CHAPTER 1

INTRODUCTION

1.1 Motivation:

The pulp and paper industry ranks third in the world among the top water-intensive industries [1]. While paper manufacturing consumes several kinds of raw materials; fibrous materials, additives, retention aids, and water in different quantities and types, it also generates a significant quantity of wastewater that can potentially be very polluting [2]. It is known that variables affecting resource consumption, wastewater generation, and their costs are highly interrelated. Therefore, in addition to a concern about production and product quality, the environmental issue is subjected to management consideration.

To optimize resource use and wastewater generation, it is necessary to determine the relationships between all variables involved. The challenge that must be met before these interrelationships can be identified and used in day-to-day application involves the selection of variables in the production process. This selection procedure can successfully determine the connections between the critical parameters and assist in the selection of operating conditions for the manufacturing process in order to achieve the balance between desirable inputs and outputs. In the example being studied in this work, the production of industrial paper, the interrelationships of quantity and quality among the input variables and the output variables are explored by mathematical and statistical analysis. Examples of input variables in this situation are the type of pulp such as virgin pulp and wastepaper pulp; the type of chemical additives such as starch and emulsifier, the quantities of alum, filler and clay, and the utility consumption. Output variables are the wastewater quantity and quality including Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), and Suspended Solids (SS).

The mathematical multivariate analysis technique called Factor Analysis (FA) is frequently used for reducing large numbers of interrelated variables into a smaller set of factors with a minimum loss of information. It can be valuable for describing complex systems such as those found in paper manufacture [3,4,5, and 6]. When accompanied by Multiple Regression Analysis (MRA), this technique enables the prediction of the change in output variables from a combination of related input variables, especially, those which are grouped by factor analysis. Hence, it is expected that the relationship between wastewater generation and production conditions in paper production can be quantified. In addition to the number of significant factors related to the material input used in industrial paper production, FA can also provide a concise description of the pattern of variation among these factors. MRA can provide a predictive model that is useful for further management applications, such as optimization of wastewater quality, while maintaining product quality and production costs within desirable limits. Of great benefit would be the development of user-friendly software that provides both input of materials and utility consumption and relates them to wastewater generation (and possibly other environmental impacts) from the production process.

At present, several research papers on modeling of paper production have been reported [3, 4, 5, and 6]. However, these studies have not emphasized the relationships between the raw materials used and the quality and quantity of the wastewater generated. Therefore, it remains a challenge to study and develop a model that predicts wastewater generation and its characteristics on the basis of the information currently available.

1.2 Objectives:

- The specific objective is to develop a model that can be used as a guideline for the manufacturer of industrial paper in controlling their operations with the aim to lower the environmental impacts from wastewater.
- The strategic objective of this study is to investigate the application of the multivariate analysis technique as an approach for the development of a management tool for characterizing of the relationships between wastewater generation and production conditions in the manufacture of industrial paper.

1.3 Hypothesis:

The applied multivariate analysis technique can provide a concise description of input conditions; raw material use and resource consumption, as well as predictive information about wastewater generation from an industrial paper production process, and can be further used as a template for wastewater management for the industrial sector beyond paper production.

1.4 Scopes of the Study:

The research focused on the determination of the relationship between input used in the production process and wastewater load as model by using the multivariate analysis techniques called Factor Analysis and Multiple Regression Analysis for the production of industrial paper at the site selected in Thailand for 21 months during January, 2001 to September, 2002. The study included the processing steps, the types of product and the quantified data for the related variables as follows:

1.4.1 Processing steps: These include the preparations of wastepaper, chemicals and papermaking.

1.4.2 Types of products: Two main kinds of industrial papers are studied.

1.4.2.1 Gypsum liner board: consisting of two types of product that are different in composition and characteristics: Gypsum Face liner (GF) and Gypsum Back liner (GB) whose basis weights are 225 and 215 rams per square meter (gsm), respectively.

1.4.2.2 Duplex coated board (DP): comprising five grades of different basis weight: 450, 400, 350, 310 and 270 gsm., respectively.

1.4.3 Related variables data: These data, which are data in a year called cross-sectional secondary data, contain the information about input and output variables that are different, depending on paper types and grades.

Measured input variables in this study include:

- Type of fibrous materials: consisting of both virgin fibers and secondary fibers, namely, A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8, and A_9 (details in Chapter 2).

- Water and electricity consumption.
- Wet end chemicals: both the types and amounts of all the chemicals, processing aid chemicals and fillers, alum, emulsifier, defoamer, cato (modified starch), starch, and clay.
- Coating chemicals: all type and amount of pigments (color), binder, (latex) and other materials that are used for coating, such as lubricant.

Measured output variables in this study include:

- Wastewater volume and quality: Suspended Solid (SS), Total Dissolved Solid (TDS), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD).

