O PAPEL vol. 74, num. 3, pp. 57 - 65 MAR 2013

ECONOMIC EVALUATION OF ADVANCED PROCESS CONTROL PROJECTS

Authors*: Ronaldo Neves Ribeiro[1]
Edson Strugo Muniz[2]
Rajendra Metha[3]
Song Won Park[4]

ABSTRACT

This paper aims to make an economic evaluation of the results already achieved through implementation of Advanced Process Control (APC) in the pulp and paper industries. For this, we firstly describe some basic concepts, and then some cases of practical applications that have reported good outcomes are cited. Companies have invested in this technology, and there are many applications already in operation. It is worth to discuss now, after the euphoria of the initial results, what effectively are the outcomes achieved over the past years and, also, how to keep them in full control capability, promoting the appropriate maintenance actions for the effects initially achieved be improved over its use.

Keywords: Advanced controls processes, cost reduction, pulp and paper, variability

INTRODUCTION

The focus on reducing production costs has leveraged many capital improvement projects, particularly through the use of automation resources, comment Figueirêdo *et al*. (2010). As examples, the adoption of Advanced Process Control (APC) systems and optimizations. In recent years, companies have invested millions dollars in systems with this purpose, aimed at reducing operating costs and improve stability in production processes. In some countries, these technologies are already used for years, but in Brazil this barrier was broken only after the end of the computer market reservation in the late '80s.

Justify improvement of control systems is always a challenge for automation professionals. Since the implementation of control systems is an engineering project, considerations on this project also include important concepts, such as performance, investment analysis, risks assessment and economic evaluation, as any expansion in business. However, systems for advanced process control as an automation project, as well as information system designs, comprise specific benefits considerations and strategies particular to the field of automation.

This text is not a tutorial or a course on economic evaluation, but a number of considerations that comes from mature experience of the authors, and able to help as a guide for future practitioners in the industry. In all cases, bibliographic references will be cited whenever possible. And, at the end of this work, summary descriptions of applications and returns related to actual industrial practice of the authors will be included.

The partnership between supplier and user - whether internal or a service provider - for the development of an APC has been a decisive factor for the success in adopting these sort of applications. Before an APC, the operation was essentially a manual process. The operators had to make set points adjustments based on personal experience. Therefore, results were not the best.

The APCs systems are designed to stabilize processes, reduce variability of critical variables, stabilize product quality, increase yield and, thus, reduce production costs by focusing on the consumption of specific inputs. To ensure these goals, APCs projects are to have clear performance indicators establishing outcomes, the existing and those expected after implementation. Therefore, to choose a skilled business partner is key for the building of a relationship with gains for both, supplier and user.

Predictive models have been used in many APCs applications, but the dynamic variables (online) composition is essential for advanced controls. Thus, once the decision to implement these tools is taken, field sensors are to provide reliable information and the final control

Authors' references:

1. Cenibra - Rodovia BR 381, km 172, Belo Oriente, MG – CEP 35196-000 – Brasil. Telefone +55-31-3829-5235. E-mail: ronaldo.ribeiro@cenibra.com.br
2. Klabin - Rodovia BR 116, km 218, Correia Pinto, SC – CEP 88535-000 – Brasil. Telefone +55-49 3243-7360. E-mail: emuniz@klabin.com.br
3. Consultant
4. Universidade de São Paulo – USP. Escola Politécnica. Av. Prof. Luciano Gualberto, 380, CEP 05508-010 - São Paulo – Brasil

Corresponding author: Ronaldo Neves Ribeiro – E-mail: ronaldo.ribeiro@cenibra.com.br

O PAPEL vol. 74, num. 3, pp. 57 - 65 MAR 2013

elements (valves, for example) must operate properly, for the APCs to have effectiveness.

With focus on cost reduction, this article is to list some practical APC applications systems in the pulp and paper industriy, in particular showing results obtained at Cenibra's and Klabin pulp mills.

METHODS

Projects for Instrumentation/automation and an economic evaluation

Every project presupposes good management, and industrial projects are not an exception to the general good rules of planning, organizing, sequencing steps, monitoring implementation and other relevant aspects of the project supervision (see, e.g. PMBOK - *Project Management Book of Knowledge* -, or a school-book by A. B. Badiru *et al.*, 2008). But the complexity of an industrial automation project comes from the fact that in addition to the effects of time and cost, there is need for a clear assessment of the advanced technologies available (which is always dynamically evolving), and the need for clear appraisal of results or benefits in sight. That is, for the experts that defined, selected and supervised these undertakings, after the completion of the automation project there will be a durable legacy of its effects, either for good or bad. As such, double attention is recommended on investment in IT programs, maintenance issues and technological upgrading of hardware and software, reciprocity with new technologies and interface and integration with the production process, which will also change over time.

That is why the human factor, be domestic or external to the project -, besides the environment and social ambience of the users -, has always a huge weight, almost as much as the economic aspect of a production process, and that's why the investments in upgrading the technological human resources team involved are so significant. But this is part of another approach to the automation matter.

