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Clustering of plugging behavior in screening room of CTMP plant

TIMO AHVENLAMPI*, MANNE TERVASKANTO*, TUOMO SIPPUS**, VILLE HIETANEN***
*Systems Engineering Laboratory, University of Oulu
P.O. box 4300, 90014 University of Oulu, FINLAND

**Stora Enso Oyj,
Research Centre, FINLAND

***Metso Automation Oy,
Tampere, FINLAND

Abstract: In this study, the plugging in the pressure screens at CTMP plant is investigated. The plugging occurs in the surface of the screen in the pressure screen and could prevent its normal operation. That can lead to the shutdowns of the screening room. The aim of the research is to study plugging in the screening room, when all the three screens are in the operation. In the research, fuzzy clustering methods are utilized in the study of the plugging behavior. With fuzzy clustering methods different operation states are diagnosed separately. The methodology is applied to the pressure screening of the chemi-thermomechanical pulping (CTMP) -plant. Different operation states were found and these can be used in the planning and diagnosis of the screening room operation.

Key–Words: CTMP, pressure screening, plugging, fuzzy modeling, fuzzy clustering, visualization, diagnosis

1 Introduction

Pressure screening is an important unit process in the pulp and paper industry. Pressure screens are widely used in mechanical, chemical and recycled fiber pulping processes to purify or fractionate fiber suspension prior to further processing. The quality of the paper is highly dependent on the functionality of the screening. [1]

Accurate models are needed for control, optimization and fault diagnosis of the processes. In industrial applications, the studied processes are usually non-linear and stochastic. In such processes, more powerful methods like fuzzy logic, see e.g. [2]-[5], are needed in aim to achieve accurate models and control. The partitioning of the available data set into subsets is an effective way to study complex systems and to approximate each subset by a simple model. Clustering, see e.g. [6] and [7], is a promising method to the partitioning.

In this study, fuzzy clustering, see e.g. [8] and [9], is applied to estimate the plugging of the reject screen in CTMP plant. Screening process has many operating states and it is useful to cluster the process into these states. The methods are compared in the validation. The purpose of the clustering is in the optimization of the screening room operation. The clustering results can also be used in fault diagnosis of the pressure screens.

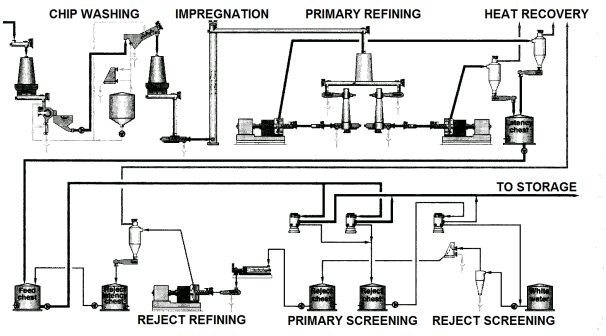

Fig. 1: CTMP- plant

In section 2, studied processes are introduced. Used methods are revised in section 3. The results are shown and compared in section 4. The discussion and conclusion are presented in sections 5 and 6.

2 Processes studied

Studied process is a chemithermomechanical pulping (CTMP)-plant (Fig. 1). The main difference between thermomechanical pulping (TMP) and CTMP- plants

is the chemical treatment prior to the refining. In the chemimechanical pulping, gentle chemical treatment stage is combined with mechanical defibration, as refining, in order to defiber wood and develop the necessary paper or board properties of the resulting pulp. CTMP is produced in pressurized refining with relatively low chemical doses and the yield is typically above 90%. [10] Even impregnation of the chemicals into the chips is essential to avoid quality variations. The quality variations in unhomogeneous raw materials, (e.g. the chip size differences, different sawmills materials, the storage of the chips and the seasonal differences in the chips) affect and can make the impregnation of the chemicals into the chips more difficult.

