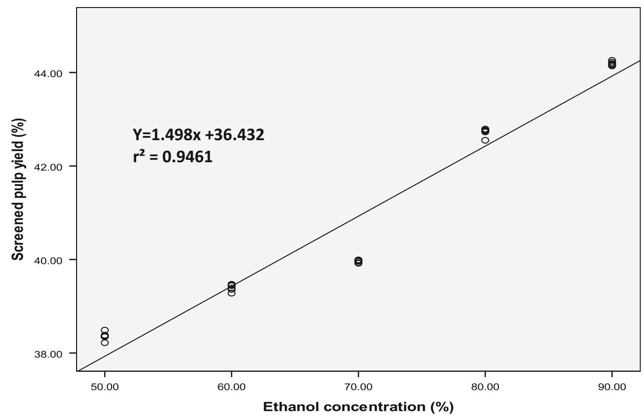

Fig. 2 Relationship between different ethanol concentrations and total screened pulp yield

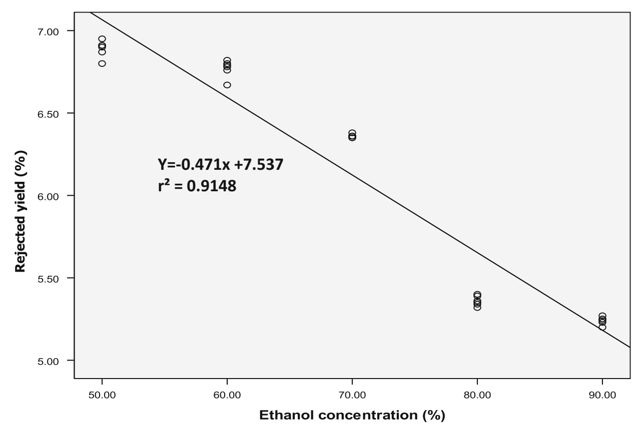

Fig. 3 Relationship between different ethanol concentrations and total rejected pulp yield

Table 1 Pulp properties result of organosolv pulping and Kraft pulping

Pulp properties	Ethanol concentration (%)					
	50	60	70	80	90	Kraft pulping
Screened yield (%)	38.36[a] [±0.86]	39.40[b] [±0.72]	39.96[c] [±0.03]	42.72[d] [±0.09]	44.19[e] [±0.04]	43.82 [±0.13]
Rejected yield (%)	6.89[a] [±0.05]	6.77[b] [±0.05]	6.36[c] [±0.01]	5.36[d] [±0.03]	5.24[e] [±0.02]	6.11 [±0.11]
Total unscreened yield (%)	45.25[a] [±0.08]	46.17[b] [±0.07]	46.32[c] [±0.04]	48.08[d] [±0.09]	49.43[e] [±0.03]	49.93 [±0.08]
Kappa number	20.25[a] [±0.20]	18.19[b] [±0.94]	17.44[c] [±0.11]	15.37[d] [±0.13]	15.32[d] [±0.08]	14.88 [±0.20]
Viscosity (cPs)	11.85[a] [±0.36]	13.58[b] [±0.38]	14.72[c] [±0.24]	15.48[c] [±0.32]	15.87[d] [±0.08]	15.59 [±0.05]

Value in the same row with different alphabets a, b, c, d, e indicates significant difference at $p \leq 0.05$ for different pulp properties

[] denotes standard deviation

also vary significantly ($p \leq 0.05$) as compared between the groups of organosolv pulp using 50, 60 70, 80 and 90 % concentration of ethanol. This explains that ethanol concentration has positive effect on the pulp yield, lowering of Kappa number and increased of pulp viscosity which is one of the advantages in pulp and paper industry since maximum screened pulp yield is desired in the industry.

