CHEMICAL ENGINEERING TRANSACTIONS

VOL. 29, 2012

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Hon Loong Lam, Jiří Jaromír Klemeš

ISBN 978-88-95608-20-4; **ISSN** 1974-9791

DOI: 10.3303/CET1229140

Supply Network Design and the Utilisation of Rubber Seed Oil as Biofuel and Biochemicals

Wendy P. Q. Ng[a], Hon Loong Lam*[a], Suzana Yusup[b]

[a]University of Nottingham, Malaysia Campus, Department of Chemical and Environemntal Engineering, Jalan Broga 43500 Semenyih, Selangor, Malaysia.
[b]Universiti Teknologi PETRONAS, Chemical Engineering Department, 31750 Tronoh, Perak, Malaysia.
honloong.lam@nottingham.edu.my

This paper presents the supply network design and the utilisation of rubber seed oil (RSO) in Malaysia. Rubber plantation covers about 20% or 1.02 Mha of commercial plantation area in Malaysia (MRB, 2012). At average, 1 ha of land yields 150 kg of oil bearing seeds (Ramadhas et al., 2005). The rubber seeds yields good amount of oil at 30-40 wt% of the seed (Yusup and Khan, 2010). At 20% seeds utilisation, 35 wt% oil extraction ratio and 96 wt% oil conversion rate (Yusup and Khan, 2010a), 10310 t/y of biodiesel could be produced. This increases the country's energy security by developing another potential renewable energy source. RSO has good potential to meet the renewable energy share in Malaysia as well as the growing biodiesel market globally. After extracting oil from rubber seeds, the biomass or seeds left over could be used to feed cows, pigs and other livestock. These applications direct the utilisation of rubber seeds to a zero-waste path. In addition, the supply network of the biomass is synthesised through mathematical programming in this paper. Centralised processing facilities are proposed and optimised biomass distribution network is displayed. A simplified real case study is presented to elucidate the model.

1. Introduction

The current world is developing towards sustainable green future. Research is carried out by most countries to increase the utilisation of biomass and substitute fossil fuel with renewable energy to improve energy security. Palm-based biodiesel is produced as one type of renewable energy since the last decade.

1.1 Biodiesel market and production

The world biodiesel market is estimated to develop at an average growth rate of over 30 % annually by 2016, reaching 140 BL (Dekeloil, 2012). The main raw materials used for biodiesel production in Malaysia are methanol and crude palm oil (CPO). Currently, Malaysia and Indonesia appears as the key players towards CPO production on the global stage. These two countries predict that the oil palm industry needs to grow by 2.5 Mt/y in order to meet the rising global appetite for palm oil (Rowe, 2012). In Malaysia, the land availability limits the expansion of oil palm industry. On the other hand, there is only 10 biodiesel production plants are under operation despite the relatively high amount of biodiesel manufacturing licences issued by the Malaysian government. This situation is caused by the increasing raw material - CPO price over the years, which diminishes the economic viability of biodiesel production.

Please cite this article as: Ng W. P. Q., Lam H. L. and Yusup S., (2012), Supply network design and the utilisation of rubber seed oil as biofuel and biochemicals, Chemical Engineering Transactions, 29, 835-840

1.2 Biomass: rubber seed in Malaysia

In Malaysia, rubber plantation appears to be the second largest agricultural sector after oil palm. Figure 1 illustrates the proportion of agricultural land use in Malaysia. Currently, the only main product extracted from rubber tree is rubber tree milk. Rubber seed as one type of biomass has been ignored and left as waste previously. Based on the current commercial rubber planting area of 1.02 Mha, it is estimated that 153 t of rubber seed are available yearly. Yusup and Khan (2010a) investigated the possibility of using 50:50 CPO and rubber seed oil (RSO) to produce biodiesel. The quality of the biodiesel produced was checked with international standards and it showed that it could be used as commercial substitute for diesel fuel (Yusup and Khan, 2010a).

