MAXIMIZING PAPER FIBRE RECOVERY USING PROPERTY CASCADE ANALYSIS TECHNIQUE

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Report submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering
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JANUARY 2012

ABSTRACT

Paper can be broadly classified into two types which high fibre paper and low fibre paper. In paper manufacturing, every stage of the paper production and consumption cycle is associated with a range of potential environmental problems. In addition, trees' harvesting to produce the paper contribute to global warming. Therefore, one of possible ways to solve this problem is by recycling the papers. In fact, paper fibre recovery options can give great impact in reducing climate change, greenhouse gases, forest preservation, water and air pollution, waste management and energy problems. Hence, this research is to establish the minimum paper fibre targets using property cascade analysis (PCA) for a paper making process after looking at the possibility of using the available fibre sources within the process to meet its fibre demands. In order to find the maximum paper recovery, constructing the property cascade table from the limiting paper fibre data is needed. The property cascade analysis eliminates any tedious steps of graphical technique and quickly yield the exact utility targets and the pinch location in order to achieve the minimum fibre targets during network design. The fresh fibre target was estimated at 1464.27 tons per year which having a reduction of 43.68% of fresh fibre.

ABSTRAK

Kertas secara umumnya boleh dikelaskan kepada dua jenis iaitu kertas serat yang tinggi dan kertas serat yang rendah. Dalam pembuatan kertas, setiap peringkat pengeluaran kertas dan kitaran penggunaan dikaitkan dengan pelbagai masalah alam sekitar. Di samping itu, penuaian pokok-pokok untuk menghasilkan kertas menyumbang kepada pemanasan global. Oleh itu, salah satu cara yang mungkin untuk menyelesaikan masalah ini ialah dengan mengitar semula kertas. Malah, pemulihan serat kertas boleh memberi impak yang besar dalam mengurangkan perubahan iklim, gas rumah hijau, pemeliharaan hutan, pencemaran air dan udara, pengurusan sisa dan masalah tenaga. Oleh itu, kajian ini adalah untuk mewujudkan sasaran serat kertas minimum dengan menggunakan analisis harta lata bagi proses membuat kertas selepas melihat kemungkinan menggunakan sumber-sumber serat yang ada dalam proses untuk memenuhi permintaan seratnya. Membina jadual harta lata dengan mengehadkan data serat kertas adalah diperlukan dalam usaha mencari pemulihan maksimum kertas. Analisis harta lata menghapuskan langkah-langkah yang rumit dalam teknik grafik dan menghasilkan sasaran utiliti yang tepat dan lokasi persentuhan untuk mencapai sasaran serat minimum dalam reka bentuk rangkaian. Sasaran serat segar dianggarkan pada 1464.27 tan setahun yang mempunyai pengurangan 43.68% serat segar.

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LIST OF SYMBOLS

CO_2	Carbon dioxide
O_2	Oxygen
%	Percentage
Ψ_k	Water fraction, Operator
Δm	Load
F_{FF}	Fresh fibre flowrate
F_{WF}	Waste fibre flowrate
F_j	Demand flowrate
F_i	Source flowrate
F_{sum}	Net flowrate
F_C	Cumulative flowrate
SH	Source of high fibre
SL	Source of low fibre
DH	Demand of high fibre
DL	Demand of low fibre

LIST OF ABBREVIATIONS

NAD	Network Allocation Diagram
PCA	Property Cascade Analysis
PCT	Property Cascade Table
PTA	Problem Table Analysis
RVP	Reid Vapour Pressure
SSAC	Source and Sink Allocation Curve
UTM	Universiti Teknologi Malaysia
WCA	Water Cascade Analysis

CHAPTER 1

INTRODUCTION

1.1 Global Paper Consumption

Nowadays, global paper consumption stills not less although new technology and innovative always created. More than a decade ago, computers, e-mail, and the Internet are being used as a means to reduce consumption of paper for printing and writing, newsprint, packaging, and other uses. But today, more than ever, paper remains the dominant and essential vehicle of modern communications. It is clearly shown that paper still dominates the publishing industry such as newspaper, pamphlets, catalogues and books. In Table 1.1 lists, the world's top 30 producing and consuming countries in 2000. Meanwhile, the production of waste paper in Asia is shown in Table 1.2.