1.5 Methodology:

The methodology used in this study consists of five major steps as shown in Figure 1.1.

1.5.1 Site surveying:

This was performed at three industrial paper production sites in order to determine the most appropriate site for the study based on the availability and quality of information. It was found that only one production site of the industrial paper plant was the most appropriate among the sites surveyed.

1.5.2 Data collection and pre-analysis:

Data collection is conducted based on the production records available from daily operations for 21 months (during January, 2001 to September, 2002) for both gypsum liner board and duplex coated board manufacture. The raw process data, consisting of resource consumption variables and wastewater variables for each product, are obtained from the following processing steps: wastepaper plant, chemical preparation, and papermaking. It is noted that the information related to wastewater is obtained by using composite samples for each day.

Data pre-analysis, data conversion and conditioning are performed to set aside any incomplete data and to reorganize the data prior to analysis.

Data converting is required to convert the units of all measured variables from time base to a production base. Data conditioning is carried out by preliminary

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screening of the data in order to identify and set aside invalid data as mentioned in Chapter 4.

Then, the spreadsheet of input and output variables for each product is organized and reformatted into an analyzable form.

1.5.3 Data Analysis and Modeling:

This is conducted to obtain as much information as possible through organization of the data by applying a multivariate analysis technique that includes factor analysis and multiple regression analysis, assisted by spreadsheet, mathematical and statistical programs: Excel, Mathcad, and SPSS.

There are two major parts of the data analysis. The first part is performed to determine the correlation between inputs and factors. The second part is performed to identify the linkages between factors and wastewater load.

The detail of data analysis and modeling are presented as the following.

1.5.3.1 Factor Analysis (FA, Model I): It is applied to reduce a large set of input conditions data to a new smaller set of data. The strategy for building the FA model consists of the following stages [8-12].

1.5.3.1.1 Data preparation: The data preparation is in terms of the types and amounts of variables for the valid data obtained from 1.4.2. In this stage, the data for 14 months (January, 2001 – February, 2002) is used for model building. The original data matrix is obtained.

1.5.3.1.2 Calculation: The input data matrix will be calculated to find the correlation coefficients for correlation matrix in order to meet the specified objectives of grouping the variables.

1.5.3.1.3 Factor determination: A large set of variables is extracted by aggromerating variables of a similar variation pattern into the same factor using the technique called principal component method. In such technique, the eigenvalues are used to identify the optimum factors that can be extracted, then the factor matrix is obtained.

1.5.3.1.4 Description of Factor: The result of factor extraction is described by either un-rotation or rotation of factors, then the significant factors are obtained.

1.5.3.1.5 Factor score determination: The factor scores are needed to be computed and used as new independent variables for regression analysis.

1.5.3.1.6 Validation: The validity is determined by moving-case-by-case with new data that was not included in the original design stage based upon the original sample size. This new data was collected within a different period of 7 months (March – September, 2002) were used for model validation.

Note that outcomes of FA are significant factors and, particularly, factor scores that are used as a new variable set for subsequent multiple regression analysis.

1.5.3.2 Multiple Regression Analysis (MRA, Model II): It is used to analyze the relationships between wastewater load and significant factors from FA model for predicting wastewater generation as follows [13-16]:

1.5.3.2.1 Data preparation: The approach leading to the design of this model combines the new independent or predictor variables (significant factors resulting from FA model) with the dependent variables (wastewater load; SS load, TDS load, BOD load, and COD load) using the same set of data that lead to building of Model I.

1.5.3.2.2 Model Investigation: This is performed through 11 different basic equations. If one of these models meet statistical significance; R^2 (coefficient of determination), SE (standard error), and F-statistics at a significance level of 0.05, it is used as the proposed model in the next step.

1.5.3.2.3 Model Testing: This is performed to test the appropriateness of the proposed model through three underlying assumptions of MRA; Independence, Normality, and Homogeneity of the residual or error term for the relationship between dependent and independent variables. These assumptions will be tested through FA for Independence, Kolmogorov-Smirmov and/or Shapiro-Wilks tests at a significance value of 0.05 for normality, and Levene's Test for homogeneity. The model resulting from this stage is used for later analysis.

1.5.3.2.4 Estimating Model Parameters: The parameters of MRA model are estimated by iteration search process. Then, the predictive equation is obtained.

1.5.3.2.5 Evaluating and Interpreting the model: The statistical significance: R^2 (coefficient of determination); and F-test including the residual plot. The underlying MRA assumptions are considered. If theses assumptions are satisfied and there is no outlier or influential observations from the 1.5 Inter-quartiles (1.5 IQR) test, then, the proper prediction equation is obtained. If the testing does not meet the assumptions and there are influential observations, the analysis from stage 5 has to be repeated once again.