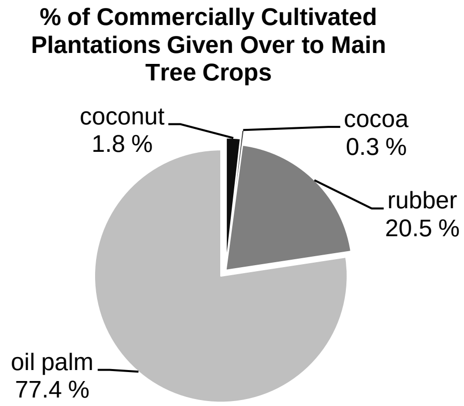

Figure 1: The land use based on the commercially cultivated main tree crops as of year 2009. (Source: MPIC, 2010)

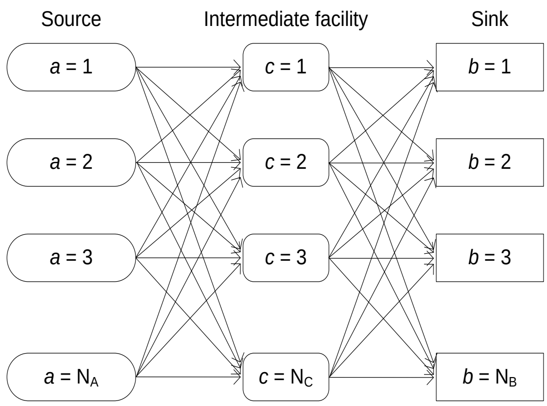

Figure 2: Source and sink (superstructure) representation of the biomass allocation problem.

2. Problem statement

The problem to be addressed in this paper is formally stated as the followings: given a set of rubber seed collection points (suppliers) to be allocated to a set of centralised processing points and then to a set of biodiesel production plants (consumers) via roadway system (by truck). The problem may be described by the superstructure representation as shown in Figure 2. The work aims to determine the optimum allocation of biomass to maximise the economic potential and to minimise the carbon foot print resulted from the transportation activity.

3. Model formulation

Biomass is transferred from sources (*a*) to intermediates processing points (*c*) to sinks (*b*) or directly to sinks, varying $a = 1...N_A$, $c = 1...N_C$ and $b = 1...N_B$. The objection function is defined as:

$$OBJ = Min\sum(COTR + CORW) \tag{1}$$

where *COTR* is the transportation cost incurred; *CORW* is the raw material cost.

$$\sum_{c\in C} WAC_{a,c} = CAPA_a \times F1 \times F2 \qquad \forall a \in A \tag{2}$$

where $WAC_{a,c}$ is the biomass flowrate from *a* to *c*; $CAPA_a$ is the limit of biomass availabilty; *F*1 is the amount of biomass available per ha of plantation; *F*2 is the proportion of biomass collected out of the total biomass available.

$$\sum_{b\in B} OCB_{c,b} = \sum_{a\in A} WAC_{a,c} \times F3 \qquad \forall c \in C \tag{3}$$

where $OCB_{c,b}$ is the oil flowrate from *c* to *b*; *F*3 is the oil extraction rate of biomass.

$$BIO_b = \sum_{c\in C} OCB_{c,b} \times F4 \qquad \forall b \in B \tag{4}$$

where BIO_b is the biodiesel production rate; *F*4 is the conversion factor of the biomass oil to produce biodiesel.

$$BIO_b \le 0.5 \times CAPB_b \qquad \forall b \in B \tag{5}$$

where $CAPB_b$ is the biodiesel production capacity.

The distance between the facilities is calculate using the straight line distance equation:

$$DT = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{6}$$

where *DT* is distance (km); x_1, x_2, y_1, y_2 are the Cartesian coordinates of supply and destination points.

The transportation cost is estimated using the equation:

$$COTR = \sum_{a\in A, b\in B, c\in C} (DT_{a,c} \times WAC_{a,c} + DT_{c,b} \times OCB_{c,b}) \times CTR \tag{7}$$

where *CTR* is roadway transportation cost per km per kg.

The raw material cost is calculated using the equation:

$$CORW = \sum_{a\in A, c\in C} WAC_{a,c} \times CRW \tag{8}$$

where *CRW* is the cost of biomass per kg.