Table 1.1: World's Top 30 Producing and Consuming Countries in 2000 (Pulp and Paper International)

Country	**Metric Tons (000)**		**Country**	**Metric Tons (000)**		**Country**	**Metric Tons (000)**
USA	85,495		USA	57,002		USA	92,355
Japan	31,828		Canada	26,411		China	36,277
China	30,900		China	17,150		Japan	31,736
Canada	20,689		Finland	11,910		Germany	19,112
Germany	18,182		Sweden	11,517		United Kingdom	12,684
Finland	13,509		Japan	11,399		France	11,376
Sweden	10,786		Brazil	7,463		Italy	10,942
France	9,991		Russia	5,814		Canada	7,476
Korea	9,308		Indonesia	4,089		Korea	7,385
Italy	9,000		Chile	2,841		Spain	6,922

Table 1.2: Production of Waste Paper (thousand MT).

	Actual			Projection		
Country	1980	1994		2000	2005	2010
ASIA	**12248**	**29173**		**40301**	**51602**	**64248**
Bangladesh	0	0		52	69	93
China, People's Rep. of	1557	7581		13110	17002	21422
Cyprus	0	0		7	13	8
Hong Kong SAR, China	402	500		583	1100	1377
India	200	531		910	1198	1532
Indonesia	110	340		770	1505	1902
Iran, Islamic Republic	55	80		113	142	182
Iraq	0	0		7	8	9
Israel	45	113		94	126	222
Japan	8079	14841		20006	23963	28399
Jordan	4	12		30	48	67
Korea, DPR	0	0		32	35	40
Korea, REP	582	2850		1349	1881	2970
Kuwait	10	15		0	0	0
Lebanon	0	0		12	17	22
Macau	3	27		11	20	51
Malaysia	58	102		259	415	736
Nepal	0	0		5	6	7
Oman	0	0		4	4	4
Pakistan	26	55		138	162	240
Philippines	78	54		68	85	147
Saudi Arabia	0	75		0	6	4
Singapore	102	350		325	247	377
Sri Lanka	5	20		6	9	31
Syrian Arab Republic	0	0		10	19	25
Thailand	148	327		475	650	689
Turkey	163	56		193	324	453
United Arab Emirates	0	0		0	2	4
Viet Nam	0	147		41	61	82
Australia	553	980		1409	2143	2739
Fiji	0	0		2	4	5
New Zealand	68	117		280	337	404
Papua New Guinea	0	0		2	4	4

Source: FOA (2010)

1.2 Fibre for Paper Production

Paper can be broadly classified into two types which high fibre paper and low fibre paper. Usually, paper is used and selected base on the fibre quantities in that paper and the usage of the paper. In paper manufacturing, every stage of the paper production and consumption cycle is associated with a range of potential environmental problems. Most wood fibre, from which pulp and paper are made, comes from natural forests managed for timber production in North America, Europe, and Asia and from plantations around the world. Only 2 percent of wood fibre comes from tropical rainforests and virgin temperate hardwood forests (World Resources 2001). Pollution could actually be worsened by a physical or economic scarcity of wood fibre in the future, particularly in developing countries. Shortages could encourage greater use of nonwood fibres for papermaking, like straw, bagasse, and bamboo. Nonwood fibres are already a significant raw material in China and India, but only about 8 percent of the world's papermaking capacity is nonwood based (FOA 2011).

1.3 Problem Statement

Global warming has been discussed over and over again. One of the factors of global warming is the amount of carbon dioxide (CO_2) or the greenhouse gas in the air. The high emissions of CO_2 in the air are because of the pollution from power plants, vehicles and harvesting the trees. Similarly with power plants, vehicles like cars, trucks, and aeroplanes also emit the carbon into the air. The Earth is now receiving 30% more solar radiation than it did 4.6 billion years ago. And there have always been cycles of ice ages and warmer “interglacial” periods, depending on the Earth’s orbit, solar radiation strength and changes in ocean currents (Eric, 2011). Figure 1.1 shows the global mean surface temperature from year 1880 until 2000.

