CHAPTER 5

GYPSUM LINER BOARD: RESULTS AND MODELING

This chapter provides the description of Gypsum liner board production (GP) model for both face liners (GF) and back liners (GB), developed to determine the patterns of variation of material input use and utility consumption for GP in order to predict the interrelations among these variables and wastewater load of interest.

5.1 Model I: FA Input Model

5.1.1 Correlation Matrix

Based upon the original input data matrix of GF and GB, the correlation matrices of GF and GB were constructed by calculation the covariance of each pair of input variables called correlation coefficient (Table 5.1, and 5.2).

From Table 5.1, it was found that the correlation matrix of the material input of GF showed a range of correlation coefficients or standardized covariances between the pair of variables. The range showed different values that indicate the degree of correlation between the variables. The degree of correlation when the number were expressed in absolute terms can be considered according to the following groupings.

1) no correlation, $| r | = 0$
2) very low correlation, $| r | >$ 0-0.29,
3) low correlation, $| r | \geq$ 0.30–0.49,
4) moderate correlation, $| r | \geq$ 0.5–0.69,
5) high correlation, $| r | \geq$ 0.7–0.99,

Among these correlations, alum, clay, and emulsifier were highly correlated with electricity (0.78 – 0.91) and also highly between the correlation of alum-clay, and alum-emulsifier (0.77 - 0.78). While the correlation between cato–starch was the highest (0.99), the correlation among the types of fibrous materials: A_2, A_3, A_4 and A_1 are moderate (0.44 - 0.73), and the correlation among alum, clay, and defoamer were the lowest (0.41 - 0.58). The correlation among these variables in this correlation matrix indicated that it was possible to group these variables into the four different groups based on moderate to high degree of correlations as shown in Figure 5.1.

Table 5.1 Correlation Matrix of Material Input of GF

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13
1.Water	1												
2.Electricity	**.65**	1											
3. A_1	.18	.2	1										
4. A_2	**.43**	.24	.73	1									
5. A_3	.21	.16	**.84**	**.84**	1								
6. A_4	-.1	-.11	**.44**	**.31**	**.54**	1							
7.Alum	**.51**	**.91**	.16	.14	.13	-.09	1						
8.Clay	**.60**	**.78**	.16	.19	.08	-.18	.77	1					
9.Defoamer	.16	**.55**	.02	.04	.14	.01	**.58**	**.41**	1				
10.Emulsifier	**.71**	**.86**	.24	.29	.11	-.09	**.78**	**.82**	**.36**	1			
11.Cato	-.04	.01	-.07	-.16	-.15	-.09	.03	.08	.12	.02	1		
12.Starch	-.03	.02	-.06	-.16	-.15	-.1	.03	.10	.12	.04	**0.99**	1	
13.Wet strength	.17	.25	-.01	-.09	-.04	-.12	**.35**	.21	.11	.24	-.21	-.22	1

Table 5.2 Correlation Matrix of Material Input of GB

Variables	1	2	3	4	5	6	7	8	9	10	11
1.Water	1										
2.Electricity	**.44**	1									
3. A_3	-.04	.02	1								
4. A_4	.18	-.14	.25	1							
5. A_5	.24	.25	-.06	-.11	1						
6.Alum	-.09	-.27	.10	**.64**	-.07	1					
7.Defoamer	.13	.06	-.02	.01	**.32**	.05	1				
8.Emulsifier	.16	.12	**.44**	.16	-.03	-.15	.13	1			
9.Cato	**.35**	**.50**	-.19	**-.44**	.70	-..20	**.46**	-.10	1		
10.Starch	-.01	**.31**	-.19	**-.42**	.70	-.20	-.05	-.25	**.59**	1	
11.Wet strength	-.19	**-.3**	**.38**	.18	**-.6**	-.001	-.19	.25	**-.68**	**-.70**	1

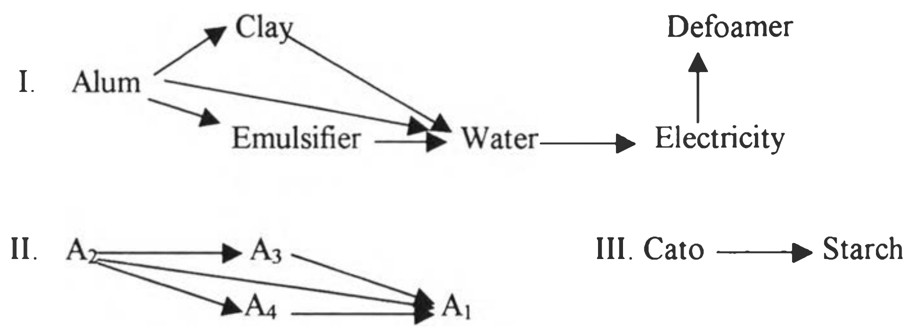


Figure 5.1 Grouping of correlation between two variables for GF

From Figure 5.1, for the first group, the moderate to high degree of correlations between the variables (alum, emulsifier, clay, water, and electricity) in this group (0.55 to 0.91) can be retained in the same factor due to their interrelationship. For the second group, the lower degree of correlations between the variables (A_1 to A_4) in this group (0.54 to 0.84) can also be retained in the same factor. For the third group, the highest degree of correlation between the variables (cato and starch) in this group (0.99) can be retained in the same factor. Some variable (wet strength agent) was ungrouped due to its lowest degree of correlation based on the correlation coefficient > 0.3.

From Table 5.2, it was found that the standardized covariance between a pair of variables or correlation coefficient of GB that has lie between –1 and +1 were about -0.7 to 0.84. It was possible to group these variables into only two distinct groups based on their correlation coefficients as shown in Figure 5.2.

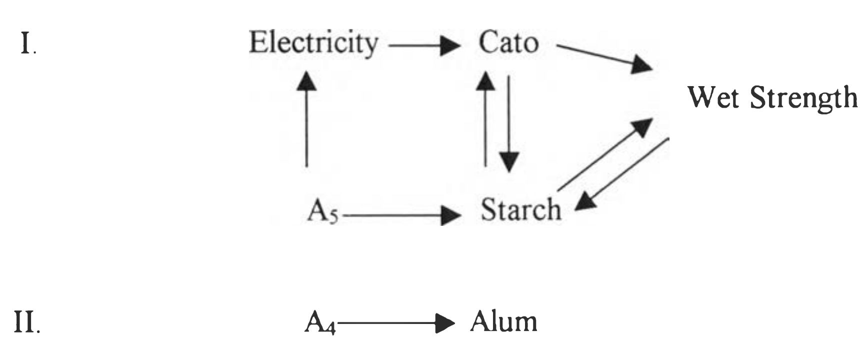


Figure 5.2 Grouping of correlation between two variables for GB

From Figure 5.2, for the first group, the moderate to high degree of correlations between the variables (cato, starch, A_5, electricity, and wet strength) in this group (-0.70 to 0.70) can be retained in the same factor. For the second group, the moderate degree of correlations between the variables (A_4, and alum) in this group (0.64) can be retained in another factor. Some variables (emulsifier, defoamer, water, and A_3) were ungrouped that either can be retained in the same factor or different factor.

5.1.2 Factor Matrix

Based on the factorization of correlation matrix where the eigenvalue greater than 1 for un-rotated factor matrix, the four significant factors for GF and GB are obtained as shown in the Scree Plot (Figure 5.3-5.4). It was found that these significant factors were extracted about 80.78% and 74.33% of the total variance explained for GF and GB, respectively. Through this extraction, based upon the significant factor loading (>0.5), the variables that correlate highly within a particular factor were reduced into the same group called "significant common factor" (Table 5.3).

Table 5.3 Total Variance Explained obtained from Extraction of GF and GB

Common Factor (F)	Percentage of Variance (%)	
	Gypsum Face Liner (GF)	Gypsum Back Liner (GB)
F_1	38.42	33.72
F_2	22.17	16.46
F_3	15.45	14.35
F_4	7.75	9.80
% Cumulative	80.79	74.33

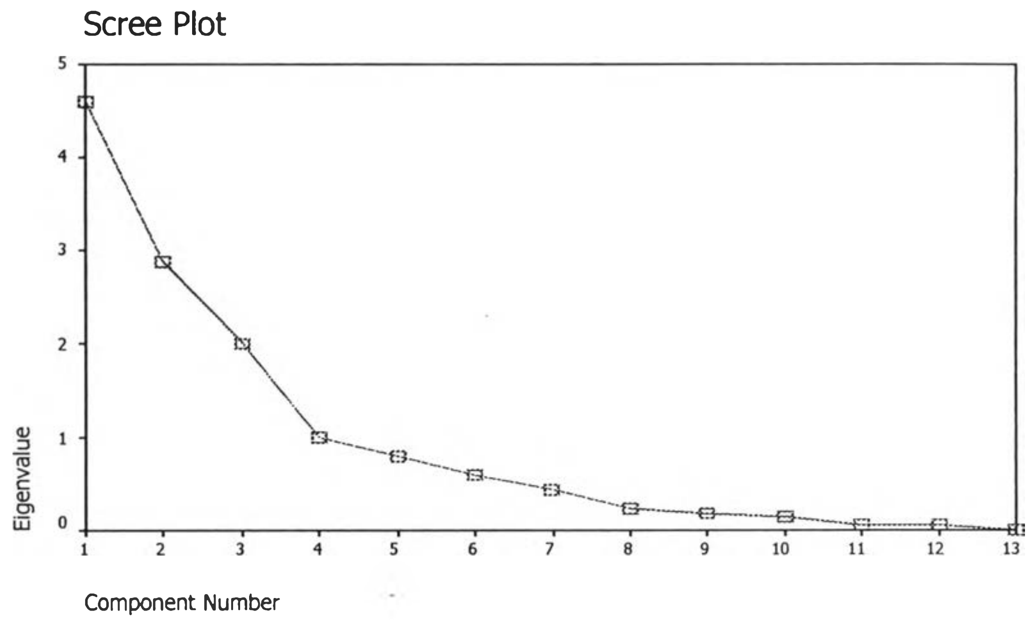


Figure 5.3 Scree Plot of Eigenvalue for GF

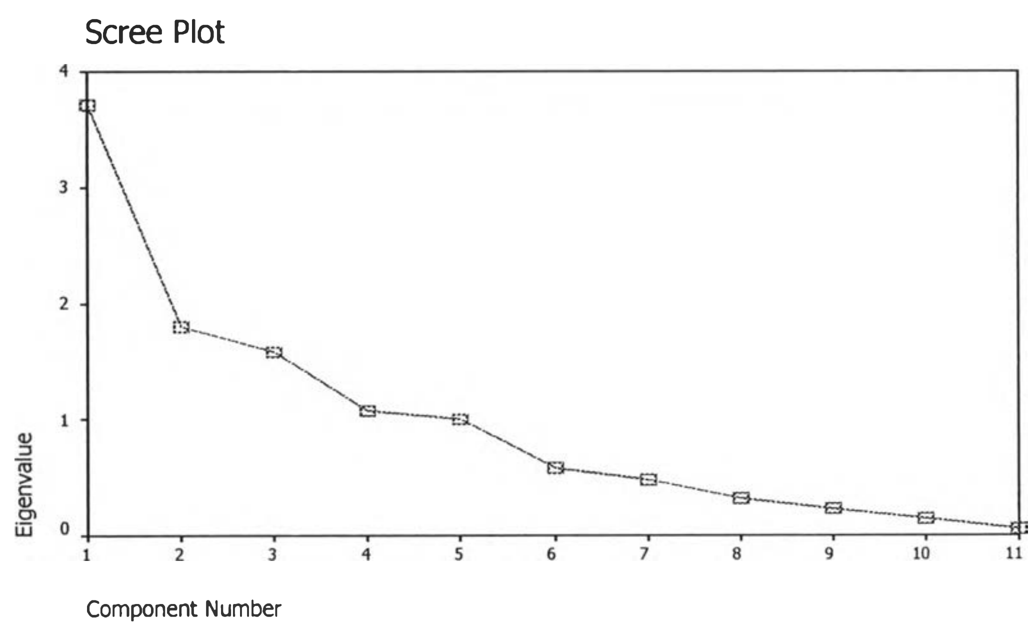


Figure 5.4 Scree Plot of Eigenvalue for GB

The first factor takes into account the largest amount of variance about 38 % and 34 % in the data sample of GF and GB, respectively. The second factor accounts for the next largest amount of remaining in the sample about 22 % and 16.5 % and is uncorrelated with the first factor. The successive factors account for smaller proportions of the total sample variance, and all factors are uncorrelated with each other.

5.1.3 Rotation of Factor (Optional)

The rotation of factor was also performed in this study (Table 5.4). However, the result of the initial extraction or un-rotated factor matrix provides variables with the percentages of total variance explained higher than these values of the rotated factor and also less ambiguous factor loading values. Thus, only the loadings of un-rotated factor matrices were used in this analysis.

Table 5.4 Total Variance Explained obtained from Un-rotated and Rotated Factor

Common Factor (F)	Percentage of Variance (%)			
	GF		GB	
	Un-rotated	Rotated	Un-rotated	Rotated
F_1	38.42	28.36	33.72	20.59
F_2	22.17	20.43	16.46	10.81
F_3	15.45	15.59	14.35	10.10
F_4	7.75	7.81	9.80	9.88
% Cumulative	80.79	72.19	74.33	51.37

5.1.4 Description of Factor

5.1.4.1 Factor Loadings

It was found that the factor loadings in factor matrices of GF and GB were obtained between (+1) and (-1) (Table 5.5, and 5.6). The factor loading indicates the correlation between a variable and a factor. The higher loadings indicate the higher correlations between variable and factor.

Usually, the factor groups together variables that are related (mathematically) to each other with a significant factor loading > 0.5, and these variables are different from other variables in the sense of their mathematics relations

5.1.4.1.1 Factor Loadings of GF

Based on the factor loadings greater than 0.5 of GF, 13 input variables can be grouped into four significant factors (Table 5.5). Each factor contains those variables whose highest factor loading is associated with that particular factor.

Table 5.5 Factor Matrix of Factor Loadings of GF

Variable	F_1	F_2	F_3	F_4	F_5
1. Water	**0.75**	-0.002	-0.006	-0.47	-0.0004
2. Electricity	**0.92**	-0.22	-0.005	0.005	-0.09
3. A_1	0.41	**0.74**	0.283	0.0004	0.18
4. A_2	0.48	**0.73**	0.182	-0.25	-0.22
5. A_3	0.39	**0.84**	0.24	0.10	0.55
6. A_4	0.007	**0.65**	0.22	0.39	0.01
7. Alum	**0.88**	-0.27	-0.007	0.22	0.003
8. Clay	**0.84**	-0.28	0.002	-0.01	-0.06
9. Defoamer	0.53	-0.22	0.11	**0.64**	-0.20
10.Emulsifier	**0.90**	-0.19	-0.003	-0.17	-0.17
11. Cato	-0.03	-0.43	**0.88**	-0.002	0.19
12. Starch	-0.002	-0.44	**0.88**	-0.03	0.18
13. Wet strength	0.30	-0.14	-0.47	0.24	**0.77**

It is found that for GF production, water, electricity, alum, clay, and emulsifier were grouped into F_1. A_1 to A_4 were grouped into F_2. Cato and starch were grouped into F_3. Defoamer was assigned to F_4. Wet strength was left out because its significant factor loading appears in F_5 and the eigenvalue of F_5 is less than 1.

5.2.4.1.2 Factor Loadings of GB

Based on the factor loadings greater than 0.5, 11 input variables of GB can be grouped into four significant factors (Table 5.6). Each factor contains those variables whose highest factor loading is associated with that particular factor.

Table 5.6 Factor Matrix of Factor Loadings of GB

Variable	F_1	F_2	F_3	F_4
1. Water	0.31	**0.60**	-0.002	-0.58
2. Electricity	**0.52**	0.39	-0.31	-0.42
3. A_3	-0.34	**0.53**	-0.21	0.35
4. A_4	-0.48	0.50	**0.59**	-0.20
5. A_5	**0.79**	0.22	0.23	0.24
6. Alum	-0.32	0.16	**0.84**	0.001
7. Defoamer	0.30	0.42	0.18	**0.52**
8.Emulsifier	-0.20	**0.66**	-0.43	0.23
9. Cato	**0.90**	0.18	0.00006	0.12
10. Starch	**0.81**	-0.24	0.005	0.008
11. Wet strength	**-0.82**	0.006	-0.35	0.0005

It was found that for GB production, electricity, A_5, cato, starch, and wet strength were grouped into F_1. Water, A_3, and emulsifier were grouped into F_2. A_4 and alum were grouped into F_3. Defoamer was assigned to F_4.

Moreover, it was seen that the eigenvalues of GF and GB were highest for the first factor and lower for successive factors, and the last factor was the lowest. This implies that the first factor explains the highest variance in the data set. Note that most of eigenvalues of GF explain the total variances in the data set of GF (4.61–1.01) more than these variances in the data set of GB (3.72-1.08). Also note that the communality of GF and GB are equal to 1. This means that a variable shares its variance in all factors. Hence, these factors are called "common factors". According to the result of factor matrices for GF and GB based upon the eigenvalue > 1 and significant factors > 0.5, the diagram of input variables of GF and GB as the common factors is shown in Figure 5.5.

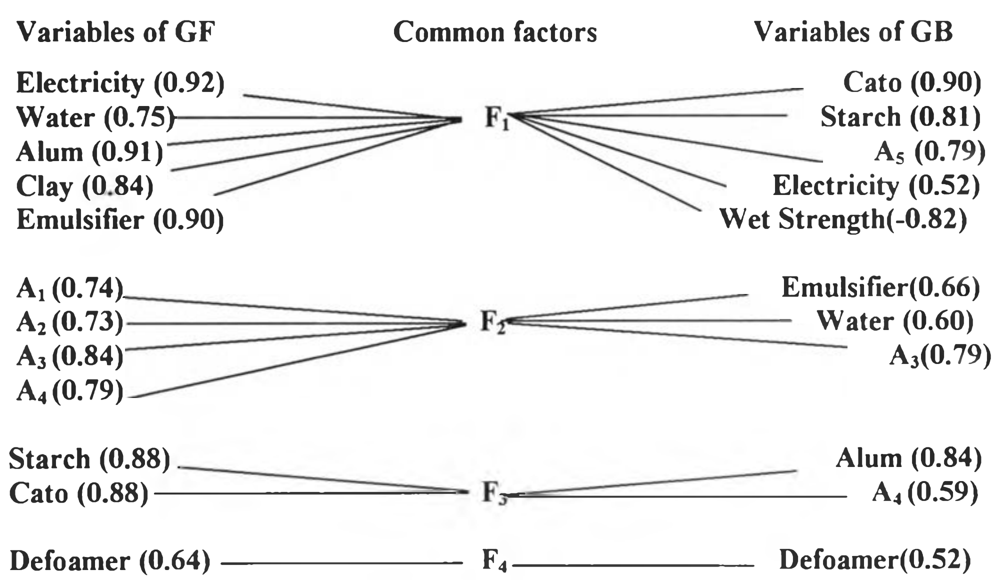


Figure 5.5 Diagram of Common Factors obtained through FA of Gypsum paper

5.1.4.2 Physical Meaning of Factors

The purpose of physical meaning is to assign a physical representation to what is common among the variables that have high loading on the factors. This is accomplished by examination the pattern of inter-correlation among variables in correlation matrix and the factor loadings in the factor matrix. The characteristic of gypsum liner board production based upon the correlation matrices and the factor loadings of un-rotated factor matrices, can be explained by the interrelationships among variables in each factor.

5.1.4.2.1 Physical Meaning of GF

The physical meaning of the common factors of GF production are shown below.

Within the factor F_1, the relationship among variables (consisting of electricity, water, clay, emulsifier, and alum) can be characterized based upon the relation in correlation matrix as follows;

1. The relationship between electricity and water can be explained through their functions in the production process. Because paper is made with water as the carrier of the fibers and as an aid to bonding. In the first step of paper making, called stock preparation, the water component in the stock is about 88-96 %. At this stage, electricity is used for pulping, screening and cleaning, and refining for recycled fiber. In the second step, electricity is also used for transport of the fiber suspension with pumps, belt, conveyors, and driving machines. Thus, when water is consumed, electricity is consumed as well. This is usually the pattern of inter-correlation between electricity and water in the factor. However, the change of water use is not always in the same direction of the change of electricity consumption, because re-circulated water is used in some situations. In this case, the changes of water usage can affect the change of electricity use in the opposite direction. The use of water re-circulated can lead to low consumption of water but high consumption of electricity. This appears as the moderate value of correlation coefficient between water and electricity (0.65). Notice that factor loading of electricity (0.92) is higher than the loading of water (0.75).

2. The relationship between chemical additives (consisting of clay, emulsifier and alum) and water can be described based upon their functions in the wet end operation. Water is used as the main medium of the furnish, which is a multi-component mixture containing several types of pulp, filler and additives. Water is also included in the preparation and dilution of the chemical additives. The chemical additives are used to improve the properties of the paper in order to reach certain desired end-use properties. Generally, when chemical additives are heavily

consumed, water consumption is also high. Thus, the pattern of inter-correlation between chemical additives and water in the factor is in the same direction. However, in some situations, where water is re-circulated as white water containing fines, fibers, and chemicals, the level of chemical additives are low but water use is relatively constant. Some additives in the white water are precipitated on the surface of fibers during deposition in the wire section of the paper machine and filtered through the filter system. In this case, white water is used as another source of the material inputs. Even though there is a sufficient amount of water, the amount of chemical additives may be less then the necessary amount resulting from their passing through the recovery system. In this case, there is a high consumption of chemical additives, but low consumption of water in the production process. In this case, the pattern of inter-correlation between chemical additives and water is in the opposite direction that typically appears among the different values of factor loadings. It is, therefore, seen that factor loadings of chemical additives are higher (0.84-0.91) than the factor loading of water (0.75).

3. The relationship between chemical additives (consisting of clay, emulsifier and alum) and electricity can also be explained through their functions in the wet end operation. In general, when chemical additives are used to improve the properties of paper, electricity is also used to transport them onto the paper machine. Thus, the pattern of inter-correlation between chemical additives and electricity is in the same direction in terms of increasing amount of their usages. Usually, the use of chemical additives per unit of production should have a constant level, and the properties of these chemicals at different times should not change substantially. However, in some situations, the change of these chemicals can be observed in the opposite direction. Although there may be other causes that affect the change in the relationship between the chemical additives and electricity use, those causes have not occurred in this situation. The possible cause should be the result of reprocessing of the out of specification product that results in lower quantities of chemical additives use and higher electricity consumption. This is because these additives are already present in the broke. Thus, it is not necessary to add more of these additives. However, the use of essentially the same amount of electricity is still necessary for material processing. In this case, the pattern of inter-correlation between the two variables is in the situation of constant additives usage but higher electricity

consumption. Notice that the correlation coefficients between alum-electricity (0.91), clay-electricity (0.78-0.86), and emulsifier-electricity (0.86) are high.

4. The relationships among chemical additives (consisting of clay, emulsifier, and alum) can be described through their roles in the production process.

Generally, chemical additives are contained not only in the furnish component but also in the white water. These additives are important in the papermaking process during the following stages in the wet end operation (Figure 5.6).