Projects of basic instrumentation and basic process control systems are reasonably integrated in the understanding of the chemical industry engineering expertise, being thereafter possible to be submitted to a quantitative risk analysis, decisions and choices in industrial projects (see basic text of Schuyler, 2001), but advanced control projects are not better objects for such tools. In short: automation, similarly to other industrial projects, takes on account the important concepts of performance, cash flow, risk, cost estimation and technical evaluation of the project. But, also, the identification of benefits such as increased production capacity, lower costs of ancillary services, increased efficiency, waste *reduction* and pollution, increased quality and operational safety.

All this requires to gather information; evaluation of the current performance; listing of operational restrictions; considerations of targets for reducing quality variability; assessment of the level of excellence when selecting hardware and software in connection with the cost of these qualities; training, operation and support costs; evaluation and cost about deciding between new technology and consolidated technologies; operations complexity, and a number of other factors impacting the project. So, thoroughly quantify or rely on the quality of the analyst of the project is a risk decision to be taken by the project managers.

As can be seen in an uncomplicated book by Friedmann (2006), there is no magic bullet for putting together and document the economic evaluation of the financial risks of an industrial automation project, but it is worth to improve the understanding of concepts that help to explain the basis of an automation design. Even so, it is very interesting to read and understand general aspects of economic evaluation in a book by Khatib (2003), where he considers project selection and evaluation in a pre-investment phase, and the approval of the investment as such, in the operational and post-operational phases.

The investment and corresponding risks are always a consideration over the long term, and are therefore important issues: the cash flow discount rate, net present values and capital recovery factor, financial evaluation of projects and their payback beyond costs and benefits, transition from financial evaluation to economic evaluation, reliability of the process as per the performance of the automation system (i.e. period of non-productivity or factory stoppage because of a not reliable automation). Estevez-Reyes (2000), in risks assessment and uncertainties on projects.

Again, it is hardly feasible to gather all these aspects quantitatively, but awareness of all those concepts favors the automation specialist when negotiating their own projects with other managers. Automation hardly delivers any physical product in an industrial chemical process; therefore, considerations of pricing, cash return and annual return make concrete sense. The approach to show benefits and costs are closer to the concepts used in effective measuring and management of ICT projects, as those by Remenyi *et al.* (2007), Liu *et al.* (2008) and Tohidi (2011).

Since economic aspects in automation design are multifaceted, what to do in relation to your project? Reassess, reassess and continually reassess all the management steps, as in Sisbot (2010). Perhaps one of the known texts on economic justification of automation is a survey by Fleischer (1985), although there have always been other more ancient texts on the matter. Very practical, but useful and sincere statements owed to the vast experience in servicing automation users comes from Blasi and Puig (2002) and Martin (2004), that it is worth to read.

As already said, for automation projects is needed to know the technologies that evolve dynamically, it could be read, for example, Isermann (2011). What has been previously said in this text, can be revisited in papers by Bauer and Craig (2008) and Craig and Hennings (2000).

The pulp and paper process

The pulp and paper manufacturing processes are of special characteristics, which differentiate them from the vast majority. One could say it is a chemical process, a class of processes generally

O PAPEL vol. 74, num. 3, pp. 57 - 65 MAR 2013

presenting a vast degrees of freedom, which makes difficult unique solutions for the problems to be addressed by the control systems, besides giving rise to many nonlinearities.

As a matter of facts, the conventional control algorithms, the PIDs (proportional-integral- derivative), have many limitations to perform their function perfectly. For this, the APCs methodologies are required and have been successfully applied in the pulp and paper industries.

According to Foelkel (2007), the paper sector presents as basic premises of needs: high productivity, high operating efficiency (few breaks, few problems, few scrap and few stops), a low production cost and a consistent quality in process and products.

It is worth to stress that all papermakers have these basic needs, no matter what type of machine or paper they are running or manufacturing. To achieve these goals, the raw material must be as uniform as possible, with properties included within a narrow range of variation, in order not to suffer disturbances and undesired surprises while running the product. To control this variability, papermaker engineers put tidy control on some properties of the stock they are using.

The controls methods

Control systems applied to industries didn't change so much in recent years, but methodologies for getting models and the applied techniques have evolved significantly with the development of computer systems, and this has brought many benefits to the industrial process control. As useful tools for the processes control could be cited:

- the digital control algorithms;
- algorithms for automatic tuning;
- adaptive controls;
- multivariable controls (MVCs);
- predictive controllers (MPCs);
- expert systems;
- fuzzy logic (FLC);
- artificial neural networks (ANN) and its derivatives;
- statistical process control (SPC).

Target of these controls is to provide operation with minimal possible variability. The final result, in a paper industry, relies on uniform and within specified quality limits, and having losses kept to an acceptable minimum throughout the process, assert Narcissus *et al.* (2006). In such ambience, many operations can be made uniform in papermaking: refining, chemical additions, drainage, steam demand, electric power, sheet consolidation, physic-mechanical-optical properties, etc. For that, it is surely crucial the correct application of mentioned control methodologies.