The main stages in the CTMP-process are:

- Pretreatment
  - The screening and washing of the chips
  - Chemical treatment
    - Presteaming
    - Impregnation
    - Prewarming
- Refining
  - Chiprefining
- Post treatment
  - Removal of latency
  - Screening
  - Reject refining
  - Bleaching and post treatment

The advantages using chemi-mechanical pulp compared to other mechanical pulps are longer fiber length, lower fines content, higher strength, more stiffness of the fibers, lower stick content in high freeness levels and purity. CTMP is mainly produced from the spruce. [10]

2.1 Pressure screening

In this research, the primary and reject screening sub processes in the CTMP plant are studied. In pressure screening, the purpose is to divide the feed mass flow into two different mass flows (accept and reject flows). Accept mass flow should contain good fibers and the reject mass flow the impurities, like stickies and shives. Therefore, the main objective of the pressure screen is to achieve a high efficiency in the separation of the certain fractions of the pulp flow while keeping some properties of the pulp unaffected. In this plant, tangentially fed pressure screens are used (Fig. 2). Two primary screens and one reject screen are operating in the plant.

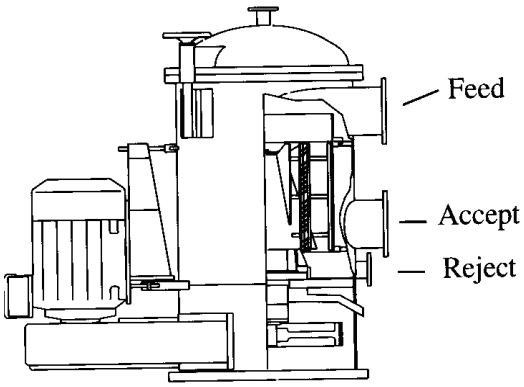

Fig. 2: Tangentially fed pressure screen

2.2 Plugging of the screen

The plugging of the screen is a problem in the screening rooms; see e.g. [11]-[12]. The prediction or elimination of the plugging can prevent shutdowns and increase production. In this study, the plugging of the reject screen is studied during the operation of both primary screens.

Due to the plugging, the control limit is usually set to some fixed pressure differential value in the industrial plants (see Fig. 3). However, this is not accurate in all situations. One method to observe the plugging is to present the squared accept flow versus pressure differential (PDI) of the the feed and accept flows, as can be seen from Fig. 3. If the screen is plugging, operation point is not in the plugging line but over it. [13] This can occur below the fixed differential pressure value.

2.3 Data

All data used in the clustering and validation are based on the industrial plant data and it is collected from the automation system. Data evaluation, identification and simulation are done with the MATLAB -program. The shutdowns and measurement failures are filtered out from the evaluated data.

3 Methods

In this chapter, used methods are presented. Clustering is discussed and fuzzy clustering methods are presented.

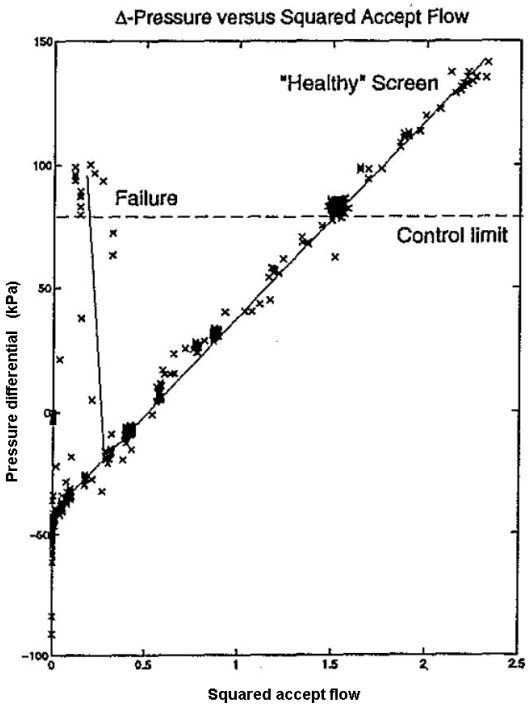

Fig. 3: The pressure differential of the accept and feed flow vs. squared accept flow relationship for screen

3.1 Clustering

The purpose of the clustering is the classification of the data according to the similarities among it and to organize the data into groups. [6], [7] Clusters are subsets of the data set and classification of the data can be done by fuzzy or crisp (hard) clustering. In hard clustering, a data point can be only in one cluster. In many situations, fuzzy clustering is more natural way to partitioning, because data points can be partly in many clusters. [2]

3.1.1 The number of the clusters

The decision of the number of the clusters is perhaps the most critical point in the fuzzy clustering. Some methods have been introduced to the selection of the clusters, see e.g. [2], [3].