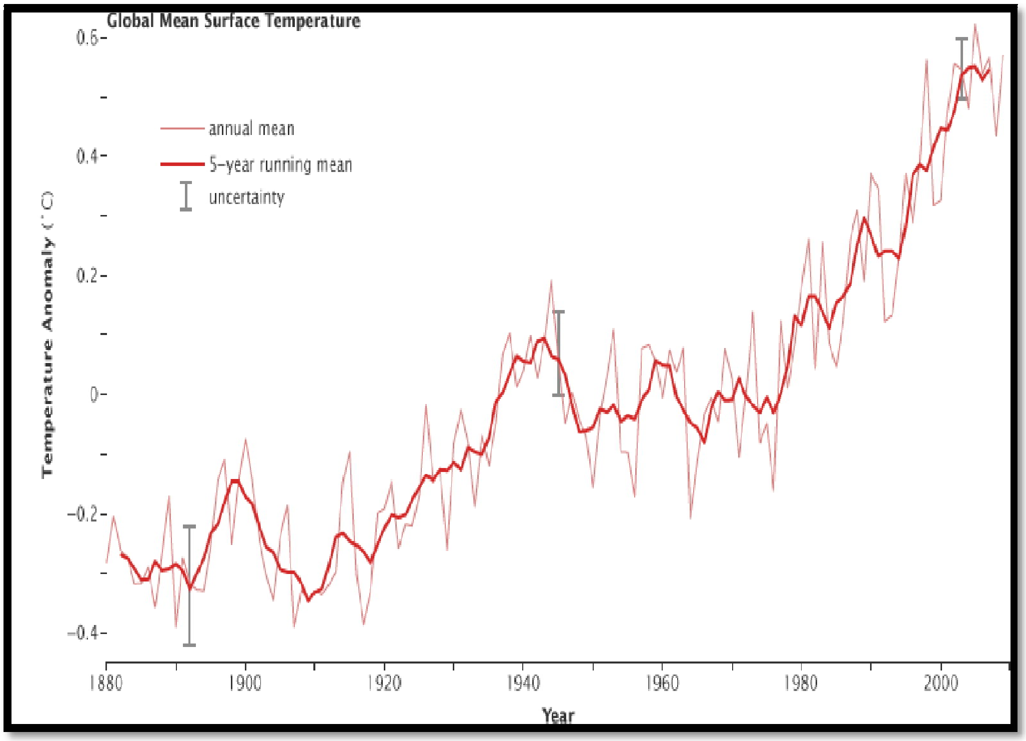

Figure 1.1: Global mean surface temperature.

Source: Riebeek (2010)

Despite ups and downs from year to year, global average surface temperature is rising. By the beginning of the 21st century, Earth's temperature was roughly 0.5 degrees Celsius above the long-term (1951–1980) average.

In addition, trees' harvesting to produce the paper also contribute to global warming. During photosynthesis process, plants use the carbon dioxide (CO_2) and release the oxygen (O_2). Decreasing of trees had caused more CO_2 in the air. Therefore, one of possible ways to solve this problem is by recycling the papers. In fact, paper fibre recovery options can give great impact in reducing climate change, greenhouse gases, forest preservation, water and air pollution, waste management and energy problems. Hence, by recycling the fibre paper used, more earth problem can be solved.

1.4 Research Objectives

There have two objectives in this research. The first objective is to establish the minimum paper fibre targets using property cascade analysis for a paper making process after looking at the possibility of using the available fibre sources within the process to meet its fibre demands. Second objective is, to assess the application of the property cascade analysis (PCA) method to an urban case study.

1.5 Scope of Study

In order to achieve the objective, three key tasks have been identified in this study.
The scope of this study includes:

a) Analyzing the potential of paper recovery
b) Establishing a new paper fibre targeting procedure for maximum paper fibre recovery using cascade analysis technique
c) Applying the property cascade technique on an urban case study to illustrate the effectiveness of the approach.

1.6 Rationale & Significance of the Study

This research is to improve the paper making process and the paper recycling. By minimizing the paper fibre targets, we can recycle more papers and reducing the fresh fibre in production.

The Property Cascade Analysis (PCA) is a new method has been developed to establish the minimum fresh fibre and waste fibre targets for paper manufacturing. PCA is a numerical technique that can quickly yield accurate targets for a maximum paper fibre recovery network. The PCA eliminates any tedious steps of graphical technique and quickly yield the exact utility targets and the pinch location in order to achieve the minimum fibre targets during network design.

