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(54) Title: A SYSTEM AND A METHOD FOR OPTIMIZATION OF CONTINUOUS DIGESTION PROCESS

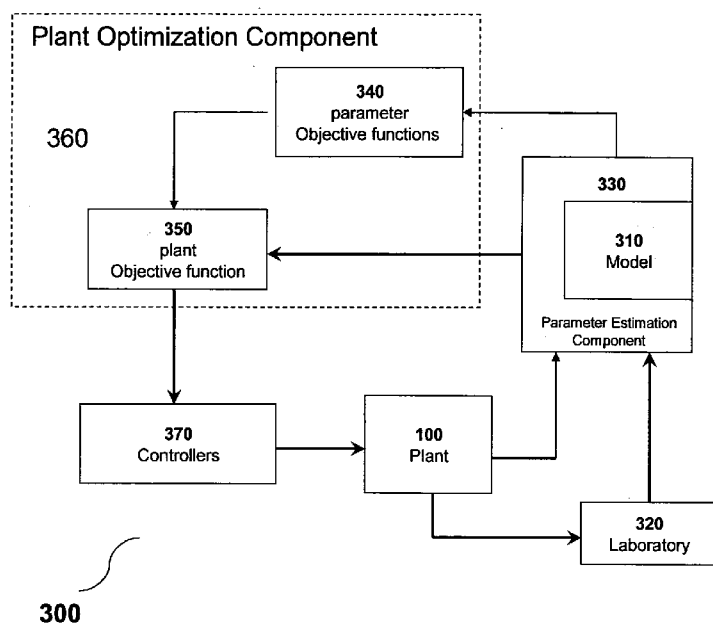


Figure 3

(57) Abstract: A method for optimization of continuous digestion process is provided which aims to control the delignification process in a continuous pulp digester in an optimal way for different pulp grades taking care of the process disturbances and model uncertainties. This is achieved by customizing a generic mathematical model for continuous digestion process which runs through software application on a dedicated electronic means. The model is updated periodically based on online information and used with a plant optimization component involving multiobjective optimization to evaluate the optimal set points for the controllers.

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A SYSTEM AND A METHOD FOR OPTIMIZATION OF CONTINUOUS DIGESTION PROCESS

FIELD OF INVENTION:

5 The present invention relates, in general, to the optimization of continuous pulp digester in pulp and paper industry. More specifically, the system and method proposed by the present invention aims to control the delignification process in a continuous pulp digester in an optimal way for different pulp grades taking care of the process disturbances and model uncertainties.

10 DESCRIPTION OF THE RELATED ART:

Continuous pulp digesters in the pulp and paper industry are used for cooking wood chips to produce pulp which in turn is used for making paper. The aim of cooking is to remove the lignin component present in the wood chips. Lignin is a complex compound present in the wood and acts as a binding material for the cellulose fibers. Wood chips along with
15 the cooking liquor are fed continuously at the top of the digester and the cooked wood chips are removed as pulp product from the bottom of the digester unit. In the dual vessel configuration, the impregnation process is carried out in a separate vessel followed by another vessel consisting of upper, lower and washing sections. In general, the cooking process involves removal of lignin from the wood chips by the cooking liquor. During
20 cooking in the continuous pulp digester, the chips always flow top-down, while the flow of the cooking liquor is either co-current or countercurrent for various sections involved. The heat required for cooking is provided by heating the cooking liquor by taking out and recirculating it back. Part of the liquor after extracting the wood components is taken out for further processing. Because of the complex nature of this process, continuous pulp
25 digester is characterized by highly nonlinear behavior. This, in addition to factors such as presence of long dead time, strong interactions between the process variables, and unmeasured changes in the characteristics of the wood chips make the control of digester very difficult.

30 The digester system has process parameters such as model states with a particular concentration of one or more components in solid, liquid and gas phase, temperatures, pressures, flow rates of the white liquor and wash liquor, the recirculation flow rates and temperatures, the flow rate of the steam in the heat exchangers, effective alkali and active alkali of white liquor and wash liquor, etc.; quality parameters such as kappa number,
35 consistency, pulp strength, effective alkali and active alkali of the extraction streams, etc.;

performance parameters such as energy efficiency, yield, inventory consumption and operating cost, etc.; and model parameters such as reaction rate coefficients, effectiveness factors, diffusion and heat transfer coefficient. All these parameters, i.e., process parameters, quality parameters, performance parameters and model parameters are collectively referred to as digester parameters from here on.

Usual practice in industry is to specifically control the kappa number of the pulp at the bottom outlet or blowline of the digester by manipulating the temperature of circulating cooking liquor flows at different sections and flow rates of make-up white liquor and wash liquor to different sections of the digester. The set-points for temperatures and flow rates of white liquor/wash liquor are adjusted based on operator experience in an ad-hoc fashion. However, recently, multivariable model predictive control strategies are also proposed to improve the control of the digester. Some of the patents and publications related to control of processes in the digester are listed below.

US Patent No. 5,301,102 describes the use of step response models and periodic measurements of kappa number and effective alkali of the cooking liquor to control the kappa number of pulp produced from a Kamyr digester.

US Publication No. 20050034824 uses a method based on on-line analyzers, dead time compensators, decouplers and a look up table (similar to fuzzy logic rules) of the effect of the various manipulated variables on the digester quality and performance parameters to achieve desired performance of the digester.

US Patent No. 6,447,639 relates to the application of heat and ion mobility spectrometry to calculate the amount of cooking liquor added based on the on-line determination of the characteristics of chips being fed into the pulp digester.

