Modeling and simulation of a Kamyr digester: methods of reducing computation time

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The Purdue model for the Kamyr digester predicts mill data with good accuracy.[1,2] This model is potentially useful for developing improved operating techniques and online process control methods for the digester. Several modifications of the model have been developed that reduce the computational time or improve the predicted values of the model.

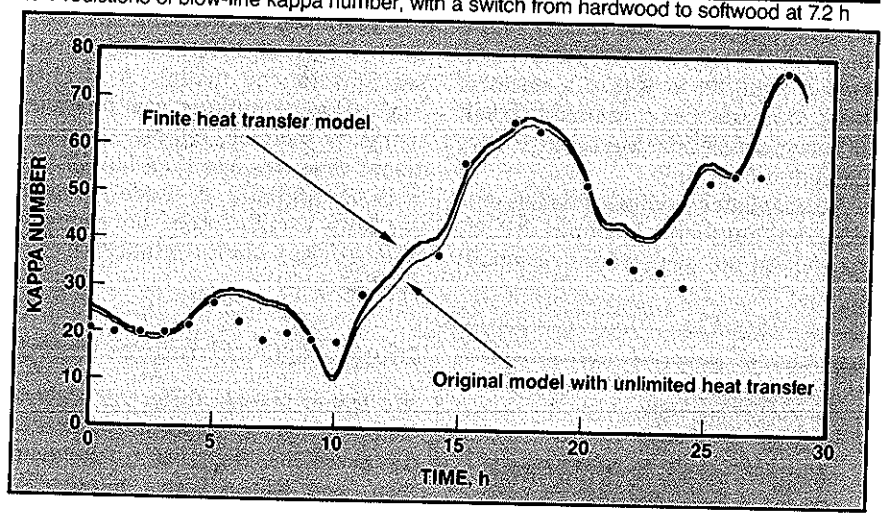
Inclusion of finite heat transfer terms

A basic assumption made in developing the Purdue model was that for any given section of the Kamyr digester, the temperatures of the pulp and of the caustic solution are identical. In other words, the heat transfer between phases is extremely fast. The model was modified in our study to include expressions for finite rates of heat transfer between the pulp and the surrounding liquid. Using heat transfer coefficients of about 600–800 Btu/(h·ft²·F), or 12,300–16,400 kW/(m²·C), results in temperature predictions that appear reasonable, compared with plant operating data. The actual value of this coefficient undoubtedly depends on the flow velocities and the degree of delignification of the wood chips. Additional plant tests will be required to establish exact values; in the meantime, these values are good estimates.

When we assumed that the heat transfer coefficient was higher, the differences in temperatures between the chips and the caustic decreased, and a more rapid cooking of the chips was predicted, as indicated by the kappa numbers in **Table I**. Kappa numbers change insignificantly with a heat transfer coefficient higher than 1000. On the other hand, heat transfer coefficients smaller than 100 cause unreasonable temperature differences between the liquid and pulp phases in the digester.

A comparison of the original model with instantaneous heat transfer and of the new model with a heat transfer coefficient of 740 was made against 28 h of plant data, as shown in **Fig. 1**. In this test, a swing from hardwood to softwood chips occurred at 7.2 h. The original model predicted slightly lower kappa numbers, but both versions predicted the plant data equally well. The revised model (including finite heat transfer) requires 4–5% more computational time. In many cases, because of the small gain to be made, the use of this improved model may not be justified, at least until more reliable heat transfer data become available.

1. Predictions of blow-line kappa number, with a switch from hardwood to softwood at 7.2 h



I. Kappa numbers resulting from the use of various heat transfer coefficients

Heat transfer coefficient		Kappa number
Btu/(h·ft²·F)	kW/(m²·C)	
200	4,100	22.91
600	12,300	20.51
1,000	20,400	20.00
2,000	40,900	19.87

[1]Christensen, T., Albright, L. F., and Williams, T. J., Report No. 129, Purdue Laboratory for Applied Industrial Control, Purdue University, May 1982.

[2]Christensen, T., Smith, C. C., Albright, L. F., and Williams, T. J., Tappi J. 66 (11): 65 (1983).

II. Effect of different numbers of sections in the Purdue Model

Sections	Predicted kappa no.	Max. time step size, h	Relative computation time
30	21.8	0.018	1.0
50	21.2	0.0143	2.1
100	21.2	0.0057	10.5

III. Effect of step size and precision for fourth-order Runge-Kutta method

Time step size, h	Precision	Comp. time, CPU's
0.014	Single	3.2
0.004	Single	11.4
0.004	Double	22.4
0.014	Double	6.2

Reaction and washing sections in simulating the Kamyr digester

The Purdue model simulates the operation of the Kamyr digester as a series of well-mixed, continuous, stirred-tank reactors. The number of sections into which the Kamyr digester was divided in the Purdue model varied from 30 to 100 in a series of tests. More sections presumably result in better predictions but require more computational time.

To adequately compare models with different numbers of sections, we had to position the sections dimensionally in the digester so that the resulting changes in temperature and caustic composition between sections occurred at identical vertical positions. The most rapid changes in temperature occurred at and near the top heater, the bottom heater, and the extraction zone. **Table II** indicates the predicted kappa numbers for a softwood using different numbers of sections in the model. A slightly higher kappa number was predicted using 30 sections, but the computational time was less than half of that with 50 sections. A model with 30 sections would likely be accurate enough for most industrial mill studies.

Integration techniques tested

We tested several different integration algorithms including the predictor-corrector, Richardson extrapolation, and Runge-Kutta integration methods to determine the one that performs the integration in the least computational time while maintaining the required accuracy. Each integration method was tested against a 28-h run of industrial mill operating data. In making this test, we used the original model—the one using 50 sections in which we assume that there is a finite instantaneous heat transfer.

An IBM 3083 computer with a word length of 32 bits was employed to solve the same basic FORTRAN programs, incorporating each of the different integration subroutines in turn. For each integration technique, a time interval, or time step, is selected. This interval should be chosen as close to the test routine's stability limits as possible to minimize the computational time required.

The fourth-order Runge-Kutta method with Runge's coefficients required the least time—3.2 CPU seconds per simulation hour. The fifth-order Runge-Kutta-Lawton method was almost as good, at 3.5 CPUs. (The CPU is the central processing unit.)

The fourth-order method was tested at different time step sizes and precisions. Single precision with a time-step size of 0.014 h resulted in the most rapid computation (**Table III**). The kappa number predictions differ by as much as 0.3, but such differences are, in general, of little concern. Thus, these values are the recommended characteristics of the algorithm.

Conclusions

Several modifications have been made that improve the Purdue model. All variations predict the kappa number data well. Computational time is reduced when the number of sections for the digester are reduced from 50 or 100 to 30. The fourth-order, single-precision, Runge-Kutta algorithm proved to be the most efficient for simulating the Kamyr digester.

Adding heat transfer terms to the model improves the mechanistic details of the model and allows a better prediction of temperatures throughout the Kamyr digester. However, the use of heat transfer terms has relatively little effect on kappa number predictions, and this improved version may not be required, particularly since computational times are increased somewhat with its use.

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