Projects at Klabin

Advanced quality control in paper machine

The purpose of the advanced quality process control in a paper machine is to make systems applied in the stock refining operation, and some other directly related to the paper machine, be controlled by a supervising controller, what could be performed by multivariable controllers modeled via neural networks. In this project there is:

- the system is a software running in a computer connected via OPC to a DCS (Distributed Control System);
- control of the most significant (fundamental) parameters via measurement of freeness and fiber morphology;
- reduced process variability;
- improved productivity of the process;
- refiners control loops are controlled through multivariable controller;
- less reliance on laboratory testing and possible handling errors, providing quick and automatic response for the process control;
- improved profitability by power and fibers conditioning additives optimization and reduced sheet breaks on the machine;
- production of paper orders within specification and reduction of off-quality product.

Neural network of the paper machine variables are shown in **Figure 1**.

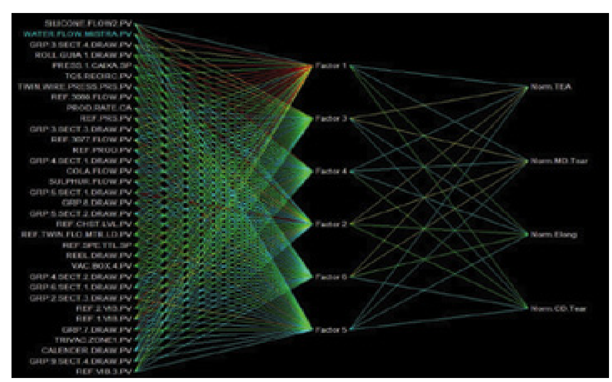

Figure 1. Structure of the paper machine neural model

Flowchart of freeness and fiber morphology control and measurement sites (**Figure 2**).

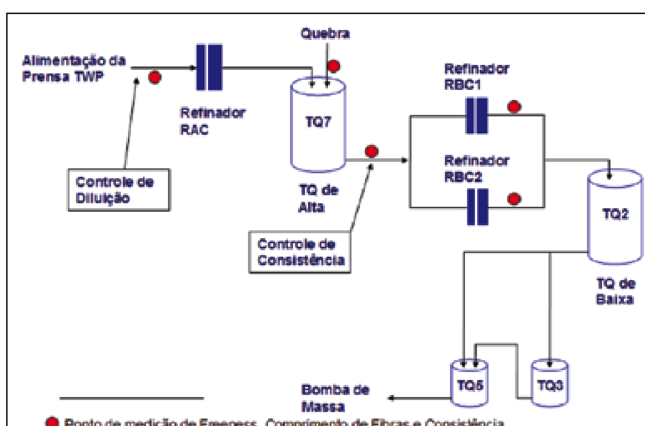

Figure 2. Freeness measurement sites

O PAPEL vol. 74, num. 3, pp. 57 - 65 MAR 2013

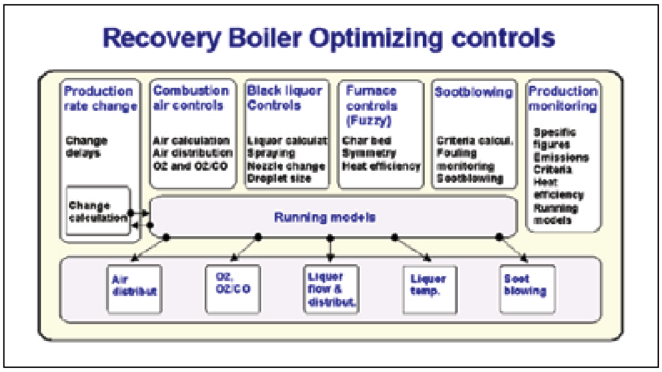

Figure 3. Screen with the variables that feed the neural model

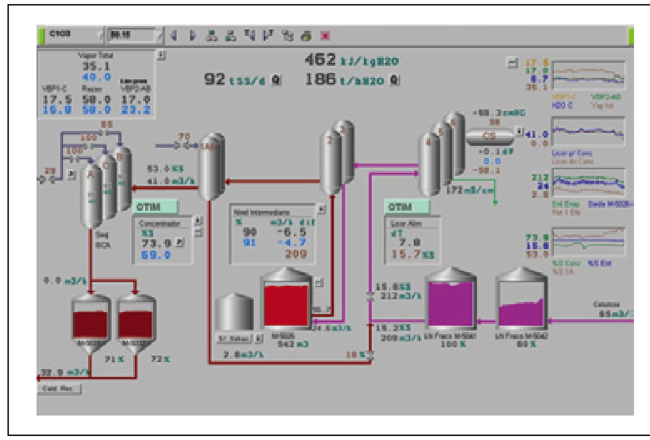

Figure 4. APC operation screen of the evaporation (Narcissus *et al.*, 2006)

Optimization of the recovery boiler

Purpose of the recovery boiler controls optimization is to stabilize the combustion process and equalize differences referred to the existing model.

By way of artificial intelligence, a layer control is used in the furnace, being it responsible for the optimization of the black liquor droplets size. The intelligent control assesses - based on the temperature profile of the furnace -, the flue gases emission, the carbon content of the layer, the current size of the liquor droplets. This artificial intelligence and the corresponding droplets dimensions classified as per size causes the controller to increase or decrease the set point of the stabilizing controller, for example, the difference in temperature between the boiling point and the measured temperature in the furnace (**Figure 3**).