US Patent No. 4,752,357 describes a method for determining the degree of cooking to which pulp has been in the digestion process. This is very useful to establish appropriate predictive control action.

Other prior art methods reported in the literature deal with application of techniques such as model predictive control using linear and nonlinear models, inferential control, and optimization of the operating conditions to produce pulp of desired kappa number from the continuous pulp digester.

Continuous pulp digester simulation models of different complexities have also been reported for different applications such as monitoring and control. Recently, Padhiyar et al., (2006) proposed some strategies which aim at controlling the Kappa number profile at various cooking zones of the digester instead of just controlling it at the blow line. This will facilitate faster process disturbance rejection as corrective action will be initiated much earlier than the consequences are manifested on the Kappa number in the blow line. Such a distributed control strategy will also ensure faster and efficient transient operation during grade change. However, the strategy is limited to the proposal of using the kappa number profile and does not extend further to teach the means to assign optimal set-points for various controllers. As discussed earlier, assigning set-points are usually based on operator experience.

To summarize, the approaches reported in the prior art are mainly focused on controlling Kappa number only in the blow line section and further improvements by controlling the profile of various important properties like Kappa number and yield along the length of the digester as well. However, the control of the profile has to be done optimally to ensure various objectives of the plant such as superior quality and performance, and processes are controlled online to meet the requirements as desired. The optimization and control problem with more than one quality parameters or performance parameters or process parameter needs to have a means to deal with the complexities of plant process, optimization problem formulation and trade offs involved in dealing with conflicting requirements. This aspect has not been a part of prior-art and is the topic of this invention.

OBJECTS OF THE INVENTION:

The principal object of the present invention is the optimization of the continuous pulp digester with respect to various digester parameters.

Yet another object of the present invention is to provide a method to provide optimal set-point profiles for one or more digester parameters along the digester length based on real time plant data.

Still another object of the present invention is to evaluate the multiobjective optimal solution profile for the continuous pulp digester.

Still another object of the present invention is to evaluate the single objective

optimization to arrive at optimal set points.

Still another object of the present invention is to update the model parameters using the parameter estimation component.

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Still another object of present invention is to provide the desired solution of the multiobjective optimization as an initial guess for the single objective optimization problem to ensure online multiobjective operations.

SUMMARY OF THE INVENTION:

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Accordingly, the present invention relates to the optimization of the continuous pulp digester parameters by evaluating the optimal set-point profiles for digester parameters along multiple sections of the digester. A single objective optimization problem is formulated using the results of the multiobjective optimization based on the desired quality requirements. The single objective optimization problem so formed involves optimization of one of the objectives and the equality constraint on the other objectives corresponding to the selected multiobjective optimal solution.

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The digester model is continuously updated using the online data and results from laboratory. The updated model is used to periodically carry out single objective optimization to update the optimal set point profile. For a significant deviation in the model predictions, the multiobjective optimization is also repeated to arrive at updated multiobjective optimal solutions.

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In the first aspect of the invention, a system for optimizing control of a continuous pulp digester is presented. The system comprises:

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a) a process model component with a process model of at least one of the many sections of the continuous pulp digester;

b) a parameter estimation component to provide estimates of one or more digester parameters for at least one of the many sections of the continuous pulp digester;

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c) a plant optimization component to perform computations for optimization of the one or more digester parameters using the process model component and the parameter estimation component of the continuous pulp digester;

d) one or more controllers for regulating the digester parameters at at least one of the many sections of the continuous pulp digester and provided with setpoint by the process optimization component;

35

wherein,

the plant optimization component further comprises of a plant objective function to perform online optimization of digester parameters formulated from plurality of parameter objective functions

In an embodiment of the present invention, the parameter estimation component of the system for optimizing control of a continuous pulp digester, wherein, the parameter estimation component is an integral part of the process model component or is an integral part of the plant optimization component.

In another embodiment of the present invention, the system for optimizing control of a continuous pulp digester has a parameter optimization component with a single parameter objective function.

In yet another embodiment of the present invention, the system for optimizing control of a continuous pulp digester has a plant optimization component with at least one plant objective function.

In yet another embodiment of the present invention, the one of the many sections of the continuous pulp digester is formed in one or many combinations of the zones such as impregnation zone, upper cooking zone, lower cooking zone, wash zone of the continuous pulp digester and wherein the one of the many sections is contained in one or more units.

In yet another embodiment of the present invention, the plant optimization component has a plant goal interface used at one or multiple phases of plant operation to obtain preference information using an user interface or using a software interface to obtain configuration data or using a rule based system to seek and analyze information such as priority information for optimization of the one or more digester parameters, desired range and operating point.

In the second aspect of the invention, a method for parameter objective optimization is presented. The method comprises the steps

a) Obtaining a process model and digesters parameters from a parameter estimation component;

- b) Providing constraints and bounds for the digester parameter using a plant goal interface;
- c) Defining one or more parameter objective functions with digester parameters from the said parameter estimation component and the said constraints and bounds from the plant goal interface;
- 5 d) Optimizing the one or more parameter objective functions under constraints imposed by the process model or the said constraints and bounds from the plant goal interface or both the constraints imposed by the process model and the constraints and bounds from the plant goal interface by manipulating the digester parameters to get one or more
- 10 optimal values of the parameter objective functions

In the third aspect of the present invention, a method for plant objective optimization is presented. The method comprises the steps of

- a) Selecting a plant objective function from a plurality of parameter objective functions through preference information obtained from a plant goal interface;
- 15 b) Obtaining a process model and digesters parameters from a parameter estimation component;
- c) Obtaining the constraint and bound information for the plurality of parameter objective functions except for the selected plant objective function defined using the plant goal interface
- 20 d) Optimizing the plant objective function under constraints imposed by the process model or the said constraints and bounds from the plant goal interface or both the constraints imposed by the process model and the constraints and bounds from the plant goal interface by manipulating the digester parameters to get optimal values of the plant
- 25 objective function.