CHAPTER 2

LITERATURE REVIEW

2.1 A Review on Cascade Analysis Technique

2.1.1 Water Cascade Analysis (WCA)

Pinch analysis has been established as a systematic tool for optimal design of resource utilization networks including heat, water, mass and gas systems. Application of pinch analysis typically involves two key stages, resource targeting and design**.**

In Manan *et. al*. (2004) work, it method mostly same with this research which they achieved the minimum water flow rate targets using the water cascade analysis (WCA) technique. The first step in the WCA is to set up the interval water balance table to determine the net water source or water demand at each purity level. Then, the next step in the WCA is to establish the fresh water and waste water targets for the process. It is to consider both the water flow rate balance and the concentration force (water purity) hence the true minimum water target obtained. Figure 2.1 shown the water cascade and pure water cascade diagram which it is to determine the interval fresh water demand.

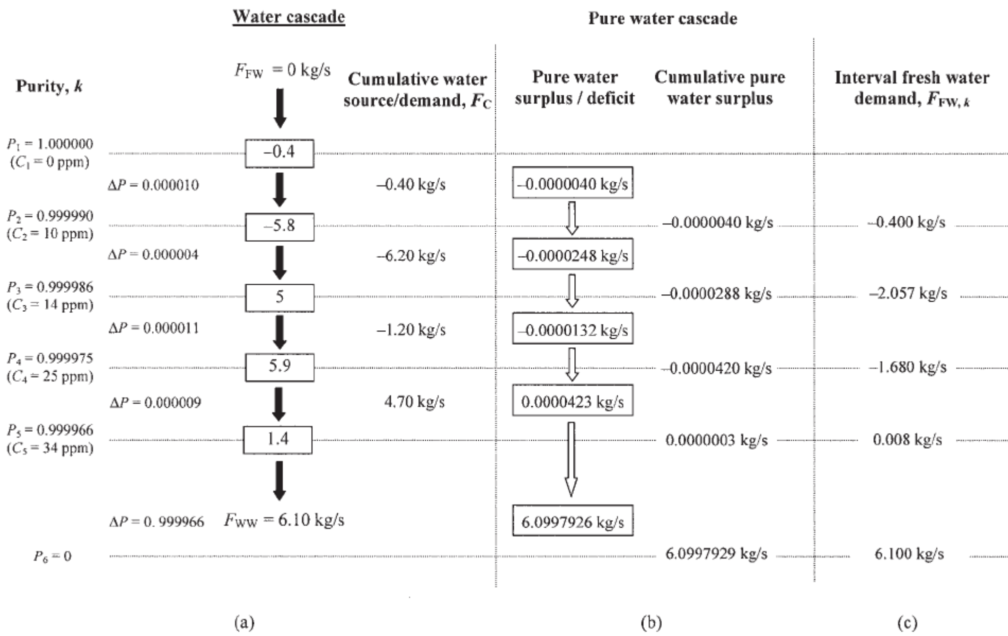

Figure 2.1: (a) Water cascade diagram with an assumed fresh water flow rate of 0 kg/s ; (b) pure water cascade is used to check the feasibility of the water cascade; (c) interval fresh water demand to determine the fresh water amount needed in each purity interval.

Source: Manan *et. al*. (2004)

2.1.2 Property Cascade Analysis (PCA)

Property surplus diagram and cascade analysis are used to determine the minimum flowrates of resource in a property-based network. Property surplus diagram is used to provide a basic framework to determine the target for minimum fresh usage, maximum recycle and minimum waste discharge. The PCA technique is next established to set the target and eliminate the iterative steps with graphical approach. The key features of PCA are the material allocation target, along with the minimum fresh and waste targets. Based on Foo *et. al.* (2006) work, the main property of solvent that used in evaluating the reuse and recycle is the Reid Vapour Pressure (RVP). RVP is important in characterising the volatility, makeup and regeneration of the solvent.

Figure 2.2 shows the final configuration of the paper making process that was achieved by Foo *et. al.* (2006).