4. Illustrative case study

A modified actual case study is presented to illustrate the application of the proposed model. The data of the case study is based on the actual crop distribution, biodiesel plants under operation and transportation cost by truck. However, the actual identities of the companies are concealed to keep the business propriety. Figure 3 shows the geographical locations of the facilities.

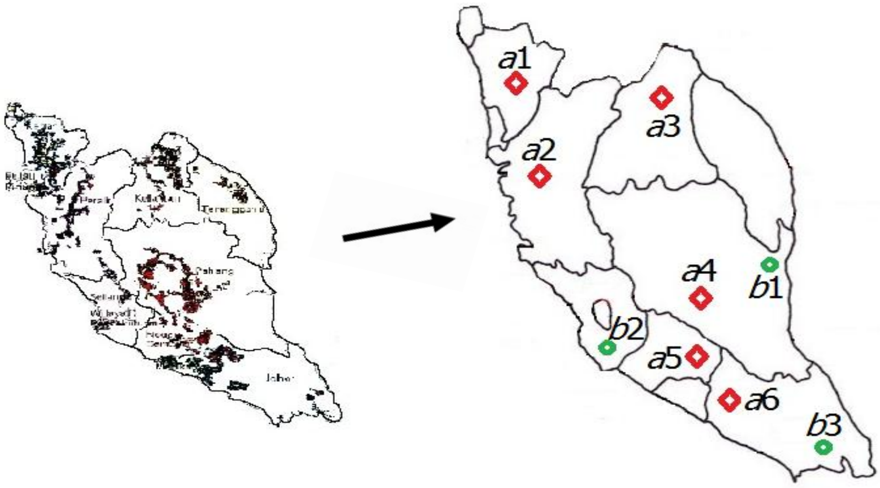

Figure 3: Location of rubber seed supplier and consumers with both the supply and demand point can act as intermediate processing points.

Table 1 shows the estimated Cartesian coordinates of the supply and demand facilities and their respective production capacities. The supply points act as the rubber seed collection points located near/in rubber plantations. The rubber seeds collected are sent to a centralised processing facility *c*, which can be *a* or *b*. RSO is extracted from rubber seeds in *c* and sent to *b* for biodiesel production. The roadway transportation system by truck is employed.

Table 1: Locations of biomass sources, processing plants and their capacities.

Biomass sources	x-coordinate	y-coordinate	Capacity (ha)	Production plant	x-coordinate	y-coordinate	Capacity (t/y)
*a*1	-1196	6223	255832	*b*1	-1461	6187	350000
*a*2	-1210	6231	77878	*b*2	-1276	6233	60000
*a*3	-1339	6197	156418	*b*3	-1531	6182	300000
*a*4	-1426	6201	150202				
*a*5	-1373	6214	191808				
*a*6	-1402	6209	119810				

Table 2 shows the parameters used for the optimisation model. The supply network model is solved with the objective function Eq (1) subjected to other constraints listed above in Section 3.

Table 2: Parameters for supply network optimisation and biomass conversion.

	Particular	Parameter
1	Rubber seed yield	150 kg/ha
2	RS utilisation / collection	20 wt%
3	RSO extraction from rubber seed	35 wt%
4	RPO/CPO conversion	96 wt%
5	Rubber seed cost	3.00 RM/kg
6	Palm fresh fruit bunch cost	0.71 RM/kg
7	Transportation cost	0.30 RM/km/t

The linear supply network model is solved using the optimisation software General Algebraic Modelling System (GAMS) 23.4.3 with the solver CPLEX. The optimum allocation scheme proposed is tabulated in Table 3.

Table 3: Allocation of rubber seed and RSO to processing facilities and biodiesel production plants.

