Computer control of batch digesters

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Pilot plant testing of the ASEA System KAPPA BATCH indicates that the standard deviation of the target Kappa no. can be reduced to less than 2.0 units. This could permit a decrease of 9% in mean Kappa no. and could result in bleach plant chemical savings of 1 Sw. Cr./ton pulp/unit decrease in Kappa no.

The past ten years have involved a rather dynamic period of development in the field of control in the pulp and paper industry. A great deal of this development has been devoted to various types of digesting systems, primarily continuous digesters. MoDoCell AB has no continuous digester as yet and that is the reason why we, in cooperation with ASEA LME Automation, have developed a control system for batch digesters. This report describes this development which has resulted in a very versatile control system easily adopted for continuous digesters as well.

The system which is called ASEA System KAPPA BATCH was primarily intended for levelling out some rather troublesome variations in the delignification degree when producing kraft pulp from softwood (Pinus silvestris) but it is now being extended to include the kraft digesters for hardwood (birch), as well as a control system for the steam consumption in the digester house. As a matter of fact, the steam control can be done in a rather simple way, once proper control of the delignification has been established.

Normal pulping results, control requirements

Due to variations in pulping characteristics as further described below, the results of pulping can deviate from the target value in a rather troublesome manner even if charging and scheduling are done very carefully. In Fig. 1, the wide curves show the deviation in Kappa no. obtained during normal pulping conditions, and the narrow curves represent the desired controlled situation. It is well known that pulping beyond a certain Kappa no. has detrimental effect on the strength of fully bleached pulps. To avoid this effect, it is necessary to keep the mean Kappa level rather high which results in an increased chemical consumption in the bleach plant. With close control of the cooking process, it is possible to decrease the mean Kappa no. without jeopardizing the pulp strength, consequently saving chemicals in the bleach plant, improving the reactivity, decreasing the knot content and creating a sound platform for bleach plant control. Another benefit is decreased pollution, since a larger proportion of dissolvable substances (lignin etc.) can be fed into the recovery plant, and less Cl₂ is brought to the effluent.

The second example in the figure shows the situation when producing unbleached pulps. The mean Kappa no. has to be kept well below a certain limit to avoid disturbances caused by extreme Kappa no. With close control of the cooking process, it is possible to decrease the mean Kappa no. which will increase yield correspondingly, improve runability and final product uniformity.

When starting this project, we felt that the standard deviation in Kappa no. ought to be decreased from the actual value of \( \sigma=3.5 \) to \( \sigma=2 \). However a control set of this kind cannot be justified merely by a good feeling of its usefulness. Although we have not yet been able to accurately evaluate all the benefits of

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system in full scale operation, we are convinced that the savings on reduced chemical charges in the bleach plant alone will give a satisfactory payback.

Let us assume that the charge of chemicals needed in the bleach plant is proportional to the Kappa no. A decrease in the standard deviation from 3.5 to 2.0 will make it possible to decrease the mean Kappa no. by 2 x 1.5 = 3 units, say from 34 to 31 i.e. 9%. According to the assumption of proportionality, the chemical consumption decreases accordingly, at least in the first stage of the bleach plant.

Because of changes in the prices of chemicals from time to time and between different sites, a further evaluation of estimated savings is not worthwhile. A fair approximation, however, indicates savings of at least 1 Sw Cr/ton/unit decrease in Kappa no. In our case this means savings around 0.6 million Sw Cr/year in the bleach plant for softwood pulps.

In addition, the control system for steam consumption will probably give savings of the same magnitude. Not mentioned are benefits of completely controllable changes in production rate, improved runability, decreased knot content and simplified bleach plant control etc.

When producing unbleached pulp, the system will make it possible to increase the mean Kappa no. and consequently increase yield and decrease alkali and steam consumptions in the pulping process, and also increase throughput. The economic consequences of this should be obvious to every experienced manager of pulp factories.

