A Model for Plate Clash in Disk Refiners

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Abstract

We present an extension of the Miles--May model of pulp flow in a wood-chip disk refiner. The extended model is aimed specifically at understanding plate clash in disk refiners, which occurs if the pulp pad between the refining plates can no longer support the axial thrust on the plates and the control mechanism allows them to touch. The model considers separately the pulp between the bars and the pulp in the grooves of the refiner. As a result of stochastic exchanges of pulp between the bar and groove regions, they contain different concentrations of pulp. The pulp that is compressed between the bars determines the axial thrust on the plates. It is shown that the thrust can reach a maximum value as the gap decreases. Past a critical gap, the thrust decreases with the gap. This decrease can explain plate clash.

Introduction

The aspect of refiner operation that is to be studied here is plate clash, also called pad collapse. The phenomenon is basically related to the control of a refiner, and in the early days of control was a challenging problem. As a problem in refiner control, pad collapse is no longer a danger, because of modern adaptive control strategies, which monitor the effects of plate-gap changes on specific energy. However, a theoretical understanding is still worth pursuing.

The standard set-point for refiner operation is specific energy, and this can be varied by changing the plate gap; other operating parameters, such as feed rate, affect specific energy, but here we concentrate on plate gap. A reduction in the gap will usually raise the specific energy of the refining action. Thus, if a refiner is below its set-point, the control strategy is to reduce the gap until the set-point is regained. However, there exist operating conditions in which a decrease in the plate gap decreases the specific energy. Therefore there is a danger that a control strategy based only on this simple idea, i.e., one that always assumes that smaller gaps mean higher motor load, might be applied to the unusual case and continually try to raise the specific energy by driving the plates closer together. In such an event, the plates eventually clash against each other. Moreover, since the situation evolves with increasing speed, it appears to be a sudden collapse of the pulp pad in the refiner. Because of this, an important early topic of research in refiner control was the rapid identification of the regime the refiner was operating in, so as to avoid this runaway situation.

The main result of this work is an explanation of the shape of the graph relating motor load, or specific energy, with plate gap, assuming that the other parameters, such as feed rate, are constant. The graph is shown below.
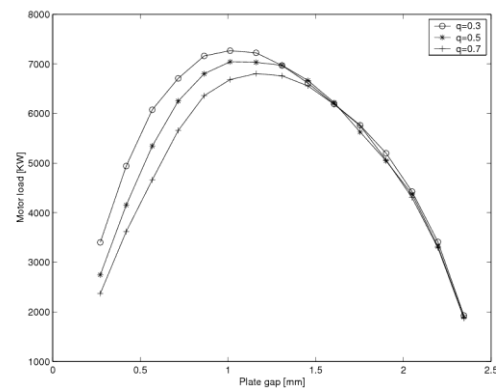
There are two reasons for looking for an explanationof this graph, even though at least one operational cure for plate clash is available. In the first place, a better cure might exist, and secondly, the problem is a new challenge for the theory of refiners.

The Miles--May model for pulp flow inside a refiner has been very successful at describing the dynamics of a disk refiner [1]. It contains, however, simplifying assumptions that prevent it from addressing all aspects of refiner operation. There is nothing wrong with this, of course, because every successful engineering theory concentrates on some aspects rather than others. Specifically, Miles and May modelled the bar and groove pattern on refiner plates by including generalized friction terms in their equations. Thus they introduced separate tangential and radial coefficients of friction to reflect the fact that it is easier for the pulp to move along the grooves rather than across the

bars. To take the bar and groove features into account more fully, Fan, Jeffrey and Ouellet [2] have derived a model to complement the work done by Miles and May. It is based on the following assumptions :

- Discontinuous medium : the pulp consists of individual flocs of wood pulp traveling through the refiner.
- The refiner is divided into 3 regions : gap, stator and rotor regions. The individual flocs move from one region to the other.
- The floc velocity u depends on the region. If v is the "Miles-May" velocity, then u=v in the rotor, u=1/2v in the gap, and u=0 in the stator.