	*a*1	*a*2	*a*3	*a*4	*a*5	*a*6	*b*1	*b*2	*b*3		*b*1	*b*2	*b*3
*a*1	7675									*a*1		2686	
*a*2		2336								*a*2		818	
*a*3			4693							*a*3		1642	
*a*4				4506						*a*4	1577		
*a*5					5754					*a*5	2014		
*a*6						3594				*a*6	1258		

Rubber seed is sold at 3000 RM/t with an oil extraction ratio (OER) of 35 wt%; whist, palm fresh fruit bunch is sold at 716 RM/t with an average OER of 20 wt% as of May 2012 (MPIC, 2012). This results in the gross costs of 8571 RM/t of RSO and 15000 RM/t of CPO excluding the processing costs. This brings a gross saving of 64 M RM/y. Furthermore, with the developed supply network for palm biomass in Malaysia, the supply network can be directly applied on rubber biomass.

5. Conclusions and future works

This paper investigates the potential of enhancing the use of biomass to produce valuable products and fuels. Biodiesel can be produced by non-edible oils and fats. Therefore, the edible palm oil can be allocated to meet the increasing vegetable oil demand whereas the RSO can replace CPO utilisation in CPO's non-edible oil sector. The partial substitution of CPO with RSO in biodiesel production increases the amount of economic return to the producers. This may accelerate Malaysia's implementation of B5 biodiesel policy over the whole country. Furthermore, this substitution may increase the international biodiesel demand by offering more attractive biodiesel export rate.

This study can be improved by incorporating more accurate case data, e.g. transportation distance can be retrieved from road maps or GIS systems for a more realistic distance calculation. In future work, the study is to be extended to (i) integrate other type of renewable biomass sources into the supply network; (ii) synthesize a supply network considering the most usage of interested biomass; (iii) consider the transportation schedule and truck loading limits. In addition, process design (Vlad et al., 2010) and exergy analysis (Jaimes et al., 2010) can be performed to further validate the feasibility of biodiesel production from RSO/CPO blend.

Acknowledgement

The financial support from Malaysia Ministry of Higher Education (MOHE) PRGS-Grant and Global Green Synergy Sdn Bhd Industrial Grant are gratefully acknowledged.

Nomenclature

c set index for centralised processing facility
a subset index of *c* (for biomass source)
b subset index of *c* (for biofuel production facility)

References

Dekeloil, 2012, Biodiesel - Global market <www.dekeloil.com/nrg_biodiesel_global%20market.html> accessed 03.05.2012

Jaimes W., Acevedo P., Kafarov V., 2010, Exergy Analysis of Palm Oil Biodiesel Production, Chemical Engineering Transactions, 21, 1345-1350, DOI: 10.3303/CET1021225

Malaysia Ministry of Plantation Industries & Commodities (MPIC), 2010, Malaysia Ministry of Plantation Industries & Commodities <www.kppk.gov.my> accessed 20.04.2010

Malaysia Ministry of Plantation Industries & Commodities (MPIC), 2012, Malaysia Ministry of Plantation Industries & Commodities <www.kppk.gov.my> accessed 14.05.2012

Malaysian Rubber Board (MRB) 2012, Natural Rubber Statistics 2011 <www.lgm.gov.my/nrstat/nrstats.pdf> accessed 03.05.2012

Ramadhas A. S., Jayaraj S., Muraleedharan C., 2005, Biodiesel production from high FFA rubber seed oil, Fuel, 84, 335-340, DOI: 10.1016/j.fuel.2004.09.016

Rowe M., 2012, Oils & Fats International, vol. 28(1): Rivals in global marketplace, 33-34, Eds. Lim S. and Lavers B., Quartz Business Media Ltd, Surrey, United Kingdom

Vlad E., Bildea C. S., Pleșu V., Marton G., Bozga G., 2010, Process Design of Biodiesel Production from Rapeseed Oil, Chemical Engineering Transactions, 21, 1267-1350, DOI: 10.3303/CET1021212

Yusup S., Khan M., 2010, Basic properties of crude rubber seed oil and crude palm oil blend as potential feedstock for biodiesel production with enhanced cold flow characteristics, Biomass and Bioenergy, 34, 1523-1526, DOI: 10.1016/j.biombioe.2010.03.022.

Yusup S., Khan M. A., 2010a, Base catalysed transesterification of acid treated vegetable oil blend for biodiesel production, Biomass and Bioenergy, 34, 1500-1504, DOI: 10.1016/j.biombioe.2010.04.027