As results, there is better operating performance due to the integration of the process parameters:

- increased efficiency of the recovery boiler and the evaporation;
- stability of combustion control;
- Increased steam output;
- reduction of oil consumption in the auxiliary boiler;
- increased stability of process controls;
- reduced maintenances costs.

Annual savings: US$ 6.0 million/year (in 2005).

Optimization of the evaporation

Purpose of the evaporation plant is to concentrate weak black liquor coming from the pulp washing line for its subsequent combustion in the chemical recovery boiler. For best operation of the recovery boiler is good practice to keep the black liquor concentration as high as possible.

Most important benefits of the evaporation plant controls are:

- steady quality of the strong black liquor;
- high dry solids content in the liquor to be burned;
- production adapted to steam availability;
- management of scaling formation;
- optimized use of the steam;
- minimization in production disturbances.

Annual savings: US$ 1.0 million/year (in 2005).

Screen of the evaporation optimization is shown in **Figure 4**.

Optimization of pulping

Intent of the pulping optimization is to allow a stable and efficient removal of lignin from wood chips. The stabilization of the operating conditions of the digester reduces the variability of the kappa number in the output, ensuring a quality product. It also allows process adjustment leading to reduced consumption of wood and/or chemicals, as well as increased production and reduced steam.

Features of the optimization system:

- automatic control of the pulping sequence;
- control of pulp quality;
- production planning.

Annual savings: US$ 2.0 million/year (in 2002).

Screen of the production planning with the optimized control is shown in **Figure 5**.

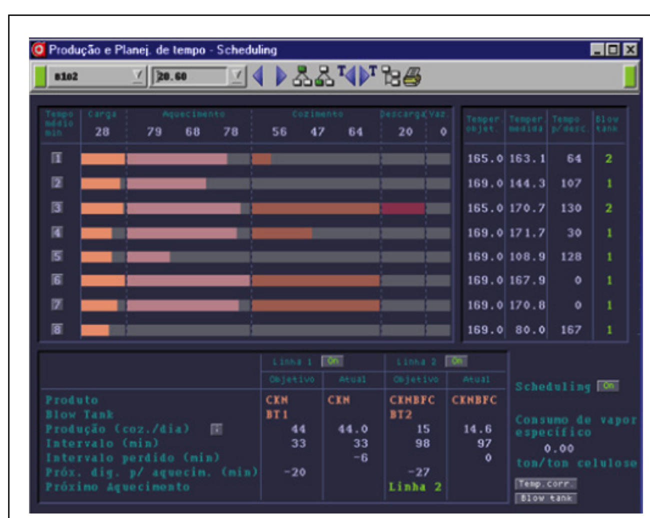

Figure 5. Screen of the production planning

O PAPEL vol. 74, num. 3, pp. 57 - 65 MAR 2013

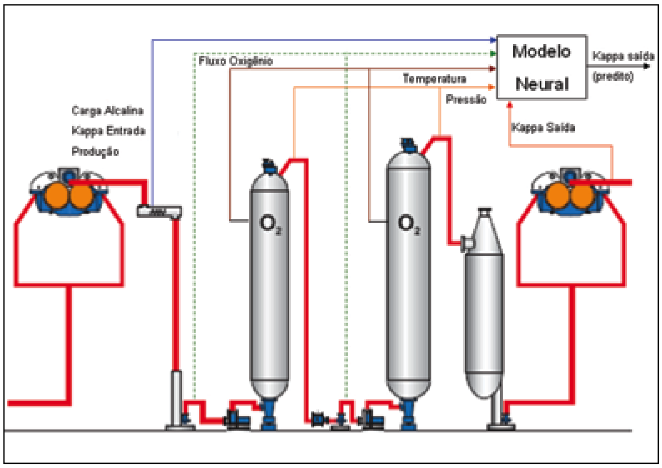

Figure 6. Screen with the variables that feed the neural model (Mine, 2010)

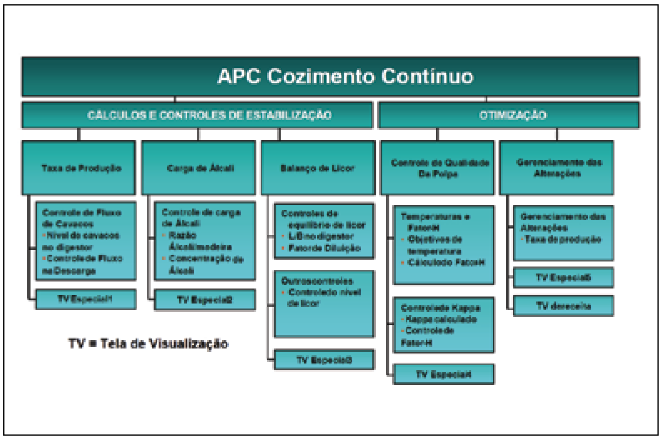

Figure 7. APC for continuous pulping - Main control modules (Figueirêdo *et al.*, 2010)

Projects at Cenibra

Pre-bleaching optimization based on neural network

Control strategies were developed through the implementation of algorithms in DCS aiming at the system optimization by use of the APC concept with automatic set points generation, according to the process variables. It was developed and implemented a neural model to predict the kappa number on the output and control process variables based on this predicted variable. The structure of this solution is shown in **Figure 6**.