In the fourth aspect of the present invention, a method for online optimization for a continuous pulp digester is presented. The method comprises of steps

- a) Obtaining estimates of digester parameters using a parameter estimation component and a process model component;
- 30 b) Obtaining measured data using means such as online measurements, data from laboratory analysis or their combinations;
- c) Obtaining difference between the said estimates of the digester parameters and the said measured data obtained using methods such as online measurements, data from
- 35 laboratory analysis and their combinations;

- d) Evaluating the significance of the difference and suitably update the process model component and suitably trigger parameter optimization component and plant optimization component to update solution for optimized digester parameters wherein the suitability of the update of the process model component and the trigger to the parameter optimization component is based on allowed tolerances on online performance and accuracy of the continuous pulp digester plant;
- e) Use the optimized digester parameters as a set-point for optimized control of the continuous pulp digester;
- 10 In the fifth aspect of the invention, a parameter estimation component is presented. The parameter estimation component comprises of one or more modules such as
- a) a prediction module to provide estimate of one or more digester parameters consisting of model parameters, process parameters, quality and performance parameters by using methods such as online measurement, data from laboratory analysis, mathematical
- 15 formulation and their combinations.
- b) an updation module to update a process model component based on the significance of difference between the estimates of one or more digester parameters and the measured data obtained using methods such as online measurements, data from laboratory analysis and their combination;
- 20 c) a trigger module to trigger an optimization solver to compute plant objective function and parameter objective functions.
- d) an interface support module to support a plant goal interface provide consequence and state information including plant trajectory information to help choice of a suitable plant objective function.

25 **BRIEF DESCRIPTION OF THE DRAWINGS:**

It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are, therefore, not to be considered for limiting of its scope, for the invention may admit to other equally effective embodiments.

- 30 Figure 1: Schematic of the continuous pulp digester process;
Figure 2: Multiobjective optimization solution for two objectives.
Figure 3: Schematic representation of optimization of continuous pulp digester according to the invention.

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DETAILED DESCRIPTION OF THE INVENTION:

In this section of the invention, various steps involved in the continuous digestion process control and the system for optimal control are described.

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Two types of digester configurations, single or dual vessel, are used for continuous pulp digesters in the industry. A single vessel continuous pulp digester is a vertical cylindrical vessel consisting of different zones such as impregnation, upper cooking, lower cooking and wash zones. Figure 1 illustrates the schematic of a typical continuous digester unit, 100, consisting of a single vessel. The aspects of the single unit continuous pulp digester may as well be represented with multiple digester units consisting of more than one vessel.

The digester unit chemically treats wood chips under increased temperature and pressure to reduce the lignin content of the pulp suitable for papermaking. The wood chips and the cooking liquor stream, 105, enters the digester unit at the top and travels downwards through various zones such as impregnation zone, 110, upper cooking zone, 120, lower cooking zone, 130, and wash zone, 140, before leaving the digester bottom through the blow line, 150, as pulp, 155.

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The digester operates as a three-phase solid-liquid-gas reactive system. The solid mass in the chips decreases as pulping proceeds through delignification creating water soluble solids that dissolve in the entrapped liquor. The water soluble solids are suitably transferred to the free liquor surrounding the pulp phase by the diffusion process.

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In the impregnation zone, 110, cooking chemicals continue to diffuse into the liquid entrapped in the void spaces of the chips. The temperature in the impregnation zone is generally not high enough to cause an appreciable rate of delignification to occur and at different zones, the temperature is maintained through use of many heaters, 160, for the individual zones. Upon leaving the impregnation zone, the chips and cooking liquor enter an upper cooking zone, 120, where the temperature is usually raised by an externally heated upper cooking circulation stream 107. Cooking liquor is partly withdrawn from the upper cooking zone as upper extraction stream, 108, and partly heated in an external heater, 160, and circulated back into the upper cooking zone. Make up white liquor and wash liquor stream, 109, is added to the circulation stream before it passes through the heater 160.

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After upper cooking zone, 120, chips and cooking liquor enter the lower cooking zone, 130, where the cooking liquor stream, 125, is circulated through an external heater, 160, to maintain the temperature. Make-up white liquor and wash liquor stream, 109, is also added to the circulating liquor before entering the heater. At the end of the lower cooking zone, part of the cooking liquor is removed as black liquor extraction stream, 135.

After lower cooking zone, the pulp enters the wash section, 140, where it is mixed with wash liquor to remove the reacted lignin from the pulp. Some amount of delignification reaction occurs in this zone also. The circulating liquor stream, 145, from the wash section is also heated in an external heater, 160. Make-up wash liquor stream, 147, is added to this stream before entering the heater. This helps in achieving further delignification reaction in wash zone. Finally, the cooked pulp is removed through the blowline, 150, from the bottom of the digester and sent to the brown stock washing section of the mill (not shown in the figure). The extraction as well as circulation streams are withdrawn from the digester through screens, 115.