### Pulp characteristics

It is well known that the result of pulping depends on a number of variables among which the most important are: wood quality; chip size distribution; liquor-to-wood ratio; alkali-to-wood ratio; sulphidity; digesting temperature and time (H-factor).

These variables can be controlled in different ways to obtain appropriate values for the variables and constants in the basic formula for delignification rate

\[
\frac{dL}{dt} = k(T) \cdot L \cdot C
\]

where, L is the "concentration" of lignin in the chips; \(k = e^{-\frac{BT}{L}}\) is the temp. dependent rate constant, A, B being constants; T is the temp. in Kelvin; C is the concentration of alkali in the chips.

Other expressions for delignification rate exist but they are basically derived from the given formula.

### H-factor

If the alkali concentration, C, in equation (1) could be expressed as a function of the lignin concentration, L, it would be possible to compute the final lignin concentration, L_f

\[
F(L) = - \int_{L_0}^{L_f} \frac{dL}{L \cdot C(L)} = \int' k(T)dt...
\]

This is done in [1] though the concentration of alkali in the liquor is used in the calculation. The right side equation (2) involves the time temperature relationship of the delignification and it can be reduced to a simple factor, H, described in [2].

\[
k(T)dt = \int' \exp \left[ \frac{32000}{R} \left( \frac{1}{373} - \frac{1}{T} \right) \right] dt = a \cdot H
\]

An obvious result when interpreting equations (2) and (3) is that the H-factor gives a measure of the final lignin concentration if other conditions are held constant, and if the chosen value for B (32000/R) is correct and applicable to the entire delignification. The two latter requirements are possibly not completely fulfilled, but from a practical point of view, small deviations from them can be regarded as less significant. It is also quite easy to modify the H-factor using other values for the activation energy (32000) and the constant a.

The conclusion is therefore that H-factor will give a reliable summary of the time-temperature relationship for the delignification.

### Charging conditions

Equation (1) contains a variable, C, that stands for the concentration of alkali. It is probably well established that effective alkali EA, defined as

\[
EA = NaOH + 0.5 NaS \text{ (as g NaOH/1)}
\]

is a very useful measure of alkali concentration. Equation (4) accounts for part of the sulphide, but presumably a further explanation of the contribution of the sulphide on the delignification may be found in the constants in (3). Though there may be doubt as to whether EA is the exact measure for alkali concentration or not, we have adopted it in this investigation. No matter how C in (1) is defined, the problem remains to measure it, or in other ways control it. A commonly used method is to continuously measure weight and moisture of the chips fed into the digester and after some computation, charge white and black liquor to obtain desired values for alkali-to-wood and liquor-to-wood ratios. It is obvious that the measurement of the seven variables involved (chips — weight and moisture, white and black liquor volumes, white and black liquor strengths and sulphidity) has to be done with very high accuracy to avoid a large cumulative error.

Let us consider just one of the possible errors. If the moisture has a measured value of 50%, the correct value being 48%, it can be shown that an increase in the final Kappa no. of approximately 5 units is obtained.

To the best of our knowledge, there is no equipment that can measure moisture in chips with accuracy better than ± 2%. Another drawback is the obvious difficulty in determining the concentration of alkali within the chip during different stages of the cook. This is illustrated by the elegant but elaborate solution of this problem given in [3].

### Wood quality

Even if the measurements mentioned in the preceding paragraph could be done perfectly, changes in wood quality will have a detrimental effect on the result of pulping. This has been shown in an exhaustive examination of MoDoCell's wood furnish which is collected from the entire east coast of Sweden.