The following were the obtained results:

- reduction of 41.02 % on pH standard deviation, obtaining better control;
- reduction of 3.44 kg/admt in specific demand of the alkaline load;
- reduction of 1.04 kg/admt in oxygen specific consumption;
- gain on selectivity of the oxygen delignification stage;
- gain of 2.26 points in viscosity (mPa.s);
- gain of 1.6 points in whiteness (ISO);
- maintaining the degree of delignification and brightness;
- decreased variability, allowing greater process stability;
- standardizing the dosages and operation of the process.

Annual savings: US$ 1.5 million/year (in 2011).

Advanced processes control in digesters 1 and 2

Making use of predictive models, dynamic data and automatic process control tools in two continuous digesters, this control system started operation in mid-2009. Several control loops were integrated into the DCS, connected via an OPC communication link.

The performance test indicated that, after the implementation of APCs in pulping line 1, 69% of the kappa number analysis remained within the specified range control, resulting in variability improvement of 93%. In line 2, 63% of the values remained within the control range, representing a 34% improvement. The gains listed above made possible financial benefits that fully justified the project.

In this system the established improvements in control are shown in **Figure 7**.

The variability in chip quality has been one of the main challenges faced by the mill, since the region where the plant is located is quite mountainous, resulting in natural variability of the wood quality.

Ribeiro (2007) comments that a good pulp quality - coupled with a low production cost -, is closely correlated with good outcomes in pulping process, hence the need of a good understanding for a good yield during the pulping step. For this, the kappa number is a variable of great importance of good operating results.

Deployment of APC in digesters 1 and 2 with the following objectives:

- output with reduced kappa variability;
- increase in digesters yield;
- improvement in pulp quality;
- reduced operation costs;
- reduction in chemical and steam consumption.

Annual savings: US$ 1.3 million/year in digester 1 and US$ 1.8 million/year in digester 2 (in 2010).

Mathematical modeling and APC implementation at the causticizing

One goal of the project was to develop a mathematical model able to describe the causticizing process, simulate, validate and criticize the results.

The developed model associated with predictive control strategies made possible gains in this step of the process. What is more, it was possible to create virtual analyzers based on concentrations prediction of soda and sodium carbonate in the process.

For this project the was need to join two technologies, the use of on-line measuring equipment of the alkali variable, and also the techniques of advanced process controls.

The on-line measurement makes possible to control the Total Titratable Alkali (TTA) and the Causticizing Efficiency (% CE) more effectively. Thus, makes possible to achieve benefits at the plant such as increased stability and concentration of

O PAPEL vol. 74, num. 3, pp. 57 - 65 MAR 2013

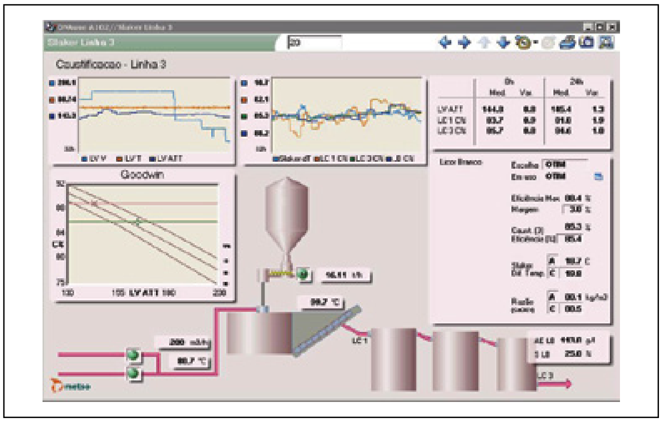

Figure 8. Screen of the causticizing operation (Figueirêdo *et al.*, 2009)

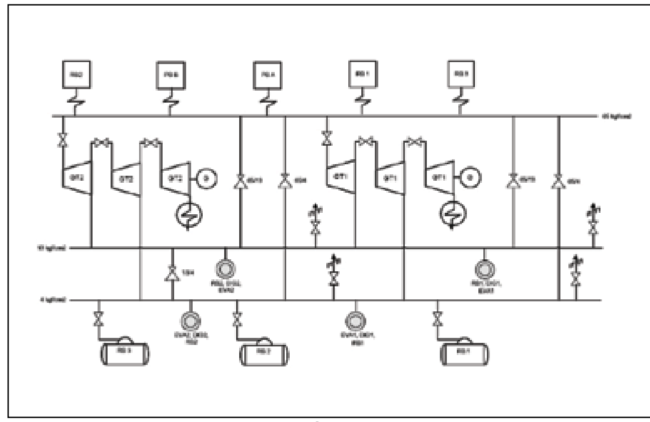

Figure 9. Main screen operation for the steam management (Ribeiro *et al.*, 2009)

the effective alkali (EA) in the white liquor, reduction of energy consumption in the digester, evaporators, boilers and limekilns, here minimizing insufficient dosage (underliming) or overdose (overliming) of lime, and reduce the frequency of the filters chemical washing (**Figure 8**).