Each floc is individually followed throughout the refining zone. To model is advanced by dividing the time into equal time steps. At each time step, the state of the refiner is defined by all the flocs' radial and regional (gap, rotor or stator) positions. The individual flocs will move from one region to another according to a probabilistic law. The aim of this paper is to continue and extend this Fan-Jeffrey-Ouellet model to investigate plate clash.

Modified Stochastic Model

We divide the interior of the refiner into 3 regions. The grooves on the rotor, the grooves on the stator and the gap between the bars (the refining region). This is illustrated below.
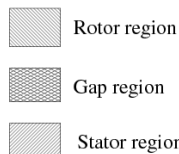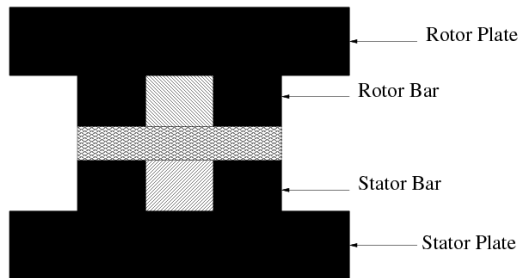
The pulp flocs move between the regions stochastically at each time step. In [2], the probability that a floc moved from one region to another was fixed. Here the probability depends upon the density of pulp in each region, and on the cross-sections of the regions. The full details are given in [3]; here we give a summary. The probability of a floc moving from a source region to a target region is assumed to be a product of two terms. The ratio of the cross-sectional areas of the target and source regions and the difference between the actual local pulp density and the maximum possible density. It should be noted that this local density varies with position in the refiner, but it can be calculated using the data of the simulation.

Compression of the Pulp Pad

In order to calculate the relation between the size of the plate gap and the specific energy, we assume that the axial thrust is supported by the flocs in the gap region, and in the first instance ignore the contribution from steam pressure. In the short time that a collapse occurs, it seems unlikely that steam pressure could change significantly. We will fix the plate gap, and our goal will be to compute the specific energy and motor load in terms of that given value.
The flocs between the bars are compressed. We use the Compression Equation from Han [3] to calculate the load each floc can support. The equation is an empirical relationship between the pulp pad density ρ and the applied stress σ. It is written as:

$$\rho = M \sigma^N,$$

where M and N are constants describing the pulp properties. For our simulation, we used M=3 and N=0.397, corresponding to black spruce.

Floc Behaviour in the Gap

We assume that under zero load, a single floc would be spherical. Its density is then ρ_{min}.
If we know the force supported by a single floc, we can calculate the total load of the refiner, as we know how many flocs are in the gap at each time step. We now assume that a floc of radius R responds to compression with a height reduction only, as illustrated below.

Before compression   After compression
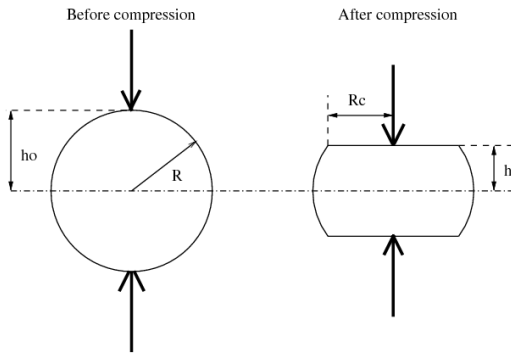
The force exerted by the plates on the floc is calculated in terms of the plate gap g, as follows. The contact area A between the floc and the plates is $\pi(R^2-g^2/4)$, and therefore the density of the floc is

$$\rho f = m/\pi g(R^2-g^2/12)$$

From the Compressibility Equation, we obtain the applied thrust on one floc in the gap as

$$L = A (m/\pi gM(R^2-g^2/12))^{(1/N)}$$

where M,N are the constants given above in the compression equation.

Compression between bars

When the gap becomes very narrow, the flocs cannot fit completely into the gap. If this is not assumed, then it is found that the model predictions are unrealistic, in that the motor load continually increases. In this situation we suppose that the floc can partially enter the gap and be compressed. The basis of the calculation is shown in the diagram.