Water/White water

Fines/Fillers

Retention **Formation**

(Stock) Raw materials $\longrightarrow$ **Flocs** $\longrightarrow$ **Paper**

Figure 5.6 The Stage of Paper Formimg in the Wet End Operations

In these stages, alum and emulsifier in furnish/white water play a major role in the retention of fines and fillers (clay). The retention mechanism is largely dependent on the formation of flocs of fillers and fines. These flocs have a major role in the formation of the paper sheet. In wet end operations, changes of alum level affects changes in levels of clay and emulsifier. This is because alum, which is a water solution of aluminum sulfate with some of the aluminum in the form of aluminum hydroxide, is used to lower the pH of the stock or furnish to about 4.5-5. While emulsifier or emulsion size, called rosin size, is slightly anionic and will tend to stick to the fibers, this emulsifier is mixed with the fibers before the alum is added to the stock [52]. The alum flocculates with the rosin size and with itself, creating flocs that adhere to the fibers. The rosin-alum flocs are water resistant after drying, and their presence helps the paper webs resist water penetration.

As for clay, which is the kaolin crystalline form composed of fine particles smaller than the fibers, it will extend the furnish because it is a material cheaper than fiber and gives a substantial increase in light scattering within the web of paper. Thus, the rosin-alum-clay flocs can be precipitated and adsorbed onto the pulp fines linking in turn with the larger fibers and yielding greater retention of all the fibers forming the paper sheet that meets the required water resistance and optical properties for the paper. These stages are important to improve the retention of fines in order to attach the fines to the fibers and to form a strong wet web of paper before water is removed.

Normally, if clay and emulsifier are consumed at high level, the alum level is also high due to their corresponding functions. This indicates that the pattern of correlation between the two variables in the factor is in the same direction. However, in some situations, where white water is used as another source of chemical additives, the presence of clay in white water is still relatively high due to its fineness. Thus, it is not necessary to add additional quantities, but it is still necessary to add some emulsifier and small levels of alum as a sizes for water resistance [53]. In this situation, the pattern of its correlation is in the opposite direction. In addition, their factor loadings are different, the factor loadings of clay (0.84) and emulsifier (0.90) are lower than the loading of alum (0.91).

Within the factor F_2, the relationship among variables (containing 4 types of wastepaper; A_1, A_2, A_3, and A_4) can be characterized based on the relationship in the correlation matrix as follows.

1. The relationships among A_1, A_2, A_3, and A_4 can be explained through their components in the layers of paper. Normally, the three layers of fibrous materials of GF consist of different ratios of wastepaper used as a source of cellulose fibers. The top layer consists of A_1 and A_2 with their percentages being 25 to 30 : 70 to 75. The middle and bottom layers consist of A_3 and A_4 with their percentages being about 80 to 100 : 0 to 20 as follows (Table 5.7).

Table 5.7 Type of Wastepaper in the Layer of GF

Layer of Paper	Type of Wastepaper			
	A_1	A_2	A_3	A_4
1. Top layer	25-30	70-75	-	-
2. Middle layer	-	-	80-100	0-20
3. Bottom layer	-	-	80-100	0-20

Thus, the patterns of inter-correlation between two variables of the fibrous materials are in the same direction either increasing or decreasing amounts of these materials in the same layer. However, in some situations, the increasing in the types of the wastepapers, A_2, A_3, A_4, can cause the decreasing in the amount of A_1. This may occur if there is a use of broke as another source of fibrous material that is very much a type of dirty fibers. The broke, then, becomes the middle and bottom layers of the paper (A_3 and A_4), including some ratio of the composition of the top of the layer (A_2) as well. Thus, fibers that are mainly used in the top layer A_1 are needed in comparatively larger proportions. In these cases, the change of various types of wastepapers, A_2, A_3, A_4 is toward a lower quantity, but the needs for A_1 is higher because of the loss of A_1 in the previous process operation. Thus, their loadings are different and the loading of A_1 (0.91) is higher than A_2 (0.74) and A_4 (0.65).

2. The relationships among A_2, A_3, and A_4 can be explained through their relative contributions to the layers of paper as well. The change of A_2 affects the changes of A_3, and A_4. The reason for this change relationship is similar to the changes described in paragraph 1 above, because of the use of broke as another source of fibrous material. However, in some situations, the ratio of A_3 is increased to the maximum level of the fibrous materials in the middle and bottom layers, therefore, it is necessary to add more of it. Thus, the pattern of inter-correlation is in the opposite direction. Notice that the loading of A_3 (0.84) is higher than the loading of A_2 and A_4.

3. The relationship between A_3 and A_4 can be described through their contributions to the components in the layers of paper as well. Usually, a change of A_4 affects the changes of A_3 in the opposite direction within the limit of their ratios in the middle and bottom layers. This means that while A_3 is increased, either A_4 is not used or is used in smaller quantities. Also if the use of A_3 is lowered, A_4 is used in larger quantities. In some cases, broke is used as another source of fibrous materials. In this situation, the components of A_3 and A_4 in the broke are sufficient. In this case, the pattern of inter-correlation of A_3 and A_4 is in the same direction. However, their loadings are still different due to the high cumulative effect of their correlation in the opposite direction that overwhelms this effect in the same direction according to their ratios as shown in Table 5.7. Hence, the factor loading of A_3 (0.84) is higher than A_4 (0.65).

Within the factor F_3, the relationship among variables (consisting of cato and starch) are discussed below.

The relationship between cato, which is a modified starch, and starch can be explained through their functions. Usually, the retention of modified starch (cato) is better than that of native starch. In general, cationic starch such as cato is used to help large amounts of native starches that are either anionic or non-ionic in nature to be fixed to the furnish leading to improved starch retention and reduced pollution. Thus, if the starch is consumed to a high degree, cato is also highly consumed within their proper proportion for the required quality of the product. Based on the correlation matrix, the correlation between these two variables is the highest, about 0.99. This means that these two variables are highly correlated in the same direction. Although cato and starch are wet end chemicals, their functions are different from other wet end chemicals, and they are grouped in another factor. Both cato and starch are used as dry strength and bonding additives to help glue or bond the fibers together. Starch is chemically quite similar to cellulose and can be used to bond to the fibers, resulting in an increase in the degree of bonding in the web. Note that both cato and starch have the same factor loadings, thus, their importances are the same due to the similar functions as bonding agents within the paper.

Within the factor F_4, the relationship of a single variable, defoamer shows a correlation of its variable and factor with the moderate factor loading (0.64). Despite its correlation with alum, clay, and electricity, defoamer has quite a low correlation coefficient between a pair of these variables. Hence, it appears as a single variable. In some situations, if white water and broke are used as another source of material inputs, the composition of the furnish in the process is different. If there is an improper amount of alum and emulsifier, insufficient pH level adjustment may result. This condition can sometimes cause poor size retention and aggravate foaming problems due to the increasing of surfactant and occurrence of bubble in the production process. When the bubbles of foam occur, more defoamer will be used to eliminate them in order to maintain the product quality.

It is noted that, through the pattern of inter-correlation between two variables in common factors of GF, some variables should be included in the material input FA model of GF, namely, broke and white water in order to obtain the best information for a deeper understanding of the large set of data for the GF production.

Furthermore, it can be concluded that F_1- F_4 are quite well represented in the original set of data variables. Although there is a pitfall due to the lack of a few variable in material input FA model, its applicability for further analysis and development of the predictive model for wastewater from GF production will bw tested in the second phase.

5.1.4.2.2 Physical Meaning of GB

Since GB is used as a back side of Gypsum liner board, the strong fiber bonding is needed for GB. Thus, china clay which is used as filler for GF is not used for GB because it adversely affects fiber bonding and affects some paper properties such as bulk, opacity and smoothness [40]. In addition, the fiber type used for GB is lesser and quite different from GF in terms of better fibrous material and cleanness. These may also affect a non-distinction in grouping input variables into factors for GB due to the less of input variables and lower variation of data for GB than GF.

The physical meaning of the variables in all of the significant common factors of GB production based on the correlation matrix and factor loading are presented below.

Within the factor F_1, the relationship among variables (consisting of cato, starch, A_5, electricity, and wet strength) can be characterized their relationships based upon the correlation matrix as follow.

Notice that wet strength has negative loading (-0.82). Thus, the relationships among wet strength, starch and cato can be classified into two groups according to their directions on the factor, having both negative and positive axes.

1. The relationship between wet strength and factor on the negative axis in the opposite direction of the other variables can be explained through its function. Due to its negative loading value (-0.82), this means that wet strength is not correlated with other variables in the factor. However, it indicates that wet strength is mathematically related with the factor in the direction of the negative axis or the opposite direction of the positive factor axis. In terms of explanatory power, -0.82 is also as good as +0.82. Thus, wet strength is also high correlated with the factor (-0.82) in a negative factor axis.

Commonly, wet strength agents, which are the most effective wet strength under acid conditions, function in the paper web to protect the bonding and also to help hold the fibers together when the web is wetted by the cross-linked resin network. It is very essential to use them for the paper product that may become wet during use, such as bag papers or paperboards like GF and GB that are required to retain a certain level of strength when moistened.

2. The relationship between starch and cato can be described through their functions in the wet end operation. According to their factor loadings, the loading of cato (0.90) is higher than the loading of starch (0.81).

Generally, the functions of starch and cato as dry strength agents are to enhance the strength of the bonds between fibers in the paper web while the fiber network forms and dries. Both cato and starch are used to increase tensile strength of the paper in the dry state. Native starch has normally poorer retention then modified starch (cato). It can be discharged into water effluent in a large quantity. Usually, the pattern of inter-correlation between starch and cato is in the same direction both increasing and decreasing together with the quantities of their usages. However, in some cases, this pattern is in the opposite direction due to the high consumption of cato and low consumption of starch. Although, broke containing both cato and starch in the paper layer, is used as a source of material input, it is still needed to add more cato. This may be due to the need for high tensile strength of GB in the dry state because of the use of GB as the back side of interior walls in construction. Therefore, the loading for cato (0.90) is different from the loading for starch (0.81).

3. The relationship between electricity use and the factor can be explained through its function in the production process. Generally, electricity is used to transport water, pulp and other substances with the various kinds of equipment used in the step of stock preparation and in the paper machine. It should thus be expected that water and electricity are correlated and appear in the same factor. However, the loading of both electricity and water appeared in F_1 and F_2 are not obvious, the classification of electricity into F_1 while water into F_2 done on the basis of factor loading higher than 0.5 may not be justified. As a result, any interpretation of physical meaning of factor in this case has to be carried out with care.

4. The relationship between A_5 and the factor can be explained through its function in the production process. Usually, A_5 is a type of fibrous material used in the top layer. It is cleaner than other fibrous materials that are used for GB. Generally, GB consists of the three layers of fibrous materials that are made from three types of wastepapers; A_3, A_4 and A_5. The top layer is type A_5 with its percentage about 100, the

middle and bottom layers are A_3 and A_4 with the same percentages about 20:80 as shown below.

Table 5.8 Type of Wastepaper in the Layer of GB

1. Top layer; $A_5 = 100$
2. Middle layer; $A_3 : A_4 = 20 : 80$
3. Bottom layer; $A_3 : A_4 = 20 : 80$

Despite its correlation with A_3 and A_4, A_5 has quite a low correlation coefficient with them (-0.3-0.44). This may cause the losses of A_3 and A_4 from factor extraction in F_1, so that only A_5 is correlated with the factor. Normally, the change of A_5 is at a constant level due to its ratio in the layer of GB. However, in some situations, broke is used and it becomes the middle and bottom layers. In this case, the need for addition of A_5 occurs due to its loss in the previous operation.

Within the factor F_2, the relationship among variables (consisting of emulsifier, water, and A_3) indicate based upon the correlation between two variables in correlation matrix are discussed below.

1. The relationship between emulsifier and A_3 with the low correlation coefficient (0.44) based upon the correlation matrix and moderate factor loadings of emulsifier and A_3 (0.66 and 0.53) can be described through its correlation and their corresponding functions. In general, emulsifier is dissolved in water, then, it is mixed with the fibers and can assist in retaining fines by adsorption onto the larger fibers in the furnish component in web formation. Generally, one should expect emulsifier to correlate with all type of fibrous materials. Nevertheless, it appears in this case that only its shows distinct correlation with emulsifier. The reason for that is not yet clear at a moment but there may be some thing to do with the characteristic of A_3 which requires the adjustment of emulsifier upon changing.

2. The relationship between water and the factor can be explained through the function of water in the production process. Although water has correlation with electricity and cato based upon the correlation matrix, their correlation coefficients are low (< 0.5). This may be because they experience losses from one factor but

continue to appear in another factor. Thus, only water is extracted and remained in F_2. Usually, water is involved in all steps of the papermaking process, not only in the composition of pulp and white water but also in the cooling water. Generally, the change of water is in the same direction as the change of F_2 with respect to increasing or decreasing its quantity. However, in some situations, where re-circulated water as white water is used, mill water is consumed at lower levels. In this situation, the pattern of its inter-correlation is in the opposite direction. Thus, the loading of mill water is moderate (0.66).

Within the factor F_3, the relationship among variables (consisting of alum and A_3) can be described as below.

The relationship between alum and A_3 can be explained through their functions in the wet end operation. Normally, alum is used as a sizing agent and is also used to adjust the pH of the papermaking process at an optimum level for adsorption of the fibers during web formation. Generally, the change of alum affects the changes of the fibrous material, A_3 in the furnish component in the same direction. However, in some situations, where broke is used to become the middle and bottom layers of the paper, it is necessary to add more alum. This is because that not only A_3 but also other kinds of fibrous materials in the broke can be adsorbed to form the paper web by use of alum. In this situation, the pattern of inter-correlation between alum and A_3 is in the opposite direction. Thus, it is seen that the factor loading of alum (0.84) is higher than the loading of A_3 (0.59).

Within the factor F_4, the relationship of a single variable (defoamer) and the factor is presented below.

The relationship between defoamer and the factor can be explained through its function in the production process. Based upon the correlation matrix, there appears to be small correlations between defoamer and A_5. These correlation coefficients are low (0.32). Thus, after factor extraction, it appears as only a single variable. In some situations, where white water and broke are reprocessed as another source of material inputs, the compositions of the stock or the furnish component are changed with respect to having more emulsifier, improper amounts of alum and unsuitable pH control. This condition can lead to the degree of foaming problems. If bubbles occur in the process, defoamer will be used to eliminate these bubbles in order to obtain the desired quality of the paper. Thus, the loading of defoamer (0.52) is low.

Besides, it is also noted that, based on the pattern of inter-correlation between two variables in common factors of GB, some variables were lost from one factor and appeared in another factor after extraction, namely, water, A_3, A_4, and defoamer. These are the result of their low degree of correlations in the data set (< 0.2). Moreover, some variables should be considered and included in the FA material input model of GB, namely, broke and white water in order to obtain the necessary information for a greater understanding of a large set of data related to the GB production. There are some pitfalls from the step of data design and factor extraction with respect to the lack of a few variables and their appearances in the FA model, respectively. This does have some effects on the interpretation of FA result. The appropriateness of actors extracted for GB thus has to be tested when the predictions of wastewater load are carried out in the second phase.

Noted that the result of physical meaning for FA model of GF indicates the importance of not only chemical additives but also utility consumption together with the type and quantity of fibrous materials. The same result of GB indicates the importance of using chemical additives in different functions in the wet end operation. This is because the thickness of GF is greater than that of GB. Thus, there is a need for more fibrous materials for GF production. Also the use of defoamer in GF production is higher than in the manufacture of GB. This implies that there is a greater problem of foam occurrence in GF than in GB due to unbalanced conditions of wet end chemicals in the process operation.

5.1.5 FA Equation of GF and GB

FA equations are the function of factor scores of material input and utility consumption for both GF and GB. They depend on different standardized variables (Z) and score coefficients that have been considered (Table 5.9).

It was found that the scores for all significant factors of GF: F_1 - F_4 depend on 13 standardized variables. The scores for all significant factors of GB: F_1 - F_4 depends on 11 standardized variables. The score values of GF and GB vary with the value of the standardized variables and score coefficients in each case or observation.

Table 5.9 FA Material Input Models of Gypsum Liner Board

GP	FA Equation of Material Input
1. GF	1. $F_1 = \mathbf{0.16}\ Z_1 + \mathbf{0.20}\ Z_2 + 0.09\ Z_3 + 0.10\ Z_4 - 0.09\ Z_5 - 0.002\ Z_6 - \mathbf{0.2}\ Z_7 - \mathbf{0.18}\ Z_8 - 0.12\ Z_9\ \mathbf{-0.2}\ Z_{10} - 0.01\ Z_{11} - 0.003\ Z_{12} + 0.06\ Z_{13}$ 2. $F_2 = -0.01\ Z_1 - 0.08\ Z_2 + \mathbf{0.26}\ Z_3 + \mathbf{0.25}\ Z_4 + \mathbf{0.29}\ Z_5 + \mathbf{0.23}\ Z_6 - 0.09\ Z_7 -0.1\ Z_8 - 0.08\ Z_9 - 0.07\ Z_{10} - 0.15\ Z_{11} - 0.15\ Z_{12} - 0.05\ Z_{13}$ 3. $F_3 = -0.03\ Z_1 - 0.03\ Z_2 + 0.14\ Z_3 + 0.09\ Z_4 + 0.12\ Z_5 + 0.11\ Z_6 - 0.30\ Z_7 - 0.001\ Z_8 + 0.05\ Z_9 - 0.02\ Z_{10} + \mathbf{0.44}\ Z_{11} + \mathbf{0.44}\ Z_{12} - 0.23\ Z_{13}$ 4. $F_4 = -0.47\ Z_1 + 0.05\ Z_2 + 0\ Z_3 -0.25\ Z_4 + 0.10\ Z_5 + 0.39\ Z_6 + 0.22\ Z_7 - 0.1\ Z_8 + \mathbf{0.64}\ Z_9 - 0.17\ Z_{10} - 0.02\ Z_{11} - 0.03\ Z_{12} + 0.23\ Z_{13}$
2. GB	1. $F_1 = 0.08\ Z_1 + \mathbf{0.14}\ Z_2 - 0.09\ Z_3 - 0.13\ Z_4 + \mathbf{0.21}\ Z_5 - 0.09\ Z_6 + 0.08\ Z_7 - 0.06\ Z_8 + \mathbf{0.24}\ Z_9 + \mathbf{0.22}\ Z_{10} - \mathbf{0.22}\ Z_{11}$ 2. $F_2 = \mathbf{0.33}\ Z_1 + 0.22\ Z_2 + \mathbf{0.25}\ Z_3 + 0.28\ Z_4 + 0.12\ Z_5 + 0.09\ Z_6 + 0.23\ Z_7 + \mathbf{0.36}\ Z_8 + 0.1 Z_9 - 0.13\ Z_{10} + 0.04\ Z_{11}$ 3. $F_3 = -0.01\ Z_1 - 0.2\ Z_2 - 0.13\ Z_3 + \mathbf{0.37}\ Z_4 + 0.14\ Z_5 + \mathbf{0.53}\ Z_6 + 0.12\ Z_7 - 0.27\ Z_8 - 0\ Z_9 + 0.03\ Z_{10} - 0.22\ Z_{11}$ 4. $F_4 = -0.54\ Z_1 - 0.34\ Z_2 + 0.32\ Z_3 - 0.19 Z_4 + 0.22\ Z_5 + 0.11\ Z_6 + \mathbf{0.48}\ Z_7 + 0.22\ Z_8 + 0.11\ Z_9 + 0.07\ Z_{10} + 0.05\ Z_{11}$

Note: 1. For GF, Z_1: water, Z_2: electricity, Z_3: A_1, Z_4: A_2, Z_5: A_3, Z_6: A_4, Z_7: alum, Z_8: clay, Z_9: defoamer, Z_{10}: emulsifier, Z_{11}: cato, Z_{12}: starch, Z_{13}: wet strength.

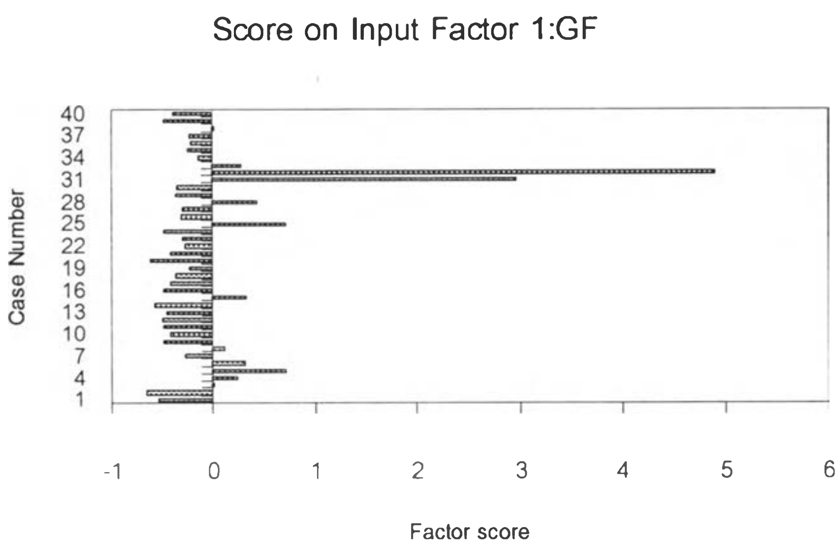
2. For GB, Z_1: water, Z_2: electricity, Z_3: A_3, Z_4: A_4, Z_5: A_5, Z_6: alum, Z_7: defoamer, Z_8: emulsifier, Z_9: cato, Z_{10}: starch, Z_{11}: wet strength.

3. $Z = \dfrac{(x_i - \bar{x})}{SD}$ where SD = standard deviation of variable.