Level, k	ψ_k	$\Sigma_j F_j$ (ton/h)	$\Sigma_i F_i$ (ton/h)	$\Sigma_i F_i - \Sigma_j F_j$ (ton/h)	$F_{C,k}$ (ton/h)	Δm_k (ton/h)	Cum. Δm_k (ton/h)
					F_F = 14.95		
1	0.738						
					14.95	3.02	
2	0.536	-40		-40			3.02
					-25.05	-1.67	
3	0.469		90	90			1.35
					64.95	5.66	
4	0.382	-100		-100			7.01
					-35.05	-7.01	
5	0.182		60	60			**0**
					F_D = 24.95	4.54	**(PINCH)**
6	0.000						4.54

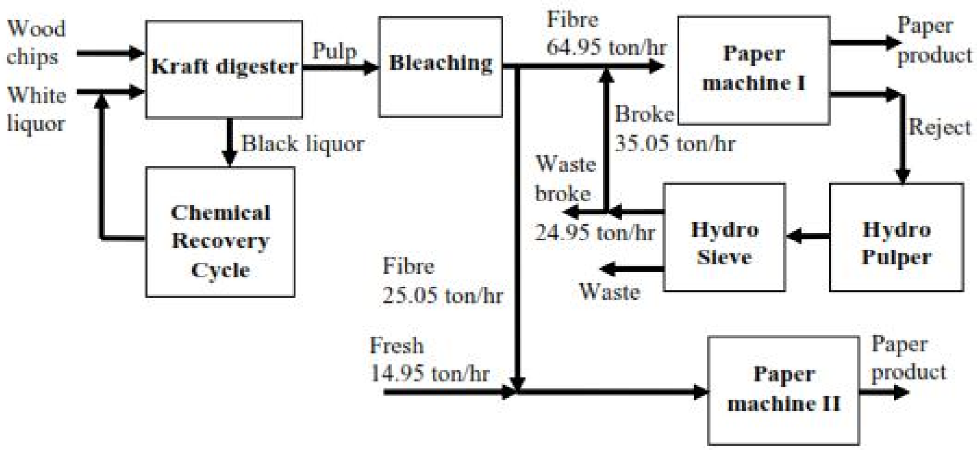

Figure 2.2: Final configuration of the paper making process.

Source: Foo *et. al.* (2006)

2.2 A Review on Paper Fibre Recovery

Application of pinch analysis for paper recycling was first introduced by Foo *et. al.* (2006). However, their method is only focused on recycling of rejected waste fibre (termed as "paper broke") from within a paper recycling plant to satisfy the relevant paper demand. The authors used a method called Property Cascade Analysis (PCA), a numerical technique for setting the minimum paper requirements that uses flowrate and reflectivity as the limiting data. Internal recycling of paper broke allows resource usage to be maximized and fresh fibre consumption to be reduced.

Kit *et. al.* (2011) work, extends the concept of pinch analysis to determine how post-consumer waste paper recycling can be maximized to produce various recycle paper types. Post-consumer waste paper being discarded by consumers after being used can come from various sources such as newspapers, magazine papers, office and printing papers, and boxes. Each type of paper has different fibre quality. For example, newspaper has the lowest fibre quality while white A4 office paper has the highest fibre quality. Mixing all these different types of papers of different qualities to produce recycle paper will reduce the purity of the highest quality fibre. Proper segregation and mixing of paper types according to their fibre qualities can produce different recycle paper qualities.

Their procedure includes targeting the minimum fresh fibre usage by determining the maximum recycle fibre allocation using the Source and Sink Allocation Curve (SSAC), and finally designing the maximum waste paper allocation network that achieves the fibre targets using the Network Allocation Diagram (NAD). Their work applies the generic graphical approach for simultaneous targeting and design of a maximum paper recovery network to determine the maximum amount of recycled waste paper that can be reused.

CHAPTER 3

METHODOLOGY

3.1 Data Gathering

There will be two types of the paper, the high fibre papers like magazine and manila card as well as the low fibre papers like tissue paper, newspaper, A4 paper and corrugated box. The limiting data is consists the amount of fibre fraction for the different types of waste paper and the amount of waste paper generated by students and staff in Universiti Teknologi Malaysia (UTM).