A control system is deployed around the digester 100 to measure, manipulate and control the various digester parameters. The control system is usually a distributed control system (DCS) with regulatory controllers. The control is exercised at various sections formed as a combination of one or multiple zones. The multiple zones to carry out similar functions, if any, and the multiple zones carrying out slightly different functions may be clubbed together to form a section.

Advanced control system modules are used for optimization. The optimization methods are based on process model. The model described in this invention is a semi-empirical model. However, other models based on first principle or empirical methods may also be used. The following paragraphs describe model formulation and estimation of various model parameters. Model parameters are the parameters that are used for formulation of model equations.

The continuous pulp digester is modeled as a tubular reactor which has one input for the feed chips and cooking liquor enters at multiple locations in the various zones to carry out digestion. The temperatures and concentrations are assumed to vary along the length of the digester (from top to bottom) through various zones or sections of the digester.

A lumped parameter approach is used for modeling the digester and the entire digester

model is built by representing it as series of interconnected CSTR's (continuous stirred tank reactors). The wood and the liquor composition is assumed and material and energy balance for each of the components entering and leaving the CSTR is carried out to derive model equations. The reaction rate equations are considered to account for the consumption/formation of various components.

The entire digester is divided into four major sections: impregnation section, upper cooking section, lower cooking section and wash section. Each section is assumed to be a series of CSTRs as described above. For each section a sub-model is developed and these are connected accordingly for developing a model for any type of digester. The model equations for each CSTR are of the following generic form:

$$V \frac{dC_i}{dt} = F_i^{in} - F_i^{out} + F_i^{reaction}; \quad i = 1 \text{ to } m; \quad (\text{Eq 1})$$

$$\rho_s C_{p,s} V_s \frac{dT_{solid}}{dt} = H_{solid}^{in} - H_{solid}^{out} + H^{reaction} + H_{liquor \rightarrow solid}^{transfer}; \quad (\text{Eq 2})$$

$$\rho_l C_{p,l} V_l \frac{dT_{liquor}}{dt} = H_{liquor}^{in} - H_{liquor}^{out} - H_{liquor \rightarrow solid}^{transfer}; \quad (\text{Eq 3})$$

Eq. 1 describes the rate of accumulation of component i in the CSTR. C_i is the concentration of the component i in CSTR. T_{solid} and T_{liquor} are the temperatures of the solid (chips) and the free liquor. F_i^{in} and F_i^{out} are the flow rates of component i in and out of the CSTR respectively, and $F_i^{reaction}$ represents the rate of formation of component i by reaction in the CSTR. m is the total number of components existing in various digester inlet/outlet streams and V is the volume of the CSTR. Eq. 2 and Eq. 3 describe the heat balance for the solid and the liquor phases.

H_{solid}^{in} , H_{solid}^{out} , $H^{reaction}$, $H_{liquor \rightarrow solid}^{transfer}$ respectively represent the rate of heat entering and leaving along with the solids for a CSTR, heat contribution due to reaction in the CSTR, and the heat transfer from liquor to solid phase. H_{liquor}^{in} and H_{liquor}^{out} represent the heat entering and leaving out of the CSTR through liquor phase. ρ_s and ρ_l are densities, $C_{p,s}$ and $C_{p,l}$ are specific heats and V_s and V_l are the volumes of the solid and liquor phases, respectively. The kinetic and diffusion parameters are incorporated in the term $F_i^{reaction}$ while the diffusion and heat transfer

terms are incorporated in the term $H_{liquor \rightarrow solid}^{transfer}$. These are the various model parameters. A more generic form will incorporate momentum balance equation as well (not reported here). For a steady state model, the left hand side terms of Eqs. 1 - 3 will be zero.

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The formulated model is tuned and validated using the plant data. In order to validate the model, model parameters are determined by minimizing the error between the actual offline plant measurements (measurements obtained from distributed control system as well as laboratory) and model predictions. Stochastic or linear or nonlinear gradients based optimization techniques can be used to minimize the error. The validated model is then used in the optimization framework.

The process model is formulated to represent process parameters such as various inputs, extraction and circulation flows and their compositions, temperatures, etc. It also includes quality parameters such as kappa number, plant consistency and emission factors and performance parameters such as yield, and operating cost. These parameters along with the model parameters are referred to as digester parameters. It is recognized that the optimization need is for multiple digester parameters and hence multiple parameter objective functions are formulated.

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The validated model is first used for solving the multiobjective optimization problem. A general statement of the multiobjective optimization problem involving "n" objectives is given by

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$$\underset{u}{\text{Min/Max}} \quad \varphi_j(u, x, y) \quad j = 1 \text{ to } n;$$

Subject to: Model equations

Constraints and bounds on u , x and y

where, φ_j is the j^{th} objective function u is a vector of input variables, x and y are vectors of state and output variables.

30

The optimization problem with multiple objectives are expected to be conflicting for some of objectives and this will result in a set of equally good solutions called as non-dominated or Pareto optimal solutions which are distributed in the multiobjective optimal dimension space (with dimension of that of total number of objectives).

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The solutions from the multi-objective optimization problem are reduced to a single

objective optimization problem depending on the definition of plant goal function through a plant goal interface. The single objective function thus obtained is referred to as plant objective function as this function guides the plant to meet its objectives in totality in the most optimized manner. The multi-objective optimization functions are referred to as parameter objective functions.