5.1.6 Factor Scores

The magnitude of factor scores are the result of the multiplication of score coefficients and the change of variables (Z). From the factor score equations (Table 5.9), the factor scores of GF and GB are obtained and graphically displayed (Figure 5.7 – 5.10). Since the case number of input variables for GF and GB production are 40 and 39 cases, respectively, there are 40 factor scores for each factor of GF and 39 factor scores for GB (Appendix A1 and A3).

a) F_1



b) F_2

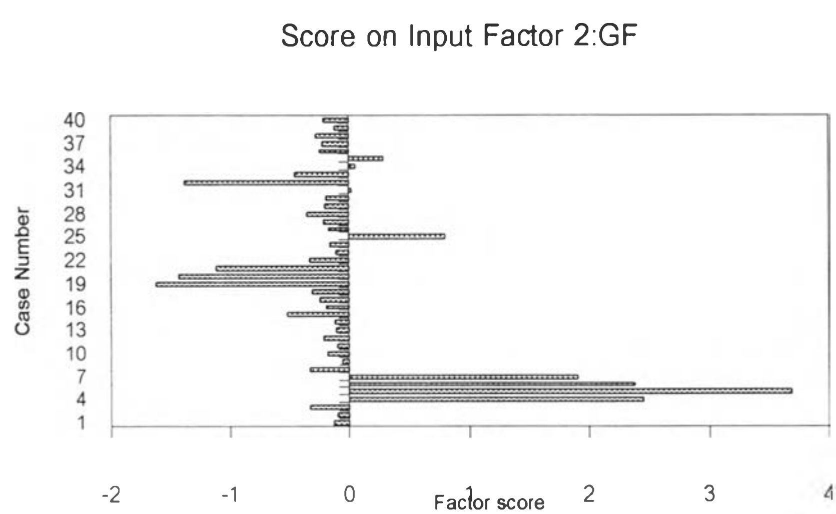
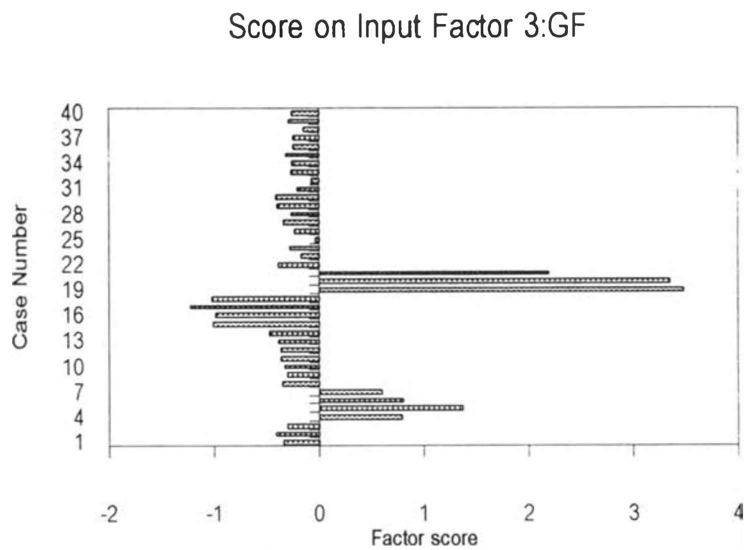


Figure 5.7 Factor Scores of GF; a) F_1 and b) F_2

c) F_3



d) F_4

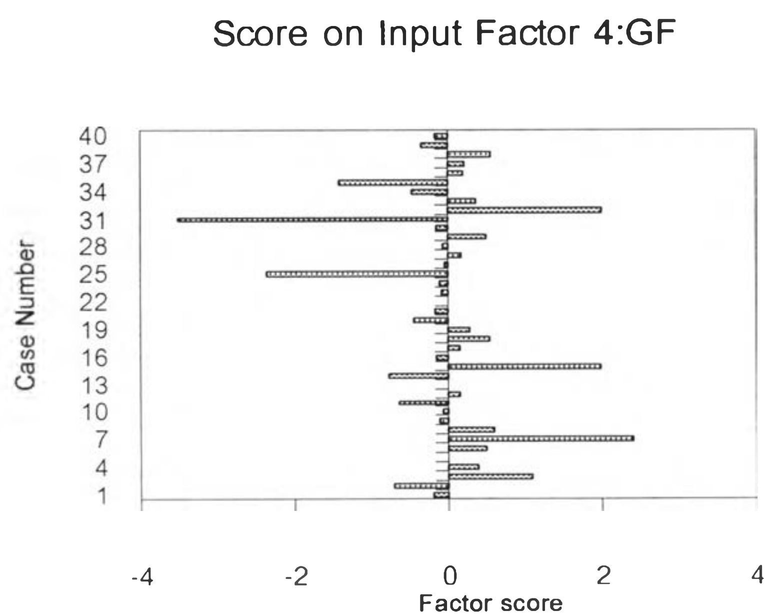
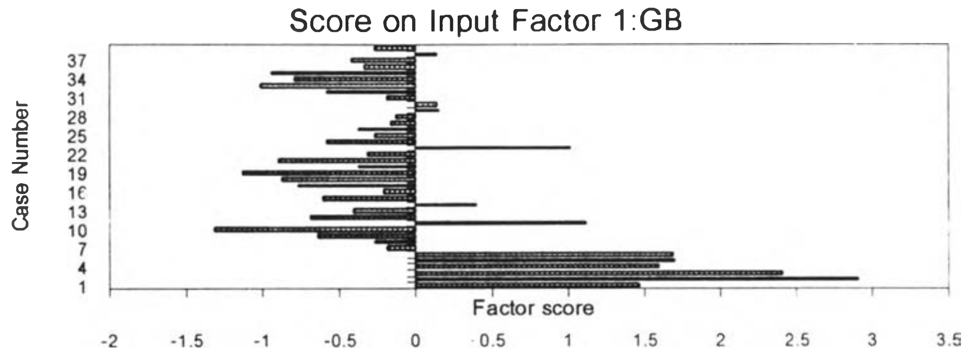
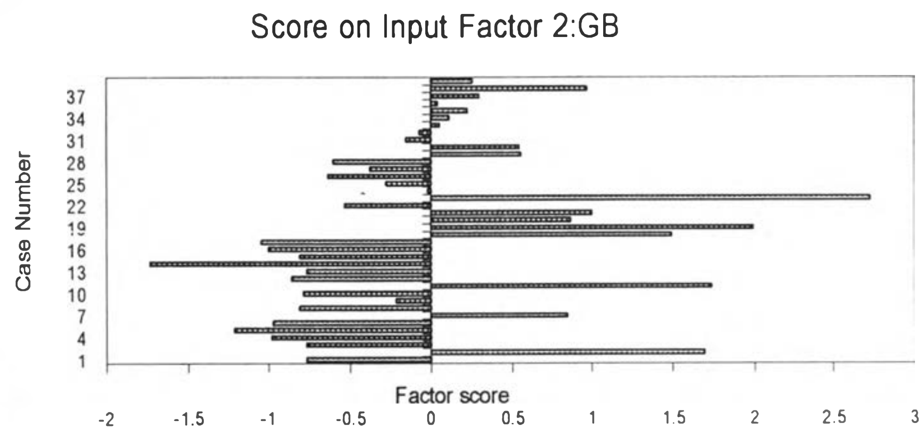


Figure 5.8 Factor Scores of GF; c) F_3 and d) F_4

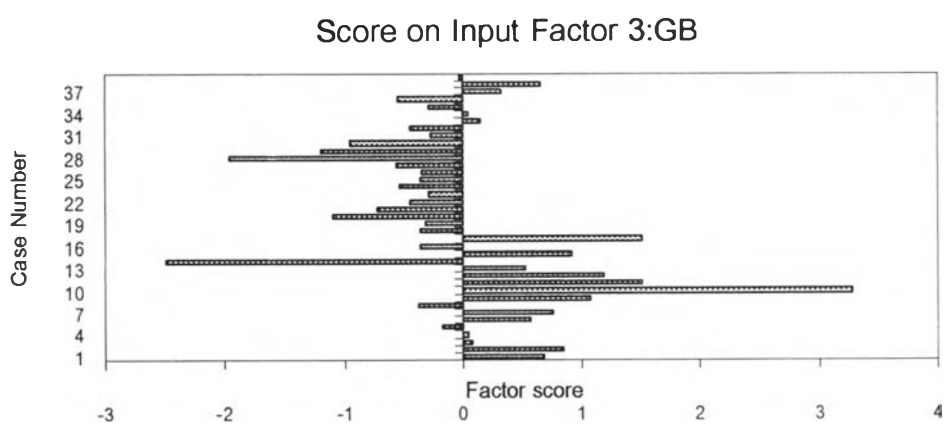
a) F_1



b) F_2



a) F_1



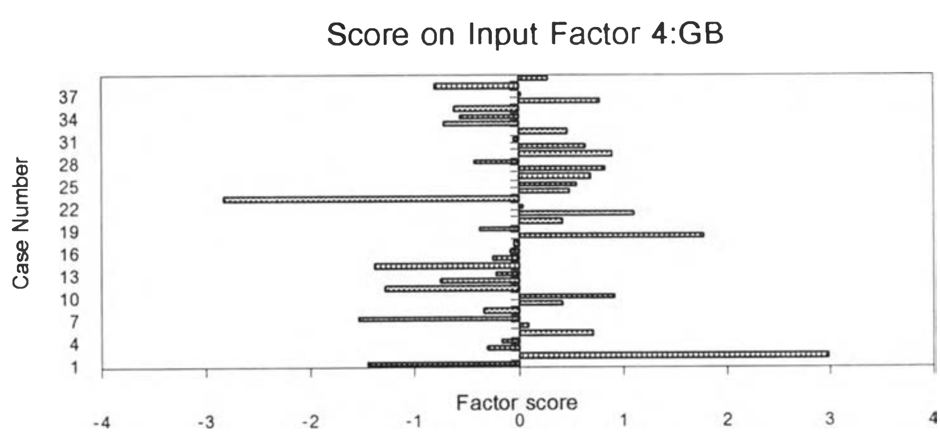


Figure 5.9 Factor Scores of GB; a) F_1, b) F_2, c) F_3, and d) F_4

Factor score with high magnitude (in absolute term) usually indicates the changes of dominant variables in the factor. If the value of factor score is low, or varies within small vicinity of zero, it is possible that either the changes of all variables are small or the effects of the variations among the dominant variables are counter-balances. The latter happens when the changes of related variables are in opposite direction or the changes occur in the same direction but their coefficients are of opposite sign.

5.1.6.1 Factor scores of GF

For factor score values in F_1 of GF (0.71 to 4.89), most factor scores are below average score, only some cases are highly above average score (Figure 5.7). This indicates that the pattern of data variation in F_1 is quite consistent with a few occurrence of unusual phenomenon. In order to explain such unusual events, the cases of highly magnitude of factor scores in F_1 are displayed in Table 5.10.

Considering the equation of factor score in F_1, it is found that the large changes of variables with quite high score coefficients have considerable effect on the value of factor score (Figure 5.10).

$$F_1 = \mathbf{0.16Z_1 + 0.2\ Z_2} - 0.09\ Z_3 + 0.10\ Z_4 - 0.09\ Z_5 - 0.002\ Z_6 - \mathbf{0.2\ Z_7 - 0.18\ Z_8} - 0.12\ Z_9 - \mathbf{0.2\ Z_{10}} - 0.01\ Z_{11} - 0.003\ Z_{12} + 0.06\ Z_{13}$$

where Z_1 : water, Z_2 : electricity, Z_7 : alum, Z_8 : clay, and Z_{10} : emulsifier

Table 5.10 Cases of highly magnitude of F_1 for GF

Standardized Variable (Z)	Case # 5	Case # 25	Case # 31	Case # 32
Z_1	- 0.36	**3.70**	**4.06**	**2.29**
Z_2	- 0.36	0.02	**2.66**	**5.12**
Z_3	**4.99**	- 0.56	1.74	0.77
Z_4	**3.15**	**2.03**	1.45	1.05
Z_5	**3.48**	**1.08**	0.32	1.14
Z_6	**1.49**	- 0.05	- 0.38	- 0.38
Z_7	- 0.16	- 0.24	**1.33**	**5.70**
Z_8	- 0.39	- 0.07	**2.81**	**4.08**
Z_9	- 0.42	- 0.19	**- 1.30**	**3.97**
Z_{10}	- 0.28	- 0.18	**3.96**	**4.25**
Z_{11}	- 0.33	- 0.24	- 0.11	0.30
Z_{12}	- 0.33	- 0.31	0.04	0.36
Z_{13}	- 0.41	- 0.41	0.73	1.75
F_1	0.71	0.71	2.96	4.89

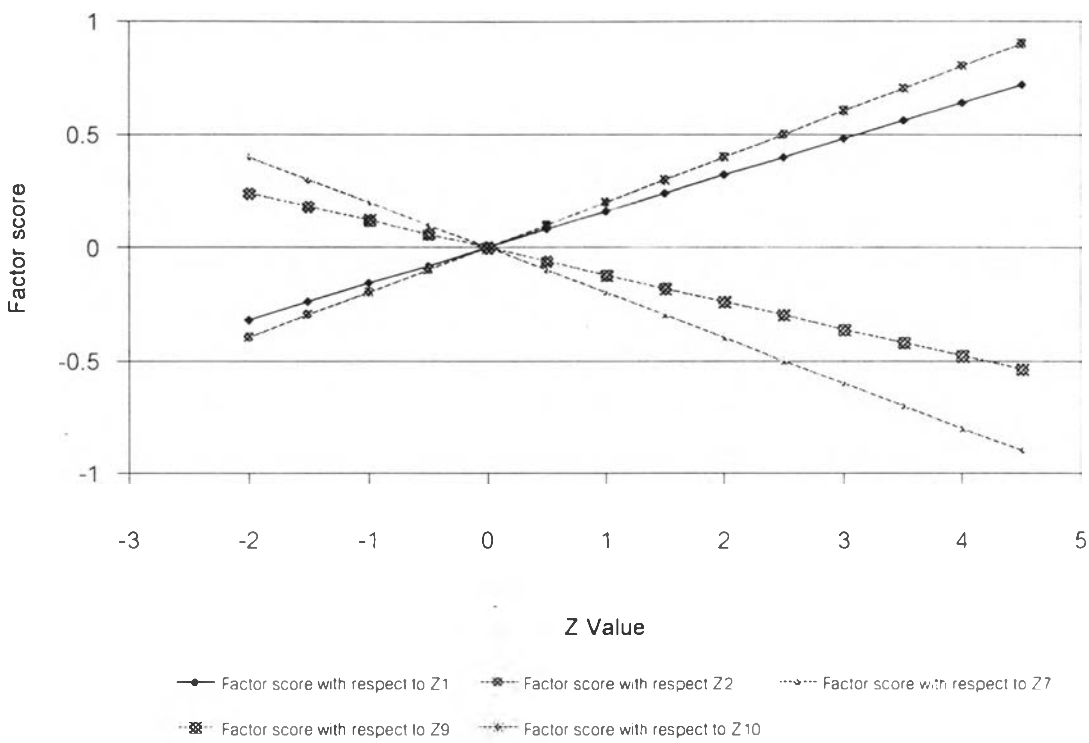


Figure 5.10 Important Variable in F_1 of GF Production

From Table 5.10, among these highly magnitude cases, 2 cases (case # 31-32) occur due to large changes of variables (Z > 1 in absolute term) in F_1 consisting of water, electricity, alum, clay, and emulsifier resulting the higher magnitudes of F_1 (2.96 and 4.89).

Based upon the mass balance of water in industrial papermaking, it is found that, of total fresh water, about 90 % is re-circulated and lost in the water circuit system through overflow of white water, reject, and leaks and spillages. The rest of water about 10 % is removed through the step of drying by evaporation. Thus, in the case # 31, if the brokes (any formed papers from the beginning of the papermaking process to the finished product that are not shipped to sale) are used as the re-processed material in the process, consumption of water can increase due to the loss of water in the step of repeated drying. The return of broke through the paper machine production loop does not result only the use of water but also the consumption of electricity. Together with the small increase of chemicals used such as alum, emulsifier and starch, it is indicated that occurrence of broke leads also the unbalance of white water system which becomes more apparent in case # 32.

Case # 5 and # 25 are good examples for other effect of broke usage on the process operation. In these cases, there seems to be no change in the use of chemicals but the consumptions of fiber materials are markedly changed. The distinction between these two cases and the previous cases lies on the level of broke usage. That is if the amount of broke usage is suddenly reduced, the proportion of other pulp stocks must be increased to compensate. This then causes the change of others used.

According to the case of highly magnitude of F_1, it is noted that there are several events occurred in the process. This is because F_1 contains the composite variables of all GF production. Through the events occurred in the process, it can be concluded that F_1 can well capture the change of broke used in the system in both directions (increase or reduction in the amount used). It should then be appropriated to name F_1 as "variations of broke generation and usage and balancing of whitewater".

For factor scores in F_2 of GF (-1.11 – 3.69), most factor scores are below average, only some cases are highly above average. This shows that the pattern of data variation in F_2 is mostly consistent. The cases of highly magnitude of factor scores in F_2 are shown in Table 5.11.

Through the equation of factor score in F_2, it indicates that the large change of variables with high score coefficients has effect on the magnitude of factor score (Figure 5.11).

$$F_2 = -0.01\,Z_1 - 0.08\,Z_2 + \mathbf{0.26\,Z_3} + \mathbf{0.25\,Z_4} + \mathbf{0.29\,Z_5} + \mathbf{0.23\,Z_6} - 0.09\,Z_7 - 0.01\,Z_8 - 0.08\,Z_9 - 0.07\,Z_{10} - 0.15\,Z_{11} - 0.15\,Z_{12} - 0.05\,Z_{13}$$

where $Z_3 : A_1$, $Z_4 : A_2$, $Z_5 : A_3$, $Z_6 : A_4$

Table 5.11 Cases of highly magnitude of F_2 for GF

Standardized Variable (Z)	Case # 4	Case # 5	Case # 6	Case # 7	Case # 19	Case # 20	Case # 21	Case # 32
Z_1	-0.16	-0.36	-0.28	-0.48	-0.40	-0.40	-0.28	2.29
Z_2	-0.31	-0.36	-0.27	-0.34	-0.29	-0.48	-0.12	5.12
Z_3	**2.14**	**4.99**	**1.11**	**0.62**	-0.09	-0.36	-0.43	**0.77**
Z_4	**1.70**	**3.15**	**2.84**	**-0.07**	-0.71	-0.58	-0.54	**1.05**
Z_5	**2.97**	**3.48**	**3.04**	**0.89**	-0.58	-0.58	-0.57	**1.14**
Z_6	**1.49**	**1.49**	**1.18**	**5.46**	-0.27	-0.27	-0.26	-0.38
Z_7	-0.25	-0.16	-0.79	-0.26	-0.14	-0.53	-0.02	5.70
Z_8	-0.43	-0.39	-0.37	-0.98	0.50	-0.25	-0.43	4.08
Z_9	-0.24	-0.42	0.72	-0.03	0.79	-0.27	-0.06	3.97
Z_{10}	-0.60	-0.28	-0.40	-0.06	-0.23	-0.25	-0.22	4.25
Z_{11}	-0.31	-0.33	-0.32	-0.34	**3.91**	**3.73**	**2.57**	0.30
Z_{12}	-0.35	-0.33	-0.34	-0.34	**3.83**	**3.87**	**2.44**	0.36
Z_{13}	-0.43	-0.41	-0.45	-0.37	-0.84	-0.84	-0.84	1.75
F_2	2.45	3.69	2.38	1.90	-1.61	-1.42	-1.11	-1.37

Among these highly cases, 4 cases (case # 4-7) are due to the large changes A_1- A_4 resulting the higher magnitude of F_2 (1.90 to 3.69).

Based on the physical meaning of GF within the factor F_2, this event occurs when A_1 is used in different ratio of A_2 in the top layer and A_3 is always used more than A_4 in the middle and bottom layers of GF. The use of a large amount of wastepapers can occur due to their degradation, fiber losses through leaks and spillages. Since the quality of wastepapers is normally consistent, thus their degradation should not much effect. As there are the number of pulpers, chests, pumps, pipes, refiners and white water tanks, it is difficult to avoid leaks and spills in the stock preparation area [53]. Also pumps and refiners can lose fiber through gland leaks if the seals are not well maintained. Thus, the use of a large amount of wastepapers can be due to fiber leaks and spills. However, the changes of these fibers are larger than due to these causes because the amount of broke used is much less than usual. But in the previous period of production, there are no gypsum brokes to use due to the production of other products (duplex coated board). This will cause the large increasing of fibers in the production process.

As for the cases of highly magnitude of F_2 in negative direction (case # 19 to 21), their magnitudes are not due to the large change of significant variables in F_2. In these cases, they show the large changes of significant variables in F_3 (starches). This means that there is special treatment of the product as detailed in F_3. In the case # 32, the large change of variables in this case is due to the broke usage as mentioned in F_1. Notice that there are also several events occurred in F_2 due to its consisting of composite variables in all GF. If only unusual change of F_2 caused by the significant variables appeared in F_2, F_2 may then be named as "variations of pulp stock composition". However, since the changes of other variables can influence the magnitude of F_2 especially the use of dry strength agents, "special treatment of product for binding property" should also be added to the name of F_2 too.

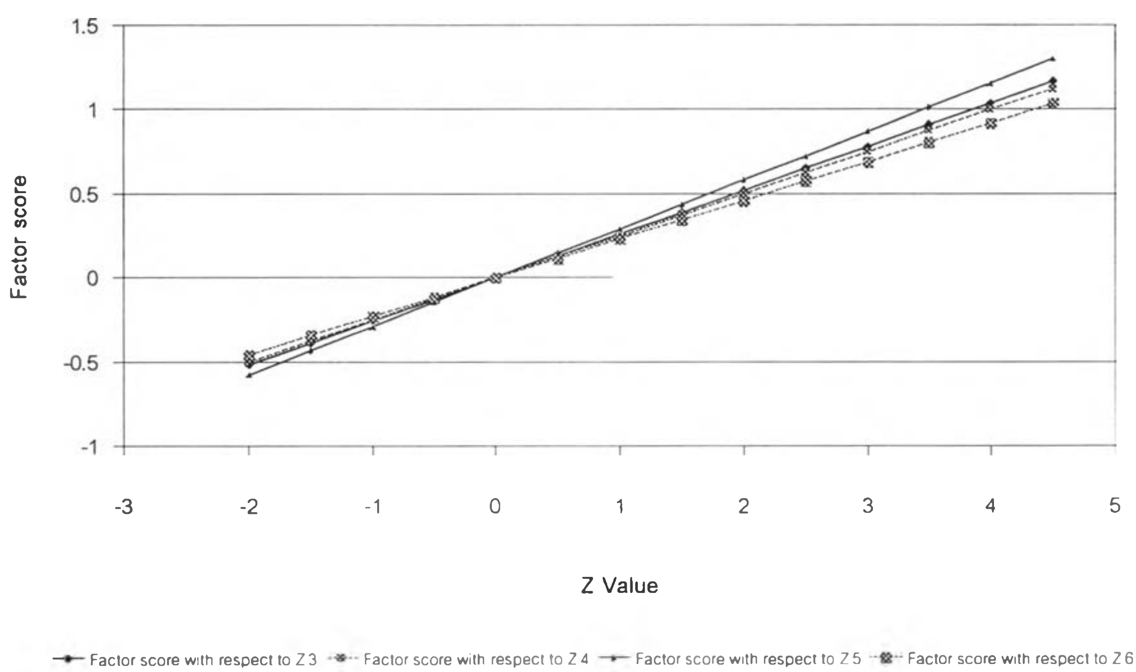


Figure 5.11 Important Variable in F_2 of GF Production

For factor scores in F_3 of GF (-0.98 to 3.48), the same pattern of factor scores in F_2 appears. The cases of factor score are mostly below average, some cases are highly above average. This means that the pattern of data variation in F_3 is quite consistent as well. The cases of highly magnitude of factor score in F_3 are shown in Table 5.12. It is found that the large changes of variables with highly score coefficients have the effect on the value of factor score (Figure 5.12).

$$F_3 = -0.03\,Z_1 - 0.03\,Z_2 + 0.14\,Z_3 + 0.09\,Z_4 + 0.12\,Z_5 + 0.11\,Z_6 - 0.30\,Z_7 - 0.001\,Z_8 + 0.05\,Z_9 - 0.02\,Z_{10} + \mathbf{0.44\,Z_{11}} + \mathbf{0.44\,Z_{12}} - 0.23\,Z_{13}$$

where Z_{11} : cato, and Z_{12} : starch

Table 5.12 Case of highly magnitude of F_3 for GF

Standardized Variable (Z)	Case # 5	Case # 15	Case # 16	Case # 17	Case # 18	Case # 19	Case # 20	Case # 21
Z_1	- 0.36	0.04	- 0.32	- 0.32	- 0.36	- 0.40	- 0.40	- 0.28
Z_2	- 0.36	- 0.15	- 0.40	- 0.43	- 0.51	- 0.29	- 0.48	- 0.12
Z_3	**4.99**	- 0.25	- 0.28	- 0.30	- 0.34	- 0.09	- 0.36	- 0.43
Z_4	**3.15**	- 0.48	- 0.62	- 0.71	- 0.65	- 0.71	- 0.58	- 0.54
Z_5	**3.48**	- 0.26	- 0.38	- 0.29	- 0.41	- 0.58	- 0.58	- 0.57
Z_6	**1.49**	- 0.22	- 0.31	- 0.31	- 0.29	- 0.27	- 0.27	- 0.26
Z_7	- 0.16	0.47	- 0.29	- 0.16	- 0.25	- 0.14	- 0.53	- 0.02
Z_8	- 0.39	- 0.09	- 0.28	- 0.43	- 0.42	0.50	- 0.25	- 0.43
Z_9	- 0.42	1.81	- 1.30	- 1.30	- 0.36	0.79	- 0.27	- 0.06
Z_{10}	- 0.28	- 0.18	- 0.54	- 0.50	- 0.33	- 0.23	- 0.25	- 0.22
Z_{11}	- 0.33	- 0.27	- 0.30	- 0.31	- 0.30	**3.91**	**3.73**	**2.57**
Z_{12}	- 0.33	- 0.34	- 0.36	- 0.37	- 0.36	**3.83**	**3.87**	**2.44**
Z_{13}	- 0.41	**2.98**	**2.09**	**3.07**	**2.41**	-0.84	- 0.84	- 0.84
F_3	1.38	- 1.01	- 0.98	- 1.23	- 1.02	3.48	3.35	2.20

Among the cases of highly magnitude of F_3, there are 4 cases and 3 cases occurred due to the large change of wet strength and starches in the case # 15 - 18 and in the case # 19 – 21, respectively.