In this study, visual evaluation and fuzzy hyper volume [14] is used in the decision of the clusters. Fuzzy hyper volume is calculated using equation (3)

$$F_{hv} = \sum_{i=1}^{c} \left[\det\left(F_i\right)\right]^{1/2} \tag{1}$$

where F_i is the fuzzy covariance matrix, see *Appendix A*.

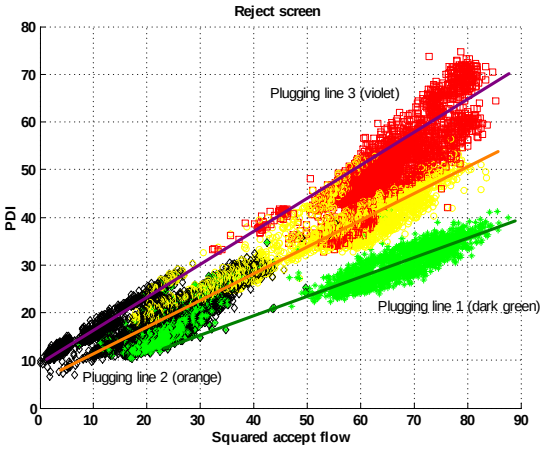

Fig. 4: The clustering results for reject screen, when GK algorithm is used with 4 clusters.

3.1.2 Visualization of the clusters

The visualization of the clusters is important part of the validation of the clustering results. In this study, traffic light colors are used in the visualization. The green color indicates good operation state (cluster), yellow slightly poor operation and red not good operation state. [15] In this study, also black and blue clusters are applied. These clusters are in good operating states as green cluster, but they are colored in different colors, due to 4 and 5 clusters used.

3.2 Fuzzy clustering

Fuzzy clustering methods are widely used in modeling, identification and pattern recognition. Many clustering algorithms have been introduced. Mostly used are fuzzy c-means (FCM) algorithm [8] and the variations of the FCM like Gustafsson-Kessel (GK) [9]. Initial parameters are needed for the fuzzy clustering algorithms. All the parameters, the number of the clusters C, the weighting exponent m, which determines the fuzziness of the resulting clusters and the termination tolerance ε, should be determined. The partition matrix could be initialized randomly.

3.2.1 Fuzzy c-means

Fuzzy c-means is a widely used algorithm for fuzzy identification. The FCM cost function is usually formulated as [8]:

$$J(Z;U,C) = \sum_{i=1}^{c}\sum_{k=1}^{N} \left(\mu_{ik}\right)^m D_{ik}^2 \tag{2}$$

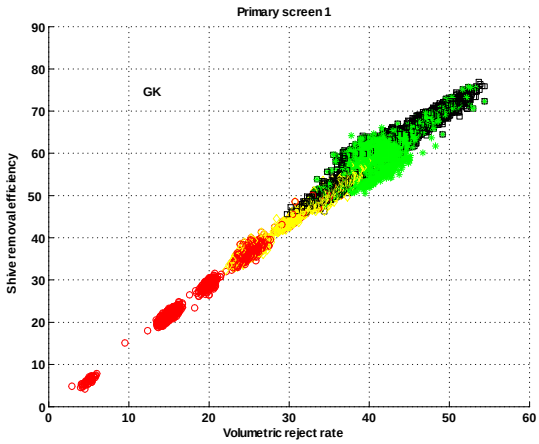

Fig. 5: The clustering results for primary screen 1, when GK algorithm is used with 4 clusters.

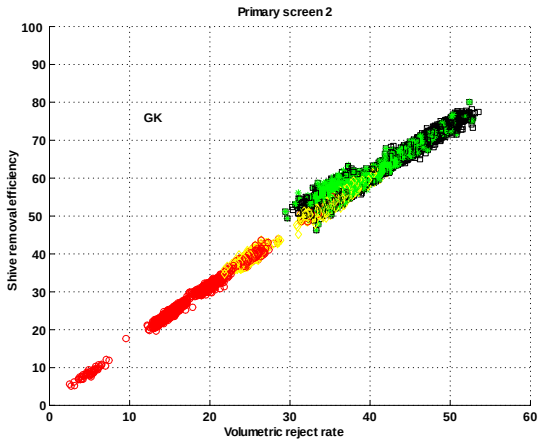

Fig. 6: The clustering results for primary screen 2, when GK algorithm is used with 4 clusters.

where $C = \{c_1, ..., c_c\}$. $\{c_1, ..., c_c\}$ are the cluster centers (prototypes) to be determined, $U = [\mu_{ik}]$ is a fuzzy partition matrix [8] and

$$D_{ik}^2 = (z_k - c_i)^T B (z_k - c_i) \quad (3)$$

is a distance (norm) defined by matrix B (usually the identity matrix), and m is a weighting exponent which determines the fuzziness of the resulting clusters.