The plant goal interface is a user interface that prompts the users with multiple solutions obtained by solving the multi-objective optimization problem formulated to optimize various digester parameters. The plant operator or manager is supported with the consequence information for each of the offered solution on various digester parameters. The consequence information is obtained through use of the validated process model to predict the state of the plant with a particular choice of solution. The process of obtaining a choice may also be automated through use of configuration files or through a rule-based system that defines conditions to exercise choice for the plant.

Figure 2 is used to illustrate an example of multiple solutions and formulation of a plant object function. In this example, a simple case of two objective functions is illustrated i.e. the parameter objective functions are for minimization of Kappa number (210) and maximization of yield (220) subject to model constraints and bounds on important decision variables.

The optimal set of solutions obtained corresponding to this problem is indicated in Figure 2. The curve represents multiple solutions that are obtained for this problem. All the solutions are better in either Kappa number or yield. Depending on the user requirement a given solution can be chosen and the set-point profile corresponding to this solution will be chosen for implementation, e.g., the points M (230) and N (240) in the curve are obtained as per the user requirement for two different quality (grade) requirements of the pulp, i.e., for application in making storage boxes and high quality writing paper the required quality of the pulp will differ significantly, captured through M and N as an example. Availability of different set point profiles for such varying requirements will facilitate better digester performance. With M as a chosen solution, corresponding to M a single objective optimization problem will involve minimization of Kappa number and equality constrain on yield corresponding to point M. The optimal profiles also need to be updated according to the change in the quality requirements of the pulp. Many more objective functions such as minimization of energy, effluents streams, etc., can also be considered together to get solutions in the multiple dimension objective function space.

Stochastic optimization algorithms are used in solving multiobjective optimization and the time involved in solving such problems is large. Therefore, for online implementation, a single objective optimization problem corresponding to the desired optimal solution from the multidimensional objective space is solved using a faster
5 gradient based approach. An important advantage here is that the initial guess which is required for convergence of the gradient based methods is provided by the solution to the multiobjective problem. It must be mentioned that, any optimization algorithms can be used to solve either of the optimization problems mentioned above if time required for optimization is acceptable.

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During online operation, the digester model predictions are likely to differ from the actual measurements of process parameters due to changes in the feed chip quality, changes in the composition of the cooking liquor, heat transfer coefficients in the heat exchangers, etc. In such situation, model parameters need to be re-estimated online using one or more
15 process, quality and performance parameters. This is done by re-tuning model parameters to minimize the deviation between the plant and the model predictions of digester parameters. Nonlinear optimization techniques are used to minimize the error. Periodic re-estimation of the model parameters reduces the model mismatch and brings the model behavior closer to the real behavior of the continuous pulp digester.

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As discussed earlier, the computational time required for implementing the multiobjective optimization problem is large, it is not feasible to solve the multiobjective optimization problem with every update in the model parameters. Instead a single objective optimization problem is solved to obtain better set-point profiles using the updated
25 model. This optimization can be carried out using conventional gradient based methods like SQP and is faster to be suitable for online implementation.

The single objective optimization problem so formulated can be solved periodically using the updated model when there is significant deviation in the plant measurements and
30 model predictions using the updated model. For major deviations in the plant measurements and model predictions using the updated model, the multiobjective optimization problem is solved.

Figure 3 is a schematic representation of online optimization system (300) of the
35 continuous digestion process proposed in this invention. The continuous pulp digester plant 100 has a process model 310 suitably updated based on the online measurement

data, laboratory analysis (320) and estimation of unmeasured or unanalyzed parameters using a parameter estimation component (330). The parameter estimation component has various modules such as:

- 5 a) a prediction module to provide estimate of one or more digester parameters consisting of model parameters, process parameters, quality and performance parameters by using methods such as online measurement, data from laboratory analysis, mathematical formulation and their combinations;
- b) an updation module to update a process model component based on the significance of difference between the estimates of one or more digester parameters and the measured
10 data obtained using methods such as online measurements, data from laboratory analysis and their combination;
- c) a trigger module to trigger an optimization solver to compute plant objective function and parameter objective functions;
- d) an interface support module to support a plant goal interface provide consequence and
15 state information including plant trajectory information to help choice of a suitable plant objective function.

For optimization of the continuous pulp digester plant 100, multiobjective optimization functions 340 and the reduced single objective function 350 are solved with optimization
20 solver 360. As discussed earlier, the multiobjective functions are formulated to optimize various digester parameters and hence termed as parameter optimization functions. Similarly, the single objective function is formulated to represent the plant objective and is termed as plant optimization function. The output of the optimization solver 360 is a set of set points for various digester parameters controlled through regulatory controller
25 370.

The optimization and model calculations are implemented as a software application on any dedicated electronics or software means which is a standard process automation system based on the concept of object oriented approach to design and operate process
30 automation systems.

It is to be noted that a modern DCS supports virtualization of various control system components and modules and a component or a module may have multiple instances of it running in the DCS system. For example, the plant optimization component may have
35 two instances of plant objective functions running simultaneously in the DCS system. The automation system is programmed to update the model 310 and trigger the

optimization solver 360 as found suitable for online operations by parameter estimation component 330. The parameter estimation component 330 determines the deviation and its significance between the values predicted by the model and the measurements made online or with the laboratory analysis. If the deviation is found significant, a trigger to the plant optimization component is provided to have the objective functions including the multiobjective functions solved again. Such a trigger may occur during the start up phase while tuning the model or during any phase of the plant operation whenever for any reasons there is a need to update the process plant model. The parameter estimation component 330 is also the component that helps predict digester parameters to determine the consequence or state information as and when required for example during the choice of a particular solution using the plant goal interface. This feature is extendable to provide plant consequence trajectory information to predict the course of plant operation with time using the model suitably.