Generally, the losses of chemicals and additives can occur during their preparation and application due to their leaks and spillages through the number of pumps, pipes, and white water tanks in the paper machine. In the cases of unusually large changes of starches (case # 19-21) and wet strength agent (case # 15-18) using for binding property both in dry & wet states, there seems to be special requirements for this property that are not normally encountered in usual processing. As for the case # 5, there are the large changes of fibers due to the unusually low usage of broke in the process as mentioned in F_2. Note that there are also several events occurred in F_3 due to its consisting of composite variables in all GF. Through the events occurred in F_3, it can be named F_3 as "special treatments of products for binding property and variation of pulp stock compositions".

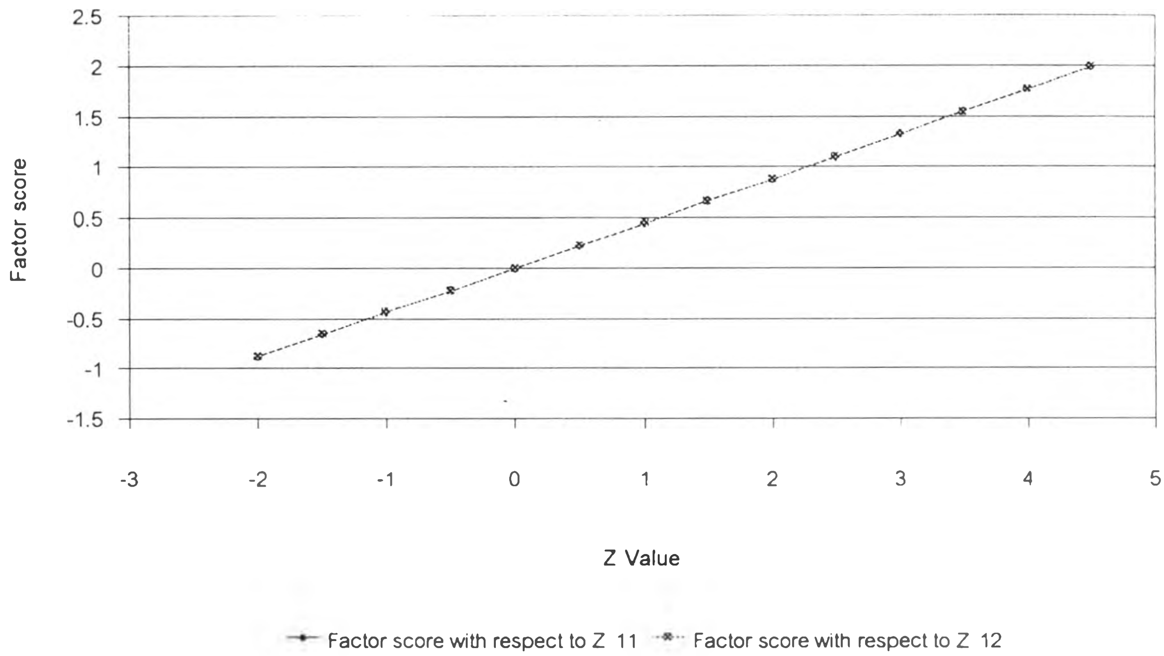


Figure 5.12 Important Variables in F_3 of GF Production

For factor scores in F_4 of GF (-1.42 to 2.41), the case numbers of factor score that are above and below average score are much different. This indicates that the data variation in F_4 is larger than those of F_1 - F_3. However, the variation of factor score in F_4 is quite balanced. The cases of highly magnitude of factor score in F_4 are shown in Table 5.13.

Considering the equation of F_4, it indicates that a variable with high score coefficient affects to the change of factor score (Figure 5.13).

$$F_4 = -\mathbf{0.47}\ Z_1 + 0.05\ Z_2 + 0.00\ Z_3 - \mathbf{0.25}\ Z_4 + 0.10\ Z_5 + \mathbf{0.39}\ Z_6 + 0.22\ Z_7 - 0.1\ Z_8 + \underline{\mathbf{0.64}}\ \mathbf{Z_9} - 0.17\ Z_{10} - 0.02\ Z_{11} - 0.03\ Z_{12} + \mathbf{0.23}\ Z_{13}$$

where Z_9 : defoamer

Table 5.13 Cases of highly magnitude of F_4 for GF

Standardized Variable (Z)	Case # 3	Case # 7	Case # 15	Case # 25	Case # 31	Case # 32	Case # 35
Z_1	-0.32	-0.48	0.04	**3.70**	**4.06**	**2.29**	-0.36
Z_2	**1.34**	-0.34	-0.15	0.02	**2.66**	**5.12**	-0.16
Z_3	-0.41	**0.62**	-0.25	-0.56	**1.74**	0.77	-0.36
Z_4	-0.54	-0.07	-0.48	**2.03**	**1.45**	**1.05**	**1.45**
Z_5	-0.17	**0.89**	-0.26	1.08	0.32	**1.14**	-0.55
Z_6	-0.21	**5.46**	-0.22	-0.05	-0.38	-0.38	-0.38
Z_7	0.25	-0.26	0.47	-0.24	**1.33**	**5.70**	-0.51
Z_8	-0.58	-0.98	-0.09	-0.07	**2.81**	**4.08**	-0.15
Z_9	**1.05**	-0.03	**1.81**	-0.19	**-1.30**	**3.97**	**-1.30**
Z_{10}	-0.72	-0.06	-0.18	-0.18	**3.96**	**4.25**	0.30
Z_{11}	-0.28	-0.34	-0.27	-0.24	-0.11	0.30	-0.33
Z_{12}	-0.35	-0.34	-0.34	-0.31	0.04	0.36	-0.34
Z_{13}	-0.38	-0.37	**2.98**	-0.41	0.73	**1.75**	-0.21
F_4	1.09	2.41	1.98	-2.36	-3.52	2.01	-1.42

Among the case of highly magnitude of F_4, there are shown the several events occurred in the process due to the large change of not only defoamer but also some wastepapers, utility consumption, sizing agents (alum and emulsifier) and filler (clay). According to the physical meaning of GF within the factor F_4 in 5.1.4.2.1, these events occur due to the degree of foaming problem resulting from the improper amount of related substances in the process. Usually, the foaming problem can occur from several factors such as the improper amount of sizing agents (alum and emulsifier) and utility consumption due to the broke usage (case # 7, 25, and 31), and the overflow of white water (case # 32). In addition, high electricity consumption due to the re-circulated water as white water usage (case # 3) can cause the foaming problem. Moreover, high consumption of some fiber in the top layer indicates the increasing of broke usage as the fibers for the middle and bottom layers affecting the decreasing of foaming problem due to the small change of defoamer (case # 35). Furthermore, there is a special treatment of product due to the large change of wet strength (case #15) as mentioned in F_3. These events happen due to F_4 consisting of composite variables of all GF production. Through the events occurred, F_4 can be named as "variations of foaming problem".

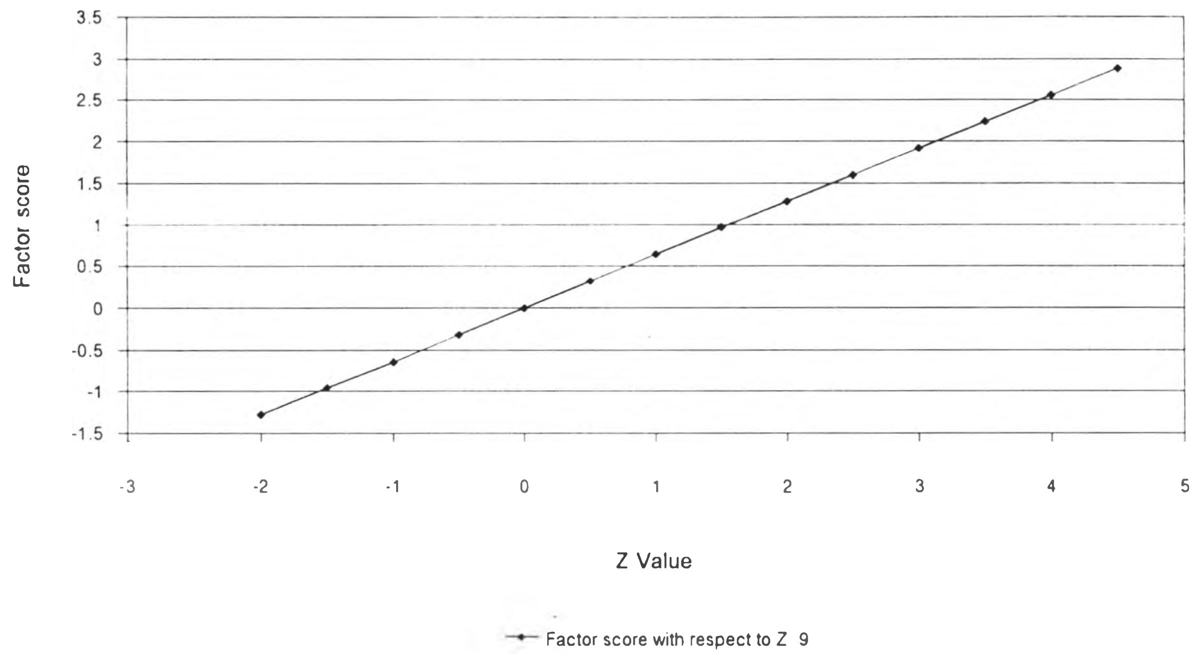


Figure 5.13 Important Variables in F_4 of GF Production

Based upon the cases of highly magnitude of factors, the significant factor scores for GF production can be named as shown in Table 5.14.

Table 5.14 Name of Significant Factors of GF

Significant Factor	Name
F_1	-Variations of broke generation and usage and balancing of whitewater
F_2	-Variations of pulp stock composition
F_3	- Special treatments of products for binding property and variations of pulp stock composition
F_4	-Variations of foaming problem.

From Table 5.14, note that several events occurred in the process can happen in several factors. In F_1, there are two events due to the broke generation and usage, and balancing of white water. In F_2, there are three events consisting of the use of broke less than usual, special treatment of the product from the large change of starches, and broke usage that shows the variations of pulp stock composition. In F_3, there are three events consisting of special treatments of the products from the large change of starches and wet strength, respectively, and the broke usage that also shows the variations of pulp stock composition. In F_4, there are four events consisting of broke usage, overflow of white water system, white water usage, and special treatment of the product from the large change of wet strength that show the variations of foaming problem occurred in the process.

Based upon the factor scores for GF production, these events indicate that GF production is very complex and all variables are somewhat dependent. Although their physical meanings of GF based on factor loadings show that the variables in factors seem to be independent, these variables of GF are not truly independent. This is because the phenomena associated within a particular factor may share the same root cause as those in other factors.

5.1.6.2 Factor Scores of GB

The factor scores in four significant common factors of GB are obtained as shown in Figure 5.9.

For factor scores in F_1 of GB (-1.31 to 2.91), most of factor scores are quite consistent, even some cases of factor score (case # 1-6, 10-11, 19, 23, and 33) are highly above average in both increasing and decreasing directions (Figure 5.10).

The large changes of variables (in absolute term) with high score coefficients in the equation of factor score in F_1 are shown in Figure 5.14.

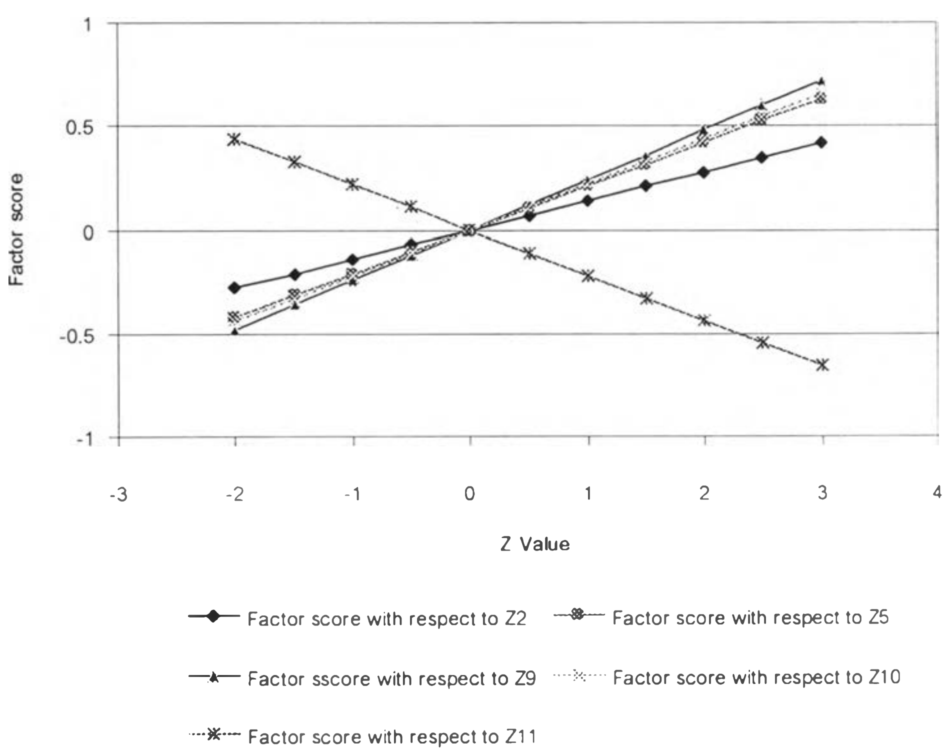


Figure 5.14 Important Variables in F_1 of GB Production

$F_1 = 0.08\ Z_1 + \mathbf{0.14}\ Z_2 - 0.09\ Z_3 - 0.12\ Z_4 + \mathbf{0.21}\ Z_5 - 0.09\ Z_6 + 0.08\ Z_7 - 0.06\ Z_8 + \mathbf{0.24}\ Z_9 + \mathbf{0.22\ Z_{10}} - \mathbf{0.22}\ Z_{11}$

where Z_2 : electricity, Z_5 : A_5, Z_9 : cato Z_{10} : starch Z_{11} : wet strength

Table 5.15 Cases of highly magnitude of F_1 for GB

Standardized Variable (Z)	Case # 1	Case # 2	Case # 3	Case # 4	Case # 5	Case # 6
Z_1	0.65	0.52	-0.48	-0.23	-0.48	0.15
Z_2	**0.75**	**0.75**	**2.16**	**0.93**	**-0.21**	**-0.58**
Z_3	-0.70	-0.04	-0.72	-0.60	-0.39	-0.70
Z_4	-0.18	-1.02	-0.71	1.12	-1.39	-1.14
Z_5	**1.21**	**3.43**	**1.96**	**1.15**	**1.18**	**1.87**
Z_6	-0.20	-0.11	-0.71	-0.56	-0.90	0.27
Z_7	-1.36	4.58	-0.25	-0.21	-0.30	-1.36
Z_8	-1.78	0.05	-1.08	-1.01	-0.46	-0.31
Z_9	**1.42**	**3.75**	**1.34**	**0.49**	**0.97**	**1.60**
Z_{10}	**1.20**	**1.02**	**3.53**	**2.11**	**2.80**	**2.28**
Z_{11}	**-1.71**	**-1.73**	**-1.70**	**-1.71**	**-1.71**	**-1.71**
F_2	1.47	2.91	2.41	1.60	1.70	1.69

Through the cases of highly magnitude of F_1 for GB, it is shown the event of the variation of electricity, the large changes of some wastepaper (A_5), dry strength agents (cato and starch), and wet strength agent as in Table 5.15.

According to the change of important variables within the factor F_1, these events occurred in the case that there are variations of electricity consumption. In addition, the large change of wastepaper (A_5) indicates that there is the use of broke more than usual according to the large change of electricity. While the smaller change of electricity indicates that broke is used less than usual. Moreover, the large changes of dry strength agents and wet strength agent indicates that there are requirements to treat products for strength property both in dry and wet states.

Through the events occurred in F_1, it can be named F_1 as "variations of broke usage and special treatments of products for strength property".

For factor scores in F_2 of GB (-1.73 – 2.73), it is shown that the pattern of variation in F_2 is quite balanced, except the cases of highly magnitude of factor (case # 2, 5, 11, 14,16-19, and 23). The largest changes of variables with high score coefficients in the factor are shown in Figure 5.15.

$$F_2 = \mathbf{0.33}\ Z_1 + \mathbf{0.21}\ Z_2 + \mathbf{0.25}\ Z_3 + \mathbf{0.28}\ Z_4 + 0.12\ Z_5 + 0.09\ Z_6 + \mathbf{0.23}\ Z_7 + \mathbf{0.36}\ Z_8 + 0.10\ Z_9 - 0.13\ Z_{10} + 0.04\ Z_{11}$$

where Z_1 : water, Z_3 : A_3, Z_8 : emulsifier

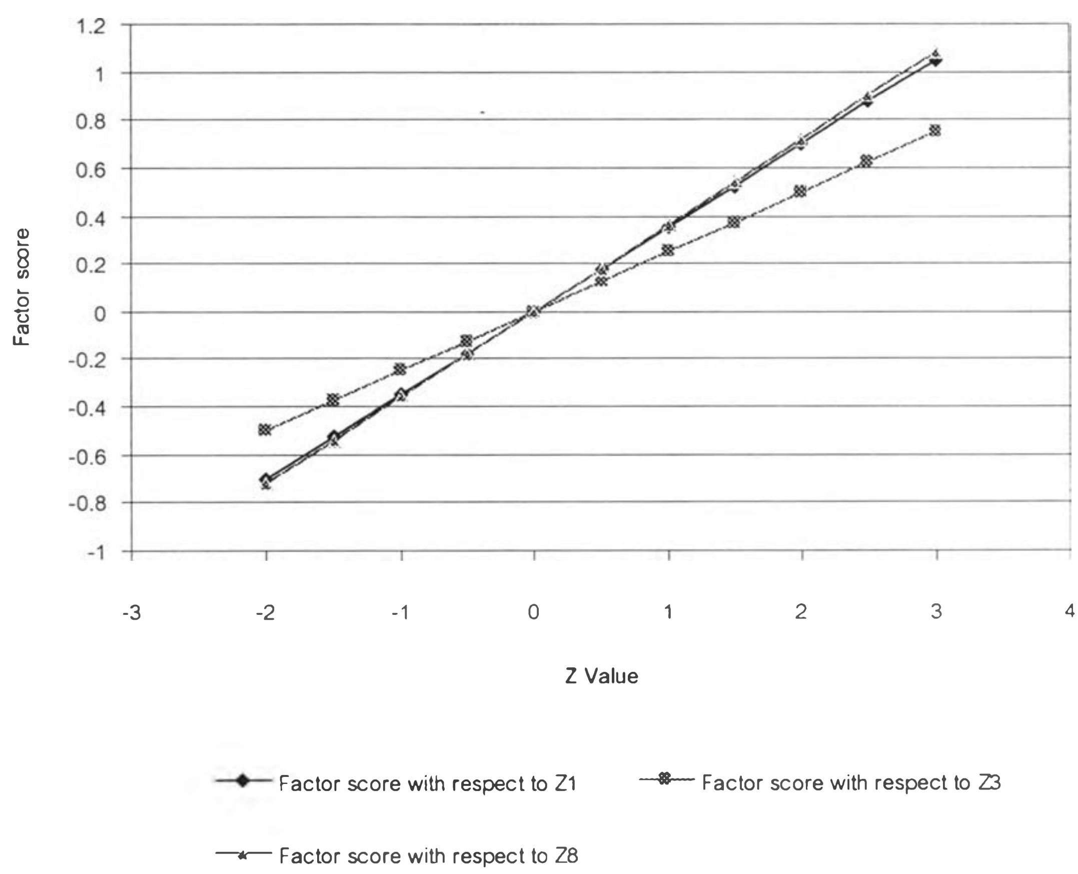


Figure 5.15 Important Variables in F_2 of GB Production

Through the cases of highly magnitude of F_2 for GB, it is shown the event of the large changes of water, emulsifier, and A_3 as in Table 5.16.

Table 5.16 Cases of highly magnitude of F_2 for GB

Standardized Variable (Z)	Case # 2	Case # 11	Case # 14	Case # 19	Case # 23
Z_1	**0.52**	**1.52**	**0.27**	**0.27**	**5.40**
Z_2	0.75	**2.13**	**1.47**	**1.27**	0.98
Z_3	-0.04	-0.27	-0.76	**3.30**	-0.33
Z_4	-1.02	1.25	-3.13	1.47	0.93
Z_5	3.43	0.40	-2.54	-0.69	1.05
Z_6	-0.11	1.46	-2.15	1.29	-0.79
Z_7	4.58	1.21	-0.14	-1.36	0.50
Z_8	**0.05**	**-0.35**	**-1.75**	**1.53**	**0.83**
Z_9	3.75	1.80	0.50	-0.68	0.89
Z_{10}	1.02	-0.38	-0.41	-0.18	-0.13
Z_{11}	-1.73	-1.75	0.33	0.81	-0.16
F_2	1.69	1.73	-1.73	1.99	2.73

Based upon the large changes of important variables and their physical meaning within F_2, the large change of water and electricity indicates that there are the occurrence of broke in the previous operation causing the unbalance of white water system resulting the large change of alum, defoamer, and cato in case # 11. While broke are used more than usual in case # 23 resulting the large change of water and some chemicals such as defoamer and cato. When there is the change of paper grade in the previous operation, the overflow of white water occurs. Then, the unbalancing of white water can appear as in case # 14 and 19, respectively. Thus, the highly consumptions of electricity as well as emulsifier and some fibers are found in both cases. Through the event occurred, F_2 can be named as "variations of broke generation and usage and balancing of white water".