3.2.2 Gustafson-Kessel algorithm

Gustafson-Kessel (GK) algorithm is the mostly used extension of the FCM in identification [2]. In this method, norm can be different with every cluster and method has the advantage of looking for variable size ellipsoids:

$$D_{ikBi}^2 = (z_k - c_i)^T B_i (z_k - c_i) \quad (4)$$

In this way, quasi-linear behaviors of the existing operating regimes are detected quite correctly. The process of the algorithm is presented in *Appendix A*.

4 Results

Fuzzy clustering algorithms are used in the clustering of the data from primary and reject screens at CTMP plant. A one month data set (about 30000 data points) was used with 25 measurements. The weighting exponent $m = 2$ is used. The fuzzy clustering method needs a number of the clusters in the initialization of the method. Visual evaluation and fuzzy hyper volume F_{hv} were used to find the number of the clusters. This method was run several times and a good number of the clusters was found to be 4. Four clusters were good also by visual evaluation. Also 5 clusters were tested to find out if that gives better results.

In Figs. 4-9, the presented values are scaled, due to the confidential reasons.

4.1 Clustering with 4 clusters

The clustering results with Gustafson-Kessel algorithm and 4 clusters for reject screen are shown in Fig. 4-6. The traffic light colors are used as in [15]. The green and black clusters are in good operation states. Also the yellow cluster is in good operation state, but the problem in this sub process is the red operation state (cluster). The red operation state indicates near plugging behavior in the reject screen.

As can be seen from Figs. 5 and 6, the primary screens 1 (Fig. 5) and 2 (Fig. 6) are in the problematic area (red cluster) when using low volumetric reject rates (RRv).

In Fig. 7, the clustering results with FCM algorithm and 4 clusters are shown. The problematic operation state (red cluster) is nearly same as with GK method (Fig. 4), but the other clusters are not similar. Especially green cluster is not as separated as in the case of GK method and it has also parts in the problematic high PDI area. Therefore the separation in this case is better when using GK method.

4.2 Clustering with 5 clusters

In Figs. 8 and 9, the clustering results with 5 clusters are shown for reject screen. Any additional information for the plugging problem did not arise by increasing the amount of the clusters.

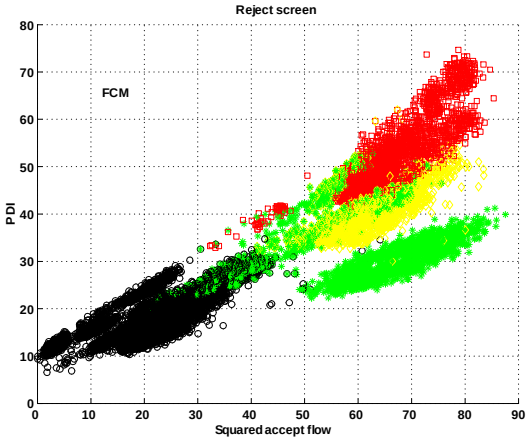

Fig. 7: The clustering results for reject screen, when FCM algorithm is used with 4 clusters.

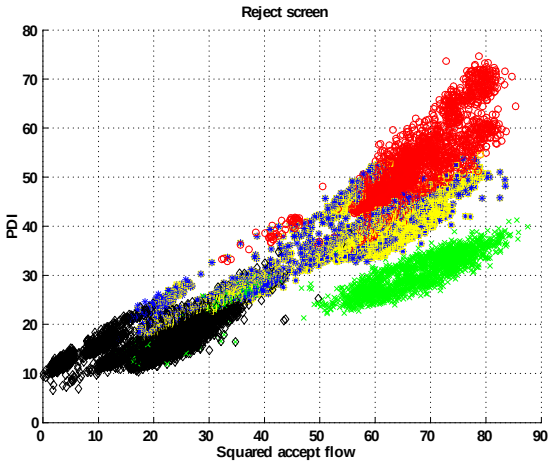

Fig. 8: The clustering results for reject screen, when GK algorithm used with 5 clusters.