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Thus, the scheme proposed provides online control of various digester parameters along the different sections of the digester for optimal control to achieve various plant objectives.

Various other modifications and alterations in the structure and method of operation of this invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific preferred embodiments and specifically for the continuous pulp digester used in paper and pulp industry, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments or a particular plant system such as the continuous pulp digester used in paper and pulp industry. It is intended that the following claims define the scope of the present invention and that structures and methods within the scope of these claims and their equivalents be covered thereby.

30 References:

Nitin Padhiyar, Akhil Gupta, Abhishek Gautam, Sharad Bhartiya, Francis J. Doyle III, Sachi Dash, Sujit Gaikwad. Nonlinear inferential multi-rate control of Kappa number at multiple locations in a continuous pulp digester. Journal of Process Control, 16, 10, 2006, 1037-1053.

I / WE CLAIM:

1. A System for optimizing control of a continuous pulp digester (300) comprising:
 - a) a process model component (310) with a process model of at least one of the many sections of the continuous pulp digester;
 - 5 b) a parameter estimation component (330) to provide estimates of one or more digester parameters for atleast one of the many sections of the continuous pulp digester;
 - c) a plant optimization component (360) to perform computations for optimization of the one or more digester parameters using the process model component and the parameter estimation component of the continuous pulp digester;
 - 10 d) one or more controllers (370) for regulating the digester parameters at atleast one of the many sections of the continuous pulp digester and provided with setpoint by the process optimization component;where in,
the plant optimization component further comprises of a plant objective function (350) to
15 perform online optimization of digester parameters formulated from plurality of parameter objective functions (340).
2. The parameter estimation component of the system for optimizing control of a continuous pulp digester as described in Claim 1, wherein, the parameter estimation
20 component is an integral part of the process model component or is an integral part of the plant optimization component.
3. The system for optimizing control of a continuous pulp digester as described in Claim 1 having a parameter optimization component with a single parameter objective
25 function.
4. The system for optimizing control of a continuous pulp digester as described in Claim 1 having a plant optimization component with atleast one plant objective function.
- 30 5. The one of the many sections of the continuous pulp digester as described in Claim 1 is formed in one or many combinations of the zones such as impregnation zone, upper cooking zone, lower cooking zone, wash zone of the continuous pulp digester and wherein the one of the many sections is contained in one or more units.

6. The plant optimization component as described in Claim 1 having a plant goal interface used at one or multiple phases of plant operation to obtain preference information using an user interface or using a software interface to obtain configuration data or using a rule based system to seek and analyze information such as priority information for optimization of the one or more digester parameters, desired range and operating point.
7. A method for parameter objective optimization comprising
- a) Obtaining a process model and digester parameters from a parameter estimation component;
 - b) Means of providing constraints and bounds for the digester parameter using a plant goal interface;
 - c) Defining one or more parameter objective functions with digester parameters from the said parameter estimation component and the said constraints and bounds from the plant goal interface;
 - d) Optimizing the one or more parameter objective functions under constraints imposed by the process model or the said constraints and bounds from the plant goal interface or both the constraints imposed by the process model and the constraints and bounds from the plant goal interface by manipulating the digester parameters to get one or more optimal values of the parameter objective functions
8. A method for plant objective optimization comprising:
- a) Selecting a plant objective function from a plurality of parameter objective functions through preference information obtained from a plant goal interface;
 - b) Obtaining a process model and digesters parameters from a parameter estimation component;
 - c) Obtaining the constraint and bound information for the plurality of parameter objective functions except for the selected plant objective function defined using the plant goal interface;
 - d) Optimizing the plant objectives function under constraints imposed by the process model or the said constraints and bounds from the plant goal interface or both the constraints imposed by the process model and the constraints and bounds from the plant goal interface by manipulating the digester parameters to get optimal values of the plant objective function.
9. A method for on-line optimization for a continuous pulp digester comprising:

- a) Obtaining estimates of digester parameters using a parameter estimation component and a process model component;
 - b) Obtaining measured data using means such as online measurements, data from laboratory analysis or their combination;
 - 5 c) Obtaining difference between the said estimates of the digester parameters and the said measured data obtained using methods such as online measurements, data from laboratory analysis and their combination;
 - d) Evaluating the significance of the difference and suitably update the process model component and suitably trigger parameter optimization component and plant optimization component to update solution for optimized digester parameters wherein the
10 suitability of the update of the process model component and the trigger to the parameter optimization component is based on allowed tolerances on online performance and accuracy of the continuous pulp digester plant;
 - e) Use the optimized digester parameters as a setpoint for optimized control of
15 the continuous pulp digester.
10. A parameter estimation component comprising of one or more modules such as
- a) a prediction module to provide estimate of one or more digester parameters consisting of model parameters, process parameters, quality and performance parameters
20 by using methods such as online measurement, data from laboratory analysis, mathematical formulation and their combinations;
 - b) an updation module to update a process model component based on the significance of difference between the estimates of one or more digester parameters and the measured data obtained using methods such as online measurements, data from
25 laboratory analysis and their combination;
 - c) a trigger module to trigger an optimization solver to compute plant objective function and parameter objective functions;
 - d) an interface support module to support a plant goal interface provide consequence and state information including plant trajectory information to help choice
30 of a suitable plant objective function.

