Mathematical Modeling of Pulper Operation

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ABSTRACT

Mathematical modeling technique was used to study the behaviour of pulper, on the basis of it, improving the operating conditions, some changes were made in the operating conditions and design of the same, which resulted in reduction of energy consumption by more than 50% and, on the same time, increase in throughput by 100%.

INTRODUCTION

Optimization through mathematical modeling is getting very popular on account of its capability to achieve the desired targets within a significantly low number of iterations of the process parameters. In most of the industrial practices, it is not very easy to change the design parameters/features frequently, as this requires a lost of time and some times capital investment also. In most of the small paper mills, where the capital cost of any equipment plays a significant role in selection of the same, the design of the pulper impeller is either based upon the mills foreman's experience, or out of available designs any one is selected. The present paper shows how data analysis on pulper operation can be used to improve the efficiency of pulper available with the mill.

CASE HISTORY

The mill had a continuous pulper of 8 m^3 capacity, originally fitted with a 75 HP motor. The pulper had an eye shape side impeller, also called as Kachhua Type (Tortoise Shape). This pulper was used for pulping of Corrugation and Duplex Coated Corrugation for the production of Media Kraft and Super Media Kraft paper. Later on, when the mill decided to switch over to Newsprint and other MG Poster paper grades, the pulper was modified by changing its grid to a smaller diameter holes, replacing the impeller to a conventional star type one, and changing the motor to 150 HP. It was observed that the pulper throughput was only 700 Kg. per day for pulping of ONP.

MODEL

The model presented here suggests-

1. Throughput from the pulper is minimum of slushing rate and rate of fiber removal from the pulper.

2. The slushing rate from the pulper is dependent on the rpm of impeller, diameter of impeller, design of impeller, pulper dimensions, type and quality of waste paper.

3. The fiber is a tubular in shape, and aligns itself to the direction of flow.

4. Tangent inverse of ratio of pulper grid thickness and hole diameter gives maximum angle of approach of fiber that will pass through grid. (Fig.1)

5. The angle of approach of fiber can be calculated as tangent inverse of ratio of

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velocity at the impeller circumference and velocity of pulp suspension passing through the holes of grid. (Fig.2)

6. The velocity at the impeller circumference can be obtained by multiplying the impeller diameter with impeller rpm.

7. Increased impeller diameter will result in increased load on pulper.

With the help of this model, it is clear that initially, the slushing rate will increase with increase in rpm of impeller, and thus the throughput will increase, but a very high speed will result in increased velocity at the impeller circumference, and hence low angle of approach of fiber to the grid, thus reducing the pulper throughput.

EXPERIMENTS WITH MODEL

In the case studied, the pulper grid design data was as under-

Drilled Area Outside Diameter:	980 mm
Drilled Area Inside Diameter:	460 mm
Hole Diameter:	05 mm
Pitch:	11 mm
Thickness of the Grid:	10 mm

From the above,

the angle of approach = $\tan^{-1}$ (5/10)= $\tan^{-1}$ (0.5) = 26.56 degrees.

Thus the fiber should attack the pulper grid at an angle of 26.56 degrees or more.

Now, we know that the fiber is a tubular shaped body, and due to its structure, aligns itself to the direction of flow of water, the carrying medium.