For factor scores in F_3 of GB (-2.49 to 3.28), the pattern of variation is quite consistent. In the cases of highly magnitude of factor (case # 9 –12, 14,17, 20, and 28-29) (Appendix A3-A4), their magnitude occurs from the large changes of some variables with high score coefficients in the factor equation as shown in Figure 5.16.

$$F_3 = -0.01\,Z_1 - 0.19\,Z_2 - 0.13\,Z_3 + \mathbf{0.37}\,Z_4 + 0.14\,Z_5 + \mathbf{0.53}\,Z_6 + 0.12\,Z_7$$
$$.\quad 0.27\,Z_8 - 0.00\,Z_9 + 0.03\,Z_{10} - 0.22\,Z_{11}$$

where Z_4 : A_4, Z_6 : alum

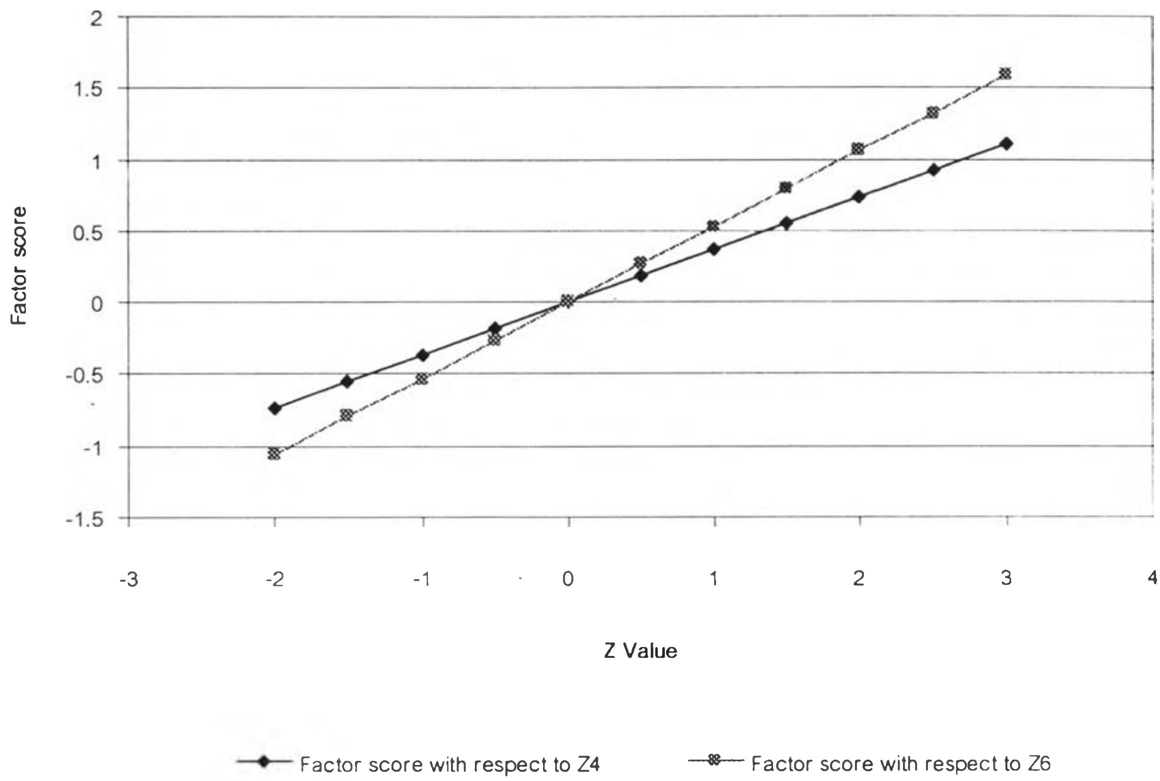


Figure 5.16 Important Variables in F_3 of GB Production

Table 5.17 Cases of highly magnitude of F_3 for GB

Standardized Variable (Z)	Case # 10	Case # 14	Case # 28
Z_1	-0.60	0.27	0.02
Z_2	-3.15	1.47	0.19
Z_3	-0.06	-0.76	0.02
Z_4	**1.76**	**-3.13**	**-1.53**
Z_5	-0.68	-2.54	-0.44
Z_6	**2.72**	**-2.15**	**-1.48**
Z_7	0.89	-0.14	-1.36
Z_8	-1.83	-1.75	0.48
Z_9	-1.45	0.50	0.15
Z_{10}	-0.48	-0.41	-0.34
Z_{11}	-0.30	0.33	0.95
F_3	3.28	-2.49	-1.97

Based upon the large changes of important variables (Table 5.17) and their physical meaning within F_3, the variations of wastepapers (A_4 and A_5) and alum indicate that there are the variations of pulp stock composition due to the use of broke both mcre and less than usual, including the requirement to treat product for paper formation. Thus, it can be named F_3 as "variations of pulp stock composition and special treatment of product for paper formation".

For factor scores in F_4 of GB (-2.83 to 2.99), the pattern of variation is quite balanced, except the cases of highly magnitude in the case # 1-2, 7, 11, 14, 18, 21 and 23 (Appendix A3-A4). The largest changes of variables with high score coefficients (water, electricity, A_3, A_5, defoamer, and emulsifier) are shown in Figure 5.17.

$$F_4 = \mathbf{-0.54\ Z_1} - \mathbf{0.39\ Z_2} + \mathbf{0.32}\ Z_3 - 0.19Z_4 + \mathbf{0.22}\ Z_5 + 0.01\ Z_6 + \mathbf{0.48}\ Z_7 \mathbf{- 0.22}\ Z_8 + 0.11\ Z_9 + 0.07\ Z_{10} + 0.05\ Z_{11}$$

where Z_7 : defoamer

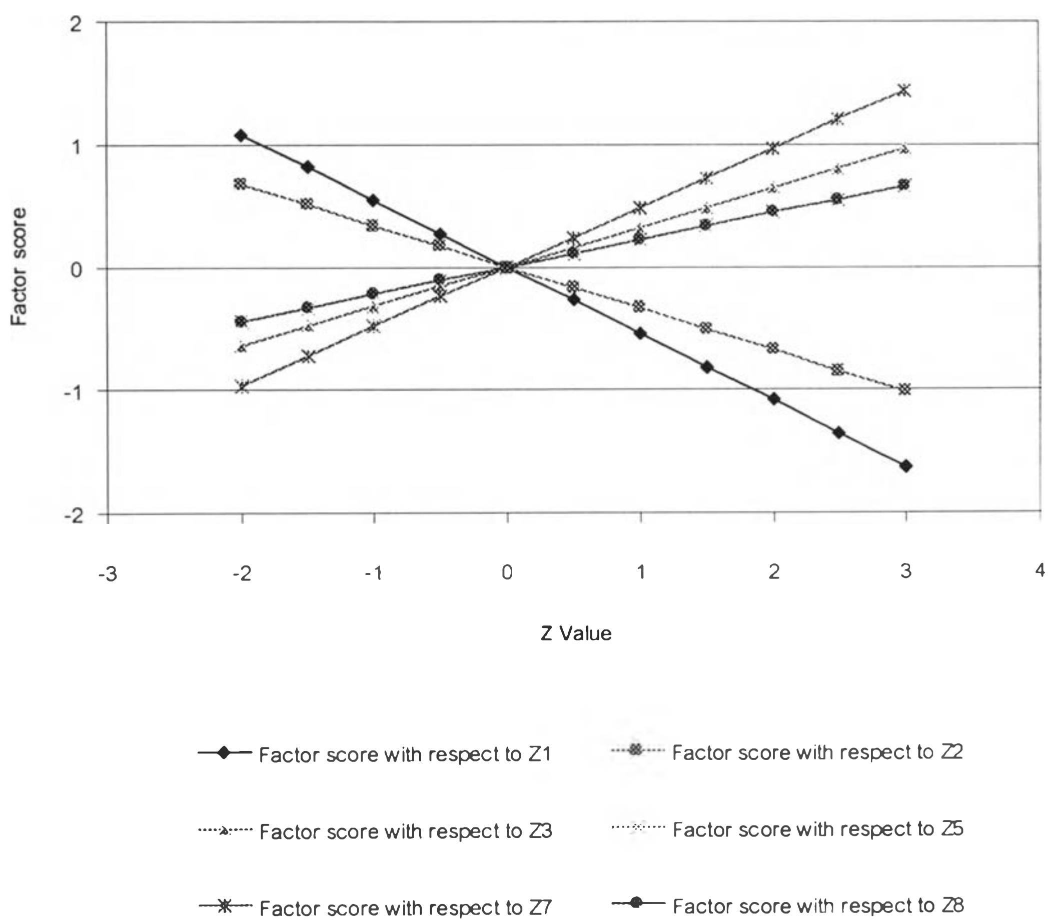


Figure 5.17 Important Variables in F_4 of GB Production

Table 5.18 Cases of highly magnitude of F_4

Standardized Variable (Z)	Case # 2	Case # 23
Z_1	0.52	**5.40**
Z_2	0.75	0.98
Z_3	-0.04	-0.33
Z_4	-1.02	0.93
Z_5	3.43	1.05
Z_6	-0.11	-0.79
Z_7	**4.58**	**0.50**
Z_8	0.05	0.83
Z_9	3.75	0.89
Z_{10}	1.02	-0.13
Z_{11}	-1.73	-0.16
F_4	2.91	-2.83

Through the cases of highly magnitude of F_4 (Table 5.18), the variation of defoamer occurs due to the broke and white water usages resulting the bubble occurrence in the process. If the broke is used more than usual, bubble less occurs resulting the small consumption of defoamer (case # 23). While the larger change of electricity than water indicates that the use of white water as re-circulated water can cause the foaming problem (case # 2). Through the event occurred in F_4, it can be named F_4 as "variations of foaming problem".

Based on the cases of highly magnitude of factors, the significant factor scores for GB production can be named as shown in Table 5.19.

Table 5.19 Name of Significant Factors of GB

Significant Factor	Name
F_1	-Variations of broke usage and special treatments of products for strength property
F_2	-Variations of broke generation and usage and balancing of white water
F_3	-Variations of pulp stock composition and special treatment of product for paper formation
F_4	-Variations of foaming problem

From Table 5.19, there are several events occurred in the factors. In F_1, there are four events consisting of the broke usages both more and less than usual, and the use of high dry strength agent and wet strength agent. These events show the variations of broke usage and special treatments of products for strength property. In F_2, there are four events consisting of the occurrence of broke and broke usage and the overflow of white water. These events show the variations of broke generation and usage and balancing of white water. In F_3, there are three events consisting of the broke usage both more and less than usual and the use of high alum. These events show the variations of pulp stock composition and special treatment of product for paper formation. In F_4, there are two events consisting of the broke usage as well as the white water usage resulting the variations of foaming problem.

5.1.7 Validation of FA Input Model

This was performed through the building of an FA model with the moving case-by-case approach that uses a new data set based on successive time interval corresponding to the original sample size.

Table 5.20 Correlation Matrix of Material Input of GF from Validation

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13
1.Water	1												
2.Electricity	.67	1											
3. A_1	.63	.75	1										
4. A_2	.68	.49	.01	1									
5. A_3	-.83	.73	.47	.65	1								
6. A_4	.05	-.05	-.22	.004	.12	1							
7.Alum	.49	.89	.59	.33	.69	-.05	1						
8.Clay	.53	.77	.69	.37	.61	0.12	.81	1					
9.Defoamer	.11	.46	.10	.002	.29	-.01	.38	.22	1				
10.Emulsifier	.68	.92	.85	.48	.65	-.17	.80	-61	.31	1			
11.Cato	-.09	-.06	.04	-.10	.16	0.05	.02	.03	.09	.01	1		
12.Starch	-.08	.01	.05	-.11	.15	0.04	.05	.05	.08	.03	0.99	1	
13.Wet strength	.11	.24	.03	.07	.25	-.01	.31	.12	.09	.22	-0.21	-.23	1

Table 5.21 Correlation Matrix of Material Input of GB from Validation

Variables	1	2	3	4	5	6	7	8	9	10	11
1.Water	1										
2.Electricity	**.50**	1									
3. A_3	-.07	.11	1								
4. A_4	**.64**	-.05	.23	1							
5. A_5	**.31**	.14	.03	.03	1						
6.Alum	-.13	-.19	.10	**.63**	.04	1					
7.Defoamer	.11	.14	.01	.03	**.39**	.10	1				
8.Emulsifier	.10	.27	**.43**	.14	.10	-.15	.17	1			
9.Cato	**.40**	**.43**	-.14	**-.38**	**.63**	-.15	**.46**	-.07	1		
10.Starch	.18	.12	.10	**-.32**	.07	-.04	.04	-.09	**.65**	1	
11.Wet strength	-.29	-.18	**.35**	.04	**-.54**	-.11	-.23	.16	**-.64**	**-.61**	1

The correlation matrices for GF and GB from validation are shown in Table 5.20 and 5.21. In average, the results of these matrices are similar to their results in model building (Table 5.1 and 5.2). From Table 5.20, the correlation matrix of GF is obtained when the first 15 cases in the original data set are replaced by 15 new data (out of totally 24 new data). This matrix of GF represents for the cases # 1 to # 15 more than the cases after case # 15, particularly, the correlation between A_1-A_4 and other variables. This will affect to grouping of A_1-A_4 in the factors. From Table 5.21, the correlation matrix of GB is obtained when the first 5 cases in the original data set are replaced by 5 new data (out of totally 17 new data). This matrix of GB represents for most of variables in the case # 1 to case # 3 more than the case # 4 to case # 9, in particular, the correlation between A_3, defoamer and other variables. This will affect to grouping of A_3 and defoamer in the factors as well.

The significant factors of GF and GB from validation are similar to those resulted from model building (Table 5.22).

Table 5.22 Validating Result of Factor Scores Model of Gypsum Liner Board

Common Factor (F)	GF		Common Factor (F)	GB	
	Building	Validating		Building	Validating
1. F_1			1. F_1		
- Electricity	X	X	- Cato	X	X
- Water	X	X	- Starch	X	X
- Alum	X	X	- A_5	X	X
- Clay	X	X	- Electricity	X	X
- Emulsifier	X	X	- Wet Strength	X	X
- A_1		7			
2. F_2			2. F_2		
- A_1	X		- Emulsifier	X	X
- A_2	X		- Water	X	
- A_3	X		- A_3	X	X
- A_4	X		- A_4		2
- Cato		7			
- Starch		7			
3. F_3			3. F_3		
- Cato	X		- Alum	X	X
- Starch	X		- A_4	X	
- A_2		7			
- A_3		7			
- A_4		7			
4. F_4			4. F_4		
- Defoamer	X	X	- Defoamer	X	
			- Water		2
			5. F_5		
			- Defoamer		2

Note: X: the existence of variable in that factor, Number: the number of new added case that causes the change of variables in the factor

For GF, among the variables in the four significant factors obtained from correlation matrix in Table 5.20, it was found that most variables were still in the same factor, except for only wastepaper variables: A_1 that was changed to F_1 in the case number 7. The change of A_1 can affect to the change of interrelationship among wet end chemicals and utility consumption in terms of either decreasing or increasing these consumptions according to its usage. Although some wastepaper variables; A_2, A_3, and A_4 are changed from F_2 to F_3, and some variables; cato and starch are changed from F_2 to F_3 in the case number 7, the physical meaning of them is not changed because each factor is normally common factor and unrelated factor. Nevertheless, F_1 and F_3 were closely related as the degree of interrelations between variables in both factor became high. This phenomenon surely leads to some errors encountered when the model built previously is to be used for predicting wastewater load in different set of data.

For GB, among the variables in four significant factors, most of the variables are also in the same factor with the exception of some variables, A_4, water, and defoamer. A_4 is changed from F_3 to F_2 due to its high correlation with A_3 in F_2 in the case # 2. Water is changed from F_2 to F_4 due to the decreasing of the correlation with electricity and other variables and increasing correlation with F_4 in the case # 2. In addition, defoamer is changed from F_4 to F_5 in the case # 2 due to its high correlation with F_5. However, in terms of physical meaning of GB, the result of the validation is not much different from the result of FA model building.

Notice that the changes of some variables (A_1-A_4 of GF and A_4 and defoamer of GB) in some factors (F_1-F_4 of GF and F_2 and F_4 of GB) are the effect of the pattern of correlation matrix from different observations in validation as mentioned above.

Based upon the physical meaning and the event occurred in the process through the factor loading and the unusual cases of factor score for each factor, therefore, the FA model resulting from validation indicates that this model is applicable for an approximate description of gypsum liner board production. In addition, it is beneficial to the manufacturers if they understand the model components (type and number of input variables, detailed in 5.1.5 to 5.1.6) and need to modify the model, and to accommodate unusual material input characteristics that resulting from the changes of process condition, not considered by the model.

However, the use of the FA input model from this task makes it possible for the manufacturers to understand the nature of industrial papermaking and to focus their attention on the interrelationships of material input conditions and utility consumption in the related common factors in order to avoid the occurrence of unusual cases for improving gypsum liner board production.

5.2 Model II: MRA predictive environmental model

5.2.1 Data collection and preparation of predictor variables

Through FA, data preparation and reduction of predictor variable were performed. Then, the predictor variables (x) obtained were reduced to a smaller number of significant factor scores. There were four significant factor scores of material input use and utility consumption for both GF and GB that were used to determine their relationships with the response variable (y), wastewater load from GP: SS, TDS, COD, and BOD loads. In the step of model building, some cases of GF and GB that were considered as outlier are excluded in the models as in Table 5.23.

Table 5.23 Outlier of Error between Wastewater load and Factors Occurred in Model Building for GF and GB

Model	Number of cases removed		Case Number		1.5 Inter-quantile (IQR)
	GF	GB	GF	GB	
SS	7	7	6, 8, 19, 25, 32-33, 37	1-2, 6, 11, 27, 30, 33	>1.5
TDS	8	8	15, 19, 23, 25, 32-34, 37	1, 3, 8-9, 11-12, 14, 18	>1.5
COD	13	11	6, 8, 11-12, 15-16, 23, 25, 31-33, 36- 37	1, 2, 8, 11, 14, 16, 18, 21, 23-24, 28	>1.5
BOD	13	12	8, 10-12, 15-16, 25, 31-33, 36-38	1, 2, 8, 11, 14, 16, 18, 21, 23-24, 27-28	>1.5

From Table 5.23, the number of cases that were considered as outlier of the models are 7, 8, 13, and 13 cases for SS, TDS, COD and BOD loads of GF, respectively. Also 7, 8,11 and 12 cases for SS, TDS, COD and BOD loads of GB, were not included in these models during the model building.

For GF, the outlier of error for the final predictive model of ZSS load is in the range of - 2.36 to 2.01 and –0.23 to 4.89 for F_4 and F_1, respectively. The outlier for the final predictive model of ZTDS load occurs from F_2 is in the range of –1.61 to 2.38, –0.28 to 4.89, and –2.36 to 2.41 for F_2, F_1 and F_4, respectively. The outlier for the final predictive model of ZCOD load is in the range of –1.37 to 2.38 and –1.01 to 0.81 for F_2 and F_3, respectively. The outlier for the final predictive model of ZBOD load is in the range of –1.37 to 2.38 and –1.01 to -0.03 for F_2 and F_3, respectively. Notice that the outlier magnitude of F_4 and F_2 is the maximum one.

For GB, the outlier for the final predictive model of ZSS load is in the range of –2.83 to 2.99 and –0.98 to 1.69 for F_4 and F_2, respectively. The outlier for the final predictive model of ZTDS load is in the range of –0.87 to 2.41 and –1.45 to 1.78 for F_1 and F_4, respectively. The outlier for the final predictive model of ZCOD load is in the range of –1.73 to 2.73 and –0.87 to 2.91 for F_2 and F_1, respectively. The outlier for the final predictive model of ZBOD load is in the range of –1.73 to 2.73 and –0.87 to 2.91 for F_2 and F_1, respectively.

5.2.2 Model Investigation

The investigation of all models using four significant factors for each wastewater load covered 11 basic forms of equations consisting of linear, logarithm, inverse, quadratic, cubic, compound, power, S, growth, exponential and logistic curves. The results for SS load of GF is shown for example in Table 5.24.

Only predictor variables that meet statistical significance ($R^2 > 0.3$ and significance level of F-test < 0.05), namely F_1 and F_4 for SS load of GF were considered for testing, estimating model parameter, and evaluating the model until the final appropriate equations are obtained. The list of those factors which meet the above criteria is given in Table 5.25. These equations contain the smaller number of sample (*n*) than the total number of sample (40 cases) from observation (Table 5.25).

The final proposed models that contain only significant factors and meet the assumption for both GF and GB demonstrate type of curves. These models meet the requirement for statistical significance with a high coefficient of determination ($R^2 >$ 0.5) at significance level (Sig) < 0.05 for F-test values with low standard error (SE) are chosen as the following proposed models (Table 5.25 and 5.26).

Table 5.24 Example of Basic Equation for SS load of GF

Predictor Variable	Basic Equation	F-test	Sig	R^2
F_1	Linear	65.40	0.00	0.63
	Logarithm**			
	Inverse	0.002	0.80	0.002
	Quadratic	32.07	0.00	0.63
	Cubic	21.24	**0.00**	**0.64**
	Compound*			
	Power*			
	S*			
	Growth*			
	Exponential*			
	Logistic*			
F_2	Linear	3.91	0.06	0.09
	Logarithm**			
	Inverse	9.42	0.00	0.20
	Quadratic	4.74	0.02	0.20
	Cubic	4.30	0.01	0.26
	Compound			
	Power*			
	S*			
	Growth*			
	Exponential*			
	Logistic*			
F_3	Linear	1.74	0.20	0.04
	Logarithm**			
	Inverse	6.23	0.02	0.14
	Quadratic	0.85	0.44	0.04
	Cubic	1.83	0.16	0.13
	Compound*			
	Power*			
	S*			
	Growth*			
	Exponential*			
	Logistic*			
F_4	Linear	0.32	0.57	0.01
	Logarithm**			
	Inverse	0.06	0.81	0.002
	Quadratic	7.31	0.00	0.28
	Cubic	6.00	0.00	**0.53**
	Compound*			
	Power*			
	S*			
	Growth*			
	Exponential*			
	Logistic*			

Note : * Dependent variable has non-positive values; no equation estimated

** Independent variable has non-positive values.

Table 5.25 Result of Model Investigation for Basic Equation of GF

Model	Predictor Variable	F-test	Sig	R^2	SE	n	Basic Equation
SS	F_1	95.98	0	0.91	0.18	33	$-0.37-0.07F_1-0.13F_1^2+0.13F_1^3$
	F_4	77.81	0	0.89	0.20	33	$-0.38+0.11F_4+0.07F_4^2-0.06F_4^3$
TDS	F_1	34.2	0	0.79	0.17	32	$-0.31-0.13F_1-0.28F_1^2+0.17F_1^3$
	F_2	97.12	0	0.76	0.17	32	$-0.17+0.03/F_2$
	F_4	34.35	0	0.79	0.17	32	$-0.35+0.01F_4+0.05F_4^2-0.03F_4^3$
COD	F_2	18.07	0	0.70	0.13	27	$-0.47-0.13F_2+0.16F_2^2-0.03F_2^3$
	F_3	17.23	0	0.69	0.14	27	$-0.42-0.01F_3-0.05F_3^2+0.03F_3^3$
BOD	F_2	0.19	0	0.54	0.17	27	$-0.48-0.15F_2+0.16F_2^2-0.03F_2^3$
	F_3	9.77	0	0.55	0.17	27	$-0.42+0.02F_3-0.05F_3^2+0.03F_3^3$

From Table 5.25, the results of the model investigation bring forth the list of response variables (y): each wastewater load and predictor variables (x): significant factors that have their relationships determined through the analysis of variance between each response variable and each predictor variable.