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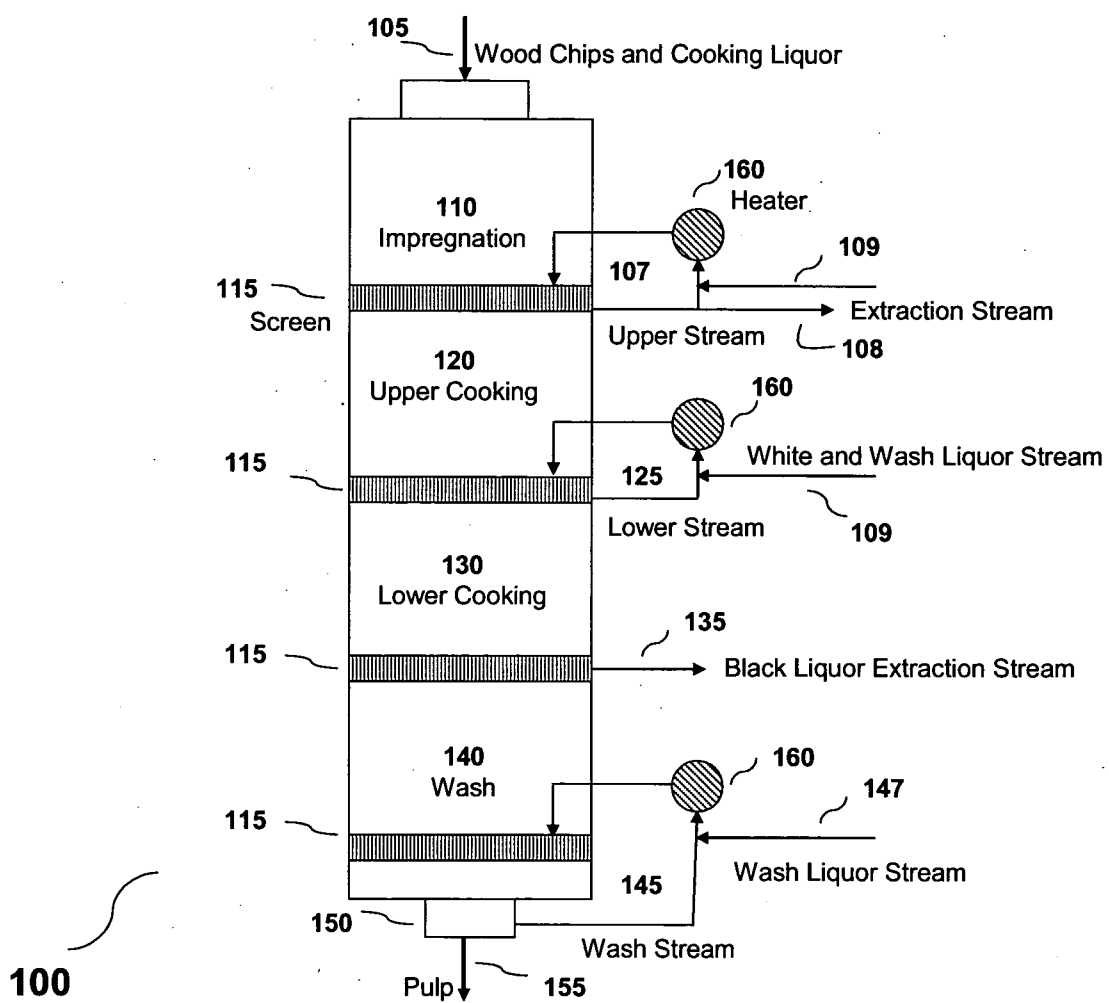


Figure1

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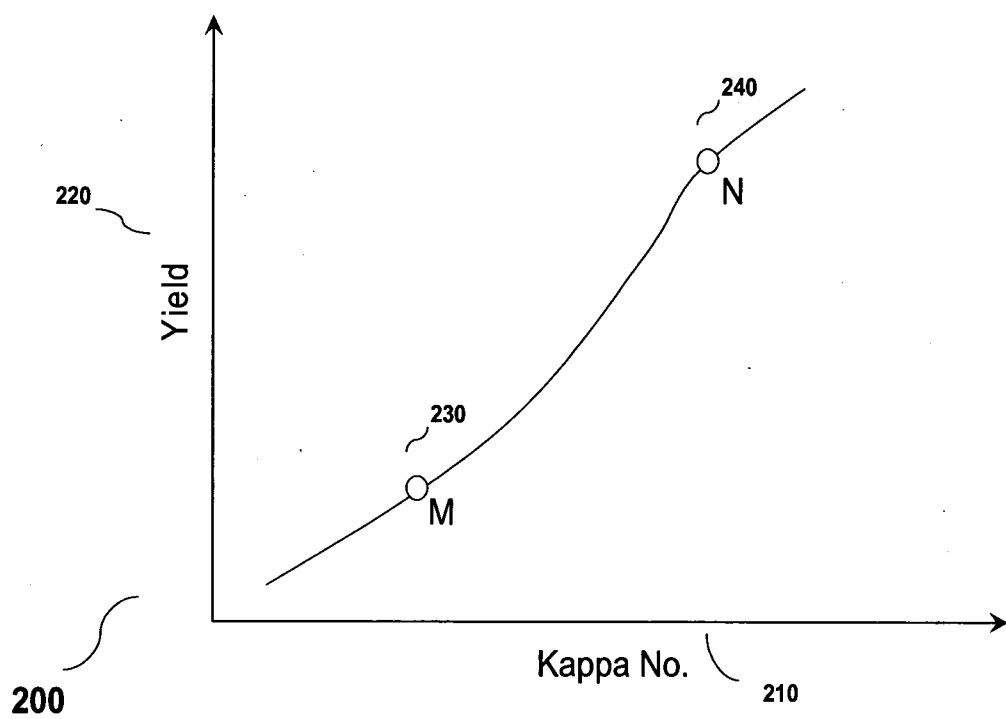