Then, the fibre fraction in different types of the paper wastes can be calculated by equation 3.1:

$$Fibre\ fraction = \frac{\text{Oven dry weight}}{\text{Air dry weight}} \tag{3.1}$$

The others data for this research are the amount of waste paper generated as a source and amount of new paper produced as a demand. The weight and fibre fraction for each type of paper (for an area of 300cm^2) are listed in Table 3.1 and Table 3.2. The amount of usable fibre contained in each type of paper can be extracted by calculating the fibre fraction for each type of paper.

Table 3.1: Weight and fibre fraction for each type of high fibre paper.

Type of paper	Initial Weight ($g/300cm^2$)	Final Weight ($g/300cm^2$)	Fibre Fraction
Magazine	3.12	3.00	0.9615
Manila Card	6.94	6.60	0.9510

Source: Kit *et. al.* (2011)

Table 3.2: Weight and fibre fraction for each type of low fibre paper.

Type of paper	Initial Weight ($g/300cm^2$)	Final Weight ($g/300cm^2$)	Fibre Fraction
Tissue Paper	0.93	0.92	0.9935
A4 Paper	2.63	2.47	0.9392
Corrugated Box	18.34	15.38	0.8387
Newspaper	1.50	1.49	0.9955

Source: Kit *et. al.* (2011)

A total of 200 surveys were distributed around UTM campus in order to estimate the weekly amount of paper used. The types of paper in the questionnaire are typically used by students and staff in UTM were averaged and scaled up according to the total UTM population of 26 800 students and staff.

The total weight for each type of paper was calculated by using equation 3.2 based on the data that were collected. Then, that used as a source for each of paper.

$$Total\,Weight = \frac{Initial\,weight(g) \times Area(cm^2) \times no.of\ pages\ \times Paper\ Amount(per\ week) \times 1kg \times 1tons}{300cm^2 \times 1000g \times 1year \times 1000kg} \tag{3.2}$$

Compared to the original paper, the amount of fibre paper recycled as source was assumed to be degraded by 10%. The data is shows in table 4.3 and 4.4 for high paper fibre; also table 4.9 and 4.10 for low paper fibre. Degradation can be happen when the paper undergoes fibre processing steps which it can be include bleaching, washing, stirring, screening and flotation process to remove all contaminants.

3.2 Targeting the Maximum Paper Recovery Using Property Cascade Analysis (PCA)

In order to find the maximum paper fibre recovery, there have two steps in this calculation. Firstly is doing limiting paper data and then constructing the property cascade table (PCT) from the data gathered.

3.2.1 Limiting paper data

Operator for paper is water fraction and it important as a data in this calculation since the water fraction of fresh fibre is zero. Water fraction can be determined by using equation 3.3:

$$\text{Water Fraction, } \Psi = 1 - \text{Fibre Fraction} \tag{3.3}$$

Water fraction was used as operator compared to fibre fraction since in fresh fibre, the water fraction is zero hence the water fraction is more suitable as an operator. The fibre fraction of paper source was assumed to be 10% less than the fibre fraction of paper demand due to degradation.

3.2.2 Constructing Property Cascade Table (PCT)

To construct property cascade table as the water cascade table in Table 3.3, a few tables and calculation were needed after gathered limiting paper data. That can be started by calculating interval property balance table, infeasible property cascade, and feasible property cascade.

Table 3.3: Water Cascade Table (WCT)

Level, k	Concentration, C_k (ppm)	Purity, P_k	$\Sigma_j F_{D,j}$ (kg/s)	$\Sigma_i F_{S,i}$ (kg/s)	$\Sigma_j F_{D,j} + \Sigma_i F_{S,i}$ (kg/s)	F_C (kg/s)	Pure Water Surplus (kg/s)	Cumulative Pure Water Surplus (kg/s)
						$F_{FW} = 2.06$		
1	0	1.000000	−1.2	0.8	−0.4			
						1.66	0.0000166	
2	10	0.999990	−5.8		−5.8			0.0000166
						−4.14	−0.0000166	
3	14	0.999986		5.0	5.0			0
						0.86	0.0000094	
4	25	0.999975		5.9	5.9			0.0000094
						6.76	0.0000608	
5	34	0.999966		1.4	1.4			0.0000702
						$F_{WW} = 8.16$	8.1568655	
6	1,000,000	0						8.1569358

Source: Manan *et al.* (2004)

3.3 Paper Fibre Network Design

PCT is constructed in order to obtain the exact utility targets and the pinch location. Then, identify the pinch-causing stream the exact paper fibre allocation for the regions above and below pinch to achieve the minimum paper fibre targets during network design.