1.5.3.2.6 Validation: The validity is determined by the same set of data used for validation of FA model for testing the generalizability of the model.

According to the multivariate technique theory, significant variables of wastewater generation are identified from among the sets of input used in process operations. Use of this technique is expected to help to manage the production of industrial paper through the identification of the root causes or events occurred in the production process. The proper actions are then purposed for management applications.

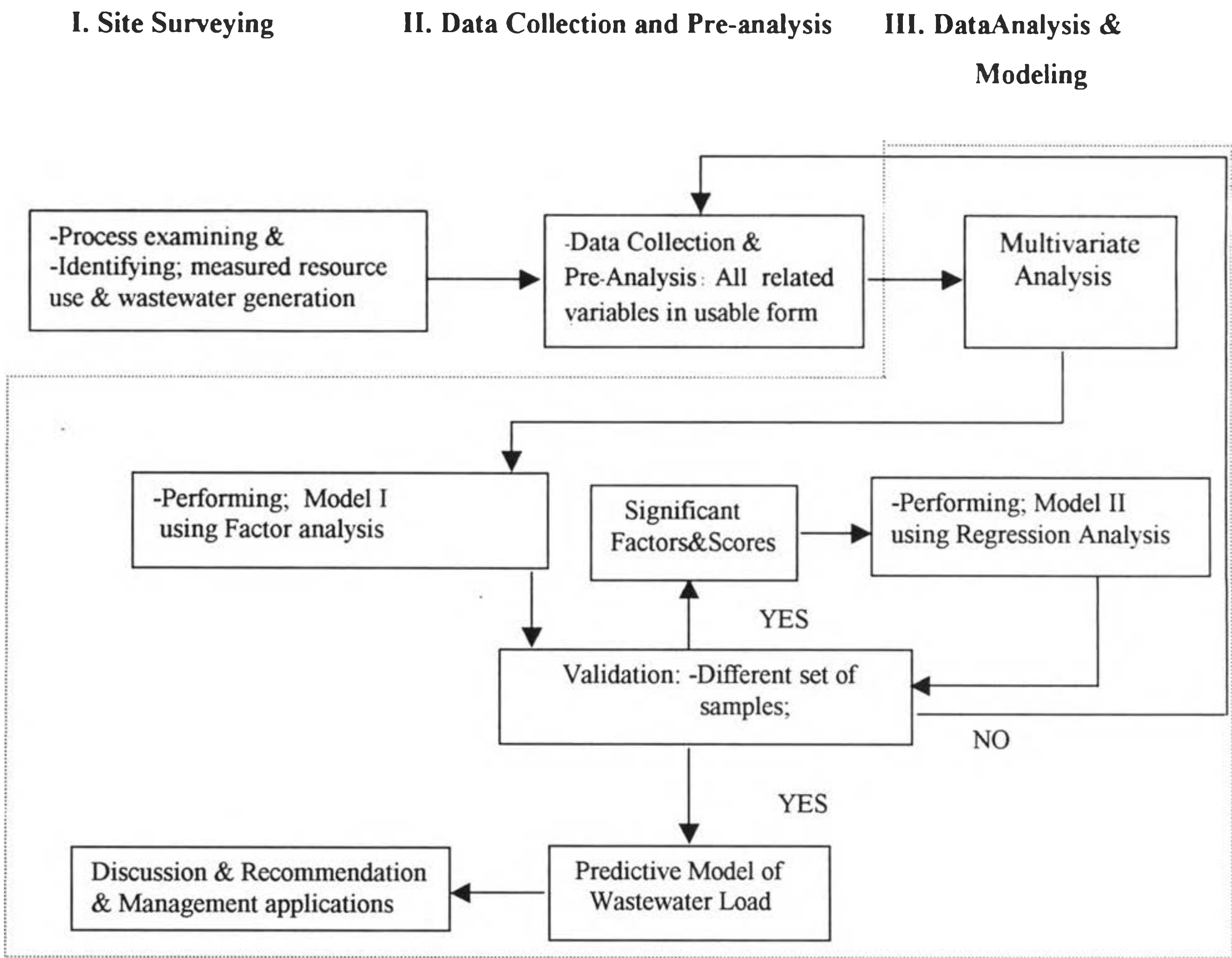

Figure 1.1 Schematic Diagram of Methodology

1.6 The Expected Advantage of this Research:

1.6.1 This research program is designed to determine the relationship between input and output of the production process through the construction of predictive model using multivariate technique consisting of FA and MRA. This can help manufacturers to have greater understanding in the relationship between these raw materials and the resulting wastewater characteristics for industrial paper production, and to obtain necessary information to manage wastewater load.

1.6.2 The outcome based upon the same modeling approach can be applied as a strategy for the production environmental management, and should be extendable to other processing industries and/or other environmental situations, particularly those resulting in the generation of wastewater.