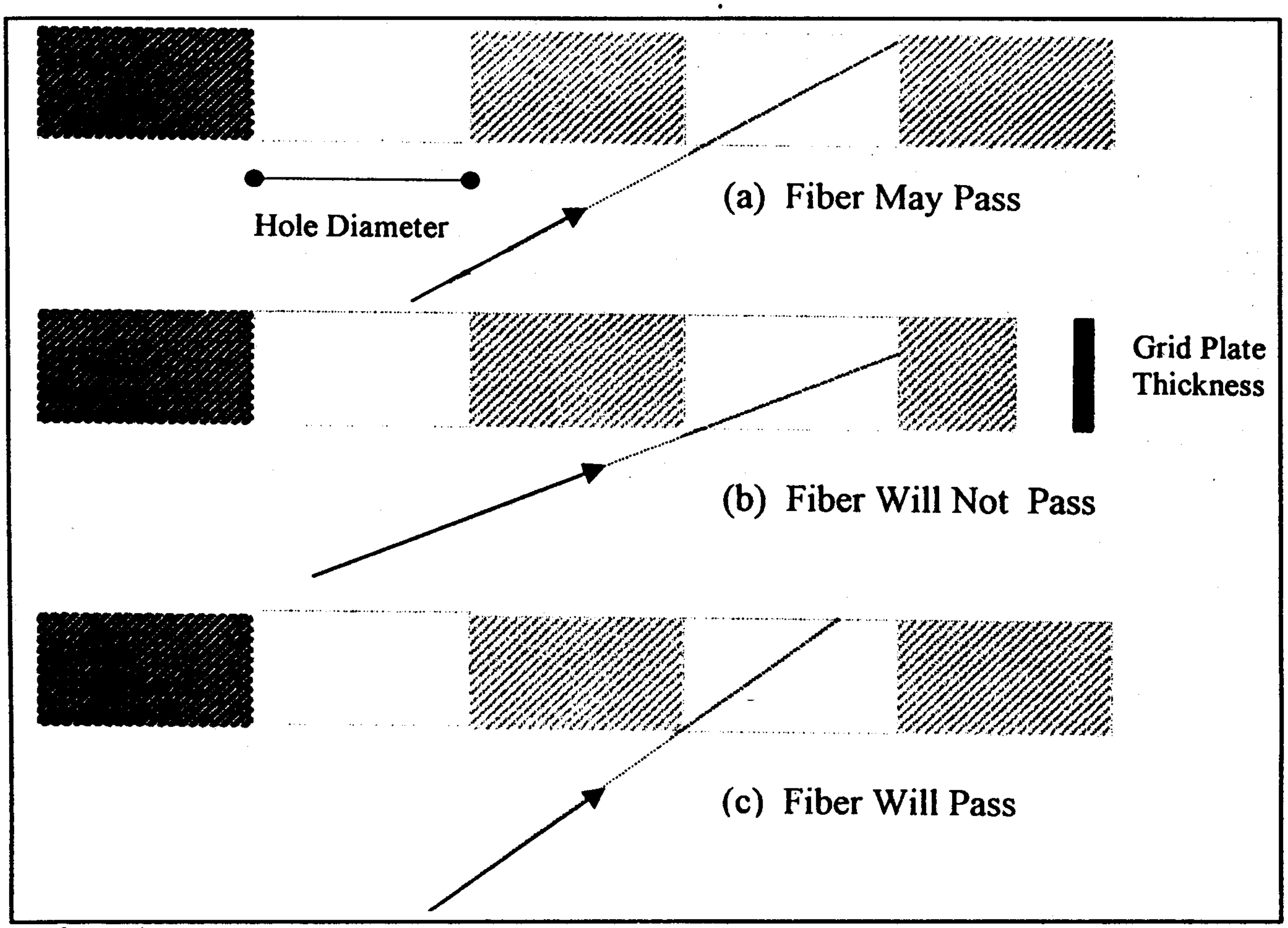
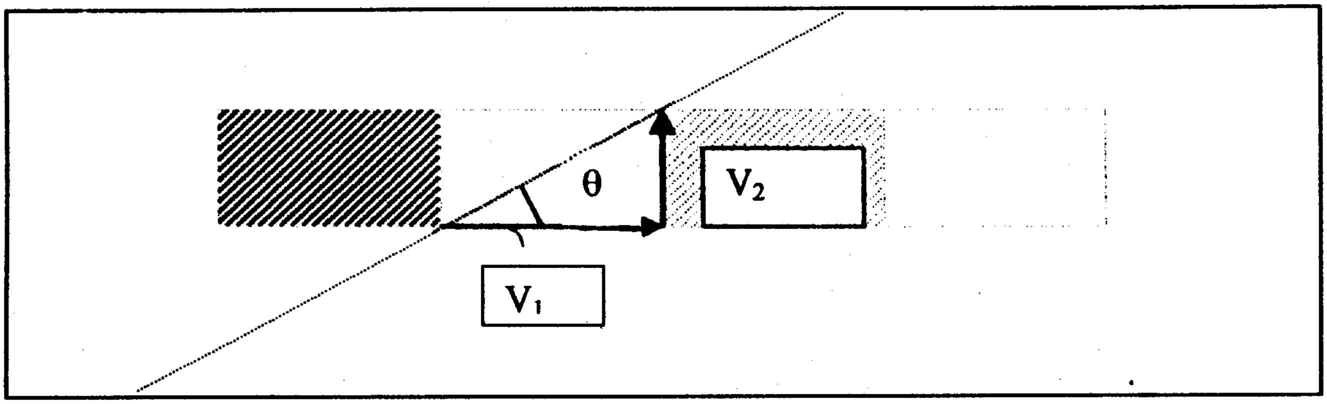


Fig. 1 : Cross Section View of Grid to Show Angle of Approach of Fiber & Possibility to Pass Through Grid Holes



V_2 = Velocity of pump suspension passing through the grid holes.

V_1 = Velocity at the impeller circumference

θ = Angle of approach of fiber towards grid

$\theta = \tan^{-1}(v_2/v_1)$

Fig. 2 : Cross Section View of Grid to Show Angle of Approach of Fiber & Velocity Gradients of Flow.

In the close vicinity of pulper grid, near the impeller, the velocity can be calculated as -

V = R* ω

Where,

V = Velocity at the circumference of impeller, m/sec.

R = Radius of pulper impeller, m

ω = Rotational velocity of impeller, Rev/Sec.

we get,

V = 0.358*7

V = 2.506 m/sec.