Figure 3.1 shows, in order to fulfill D01 requirement, 285.93 tons of fresh fibre per year and 114.07 tons of S01 (old magazine fibre) need to be fed into the system. For D02, 254.89 tons of fresh fibre per year and 145.11 tons per year of S01 are needed to fulfill the requirement. Excess fibre source will be considered as waste fibre, but for high fibre grade, a total of 78.84 tons per year of waste fibre will be sent to low grade for further usage. Kit *et. al.* (2011).

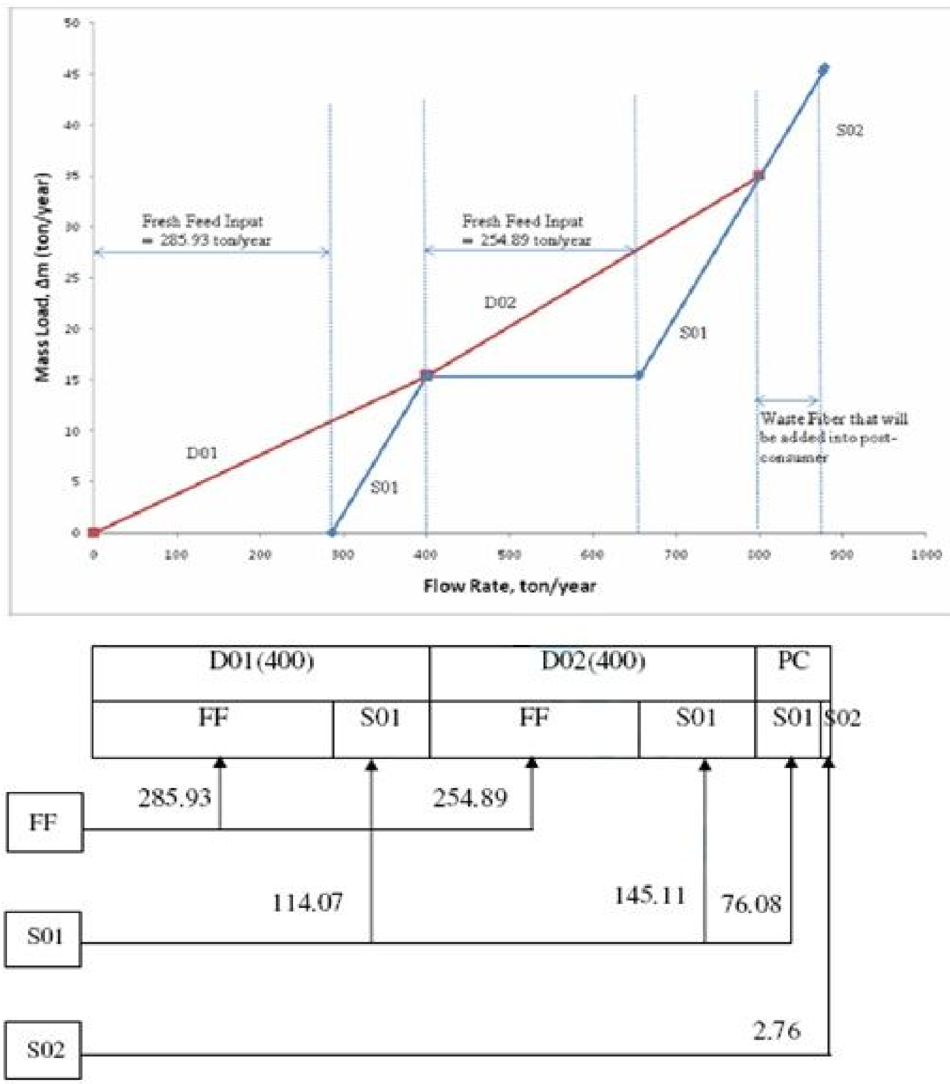

Figure 3.1: Example of Network Allocation Diagram (NAD)

Source: Kit *et. al.* (2011).