Also, with the APC it was possible to achieve operational stability during changing conditions of the production rhythm, perfect coordination between the measurements of process variables and their associated controls, improvement in white liquor quality, operation closer to the optimum causticizing efficiency (CE) point and its elevation. The model developed made use of predictive control strategies.

The research, carried out on the mathematical model of the kinetics of the causticizing reaction, enabled the development of an automatic routine control and the optimization of lime dosage, resulting in the following gains:

- 4% reduction in lime dosage (kg lime/m^3 of liquor);
- 3% reduction in specific consumption of lime produced per ton of pulp, generating savings in limekilns of about US$ 540,000;
- reduction of 14% in lime purchase for the make-up, generating savings of about US$ 190,000;
- 10% reduction of the "dead load" (Na_2CO_3) in the recovery circuit.

Elimination of overliming occurrences resulting in:

increased availability and efficiency of the lime mud filter, generating a sludge with higher solids content and consequent improvement in thermal efficiency of the limekilns;

- increased stability of effective alkali in white liquor, resulting in lower consumption in volume by the digester;
- less solids dissolved in the white liquor, improving quality, reducing dead load on the recovery cycle and decreasing the degree of fouling mainly in the digesters, evaporators and recovery boilers.

Gains around US$ 1.8 million/year (in 2010).

Steam management control

The Steam Manager is an advanced control application used to manage the steam distribution network. Through the monitoring and adjustment of the whole network is ensured the process steam be always of proper quality and available to meet consumers' demands of heat and power.

Steam Manager incorporates predictive control based on multivariable model, as simultaneously coordinates process multiple inputs, measurements and disorders. This product is able to simultaneously control several variables in the steam network, diagnose primary variables and directly treat limiting factors. The main screen of operation can be seen in **Figure 9**.

The start-up went smoothly and operating effects were being seen from the first day of operation. Two months after the implementation of the project, the initial performance testing was carried out and the target of 90% reduction in steam disposal to the atmosphere was reached.

Achievements:

- Improved management of power and steam balances at normal production levels;
- significant improvement of process control during disturbances due to steam and power variations, consolidating excellent results;
- 90% reduction in losses of relief steam to the atmosphere, equivalent to 10,000 t/month;
- reduction in steam loss equivalent to 715 tons of oil per month. Reduction of 2,200 tonnes of CO_2 emissions per month.

Gains of approximately US$ 5.1 million (in 2009).

Optimization of limekilns using APC concept and equations of energy and mass balances

Calcination is the process of converting lime mud (mainly $CaCO_3$) generated at the causticizing plant to lime (CaO). This reaction

O PAPEL vol. 74, num. 3, pp. 57 - 65 MAR 2013

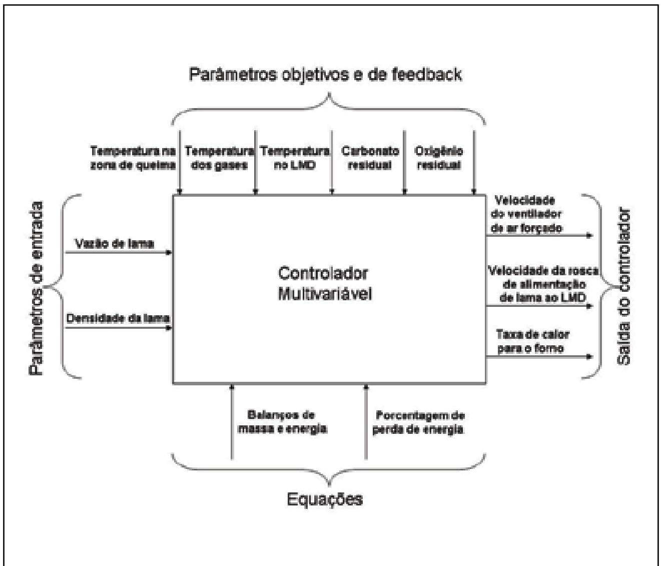

Figure 10. Simplified diagram of the adopted multivariable strategy (Castro & Figueirêdo, 2012)

occurs at high temperatures in a rotary kiln which is both, a chemical reactor and a heat transfer equipment. In this design, a multivariable controller for limekilns was developed in order to decrease variability in the calcination process and lessen specific fuel consumption.

The multivariable controller has been developed based on the APC concept with automatic generation of set points, which adjustments are automatic, in accordance with changes in the process characteristics. Its operation is based on the thermodynamic principles of a limekiln operation, as well as the physico-chemical combustion and calcination reactions. In this project, the multivariable controller has been developed at the DCS, through which the main limekiln control variables are automatically adjusted, without any operator's involvement.

In the past, the heat control method of the kiln was quite simple, and dependent on the manual intervention of the operators. The heat set point of the kiln was set as mega calories (Mcal). Some control strategies operated in automatic, working in cascade with some process variables:

- speed variation of the forced air fan in cascade with oxygen excess in the combustion gases at the exit of the furnace;
- speed variation of the screw feeding mud to the LMD (lime mud dryer) in cascade with the temperature of the combustion gases of the kiln and the temperature of the LMD.