Samples of chips from about 400 rafts were collected at Husum during one year. Each sample was a mixture of chips from one raft. We mixed these samples to form about 50 new samples each being representative for a specific harvesting area. Each sample was then split into three parts which were cooked under strictly controlled conditions at three different levels of alkali charge using the following cooking schedule. Liquor-to-wood, 3.50 l/kg adw.; Sulphidity, 30%; Temp. rise, 1°C/min; Maxi. temp., 170°C; H-factor (Vroom), 2200;
Alkali charges, 18.5, 19.5, 20.5% (100 x kg/kg adw). The results shown in Fig. 2 prove very dramatically that wood quality has a major influence on the result of pulping.

**Model building**

**Basic control strategy**—Due to the fact that wood quality cannot be measured automatically with conventional techniques, and as it is difficult to measure moisture and chip weight accurately, we concluded that an existing control system based on measurements of all charging variables simply could not give us sufficiently good results without unreasonable expenditure on measuring equipment, silos for mixing different grades of chips and manpower to perform necessary continuous Kappa no. determinations for feed-back control of such systems. Consequently, we had to find new ideas on which a control system giving the desired results could be based.

The idea on which KAPPA BATCH is based is illustrated by Fig. 3 which shows the degradation of alkali during the cook. At the beginning of the cook, the alkali concentration decreases very rapidly due to several reasons: neutralizing of acidic extractives; dissolving of certain carbohydrates; diffusion of liquor into the chips; all of which could be assigned as wood quality dependent and to some extent unpredictable. The bulk delignification which begins when these reactions are almost completed is not associated with a similar large alkali consumption but nevertheless, the reaction rate is strongly dependent on the alkali concentration (cf. eq. 1). Furthermore, the concentrations of alkali in the liquor and in the chips are closely related to each other when the bulk delignification begins.

The obvious conclusion is therefore: Measure the concentration of alkali when the initial reactions have terminated. The concentration of alkali thus obtained ought to be suitable for feed-forward control of the time temperature schedule (H-factor) to obtain a pulp with a predetermined Kappa no., irrespective of wood quality and deviations from normal charging routines.

There is nothing in this basic control strategy that impedes usage for continuous digesters. It is also emphasized that the obtained concentration value can be utilized for determination of the amount of white liquor, etc. to be injected into the digester to obtain a predetermined concentration value, if the time temperature schedule is fixed.

**Laboratory investigations**—It was shown that the basic control strategy was sound and we obtained a significant relationship between Kappa no., EA and H-factor as shown in Fig. 4. The investigations also showed that the obtained relationship was unaffected by changes in wood quality (e.g. it is valid for species as well as different grades of pine) and that it covered a very wide range of charging conditions. Similar relationships are readily obtained for other species including hardwood of different kinds. [4, 5].

The relationship was then used to produce pulp with a fixed Kappa no. using a simplified relationship according to Fig. 5. This investigation showed that it was possible to reach the predetermined Kappa no. with a standard deviation less than 1.0 Kappa no. unit under laboratory conditions. The concentration of alkali was measured in a sample withdrawn from the digester at 150°C (dT/dt = 1.0°C/min from 90°C).

We had thus reduced the rather complex problem of measuring weight, moisture, white and black liquor, strength and volumes, wood quality etc. to measure instead the alkali concentration of black liquor. The measurement is performed once per cook at a well determined sampling moment.

Figure 4 shows that a decrease in effective alkali of 1 g/l will increase the Kappa no. by 2-4 units, if the H-factor is held constant. Likewise, it can be shown that a temperature decrease of 1°C (cooking time and alkali concentration are fixed) will increase the Kappa no. by 2-4 units.

To obtain the stated standard deviation = 2 units we concluded that the accuracies should be ±0.5 g/l in alkali measurement and ±0.3°C for temperature measurement. Without going into details, we can say that we have solved the problems of temperature measurement.

**Analysis of alkali concentration**—Extensive work finally led to the conclusion that conductivity titration was the only method to fulfill our specification with accuracy and stability were taken into consideration.
The principles of conductivity titration are shown in Fig. 6. By adding $H_2SO_4$ to black liquor, its conductivity decreases in a linear manner until a certain amount of acid has been added whereafter it reaches a constant value. The crossing point between the two lines gives the equivalent volume of acid from which the alkali concentration in the black liquor is calculated using the formula in the figure. The calculation can be done very accurately and is suited for computer evaluation which ensures high accuracy if the calculation is performed, e.g., according to the least square method.