It was found that wastewater loads of GF are in the forms of cubic equation : $Y = b_0 + b_1F + b_1F^2 + b_1F^3$ where Y = each wastewater load. SS load is related to F_1 and F_4 in the form of cubic curve. TDS load is related to $F_1$and F_4 in the form of a cubic curve, and F_2 in the form of inverse curve. COD load is related to F_2 and F_3 in the form of a cubic curve, and BOD load is also related to F_2 and F_3 in the form of a cubic curve.

Table 5.26 Result of Model Investigation for Basic Equation of GB

Model	Predictor Variable	F-test	Sig	R^2	SE	n	Basic Equation
SS	F_2	18.89	0	0.67	0.33	32	$-0.38 - 0.07 F_2 + 0.02 F_2^2 + 0.12 F_2^3$
	F_4	14.27	0	0.60	0.36	32	$-0.36 - 0.001 F_4 + 0.02 F_4^2 - 0.09 F_4^3$
TDS	F_1	49.08	0	0.85	0.44	31	$-0.21 - 0.70 F_1 - 0.25 F_1^2 + 0.38 F_1^3$
	F_4	76.60	0	0.90	0.36	31	$-0.19 - 0.35 F_4 + 0.26 F_4^2 + 0.16 F_4^3$
COD	F_1	3.74	0	0.53	0.46	28	$-0.04 + 0.21 F_1 - 0.26 F_1^2$
	F_2	20.38	0	0.72	0.28	28	$-0.21 + 0.99 F_2 + 0.30 F_2^2 - 0.36 F_2^3$
BOD	F_1	16.22	0	0.78	0.66	27	$0.03 + 0.21 F_1 - 0.26 F_1^2$
	F_2	24.62	0	0.62	0.44	27	$-0.27 + 1.06 F_2 + 0.39 F_2^2 - 0.42 F_2^3$

From Table 5.26, it has been found that wastewater loads of GB are in the forms of both cubic and quadratic equations : $Y = b_0 + b_1F + b_1F^2$, $Y = b_0 + b_1F + b_1F^2 + b_1F^3$ where Y = each wastewater load. SS load is related to F_2 and F_4 in the form of cubic curve. TDS load is related to F_1 and F_4 in the form of cubic curve. Both COD and BOD loads are related to F_1 and F_2 in the form of quadratic and cubic curves, respectively.

These models of GF and GB were subjected to test for their appropriateness under the MRA assumptions in the next step.

5.2.3 Model Testing

Following the statistical test, the proposed models that meet the MRA assumptions are shown. The results of the appropriateness properties of the models for GF and GB are in Table 5.27 and 5.28.

Table 5.27 Result of Model Testing for Basic Equation of GF

Model	Kolmogorov-Smirnov	Sig.	Shapiro-Wilk	Sig	Mean of error & SE	Basic Equation
SS	0.13	0.2	0.95	0.14	0	$-0.37-0.07\ F_1-0.13\ F_1^2+0.17\ F_1^3$
	0.12	0.2	0.96	0.43	0	$-0.38+0.11\ F_4+0.07\ F_4^2-0.06\ F_4^3$
TDS	0.12	0.15	0	0.5	0	$-0.31-0.13\ F_1-0.28\ F_1^2+0.17\ F_1^3$
	0.1	0.2	0	0.9	0	$-0.17+0.03/F_2$
	0.17	0.2	0	0.5	0	$-0.35+0.01\ F_4+0.05\ F_4^2-0.03\ F_4^3$
COD	0.15	0.15	0.93	0.1	0	$-0.47-0.13\ F_2+0.16\ F_2^2-0.03\ F_2^3$
	0.1	0.2	0.97	0.56	0	$-0.42-0.01\ F_3-0.05\ F_3^2+0.03\ F_3^2$
BOD	0.14	0.19	0	0.28	0	$-0.48-0.15\ F_2+0.16\ F_2^2-0.03\ F_2^3$
	0.1	0.2	0	0.82	0	$-0.42+0.02\ F_3-0.05\ F_3^2+0.03\ F_3^2$

Note: Values of Levene's test are 0.5 and 0.9 for SS, 0.3 and 0.9 for TDS, and 0.65 and 0.97 for COD and BOD

From Table 5.27, means of error for all proposed models are zero with low standard errors. Moreover, the Kolmogorov – Smirnov statistic (0.1) and Shapiro-Wilk statistics (0 to 0.98) and Levene's test (0.3 to 0.97) have higher significance values (0.2) than the values at a significance level of 0.05 for all wastewater loads.

Table 5.28 Result of Model Testing for Basic Equation of GB

Model	Kolmo gorov-smirnov	Sig.	Shapiro -Wilk	Sig	Mean of error & SE	Basic Equation
SS	0.14	0.11	0.96	0.3	0	$- 0.38 - 0.07\ F_2 + 0.02\ F_2^2 + 0.12F_2^3$
	0.11	0.2	0.97	0.7	0	$- 0.36 - 0.001\ F_4 + 0.02\ F_4^2 - 0.09\ F_4^3$
TDS	0.1	0.2	0	0.7	0	$-0.21 - 0.70\ F_1 - 0.25\ F_1^2 + 0.38\ F_1^3$
	0.1	0.2	0	0.7	0	$-0.19 - 0.35\ F_4 + 0.26\ F_4^2 + 0.16\ F_4^3$
COD	0.14	0.2	0.98	0.8	0	$-0.04 + 0.21\ F_1 - 0.26\ F_1^2$
	0.09	0.2	0.96	0.8	0	$-0.21 + 0.99F_2 + 0.30\ F_2^2 - 0.36\ F_2^3$
BOD	0.15	0.2	0.95	0.3	0	$0.03 + 0.21\ F_1 - 0.26\ F_1^2$
	0.12	0.2	0.94	0.2	0	$-0.27 + 1.06\ F_2 + 0.39\ F_2^2 - 0.42\ F_2^3$

Note: Values of Levene's test are 0.55 and 0.9 for SS, 0.25 and 0.8 for TDS, and 0.55 and 1 for COD and BOD

From Table 5.28, the results of GB were also obtained in the same pattern of GF and can be used for the next step.

5.2.4 Estimation of Model Parameters

The estimated model parameters that meet the statistical significance for the appropriateness test of the model under the MRA assumptions were used as model parameters for each wastewater load. Based upon these parameters and their high coefficient of determination (R^2) with low standard error (SE), the relationships between factors and each wastewater load were determined as shown in Table 5.29, and 5.30 for GF and GB, respectively.

Table 5.29 Result of Estimation of Model Parameters in Predictive Equation of GF

Model	R^2x100	SE	n	Estimated Model Parameters in Composite Predictive Equation
SS	91.75	< 0.5	33	$-0.31 - 0.07\ F_1 - 0.30\ F_1^2 + 0.36F_1^3$ $-0.1\ F_4 - 0.1\ F_4^2 + 0.06\ F_4^3$
TDS	84.97	< 0.5	32	$-0.25 - 0.26\ F_1 - 0.13\ F_1^2 + 0.06F_1^3$ $+0.02/F_2 + 0.01F_4 - 0.01F_4^2 - 0.02F_4^3$
COD	73.93	< 0.5	28	$-0.45 - 0.16\ F_2 + 0.17\ F_2^2 - 0.04F_2^3 - 0.001\ F_3$ $-0.09F_3^2 + 0.03\ F_3^3$
BOD	75.44	< 0.5	27	$-0.46 - 0.22\ F_2 + 0.21\ F_2^2 - 0.1F_2^3 - 0.11\ F_3$ $+0.03\ F_3^2 + 0.03\ F_3^3$

For GF (Table 5.29), the prediction of SS load is dependent on F_1 and F_4 in the cubic form. The prediction of TDS load depends on F_1 and F_4 in the form of cubic curve and F_2 in the form of inverse. The predictions of COD and BOD loads depend on F_2 and F_3 in the cubic form. The model parameters or estimated coefficients of these predictive model have low standard errors (< 0.5) and high coefficient of determination ($R^2 > 0.5$). Thus, these models were correctly built through step I to step III for the MRA predictive model.

For GB, the prediction of SS load is dependent on F_2 and F_4 in the cubic form. TDS load is dependent on F_1 and F_4 in the form of cubic curve. The predictions of COD and BOD loads depend on F_2 and F_3 in the cubic curve. The model parameters of predictive models for GB also have the same pattern of result of GF as shown in Table 5.30.

Table 5.30 Result of Estimation of Model Parameters in Predictive Equation of GB

Model	R^2x100	SE	n	Estimated Model Parameters in Composite Predictive Equation
SS	74.16	<0.5	32	$-0.32+0.06\ F_2+0.01\ F_2^2+0.07\ F_2^3$ $-0.11F_4 - 0.08\ F_4^2 - 0.04\ F_4^3$
TDS	91.00	<0.5	31	$-0.08+0.24\ F_1-0.14\ F_1^2 - 0.09\ F_1^3$ $-0.41\ F_4+0.38\ F_4^2+ 0.22\ F_4^3$
COD	74.86	<0.5	28	$-0.12 + 0.11\ F_1-0.11F_1^2 + 0.88\ F_2$ $+0.31\ F_2^2-0.32\ F_2^3$
BOD	79.46	<0.5	27	$- 0.20 + 0.07\ F_1 -0.09\ F_1^2 +0.98\ F_2$ $+0.40\ F_2^2-0.39\ F_2^3$

Then, these final models for GF and GB were evaluated on related statistical test in the same procedure of step II as the last step before application.

5.2.5 Evaluation and Interpretation of the Model

Evaluating the model was performed for composite model as the same procedure of model testing in step II for testing the MRA assumptions. The final proposed models that meet the assumptions were obtained for GF and GB (Table 5.31 and 5.32).

From Table 5.31 and 5.32, the results show that all of the proposed models meet the statistical significance under MRA assumptions due to the zero mean of residuals with low values of standard errors (SE) at a significance level of 0.05. Moreover, the values of Kolmogorov-Smirnov and Shapiro-Wilk and Levene's test are higher than the values at significance level of 0.05 loads including the constant variance through the residual plot that has data distribution near the zero value. Furthermore, the residuals values are less than 1.5 IQR. Thus, outlier or influential observations in some cases as mentioned in Table 5.22 are not included in the predictive model. This indicates that the residual distributions have a normal distribution, independence and homogeneity of variance according to MRA assumptions. Therefore, all of the predictive models obtained were accepted for validation in a further step.

Table 5.31 Result of Evaluation of the Model for Predictive Equation of GF

Model	Kolmogorov-smirnov	Sig.	Shapiro-Wilk	Sig	Mean of residuals & SE	Composite Predictive Equation
SS	0.10	0.20	0.93	0.10	0	$-0.31 - 0.07 F_1 - 0.30 F_1^2 + 0.36F_1^3 - 0.1 F_4 - 0.1 F_4^2 + 0.06 F_4^3$
TDS	0.10	0.20	0.97	0.50	0	$-0.25 - 0.26 F_1 - 0.13 F_1^2 + 0.06F_1^3 + 0.02/F_2 + 0.01F_4 - 0.01F_4^2 - 0.02F_4^3$
COD	0.14	0.14	0.92	0.30	0	$-0.45 - 0.16 F_2 + 0.17 F_2^2 - 0.04F_2^3 - 0.001 F_3 - 0.09F_3^2 + 0.03 F_3^3$
BOD	0.11	0.20	0.97	0.55	0	$-0.46 - 0.22 F_2 + 0.21 F_2^2 - 0.1F_2^3 - 0.11 F_3 + 0.04 F_3^2 + 0.03 F_3^3$

Note: Values of Levene's test are 0.45 for SS, TDS, and BOD, 0.85 for COD

The interpretation of evaluated predictive models for GF can provide the necessary information of input used in the process in terms of significant factors and important variables for manufacturers. Based upon the model parameter (coefficient), it indicates the sensitivity of predictive model to the factors. The SS model is dependent on F_1 and F_4, but it is more sensitive to F_1 than F_4 according to the higher coefficient of important variables in F_1 (water, electricity, alum, emulsifier, and defoamer) than in F_4 (defoamer). The TDS model is dependent on F_1, F_2, and F_4, but it is more sensitive to F_1 than F_2 and F_4 (detailed in 5.2.6). The COD and BOD loads are dependent on F_2 and F_3 but it is more sensitive to F_3 than F_2 according to the higher coefficient of important variables in F_3 (starch) than in F_2 (A_1 to A_4).

Based upon the names and events occurred in factors for GF (detailed in 5.1.6.1), the SS and TDS models are mainly related to variations of broke generation and usage and balancing of white water. The COD and BOD models are mainly related to special treatment of products and variation of pulp stock compositions (F_3).

Table 5.32 Result of Evaluation of the Model for Predictive Equation of GB

Model	Kolmogorov-smirnov	Sig.	Shapiro-Wilk	Sig	Mean of error & SE	Composite Predictive Equation
SS	0.13	0.2	0.95	0.2	0	$-0.32+0.06 F_2+0.01 F_2^2+0.07 F_2^3 - 0.11F_4 - 0.08 F_4^2 - 0.04 F_4^3$
TDS	0.1	0.2	0.96	0.44	0	$-0.08+0.24 F_1-0.14 F_1^2 - 0.09 F_1^3 - 0.41 F_4+0.38 F_4^2+ 0.22 F_4^3$
COD	0.1	0.2	0.99	0.96	0	$-0.12 + 0.11 F_1-0.11 F_1^2 +0.88F_2 + 0.31 F_2^2 - 0.32 F_2^3$
BOD	0.12	0.2	0.94	0.22	0	$-0.20 + 0.07 F_1 - 0.09 F_1^2 +0.98F_2 + 0.40 F_2^2 - 0.39 F_2^3$

Note: Values of Levene's test are 0.55 for SS, 0.45 for TDS and COD, and 0.65 for BOD

The interpretation of evaluated predictive models for GB can also provide the necessary information for manufacturers. The SS model indicates that SS depends on F_4. The TDS load model indicates that TDS is dependent on F_1 and F_4, but it is more sensitive to F_4 than F_1 (detailed in 5.2.6). The COD and BOD loads are also dependent on F_1 and F_2, but it is more sensitive to F_2 than F_1.

Based upon the names and events occurred in factor for GB (detailed in 5.1.6.2), the SS model is mainly related to the increased use of broke and the overflow of white water (F_2). The TDS model is mainly related to variation of foaming problem due to both the decreased use of broke and the use of white water (F_4). The COD and BOD models are mainly related to the broke generation and usage and the overflow of white water due to the decreased use of broke as well as increased use of broke (F_2).

5.2.6 Predictive Equation of Wastewater Load

The results of predictive environmental model for wastewater load for GF and GB are shown in the forms of standardized variables for model building (MB) and model validation (MV) as in Table 5.33.

Table 5.33 Predictive Environmental Model for Wastewater of Gypsum Liner Board

Gypsum liner board	Predictive Environmental Model	% Relation (R^2x100)	
		MB	MV
1. GF			
	1. ZSS load $= -0.31-0.07\ F_1 - 0.30\ F_1^2 + 0.36\ F_1^3 - 0.1F_4 - 0.1F_4^2 + 0.06F_4^3$	91.75	68.05
	2. ZTDS load $= -0.25 - 0.26\ F_1 - 0.13\ F_1^2 + 0.06F_1^3 + 0.02/F_2 + 0.01F_4 - 0.01F_4^2 - 0.02F_4^3$	84.97	87.54
	3. ZCOD load $= -0.45 - 0.16\ F_2 + 0.17\ F_2^2 - 0.04F_2^3 - 0.001\ F_3 - 0.09F_3^2 + 0.03\ F_3^3$	73.93	82.56
	4. ZBOD load $= -0.46 - 0.22\ F_2 + 0.21\ F_2^2 - 0.1F_2^3 - 0.11\ F_3 + 0.04\ F_3^2 + 0.03\ F_3^3$	71.44	80.47
2. GB			
	1. ZSS load $= -0.32 + 0.06\ F_2 + 0.01\ F_2^2 + 0.07\ F_2^3 - 0.11F_4 - 0.08\ F_4^2 - 0.04\ F_4^3$	74.16	67.22
	2. ZTDS load $= -0.08 + 0.24\ F_1 - 0.14\ F_1^2 - 0.09\ F_1^3 - 0.41\ F_4 + 0.38\ F_4^2 + 0.22\ F_4^3$	91.00	77.10
	3. ZCOD load $= -0.12 + 0.11\ F_1 - 0.11\ F_1^2 + 0.88F_2 + 0.31\ F_2^2 - 0.32F_2^3$	74.86	62.16
	4. ZBOD load $= -0.20 + 0.07\ F_1 - 0.09\ F_1^2 + 0.98F_2 + 0.40\ F_2^2 - 0.39\ F_2^3$	79.86	61.66

Note : % Relation = Determination of coefficient (R^2) x100 for MB Model building excluding outliers, and for MV Model validation including outliers

From Table 5.33, the details of each type of predictive environmental model are discussed in the following sections.

5.2.6.1 Predictive Model of Wastewater load for GF

1) SS Load :

As the standardized value of SS load or ZSS load was dependent on both F_1 and F_4, it is interesting to distinguish the influence of each factor. In doing so, the effect of each factor must be isolated. This was done by selecting one factor of interest and letting the rest be zero. Then, the relationship between ZSS load and each factor can be shown graphically as in Figure 5.18 and in Table 5.33.

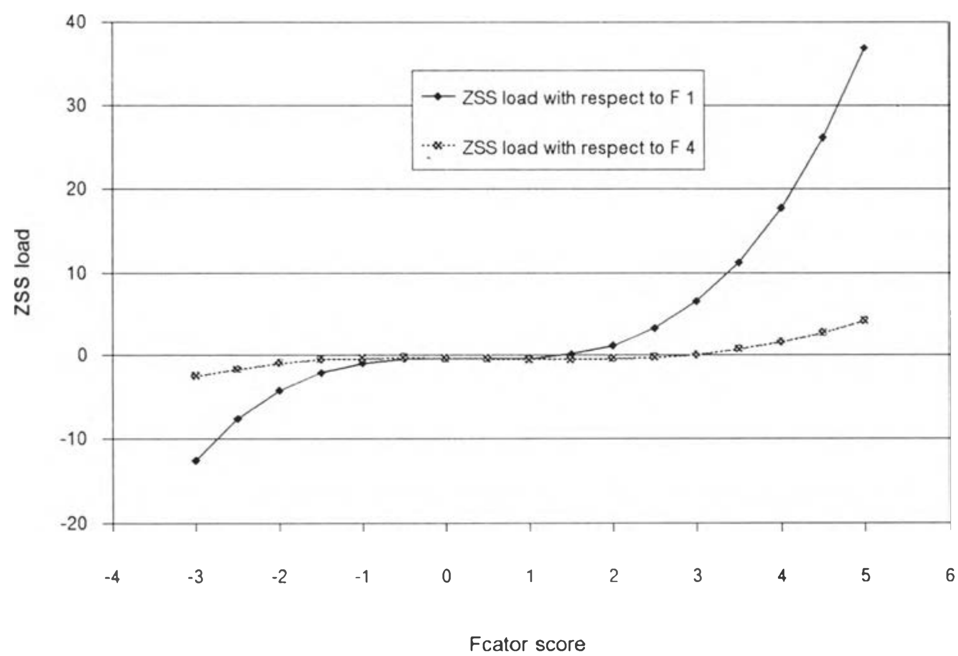


Figure 5.18 Relationship between ZSS Load of GF and F_1 and F_4

From Figure 5.18, it is found that ZSS load was more sensitive to F_1 than F_4 at magnitude of factor score > |1|. In practical situation, there was high deviation of F_1 in positive direction that can easily cause the increasing of ZSS load. Since F_1 was a composite factor containing various variables: water, electricity, alum, emulsifier, and defoamer, the pattern of variation of ZSS load had to be investigated in conjunction with the change pattern of all variables presented in F_1.

Table 5.34 Unusual cases of ZSS Load

Case #	Factor Score		ZSS load
	F_1	F_4	
8	0.12	0.59	- 0.40
19	-0.23	0.27	- 0.35
25	0.71	- 2.36	- 1.49
32	**4.89**	- 2.01	**34.23**
33	0.27	0.36	- 0.39

From Table 5.34, it is found that the unusual case of the highest value of ZSS load (case # 32) occurred due to the larger magnitude of F_1 (4.89), that was > |1|, than F_4 (-2.01). The other unusual cases, ZSS load occurred due to the smaller magnitude of F_1 (-0.23 to 0.71) than F_4 resulting the more decreasing of ZSS load. Notice that the prediction of ZSS load in the unusual cases can provide both the increasing and decreasing of ZSS load less than the measured value as shown in Figure 5.26 (a).

Through the highly case of the dominant factor, F_1 (4.89) in the model and its name, it indicates that the root event and cause for ZSS load increase was due to the overflow of white water from the change over of paper grade. The white water in the process from the previous operation was drained off. This water called white water contains fibers and dispersed materials that could not dissolve and affected the increasing of SS load due to the loss of these materials from the overflow of white water during the change over of paper grade. In this case, not only water and electricity but also other chemicals was highly consumed in the process.

2) TDS load :

As for TDS load, the standardized value of TDS load or ZTDS load was dependent on both F_1, F_2 and F_4, it is interesting to distinguish the influence of each factor.