▨ Compressed part of the floc

▨ Uncompressed part of the floc
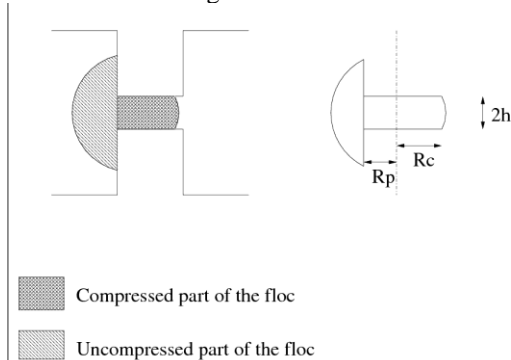
The proportion of the floc in the gap is denoted by p and is given as a function of gap g and floc diameter d by the equation $p=(g/d)^q$, where q is a constant. In practice, the value assumed for q has not much influence on the computed motor load. The various curves presented above for motor load against gap were computed using various values of q. This assumption is similar to the common assumption that flocs are stapled onto the leading edge of the bars, and consistent with the observation that narrow gaps lead to fibre cutting.

Calculation of the Motor Load

At each time step, we calculate the drag created by each floc on the plates, and add this up over all flocs. Thus if we suppose that the same μ tangential coefficient of friction applies to each floc, then the i-th floc contributes to the motor load

Motor load from one floc = $\mu L \omega r$,

where ω is the rotation rate and r is the radial position of the floc (which will be different for each floc). During the simulation, a record is kept separately of the radial position and the region of each floc, therefore the computer simulation can run through the table of flocs and compute the contribution to the motor load from each floc.

Implementation

A program was written in C to calculate the properties of this model. Up to 10000 flocs could be simulated within the refiner without difficulty. A table is maintained during the simulation with one entry for each floc. As flocs enter the refiner, they are added to the table,and those leaving are removed. For each floc, its current radial position, together with its region and velocity are recorded. From this table, the local densities throughout the refiner can be computed.

The physical parameters used were
Floc size (mass): 0.11 g
Minimum floc density: 146 kg/m^3
Uncompressed floc radius: 5.6 mm
Maximum density in any region: 1000 kg/m^3.

The refiner parameters were typical values:
Inner radius: 43 cm
Outer radius: 57 cm.
Rotation speed: 188 rad/s
Feed rate: 1.05 kg/s

Results and Discussion

The computed motor load as a function of plate gap has already been presented in the introduction. Since feed rate is assumed constant, the graph of specific energy is similar. The order of magnitude of the computed load is reasonable

for a refiner, but the real interest lies in the shape of the curve. It has the same shape as the qualitative curve postulated by [5] to describe the problem of plate clash. The main contribution of this model has been to demonstrate a mechanism to explain this curve.

Since this has been a purely theoretical investigation, the next step would be to compare with experiment. Unfortunately, since commercial practice requires that plate clash be avoided, there is no quantitative data available in the literature.

A shortcoming of this investigation is the fact that the simulation has been conducted assuming that the operating conditions are steady. Discussions with mill operators suggest that the main danger of plate clash does not arise during steady operation, but rather during the period in which a refiner is being moved from one operating set point to another. The basic simulation method used here can handle time dependent conditions, and some results were included in [3], but they do not shed any additional light on plate clash.

From the theoretical point of view, a reason for pursuing this work is that plate clash is a qualitative phenomenon. Most models of refiner operation contain many adjustable parameters. If the only test is quantitiative agreement with measurements, then it is difficult to test a theory with many adjustable parameters. The problem of plate clash, however, is a qualitative effect that should be subject to simulation and testing while remaining insensitive to actual parameters.

References:

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[5] G.A.DUMONT, N.D.LEGAULT, J.S.KACK, J.H.ROGERS, Computer Control of a TMP Plant. Pulp and Paper Canada 83(8) T224—229, 1982.