The instrument chosen for conductivity measurement is a Kemotron with four electrodes which has been proven to work satisfactorily for extended periods in black liquor.

The alkali concentration obtained in this way is theoretically almost exactly equal to the EA, a result which also could be obtained by conventional titration at about pH 11. In the latter case, it is unlikely that the electrodes will work satisfactorily during prolonged periods in black liquor. Another drawback when using pH titration is poor accuracy.

In an attempt to make the measurement in an easier way, we tried to measure the conductivity without titration but this approach was not successful due to uncontrollable contributions to the conductivity from inorganic ions in the black liquor, and variations in temperature.

Factory investigations—At this stage, we started to build a pilot plant for further investigations on full-scale digesters and to test the preliminary laboratory model.

ASEA have built an automatic analyser working according to the described principle. This analyzer, further described below, and a minicomputer (PDP-8) were installed in MoDoCell’s Kraft pulp mill at Husum. Four digesters (125 m³, indirectly heated) were connected to the system in order to collect significant data, and we confirmed that the laboratory model was applicable to full-scale digesters with some minor modifications.

The final model was derived as a mathematical model according to the general formula

$$\frac{1}{H} = \sum_{i=0}^{n} \sum_{j=0}^{n} a_{ij}EA^i K^j$$

(5)

where the constants $a_{ij}$ are computed with standard multiple regression routines, EA is the measured value for effective alkali, K is the desired Kappa no. and H is the H-factor necessary to reach that Kappa no.

Results from pilot plant operation

During a prolonged period we have tested the model using a rearrangement of (5)

$$K = f(EA, H)$$

(6)

The standard deviation obtained when comparing actual (measured) Kappa nos. with predicted values was 1.7 in spite of large variations in pulping variables e.g.

Wood—Normal supply from the whole of Sweden (almost); screened but not mixed chips of “average” quality.

Charge—Liquor-to-wood ratio 3.5 to 4.0 l/kg; alkali-to-wood ratio 18 to 24% sulphidity 30 to 40%.

Pulping—Heating period to max. temp., 70 to 150 min., max. temp., 160 to 180°C; pipping time (including charging), 3.5 to 7 hr.

The remaining deviation is, to a great extent, a result of the established fact that there are certain variations in Kappa no. within a cook, and that the determination of Kappa no. has an inherent inaccuracy.

Other variables that may influence the remaining deviation are the chip size distribution and sulphidity. It is emphasized that the observable standard deviation will be considerably less during normal pulping conditions utilizing a number of digesters with a common blow tank in which the batches are mixed.

The control system

Based on the results given above, which surpassed our expectations, a decision was made to install a control system for the entire softwood digesting house (16 digesters). The system will be delivered by ASEA, Västerås, Sweden and is scheduled to be in full operation in April 1973. The description given here is somewhat brief.

Alkali analyzer—A schematic drawing of the analyzer used during the testing period is shown in Fig. 7. Liquor from one digester is fed into the sampling vessel from the circulation pipe of the digester. The sample is then fed into the titration vessel where it is diluted with water. The mixing is performed with a pump until the conductivity reading is steady and the value is stored in the computer. A small portion of $H_2SO_4$ is automatically added, a new value is read and stored and so on until the whole titration cycle is completed and automatically stopped. One complete titration is done in less than 10 minutes if the alkali concentration is less than 20 g/l.

The analyzer is equipped with an automatic washing system and a control system based on measurement of levels as well as temperature and timing measurements.
not shown in this figure. The control system automatically alarmed any malfunction in the analyzer to the computer. The original analyzer used for factory investigations has proven to be reliable. It will be slightly modified and used in the final installation.