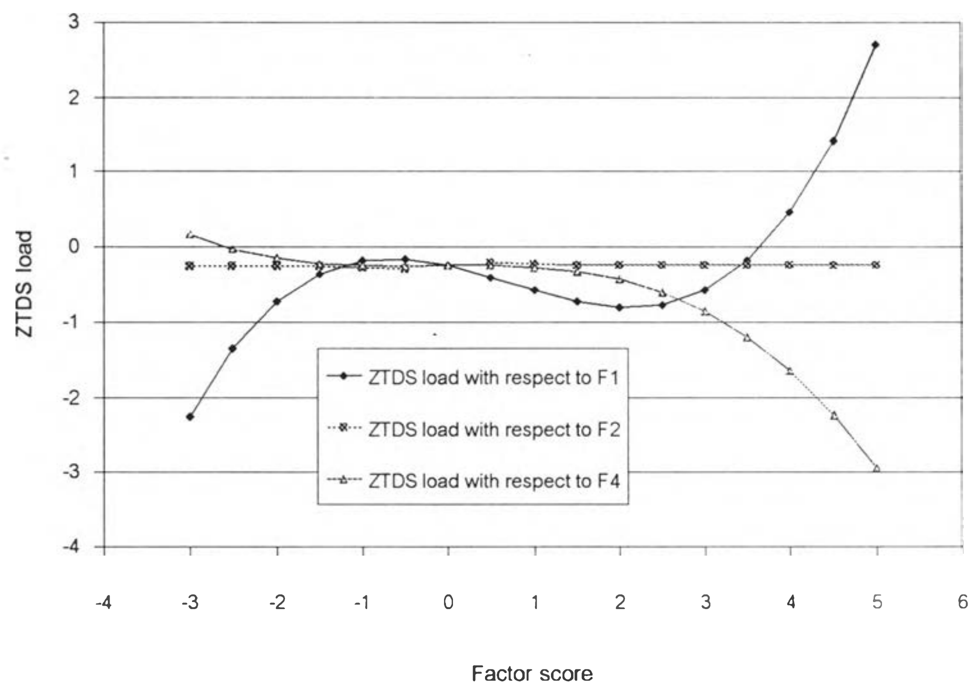


Figure 5.19 Relationship between ZTDS Load of GF and F_1 to F_2 and F_4

In doing so, the effect of each factor must be isolated. This was done by selecting one factor of interest and letting the rest be zero. Then the relationship between ZTDS load and each factor can be shown graphically as in Figure 5.19 and in Table 5.33.

From Figure 5.19, it is found that ZTDS load was not quite sensitive to F_2. It was more sensitive to F_1 than F_4 at magnitude of factor score > 3.5. The large change of all variables within the important variables, F_1, based on its physical meaning and name was due to the events occurred in F_1 as the following discussed.

Table 5.35 Unusual cases of ZTDS Load

Case #	Factor score			ZTDS load
	F_1	F_2	F_4	
15	0.32	-0.52	1.98	- 0.56
19	-0.23	-1.61	0.27	- 0.21
25	0.71	0.81	-2.36	- 0.27
32	**4.89**	-1.37	2.01	**2.20**
33	0.27	-0.45	0.36	- 0.37
34	-0.14	0.06	-0.46	0.14
37	-0.23	-0.22	0.22	-0.29

From Table 5.35, it is found that the unusual case that has highest value of ZTDS load (case # 32) occurred due to the larger magnitude of F_1 (4.80) than F_2 (-1.37) and F_4 (2.01) resulting the increasing of ZTDS load. In some unusual case, ZTDS load that was slightly increased (case #34) due to the smaller magnitude of F_1 than F_2 in opposite direction and F_4 in negative direction resulting the decreasing of ZTDS load. The other unusual cases (case # 15,19, 25, and 33), ZTDS loads occurred due to the smaller magnitude of F_1 than F_2 and F_4 resulting the decreasing of ZTDS load. Also in some unusual case (case # 37), ZTDS load occurred due to the same range of magnitude of F_1, and F_2 in negative direction but F_4 in positive direction resulting the decreasing of ZTDS load. Also notice that the prediction of ZTDS load in the unusual cases can provide both the increasing and decreasing of ZTDS load. In particular, some prediction loads can be both less and more than the measured value as shown in Figure 5.26 b) (case # 32 and 34).

Through the highly case (case # 32) for the change of magnitude of dominant factor, F_1 (4.89) in the model and its name, it indicates that the root event and cause for ZTDS load increase was also due to the overflow of white water from the change of paper grade. The drained water affected the increase of ZTDS load due to the loss of other chemicals such as emulsifier and alum that can dissolve in water. Thus, these chemicals were highly consumed in the process.

3) COD load :

The standardized values of ZCOD load or COD load were dependent on F_2 and F_3. By selecting one factor of interest and letting the rest be zero, the relationship between ZCOD load and each factor can be shown graphically as in Figure 5.20 and in Table 5.33.

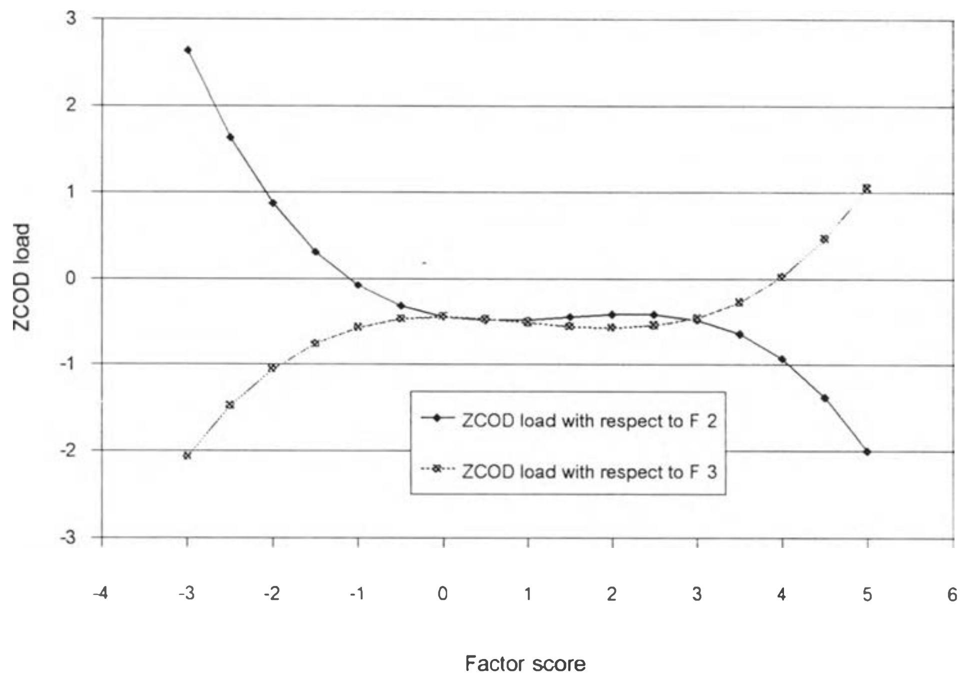


Figure 5.20 Relationship between ZCOD Load of GF and F_2 to F_3

From Figure 5.20, it is found that ZCOD load was more sensitive to F_2 than F_3 at magnitude of factor score > -1. This indicates that the important variables within F_2 had more effect to the change of ZCOD than the variables in F_3. The large change of all variables within the important variables, F_2, based on its physical meaning and name was due to the events occurred in F_2.

From Table 5.36, it is found that the unusual case of the highly ZCOD load (case # 32) occurred due to the larger negative of F_2, that is <-1, (-1.37) than F_3 (-0.08) in negative direction resulting the increasing of ZCOD load. The other unusual cases (case # 6, 25, and 31), the larger magnitude of F_2 than F_3 in the positive direction can cause the decreasing of COD load. However, the larger magnitude of F_2 than F_3 in the negative direction but > 1 (case # 33) can also cause the decreasing of ZCOD load. The rest of unusual cases, the smaller magnitude of F_2 than F_3 in negative direction can cause the decreasing of ZCOD load. Note that the prediction of ZCOD load in the unusual cases can provide both the increasing and decreasing of ZCOD load less than the measured value as shown in Figure 5.27 c.

Table 5.36 Unusual cases of ZCOD Load

Case #	Factor Score		ZCOD load
	F_2	F_3	
6	2.38	0.81	- 0.45
8	- 0.32	-0.35	- 0.39
11	- 0.09	-0.37	- 0.45
12	- 0.21	-0.36	- 0.42
15	- 0.52	-1.01	- 0.44
16	- 0.19	-0.98	- 0.53
25	0.81	-0.03	- 0.49
31	0.02	-0.21	- 0.46
32	**-1.37**	-0.08	**0.19**
33	- 0.45	-0.26	- 0.35
36	- 0.24	-0.25	- 0.41
37	- 0.22	-0.24	- 0.41

Through the highly case (case # 32) for the change of magnitude of dominant factor, F_2 (-1.37) in the model and its name, it indicates that the root event and cause of increasing COD load was due to the overflow of white water from the change of paper grade. The drained water affected the increase of ZCOD load due to the loss of fibers that were the organic matter sources of ZCOD and ZBOD loads.

4) BOD load :

The standardized value of BOD load or ZBOD load was dependent on F_2 and F_3 (Figure 5.21). To distinguish the influence of each factor, one factor of interest was selected and letting the rest were set as zero. The relationship between ZBOD load and each factor can be shown graphically as in Figure 5.21 and in Table 5.37.

From Figure 5.21, it is found that the increasing of ZBOD load was more sensitive to F_2 than F_3 at magnitude of factor score < -1 or higher than 2. This also indicates that the important variables within F_2 had more effect to the change of ZBOD than the variables in F_3. Based on its physical meaning and name, the large change of all variables within the important variables, F_2 was due to variations of pulp stock composition.

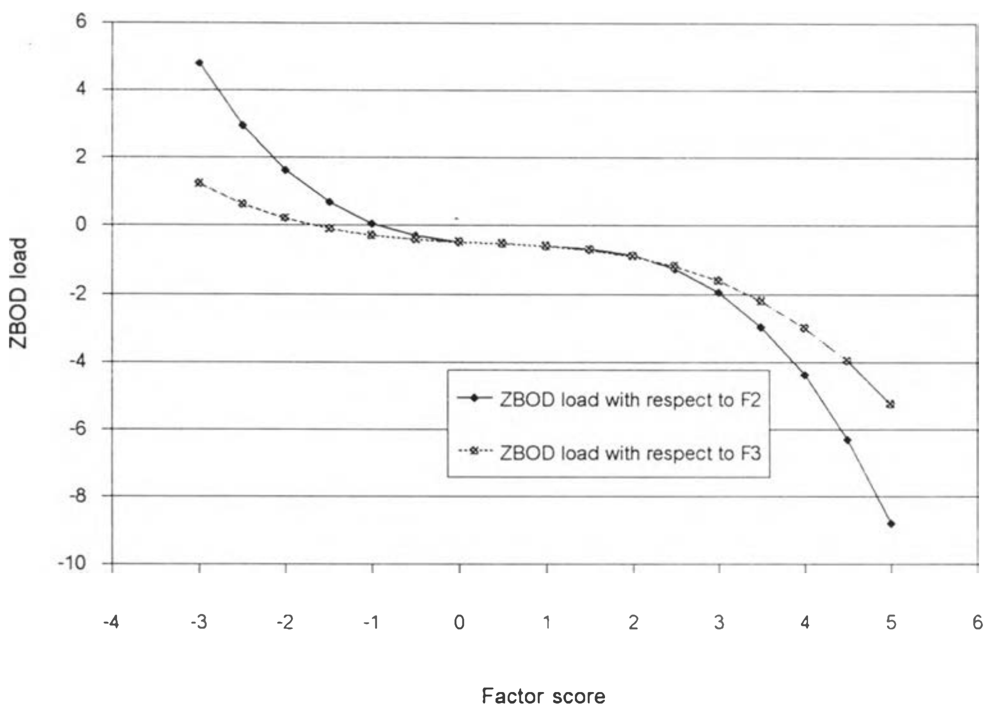


Figure 5.21 Relationship between ZBOD Load of GF and F_2 to F_3

From Table 5.37, it is found that the unusual case of the highly ZBOD load occurred due to the larger magnitude of F_2 (-1.37) than F_3 (-0.08) in negative direction resulting the increasing of ZBOD load. The other unusual cases, the larger magnitude of F_2 than F_3 in the positive direction (case # 25 and 36) can cause the decreasing of ZBOD load. Although there was larger magnitude of F_2 than F_3, this magnitude that was > 1 can cause the decreasing of ZBOD load. The rest of unusual cases, the smaller magnitude of F_2 than F_3 in negative direction can also cause the decreasing of ZBOD load. Also note that the prediction of ZBOD load in the unusual cases can provide both the increasing and decreasing of ZBOD load. In particular, some prediction loads can be both less and more than the measured value as shown in Figure 5.19 (case # 32 and 38).

Table 5.37 Unusual cases of ZBOD Load

Case #	Factor Score		ZBOD load
	F_2	F_3	
8	- 0.32	-0.35	- 0.33
10	- 0.18	- 0.33	- 0.40
11	- 0.09	-0.37	- 0.43
12	- 0.21	-0.36	- 0.38
15	- 0.52	-1.01	- 0.22
16	- 0.19	-0.98	- 0.40
25	0.81	-0.03	- 0.57
31	0.02	-0.21	- 0.48
32	**-1.37**	-0.08	**0.69**
33	- 0.45	-0.26	- 0.26
36	- 0.24	-0.25	- 0.38
37	- 0.22	-0.24	- 0.39
38	- 0.27	- 0.15	- 0.39

Through the highly case (case # 32) for the change of magnitude of, F_2 (-1.37) in the model and its name, it indicates that the root event and cause of increasing BOD load was also the overflow of white water from the change of paper grade. The drained water affected the increase of ZBOD load due to the loss of fibers that were the organic matter sources of ZCOD and ZBOD loads.

Based upon the unusual cases of ZSS load, ZTDS load, ZCOD load, and ZBOD load, the root event and cause of the wastewater generated from GF production can be concluded as shown in Table 5.38.

Table 5.38 Root cause and effect relating wastewater generated of GF

Effect on Wastewater Load	Root Event &Cause	Indicator
1. Increasing SS load	-Overflow of white water system due to the change over of paper grade	-High water consumption -High electricity consumption -High sizing agents and filler usages
2. Increasing TDS load	same	-High sizing agents usage -High utility consumption
3. Increasing COD load	same	-High chemicals usages -High utility consumption
4. Increasing BOD load	same	-Same as COD load

5.2.6.2 Predictive Model of Wastewater load for GB

As for GB production, the wastewater loads of GB are shown in Figure 5.22 to 5.25.

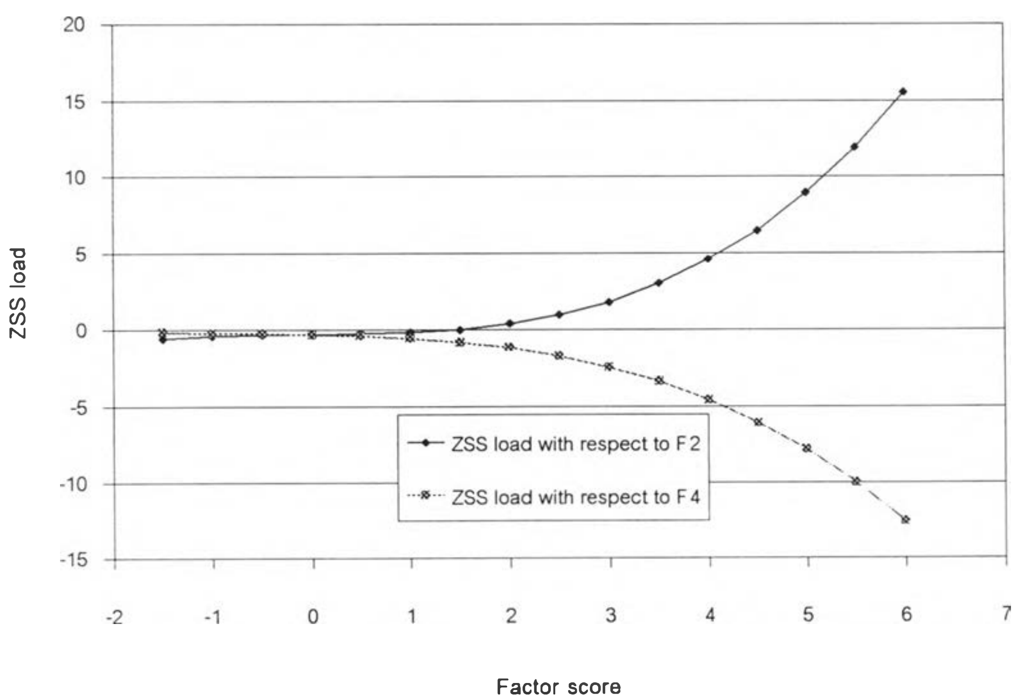


Figure 5.22 Relationship between ZSS Load of GB and F_2 and F_4

1) SS Load :

From Figure 5.22, the increasing of ZSS load for GB was more sensitive to F_2 than F_4 when the magnitude of F_4 is > 2. Note that for SS load of GB, the real magnitude of factor score is between -1.73 to 2.73 for F_2, and between - 2.83 to 2.99 for F_4 (Appendix A3).

Through the highly case (case # 19, and 23) of the magnitude for the dominant factor, F_2 (1.99, and 2.72) in the model and its name, it indicates that the root cause of increasing ZSS load was due to the overflow of white water from the change of paper grade and the more usage of broke. In this case, the use of broke more than usual can cause the ZSS load increase due to the loss of dispersed materials that existed in broke and the loss of fibers and other dispersed substances that contain in the white water.

2) TDS load :

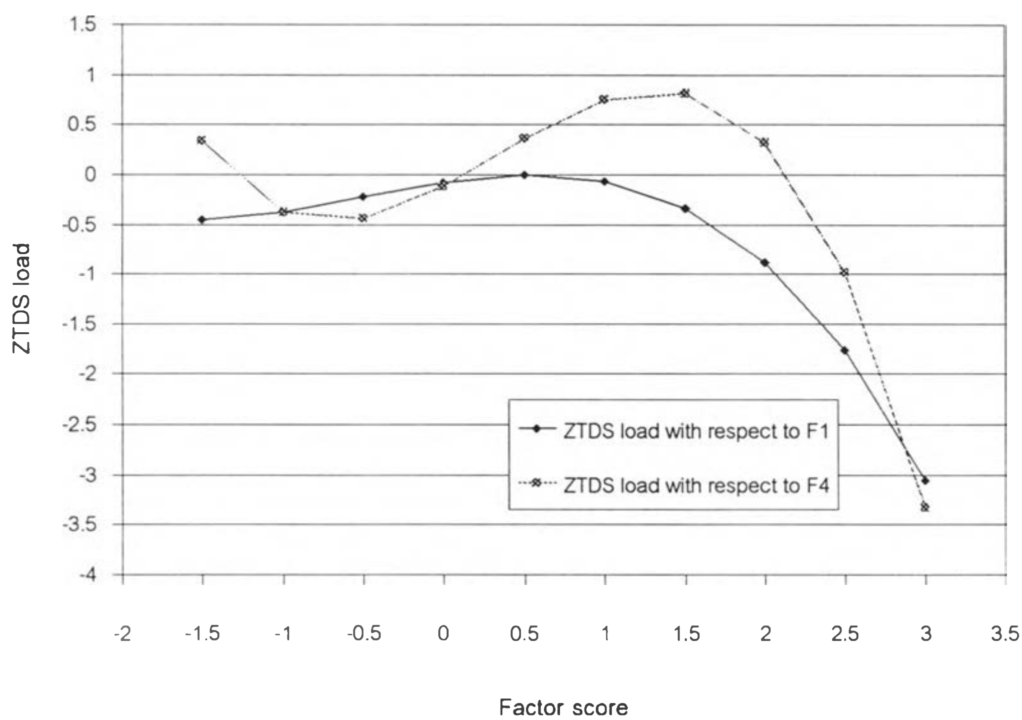


Figure 5.23 Relationship between ZTDS Load of GB and F_1 and F_4

From Figure 5.23, the ZTDS load for GB is more sensitive to F_4 than F_1 in terms of increasing load when the magnitude of F_4 was between 0.5 to 2, and less than –0.5 and in terms of decreasing load when the magnitude of F_4 is > 2. Note that for ZTDS load of GB, the real magnitude of factor score was between -2.83 to 2.9 for F_4, and between -1.31 to 2.91 for F_1 (Appendix A3).

Through the highly cases (case # 1-2, 7, 10, 14, 18, and 23) of the magnitude for the dominant factor, F_4 (-2.83 to 2.99) in the model and its name, it indicates that the root cause of increasing ZTDS load was due to the increased use of broke. The deteriorated fibers that exist in broke causing the loss of dissolved substances within the broke affected the increase of ZTDS load.

3) COD Load :

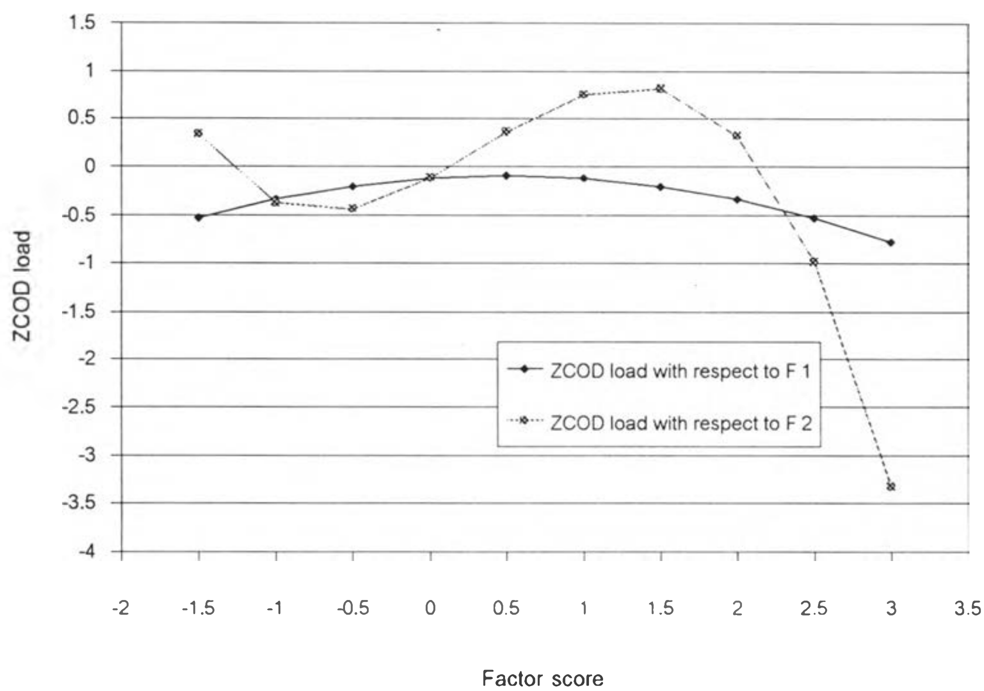


Figure 5.24 Relationship between ZCOD Load of GB and F_1 and F_2

From Figure 5.24, the ZCOD load for GB was more sensitive to F_2 than F_1 in terms of increasing load when the magnitude of F_2 was between 0.5 to 2, and less than –0.5, and in terms of decreasing load when the magnitude of F_2 is > 2 . Note that for COD load of GB, the real magnitude of factor score was between -1.73 to 2.73 for F_2, and between -1.31 to 2.91 for F_1 (Appendix A3).

Through the highly cases (case # 2, 7, 11, 18-21, 23, 29-30, and 38) of the magnitude for the dominant factor, F_2 in the model and its name, it indicates that the root cause of increasing ZCOD load was due to the increased use of broke and the overflow of white water. In this case, both events contributed to not only ZCOD load but also ZBOD load due to the highly chemical additives that need to be added.