Even with the main heat control of the kilns being fully manual, the Cenibra limekilns had a specific average consumption of 1.4 Gcal/t lime, targeting a residual carbonate in the range of 2% to 3%. According to Tran (2011), this value may already be considered a good number for specific energy consumption in modern limekilns.

With aim to further reducing the specific fuel consumption of limekilns looking for improvement of the mill competitiveness, a project was developed to improve the controls. In the diagram of **Figure 10** is shown the operating principle of the multivariable controller implemented in the DCS.

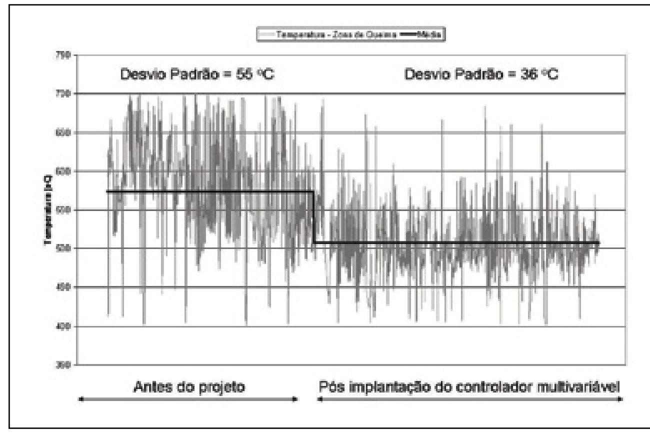

Figure 11. Firing zone temperature (optimization and drop in standard deviation) (Castro & Figueirêdo, 2012)

Following gains were achieved after implementation of this project:

- reduction of over 3% in fuel consumption (annual savings of about US$ 450,000);
- better stability of the kilns temperatures;
- residual carbonate kept within the desired limits;
- improved lime quality for the causticizing process.

Besides reduction in specific fuel consumption, another significant gain has been the decrease of about 65°C in temperature of the burning zone, as well as a better stability with a decline of about 35% in its variability, as shown in **Figure 11**. It is to note that such facts help the preservation of the firebricks, favoring longer integrity of the limekilns.

Gains of approximately US$ 0.45 million (in 2009).

For this project, it is to notice that all said developments were been financed by Cenibra's own resources.

RESULTS AND DISCUSSION

The APCs have brought, over the years, many operating costs reductions in different industrial sectors. For the cases of Cenibra and Klabin, the advanced controls techniques employed have allowed a relevant effect in production costs, as can be seen in **Table 1**.

Obviously, all these techniques and efforts are not of low implementation cost, however, when done a proper study of the processes of interest, methodologies that assist and facilitate the calculations of the returns that each investment can offer will be perceived.

Implementation of APCs still requires an adjustment in existing infrastructure to meet some basic requirements, such, e.g. improvement in sensing. This includes improvement of the basic care of the day to day job; properly tune existing PID controllers, since many APCs techniques will keep them inserted in the control strategy; dedicate good care to the final control devices (valves, actuators and others), as they are the elements responsible for performing the dynamics adjustments in processes, and, being the performance not adequate, the whole applied strategy will not retributes the expected good results.

O PAPEL vol. 74, num. 3, pp. 57 - 65 MAR 2013

Table 1. Results of APCs projects at Cenibra and Klabin

Company	Project	Result US$ Mi/Year	In year
Klabin	Advanced quality control in paper machine	N/C	N/C
	Recovery boiler optimization	6.0	2005
	Evaporation optimization	1.0	2005
	Cooking optimization	2.0	2002
Cenibra	Pre-bleaching optimization based on neural networks	1.5	2011
	Implementation of advanced control processes in digesters 1 and 2	1.30 + 1.80	2010
	Mathematical modeling of the causticizing process and APC implementation	1.8	2010
	Implementation of the steam manager control	5.1	2009
	Optimization of limekilns using the APC concept and equations of energy and mass balances	0.5	2009

Outcomes recorded in this paper have been achieved along the first year of the cited projects operation. Worthwhile to keep present that for maintaining and improve such results a continuous follow-up of systems, sensors, valves and also the tuning of the controls are to be checked regularly, in order to get even better results. For this, it is important to set up performance indicators and a properly trained staff to support the necessary improvements, be the staff hired or outsourced.

CONCLUSION

It is to note that APCs not only bring financial benefits to the processes, but also additional gains not feasible to quantify directly, but of considerable value in the production chain. Decrease in variability, as per itself, lessens fatigue of mechanical equipment, therefore favoring more reliable availability of the equipments.

For the projects studied in this work, evidence has been given to the significant financial results they have brought. Despite the outcomes here exposed, advanced process controls are not easy to be approved, since, in most cases, they still demand high values in the annual investment budget. With this work, the authors intend to offer subsidies through the presentation of real cases (users) so as to possibly make easier approvals of projects under consideration.