The obtained accuracy of the system is given in the figure. The standard deviation in the difference between the automatic analysis and the laboratory analysis is partly caused by the sampling technique because it was impossible to take sample from the sampling vessel in this system. This has caused a small delay between the samples. If 50% of the deviation is explained in this way, the obtained accuracy is ±0.3 g/l according to the specification. As a matter of fact, it is probably even better since the computer calculates the lines and the crossing point more exactly than can be done manually.

Computer—The computer chosen for the final installation is a PDP-11/05 with 12k core memory (expandable to 28 k). It will perform the following calculations and control actions:

- Calculate and add incremental H-factors once per minute.
- Determine the sampling moment which is done in an accurate manner, no matter how the heating is done, using a new pulping variable called the Q-factor.
- Supervise the analyzer and calculate the alkali concentration.
- Calculate the desired H-factor to reach a predetermined Kappa no.
- Control the steam and blow valves.
- Monitor the H-factor for each cook.
- Report the status of each digester to the operators panel.
- Alarm malfunctions.
- Report a summary of each cook on the typewriter.

Communications—An operators panel will be attached to the system permitting the operator to change certain constants e.g. production rate, desired Kappa no. etc. He can also display various digesting variables on a set of x-nixie tubes (or a video display unit). These variables could be temp., EA, predicted time for blowing, etc.

Further communication is performed via an attached typewriter, which is primarily intended for summary reports.

Application to continuous digesters

The basic control strategy can be applied to continuous digesters in different manners, each of which is described below.

The process is best understood if the digester is considered as a number of batch digesters placed on top of each other, and the digester content displaced in discrete steps from one section of the digester to the next. The residence times in each section is determined from measurements of the blow rate and the feed rate. The temperature is measured continuously using a number of measuring points arranged so that a continuous temperature profile in the digester can be determined. From this temperature profile, the temperature of each section is determined as a mean during the actual residence time. Thus it is possible to follow each section of the wood through the digester and to calculate appropriate values for H and the aforementioned Q-factor, which is used to transform alkali concentration values obtained from a continuously working analyzer connected to the liquor circulation system, preferably between the impregnation and high temperature zones in the digester, to a specific “normalized” pulping schedule. The control actions performed according to the obtained concentration value can be of any conceivable kind, e.g. feed forward control of the high temperature profile in the digester, feed forward control of the blow rate, back control of the amount of liquors charged to the top of the digester or control of pumps or other devices to inject black or white liquor to obtain a predetermined concentration value for the delignification.

Summary

From the results described above we can conclude that the ASEA System KAPPA BATCH for controlling batch digesters makes it possible to produce pulp with a predetermined Kappa no. with extremely good accuracy without a complex system of measuring equipment, except for the analyzer, without chip mixers and without any manpower for continuous Kappa no. monitoring etc.

No extra care is needed in charging, and the system can handle a great variety of pulping schedules, permitting a close control of the steam consumption in the digester house at different levels of production rate.

References


ABSTRACT: The KAPPA BATCH control system for Kraft batch digesters, which is based on one single measurement of the alkali concentration during the cook, is described. The automatic alkali analyzer working according to conductometric titration principles and developed for this purpose, is presented. During prolonged periods it was shown that the standard deviation in Kappa no. produced pulp could be held well below 2.0 units with the aid of the system, in spite of great variations in digesting characteristics. A control system for continuous Kraft digesters based on the same idea is outlined.

KEYWORDS: KAPPA NUMBER, H-Factor, EFFECTIVE ALKALI, CONTROL SYSTEMS, BATCH PROCEES, CHEMICAL PULPING, COMPUTER AUTOMATIC CONTROL, INSTRUMENTATION, CHEMICAL ANALYSIS, PULPING ANALYSIS, COMPUTER AUTOMATIC CONTROL SYSTEMS, CONDUCOMETRY.