4) BOD Load

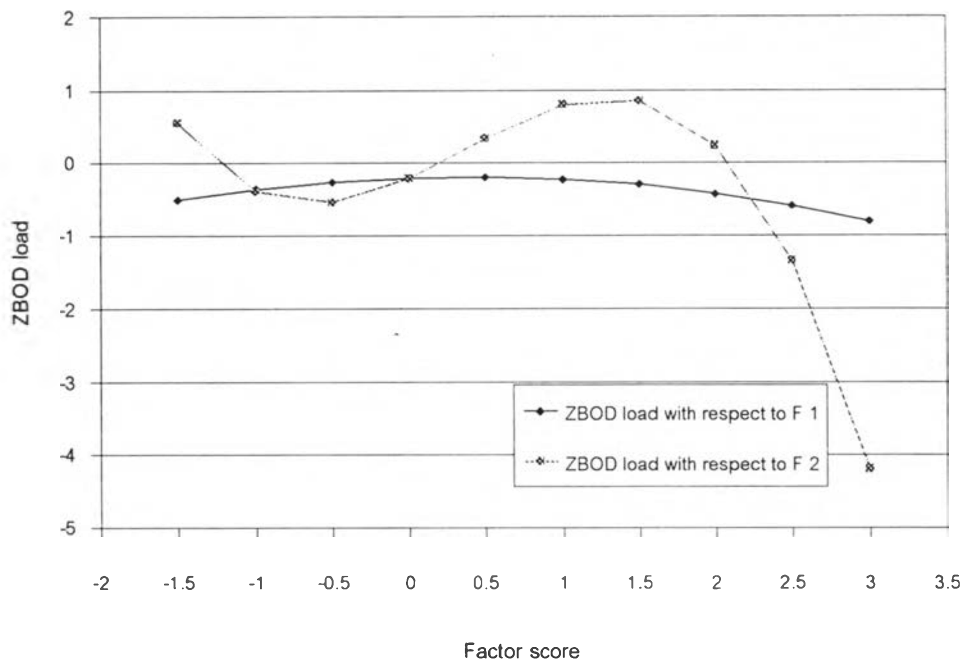


Figure 5.25 Relationship between ZBOD Load of GB and F_1 and F_2

From Figure 5.25, ZBOD load for GB was also more sensitive to F_2 than F_1 in terms of increasing load when the magnitude of F_2 was between 0.5 to 2, and less than –0.5, and in terms of decreasing load when the magnitude of F_2 was > 2. Note that for BOD load of GB, the real magnitude of factor score was also between -1.73 to 2.73 for F_2 and between -1.31 to 2.91 for F_1.

Through the highly cases of (case # 2, 7, 11, 18-21, 23, 29-30, and 38) of the magnitude for the dominant factor, F_2 in the model and its name, it indicates that the root cause of increasing ZBOD load was due to the increased used of broke, as well as the overflow of white water. In this case, the use of broke and the overflow of white water contributed to not only ZBOD load but also ZCOD load due to the same reason as mentioned above.

From Figure 5.22 to 5.25, the root event and cause of increasing wastewater loads for GB can be concluded as in Table 5.39.

Table 5.39 Root cause and effect relating wastewater generated of GB

Effect on Wastewater Load	Root Event & Cause	Indicator
1. Increasing ZSS load	-Overflow of white water system due to the change over of paper grade -Increased use of broke	-High utility consumption -High some fiber consumption -High dry strength agents and wet strength agent usages
2. Increasing ZTDS load	-Increased use of broke	-High utility consumption -High some dry strength agents and wet strength agent usages
3. Increasing ZCOD load	-Same as ZSS load	- Same as ZSS load
4. Increasing ZBOD load	-Same as ZCOD load	-Same as ZCOD load

Note that the real root causes of wastewater generation for all cases of GF and GB production include not only the overflow of white water due to the change over of paper grad, and scheduling of operation between paper machine and the wastepaper plant but also the increased use of broke and the excess chemicals in the white water due to poor control over the addition of chemicals and poor retention of fines and filler. The presence of excess chemicals can be easily identified through special product treatments for the desired property of the product. This is because the outliers of the MRA predictive model building were included in all real cases, just as the FA input model. Thus, the real root causes should be considered from all real cases. These root causes will be used for management applications.

5.2.7 Validation of the Predictive model

The predictive environmental models of wastewater load from Gypsum liner board production for both GF and GB with the percentage of the relationship between each response variable (wastewater load) and input factors were validated based on all real cases.

Based upon the prediction accuracy (% of relation for all cases of the predictive model from model validation (MV) x 100)/ % of relation of the predictive model from model building (MB) for GF and GB, the predictive ability of these models was quite high (> 70%) on average as shown in Table 5.40.

Therefore, these models are applicable and can serve a good predictive purpose.

Table 5.40 Validity of predictive model for wastewater from Gypsum liner board

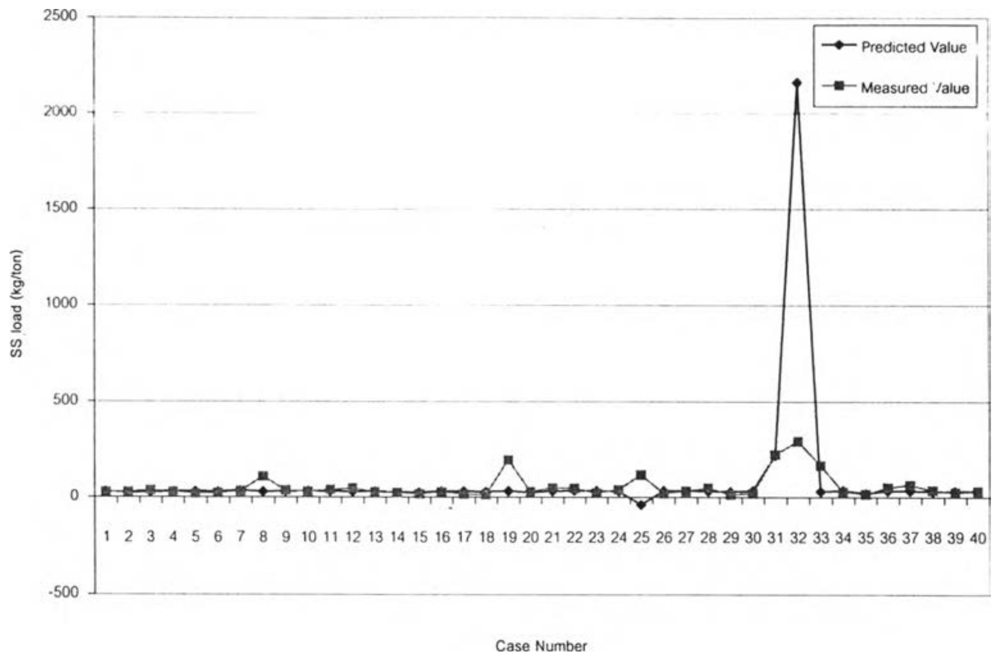
Wastewater load	Prediction accuracy (%) (% relation of MV x 100) / % relation of MB	
	GF	GB
1. SS load	74.17	90.64
2. TDS load	103.00	84.73
3. COD load	111.67	83.03
4. BOD load	106.67	77.60

The result of calculation from these models for total GP in comparison with all measured value of each wastewater load in the forms of original variables were shown in Figure 5.26 to 5.29.

For GF, it was found that the predictive model for SS load can provide correct trends for most value of SS. The different value between predicted value and measured value was due to an outlier of the following cases: the outlier of error between ZSS load and each related factor (as shown in Table 5.23), the outlier of SS load (case # 8, 19, 25, and 31-33), and the outlier of each factor (F_1: case # 28, and 31-32, F_4: case # 31). The TDS load can also provide quite a good predicted value. The outliers occurred were the outliers of error between ZTDS load and each related factor (as shown in Table 5.23), the outlier of TDS load (case # 19, 25, and 31-33), and the outlier of each factor (F_1: case # 28, and 31-32, F_2: case # 5, 8, 23, 31, and 35, F_4: case # 31). The COD load can provide a compromised predicted value. The outliers occurred were the outliers of error between ZCOD load and each related factor (as shown in Table 5.23), the outlier of COD load (case # 25 and 31-33), and the outlier of each factor (F_2: case # 5, 8, 23, 31, and 35, and F_3: case # 19, 21, and 32). The BOD load also can provide quite a compromised predicted value except in the case of outliers (Table 5.23). The outliers occurred were the outliers of error between ZCOD load and each related factor (as shown in Table 5.23), the outlier of COD load (case # 25 and 31-33), and the outlier of each factor (F_2: case # 5, 8, 23, 31, and 35, and F_3: case # 19, 21, and 32). Note that the influences of outliers occurred in the predictive model were due to the outliers from wastewater load more than each factor and errors between each wastewater load and related factors. Even though the outliers of wastewater load had the highest effect on the high fluctuation of the model, the numbers of these outliers were less than other outliers. Therefore, when all kinds of outliers included in the predictive models of GF, these models were still valid with high prediction accuracy.

As for GB, the prediction for wastewater load of GB was the same pattern of GF. These models can provide quite a good predicted value for overall prediction (Table 5.23 and Appendix A4). The outliers of the predictive model were also due to the outlier of each type of wastewater load (case # 2, 11, 23 and 30 for SS, case # 2 and 11 for TDS, and case # 2, 11, and 23 for COD and BOD) more than the outlier of related factors (case # 3, 4, 6, 11, and 14 for F_1, case # 2 for F_2, case # 11 and 23 for F_4) and the outlier of error between wastewater load and factors (as shown in Table 5.23). Although the outliers of wastewater load had the most effect to the high fluctuation of the model, the numbers of these outliers were less than other outliers. Therefore, when all kinds of outliers included in the predictive models of GB, these models were also still valid with high prediction accuracy.

a) Calculated Result for SS load of Total GF



b) Calculated Result for TDS load of Total GF

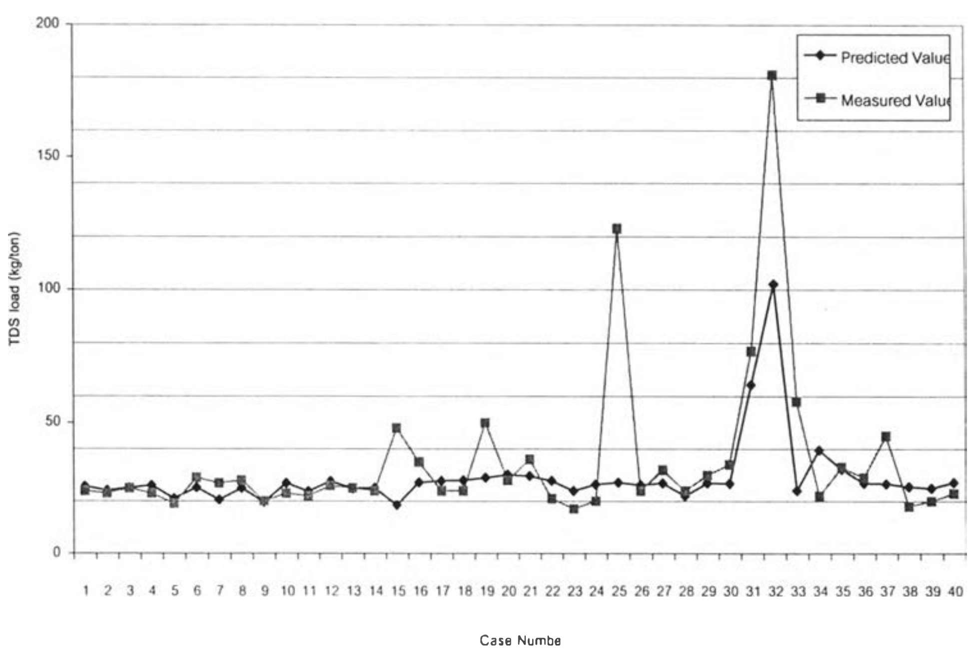
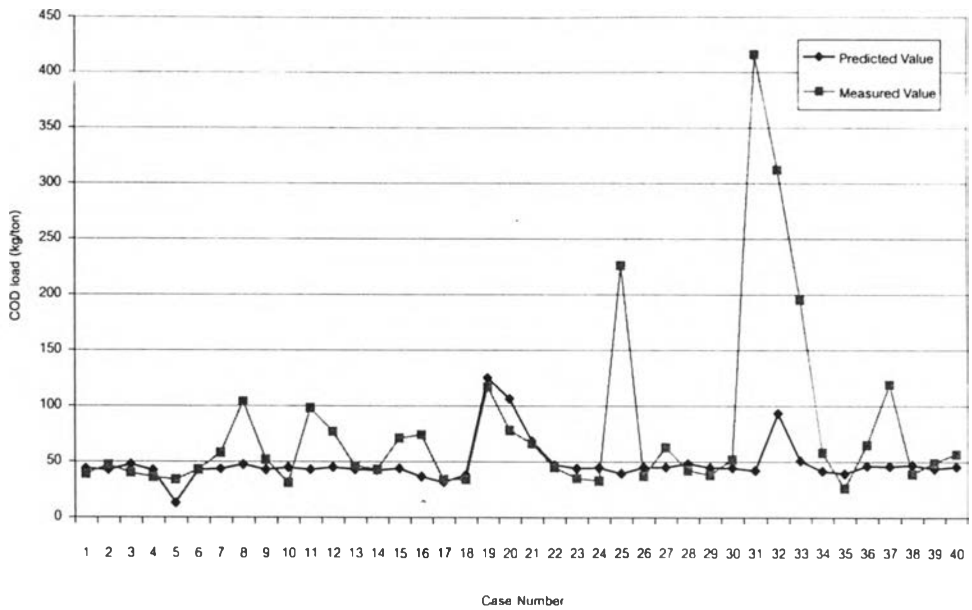


Figure 5.26 Result of Calculation for SS and TDS Loads of Total GF

c) Calculated Result for COD load of Total GF



d) Calculated Result for BOD load of Total GF

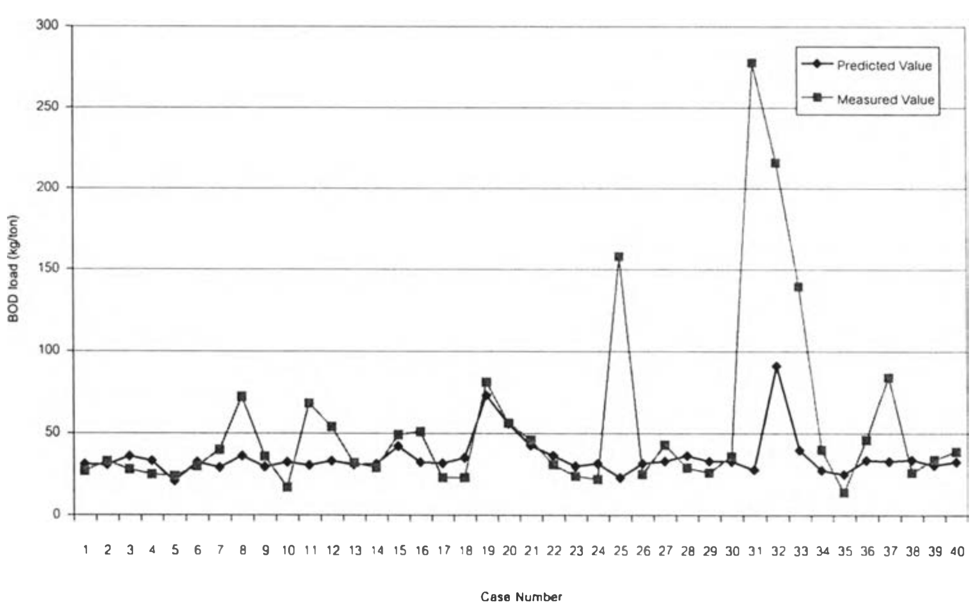
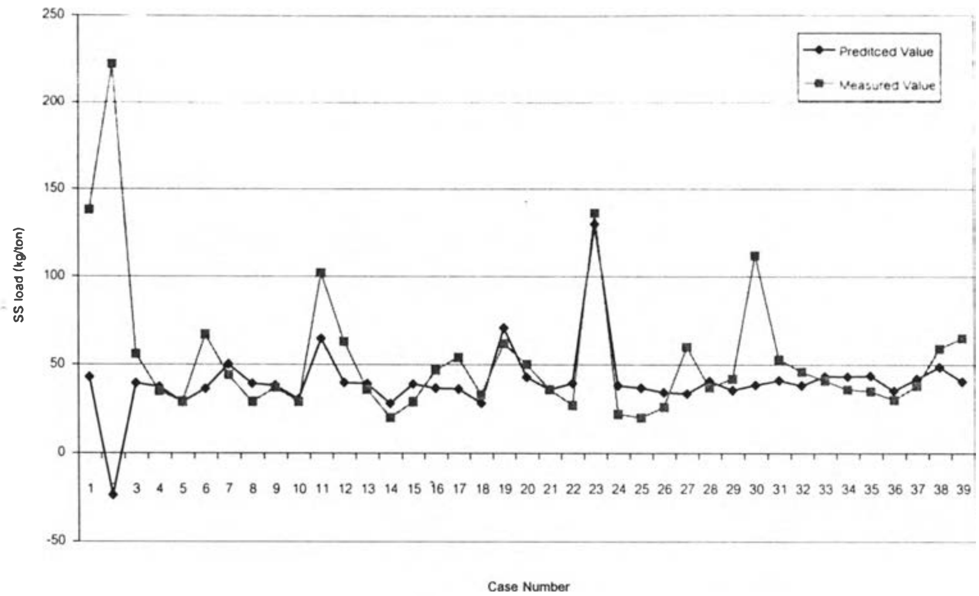


Figure 5.27 Result of Calculation for COD and BOD Loads of Total GF

a) Calculated Result for SS load of Total GB



b) Calculated Result for TDS load of GB

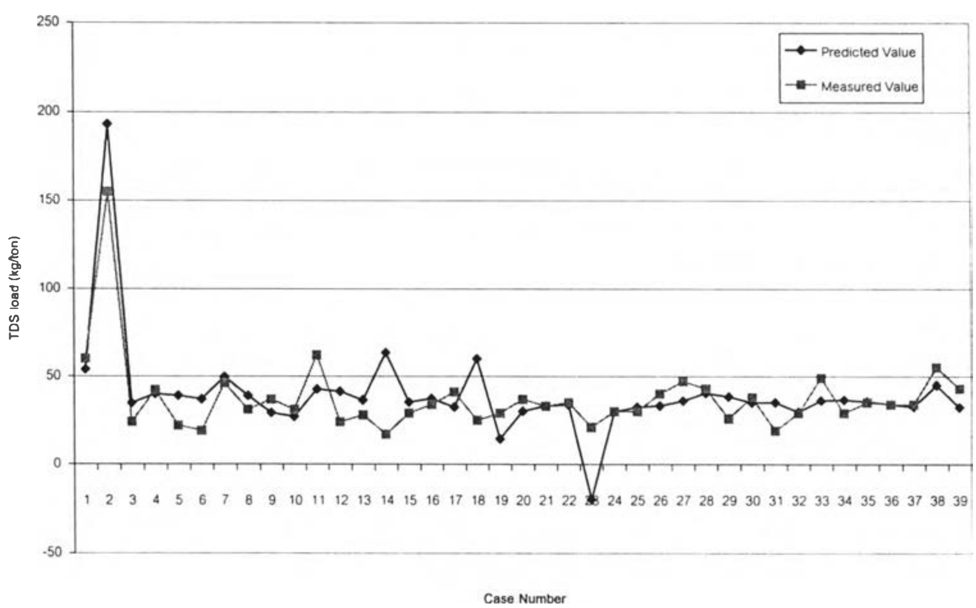
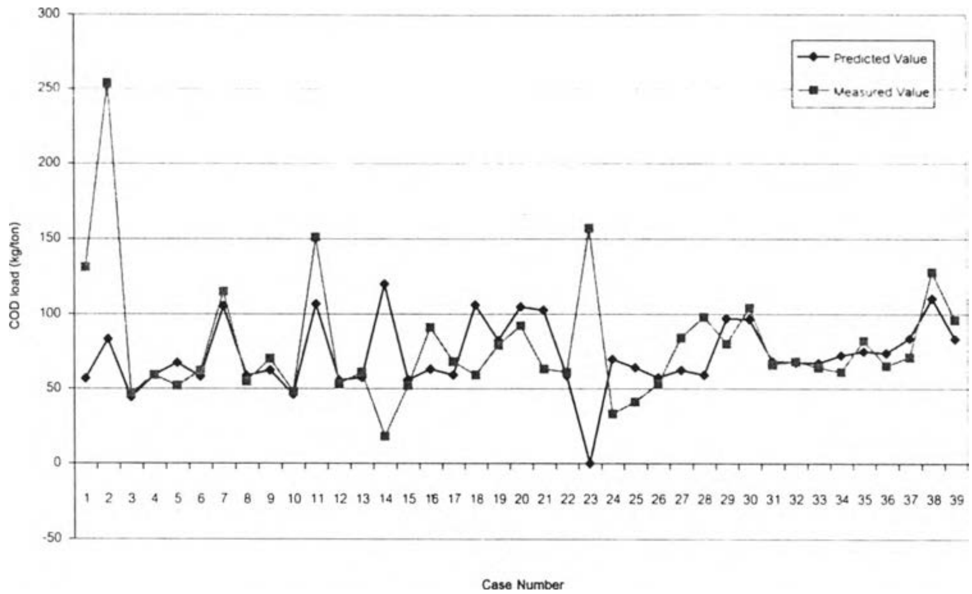


Figure 5.28 Result of Calculation for SS and TDS Loads of Total GB

c) Calculated Result for COD load of Total GB



d) Calculated Result for BOD load of Total GB

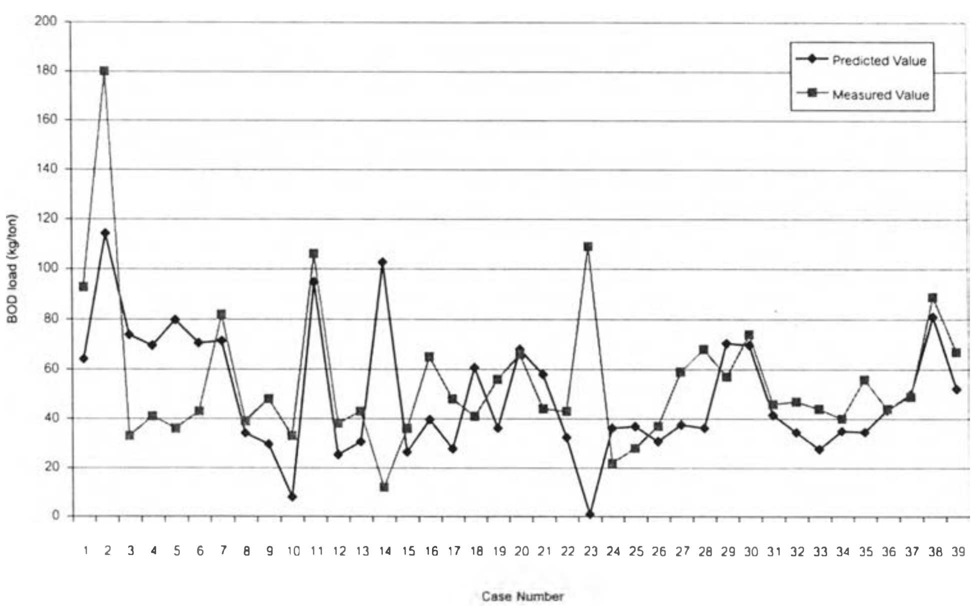


Figure 5.29 Result of Calculation for COD and BOD Loads of Total GB