Figure 2

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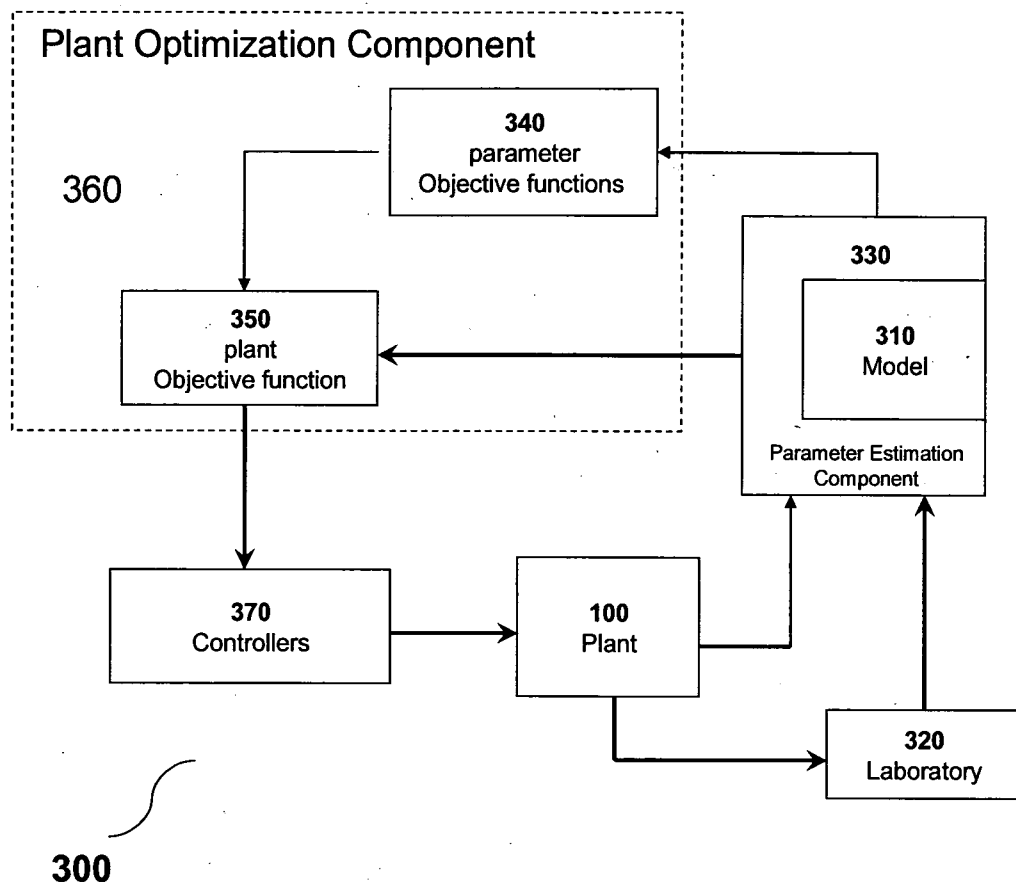


Figure 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 2009/007841

A. CLASSIFICATION OF SUBJECT MATTER

IPC⁸: **G05B 13/02** (2006.01); **G06F 15/18** (2006.01); **G06F 17/17** (2006.01); **D21C 7/12** (2006.01); **D21H 15/00** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC⁸: D21C, D21H, G06F, G05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005071137 A1 (SELVARAJ et al.) 31 March 2005 (31.03.2005) <i>Claims; figures; page 1, paragraph 3</i>	1-10
X	EP 1528148 A2 (SIEMENS AG) 4 May 2005 (04.05.2005) <i>Claims; figures</i>	1-10
X	WO 1998/028487 A1 (SIEMENS AG) 2 July 1998 (02.07.1998) <i>Claims; figures</i>	1-10

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
19 April 2010 (19.04.2010)Date of mailing of the international search report
27 April 2010 (27.04.2010)Name and mailing address of the ISA/ AT
Austrian Patent Office
Dresdner Straße 87, A-1200 ViennaAuthorized officer
PAMMINGER W.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 2009/007841

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DD 216747 A (VEB ZELLSTOFFWERK GRÖDITZ) 19 December 1984 (19.12.1984) <i>Claims; figures</i>	1-10
X	DE 19 653 532 A1 (SIEMENS AG) 25 June 1998 (25.06.1998) <i>Claims; figures</i>	1-10

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB 2009/007841

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				DE	A1	10350075	2005-06-09
WO	A	9828487		EP	A1	0946816	1999-10-06
				WO	A1	9828487	1998-07-02
				AT	T	223983T	2002-09-15
				DE	C1	19653530	1998-07-23
DD	A	216747		DD	A1	216747	1984-12-19
DE	A	19653532		EP	A1	0946815	1999-10-06
				WO	A1	9828486	1998-07-02
				AT	T	214441T	2002-03-15
				DE	A1	19653532	1998-06-25