The velocity through the holes of pulper grid can be calculated by -

V = Q/A

Where,

V = velocity through the pulper grid holes, m/sec.

Q = Flow rate through the pulper grid, m^3 sec.

A = Effective Open area in the pulper grid, m^2

The available open area represents the area available for transfer of pulp suspension away from the pulper. Hence, during calculation the holes covered by the rotating impeller have been discarded considering these blocked. This can be calculated by multiplying the number of holes of the grid not covered by the rotating impeller with the area of one hole (= π. hole radius²); for simplicity of measurement of number of holes, the drilled area of pulper grid which is not blocked by impeller can be multiplied with number of holes per unit area.

In our case,

V = 0.0089/0.064

= 0.14m/sec.

This significant difference between two velocities indicated that there is some error in our earlier assumptions. On further analysis, the concept employing angle of approach of fiber had to be reviewed because of possibility of fiber flexibility resulting into twisting and bending of fiber and hence ability of fiber to pass through narrow holes. To consider the effect of fiber flexibility, a factorτ ("tau") was included and the angle of approach of fiber was rewritten as-

Angle of approach = tan-1 (τ* V/v)

Now,

$\tan^{-1}(5/10) = \tan^{-1}(\tau^* V/v)$

Or, $\tau = 8.95$

This is evident from the present case that the velocity through the holes is extremely low, as the fibers are flown away with the fast moving stream of water. On further studying the pulper operation, it was observed that on throwing a significantly big (40-50 kg.) ONP bundle towards the impeller, it got slushed away within a few seconds and during this period, the load increased by only 5-8 Amp., against running load of 135-145 Amp. This indicated that the pulping of ONP needs relatively lower energy than it was being supplied, and a significant part of energy supplied was being transferred to rotate the pulp only in the pulper. Similarly, on operating the pulper with its delivery valve closed and maintaining a consistency as that during normal operation, only a slight load reduction was observed.

Working on this concept, it was decided to reduce the slushing in order to increase the pulp discharge from the pulper. For the same, there were two options available -

1. Reduce impeller diameter.
2. Reduce impeller radial speed.

The reduction in impeller diameter will also increase the available open area of the pulper grid, and that is why on the priority, the pulper impeller was cut short to reduce its diameter to only 600 mm. Mathematically, this was supposed to result in following-

1. Increase in open area available by around 69%
2. Decrease in velocity at the circumference by 16%

It was estimated that this would result in increase in flow rate to 0.01267 m^3/sec. But on further operation it was noted that due to reduction in flow velocity at the impeller circumference, the discharge consistency increased considerably, and the net throughput from the pulper increased to around 1350 kg/hr.

RESULTS

As obvious, a reduction in impeller diameter resulted in decreased power consumption, which suggested to decrease the motor rating, and a motor of 75 HP was fitted instead of 150 HP running earlier. **As a result the power consumption for pulping reduced from 140 units per ton to only 30-32 units per ton.**

DISCUSSION

The quality of waste paper is very important for pulping operation. Before the impeller was modified, the mill had not accepted any order for MG white or colored poster. That is why the impact of raw materials for these grades such as white cuttings, copy cuttings, white record, office record II, lottary printing, LCC, new book farma etc. could not be observed. The mill, of course, uses some quantity of corrugation for production of low grammage kraft paper along with ONP, but in absence of a separate pulper so that both the waste paper may be pulped separately, the pulping rate improvements cannot be calculated. The mill only used pure ONP as a raw material both before and after impeller modification, and hence the findings may be considered for the same. The author, of course, believes that the results would be similar for other waste paper also.

AUTHOR'S RECOMMENDATIONS

The results obtained by the mathematical modeling were highly encouraging and tremendous saving in power consumption created a pressure to further reduce the power consumption. But, some restrictions do exist and we must not ignore these.

1. The velocity at the circumfrerence of pulper impeller should not go below a fixed value, as at very low velocity, floc formation will take place, which will reduce the pulper throughput significantly. This threshold velocity will be higher for longer fibers, and lower for smaller fibers.

   The author used pulp rheology to determine critical velocity below which flocculation starts. Duffy & Titchener (1) - have suggested this critical velocity

   V_C OC C^x

   Where, C is the pulp consistency and x is a constant

2. The power supplied to pulper does basically three jobs-Rotate the pulp suspension, slush the waste paper due to high shear forces and break the flocks of fibers. Though slushing seems to

consume only a significantly low amount of energy (5-10 Amp. load, i.e. around 3-5 units per ton), it could take place only if the pulp is circulating in pulper. That is why achieving very low power consumption is perhaps very difficult.

3. Our experimentation was based only for a particular type of impeller. Due to process limitations, it is not possible to change and modify the impeller etc. every now and then. It is recommended to other mills as well as research organizations to start research work in this area if not already in process.

REFERENCE

1. G.G. Duffy & A.L. Titchener, Tappi 57 (5): 162 (May 1974).