5 Discussion

The fuzzy clustering algorithms are efficient tools for modeling, identification and pattern recognition. They provide a possibility to the data partitioning to smaller groups. These new groups can be modeled separately. In the study, fuzzy clustering algorithms were used to evaluate plugging behavior in the screening room at the CTMP plant. In the Gustafson-Kessel method, the algorithm tries to find hyper ellipsoids and in the FCM method the clusters are circles, due to the Euclidean distance is used. Therefore the results differ from each other methods.

Fuzzy clustering algorithms can give good results for non-linear applications as pressure screening if the number of the clusters can be selected correctly. Especially this is difficult for high dimensional data spaces, where the clusters cannot be seen visually. The methods like (6) can give good starting point for this kind of problems. Also the 2- dimensional visual evaluation is a good starting point, if there are some specially evaluated measurements.

The results of 4 clusters are shown in Figs. 4-7 and it can be seen that the problematic area (red cluster) is found with both methods (GK and FCM). However, the separation with GK method (Fig. 4) is more accurate in the high PDI area and using the FCM method (Fig. 7) the clusters are not as compact. The operation of the screens can be planned differently using the clustering information. The red cluster should be avoided, because it is more probable that plugging occur in that operation state compared to other operation states (clusters). Especially low volumetric reject rates in the primary screens 1 and 2 are in the problematic area. The operation should be tested by using higher volumetric reject rates in that same production as used in Figs. 4-7. As seen in Fig.4, there are three different plugging lines (operation states). Green, yellow and red operation states can be seen as separated plugging lines 1, 2 and 3. By controlling the process to green operation state, e.g by using different volumetric reject rate as in the red operation state, more production could possibly pass the reject screen. The red operation state is very near to the control limit, thus controlling the process so that operation point is in the green operation state the control limit is not a problem.

By using 5 clusters (Figs. 8 and 9) new information is not achieved and 4 clusters are enough in this case.

6 Conclusion

The applicability of fuzzy clustering methods for the investigation of the plugging in the pressure screen room of the CTMP plant was considered. The clustering results were good and they can be used in the helping of the planning of the operation.

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Appendix A

Process of Gustafson-Kessel algorithm:

Step 1: Compute the cluster centres:

$$c_i^{(l)} = \frac{\sum \left(\mu_{ik}^{(l-1)}\right)^m z_k}{\sum \left(\mu_{ik}^{(l-1)}\right)^m}, 1 \leq i \leq C$$

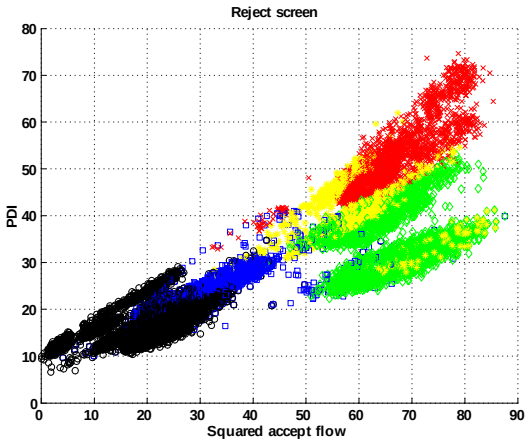

Fig. 9: The clustering results for reject screen, when FCM algorithm used with 5 clusters.

Step 2: Compute fuzzy covariance matrix:

$$F_i = \frac{\sum_{k=1}^{N} \left(\mu_{ik}^{(l-1)}\right)^m \left(z_k - c_i^{(l)}\right)\left(z_k - c_i^{(l)}\right)^T}{\sum_{k=1}^{N} \left(\mu_{ik}^{(l-1)}\right)^m},$$

$$1 \leq i \leq C$$

Step 3: Compute the distances:

$$B_i = \rho_i \det\left(F_i\right)^{1/n} F_i^{-1}, 1 \leq i \leq C$$

$$D_{ikBi}^2 = \left(z_k - c_i\right)^T B_i \left(z_k - c_i\right), 1 \leq i \leq C, 1 \leq k \leq N$$

Step 4: Update the partition matrix:

$$\mu_{ik}^{(l)} = \frac{1}{\sum_{j=1}^{C} \left(D_{ikBi}/D_{jkBi}\right)^{2/(m-1)}}$$

Step 5: iterate all steps until $\left\|U^{(l)} - U^{(l-1)}\right\| < \varepsilon$.

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