ACKNOWLEDGEMENT

Special thanks to Cenibras' automation engineers Alessandro S. Castro and Flávio H. Mine for their gathering of data making possible the completion of this work. ■

REFERENCES

1. BADIRU, A.; BADIRU, A.; BADIRU, A. - *Industrial Project Management*. CRC Press. 2008.
2. BAUER. M.; CRAIG, I.K. - *Economic assessment of advanced process control – A survey and framework.* J. Process Control vol. 18, pp 2-8, 2008
3. BLAISI D. A.; PUIG V. F. - *Conditions fpr succesful automation in industrial application - a point of view.*16th World Congress IFAC, Barcelona 21-26 July 2002.
4. CASTRO, A. & FIGUEIRÊDO, L. (2012) - *Projeto de um controlador multivriável para fornos de cal utilizando equações de balanços de massa e energia*. Controle & Instrumentação, 36-43.
5. CRAIG, I. K.; HENNINGS, R.G.D. - *Evaluation of advanced industrial control projects: a framework for determining economic benefits.* Control Engineering Practice vol 8, pp. 769-680. 2000.
6. ESTEVEZ-REYES L. - *Process control reliability: the key to investing in your infrastructure*. ISA Transactions vol.39 pp.115-121. (2000)

O PAPEL vol. 74, num. 3, pp. 57 - 65 MAR 2013

7. FIGUEIRÊDO, L. S. - *Modelagem e Simulação do Processo de Caustificação*. Monografia de Conclusão Curso (Pós Graduação Lato Sensu em Tecnologia de Celulose e Papel) – Universidade Federal de Viçosa, Departamento de Engenharia Florestal, Viçosa, 2006.

8. FIGUEIRÊDO, L. S. - Modelagem Matemática do Estado Estacionário de um Real Sistema de Caustificação em uma Fábrica de Celulose**.** Dissertação (Conclusão do Curso de Pós Graduação Strictu Sensu em Engenharia Industrial) – Centro Universitário do Leste de Minas Gerais – Unileste-MG, Programa de Pós Graduação em Engenharia, Coronel Fabriciano, 2009.

9. FIGUEIRÊDO, L. S., BRANDÃO, H. M.; ONOFRE, R. C.; MAIRIM, M. M.; FURLEY, M. H. & RIBEIRO, R. N. (14 de Outubro de 2010) - *Melhoria na qualidade e redução dos custos operacionais iniciam-se com a utilização de APCs na etapa de cozimento em uma indústria de celulose. CONGRESSO ANUAL DA ABTCP - SEÇÃO DE AUTOMAÇÃO*, p. 13.

10. FOELKEL, C. (15 de Outubro de 2007) - *As fibras dos eucalíptos e as qualidades requeridas na celulose kraft para a fabricação de papel.* Congresso anual da ABTCP ano 2007.

11. FRIEDMANN, P. - *Automation and control systems economics*. 2nd edition. ISA. 2006

12. ISERMANN, R. - *Perspectives of automatic control*. Control Engineering Practice vol 19, pp. 1999-1407. 2011.

13. KHATIB, H. - *Economic evaluation of projects in the electricity supply industry*. IEE Press.2003.

14. Liu, J.Y-C.; Chen, V.J.; Chan, C-L.; Lie, T. - *The impact of software process standardization on software flexibility and project management performance: Control theory perspective.* Information and Software Technology vol 50 pp. 889–896 (2008)

15. MARTIN, G. - *Improvements in process control through model based techniques- a control system vendor´s perspective.* Hydrocarbon Processing 83 (10) 43-46 Oct 2004.

16. MINE, F. H., FIGUEIRÊDO, L. S., TEIXEIRA, R. A. - *Otimização do Processo de Deslignificação com Oxigênio – Estudo de Caso Cenibra*. Revista O Papel, volume 71, número 12, Dezembro 2010.

17. NARCISSUS, A. G.; WALTRICK, C.A.; MUNIZ, E.S.; HOSS, C.P. (2006) - *Otimização do processo de evaporação e da caldeira de recuperação.* Revista O Papel.

18. PORANEN, T., WILLIAMSON, M. - Variable chips make uniform pulp at Cenibra. METSO'S Customer Magazine, Fevereiro, 2011.

19. REMENYI, D.; BANNISTER, F.; MONEY, A. - *The effective measurement and management of ICT Costs and Benefits*. Elsevier. 3rd edition. 2007.

20. RIBEIRO, J. C T., ONOFRE, R. C., MÄKILÄ, J., AIRIKKA, P., & RIBEIRO, R. (Outubro de 2009) - *Improvement on the Utilities Area Using Advanced Process Control for Steam Management*. Congresso anual da ABTCP 2009.

21. RIBEIRO, R. N. (2007) - *Utilização de redes neurais artificiais e tecnologia FT-NIR para predição do número kappa em um processo kraft de cozimento de madeira em indústria de celulose.* Coronel Fabriciano: Unileste-MG.

22. SCHUYLER, J. - *Risk and decision analysis in projects.* 2nd edition. PMI 2001

23. Tohidi, H. - *Review the benefits of using Value Engineering in Information Technology Project Management.* Procedia Computer Science vol. 3 pp. 917–924 2011

24. TRAN, H.; VILARROEL, R. - *Challenges in Black Liquor Recovery in Modern Kraft Pulp Mills.* 5th International Colloquium on Eucalyptus Pulp. Porto Seguro, Brazil, May 9-12, 2011.