The increasing trend of screened pulp yield had indirectly shown that pulp rejected was reduced as the addition of ethanol concentration increased. The result showed a contrast to certain studies which resulted in decreased screened pulp yield when alkali concentration increased due to cellulose degradation. However, in this study, it was believed that addition of ethanol concentration was able to help to reduce cellulose degradation which caused reduction in rejected pulp and increased screened pulp yield at the same time. This is supported by a few researches. Alcohol solvents such as ethanol and methanol were among the most prominent solvents used in organosolv pulping since they played the important role in solvolysis reaction (Balogh et al. 1992; Bendzala et al. 1995; Sridach 2010). It is also said that such organic solvents were capable to promote better penetration and diffusion of chemical into the wood chips (Sridach 2010). Moreover, ethanol added in pulping showed positive effect by preventing cellulose from degradation and prevent high rate of delignification (Akpakpan et al. 2012). Similar result was obtained in the study done by Zainuddin et al. (2012) whereby the ethanol concentration increased from 15 to 75 % when other parameters remained constant, screened pulp yield increased from 26.57 to 28.01 %. This can be caused by the force of degradation process of carbohydrate and prevent lignin from condensation (Zainuddin et al. 2012).

The gradual screened and unscreened yield increment was probably caused by the high alcoholic cooking environment which able to protect carbohydrates content such as hemicelluloses and cellulose of pulp from hydrolysis process. Again, it is mentioned that the main reason of yield increment in ethanol pulp was caused by carbohydrate retention (Sahin 2003; Akgul and Kirci 2009; Ogunsile and Quintana 2010). Study also shown that soda-ethanol pulping produced higher yield compared to soda pulping (Akpakpan et al. 2012). This also reveals that there is a tendency where organic solvent (ethanol) is able to reduce the effect on cellulose degradation while soda causes degradation in cellulose fibres since it involves removal of glucose units and able to degrade the degree of polymerization of cellulose molecule (Muurinen 2000).

Another study done by Akgul and Tozluoglu (2010) on cotton stalks (*Gossypium hirsutum* L.) at a constant temperature of 160 °C for 90 min also clarified that the addition of ethanol concentration of 20, 30, 40 and 50 % into soda pulping increased the pulp yield produced from 7.71, 9.44, 13.5 to 14.0 % respectively. It caused similar result even when AQ catalyst was added to the soda pulping. As ethanol concentration in soda AQ-pulping increased from 20 to 50 %, pulp yield increased by 12.1, 14.6, 14.9 and 15.0 % respectively. Hence, high yield of pulp can be due to the addition of ethanol that causes selective delignification and rapid reaction in pulping when compared with mere soda pulping (Sahin 2003). This is also preferable in the pulp and paper industry since higher concentration of ethanol added was able to accelerate delignification process thereby help to reduce energy consumption (Akgul and Tozluoglu 2010).

Furthermore, it was shown in a study that significant difference at 99.3 % confidence level between the use of ethanol and methanol as organic solvent in pulping *Eucalyptus* *globules* where pulping using ethanol provide higher yield than methanol because higher screened yield with less lignin content and Kappa number less than 10 were obtained (Oliet et al. 2002). This is related to solubilisation of lignin as the amount of lignin being solubilised increases with ethanol concentration (Zainuddin et al. 2012). As compared the yield of organosolv pulping with conventional Kraft pulping, the average screened yield of Kraft pulp was comparatively higher than the pulp using 50–80 % ethanol concentration in organosolv pulping. The result showed that the average screened yield of 50 % ethanol organosolv pulp was 12.46 % lowered than Kraft pulp, followed by 10.09 % (60 % ethanol organosolv pulp), 8.81 (70 % ethanol organosolv pulp), and 2.51 % (80 % ethanol organosolv pulp) lowered as compared to the Kraft pulp. However, the average screened yield of 90 % ethanol organosolv pulp was 0.84 % higher than Kraft pulp.

Referring to Table 1, as the average rejected yield of the five concentrations of organosolv pulps were compared with the Kraft pulps, it showed that the average rejected yield of 50 % ethanol organosolv pulp was 12.77 % higher than the Kraft pulp. It followed by 10.80 and 4.09 % higher as compared 60 % ethanol organosolv and 70 % ethanol organosolv pulp with the Kraft pulp respectively. However, Kraft rejected yield was higher than 80 and 90 % ethanol organosolv pulp which were 12.27 and 14.24 % respectively. On the other hand, the average total unscreened yield of Kraft pulp was the highest which stated 49.93 % as compared with the organosolv pulps from 50 % ethanol concentration to 90 %. The 50, 60, 70, 80 and 90 % of ethanol organosolv pulp were lowered than Kraft pulp by 9.37, 7.53, 7.23, 3.71 and 1.00 % respectively.

Based on the results, it showed that organosolv pulping has the potential to be an alternative to Kraft pulping since the result of average pulp yield was slightly the same as Kraft pulping. It can be seen that average screened yield of 90 % ethanol concentration in organosolv pulping was obviously higher than Kraft pulping while the rejected yield was lowered than 80 % ethanol concentration and 90 % ethanol concentration of organosolv pulp. This implied that delignification of organosolv pulping is more selective which reduced degradation of cellulose content in pulp compared to Kraft pulping.

Conclusions

The increase in the concentration of ethanol leads to generate higher yield and lower Kappa number which is desirable in pulp and paper industry. This suggested that fibres were less degraded after cooking in the ethanol solvent with sodium hydroxide as catalyst. The reduction of Kappa number by increased ethanol greatly influenced the end product because it reduced the lignin content in the pulp which also benefits bleaching process after pulping.

Acknowledgments The authors would like to extend their gratitude to Ministry of Higher Education Malaysia for the Fundamental Research Grant (FRG0198-SG-1/2010), Universiti Malaysia Sabah, Politeknik Kota Kinabalu and Sabah Forest Development Authority (SAFODA) for their support and assistance.

References

Akgul M, Kirci H (2009) An environmentally friendly organosolv (ethanol-water) pulping of poplar wood. J Environ Biol 30:735–740

Akgul M, Tozluoglu A (2010) Alkaline-ethanol pulping of cotton stalks. Sci Res Essays 5:1068–1074

Akpakpan AE, Akpabio UD, Ogunsile BO, Eduok UM (2012) Influence of cooking variables on the soda and soda-ethanol pulping of *Nypa fruticans* petioles. Aust J Basic Appl Sci 5:1202–1208

Balogh DT, Curvelo AAS, De Groote RAMC (1992) Solvent effects on organosolv lignin from *Pinus caribea* Hondurensis. Holzforschung 46:343–348

Bendzala J, Pekarovicova A, Kokta BV (1995) Surface characteristics of fibers in high-yield pulping with ethanol. Cell Chem Technol 29:713–724

MacLeod M (2007) The top ten factors in kraft pulp yield. Pap Timber 89:417

Muurinen E (2000) Organosolv pulping: a review and distillation study related to peroxyacid pulping. Doctorate of Philosophy Dissertation. Oulu University

Ogunsile BO, Quintana GC (2010) Modeling of soda-ethanol pulps from *Carpolobia lutea*. BioResources 5:2417–2430

Oliet M, García J, Rodríguez F, Gilarrranz MA (2002) Solvent effects in autocatalyzed alcohol–water pulping comparative study between ethanol and methanol as delignifying agents. Chem Eng J 87:157–162

Sahin HT (2003) Base-catalyzed organosolv pulping of jute. J Chem Technol Biot 78:1267–1273

Sridach W (2010) The environmentally benign pulping process of non-wood fibres. Suranaree J Sci Technol 17:105–123

UNEP (1997) Environmental management in the pulp and paper industry. United Nations Environment Programme Technical Report No. 34, Sweden, pp 240

Zainuddin Z, Wan Daud WR, Ong P, Shafie A (2012) Wavelet neural networks applied to pulping of oil palm fronds. Bioresour Technol 102:10978–10986