Improved Energy Efficiency in Paper Making Through Reducing Dryer Steam Consumption Using Advanced Process Control

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ABSTRACT

Over the last two or three years, the increasing costs of energy and worsening market conditions have focussed even greater attention within paper mills than before, on considering ways to improve efficiency and reduce the energy used in paper making. Arising from a multivariable understanding of paper machine operation, Advanced Process Control (APC) technology enables paper machine behaviour to be controlled in a more coherent way, using all the variables available for control. Furthermore, with the machine under better regulation and with more variables used in control, there is the opportunity to optimise machine operation, usually providing very striking multi-objective performance improvement benefits of a number of kinds. Traditional three term control technology does not offer this capability.

The paper presents results from several different paper machine projects we have undertaken around the world. These projects have been aimed at improving machine stability, optimising chemicals usage and reducing energy use. On a brown paperboard machine in Australasia, APC has reduced specific steam usage by 10%, averaged across the grades; the controller has also provided a significant capacity to increase production. On a North American newsprint machine, the APC system has reduced steam usage by more than 10%, and it provides better control of colour and much improved wet end stability. The paper also outlines early results from two other performance improvement projects, each incorporating a different approach to reducing the energy used in paper making. The first of these two projects is focussed on optimising sheet drainage, aiming to present the dryer with a sheet having higher solids content than before. The second project aims to reduce specific steam usage by optimising the operation of the dryer hood.

1. INTRODUCTION: THE ENERGY USED IN PAPER MAKING

In recent times increases in the cost of oil and gas, allied with increasingly vociferous customer demands for industry to reduce its environmental footprint, have sharpened the focus in most paper mills world-wide on ways to make paper using less energy. Advanced Process Control (APC) offers a number of possible ways to achieve this. Some of the approaches by which this can be done on paper machines are described in this paper.

It is well known that paper making is a very energy- intensive industrial activity. According to UK Government statistics, in 2008 UK paper making used on average 4MWhr per tonne of paper made; see Table 1. Siitonen and Ahtila [1] report the results of a survey undertaken in the Finnish paper industry in 1995, in which energy use figures are presented over a range of paper making categories. Finnish energy use is reported to lie in the range 2 MWhr/t to 3 MWhr/t.

1.1 Paper Drying Uses Most of Paper Making Energy to Remove Less than the Last 1% of Sheet Moisture

Siitonen and Ahtila [1] report that 80% of the energy used in paper making is consumed in the dryer, primarily in the steam supplied to the dryer. Furthermore it is easily demonstrated that this 80% of paper making energy used in the dryer removes less than 1% of total sheet water [2]. Consider 100 gm of 0.9% thin stock laid onto the wire at the headbox. Of this 100 gm, 99.1 gm is water and 0.9 gm is solids. For purposes of illustration, let us take the sheet moisture content at the end of the press section to be 50%, where sheet moisture M is defined in terms of the weight of water and of total solids per unit area of the sheet as:

$$M = \text{weight of water}/(\text{weight of solids} + \text{weight of water}).$$

Then, of the original 100gms of stock laid onto the wire, at the end of the press section the original 0.9 gm of solids remains in the sheet (assuming 100% retention) but just 0.9 gm of the original water remains. That is, 98.2 gm water has been removed at the wet end and in the press section and less than 1gm water is to be removed in the dryer.

Figure 1 [1] shows the proportion of water removed in each of the three sections of a paper machine and the fraction of energy used across those three sections.

Paper Type	Energy Consumed
Packaging board	2 – 3 MWhr/t paper made
Newsprint	3 – 4 MWhr/t
Tissue	5 – 7 MWhr/t
Fine Papers	4 – 8 MWhr/t
Specialty papers	Up to 20 MWhr/t
UK Average	**4 MWhr/t**

Table 1: UK Energy Use in Paper Making by Paper Type

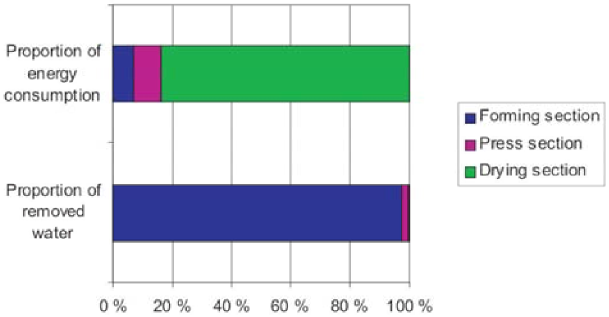

Fig 1: Water Removal and Energy Consumption by Section

Further understanding of the use of energy in drying is provided by the fact that dryers are typically only about 50% energy-efficient [3]. Recently collected data from two UK mills confirms this, as follows. Assuming again that the moisture content of the sheet entering the dryer is 50%, and that the sheet is to be dried to an 8% moisture target, the water to be evaporated in the dryer for each 100g of thin stock laid on the wire from the headbox is 0.9g – 0.078g = 0.822 g. This makes 0.9g (fibre) + 0.078g (water) = 0.978g finished paper. Thus to make 1 tonne of finished paper the weight of water to be evaporated in the dryer will be:

$$0.822 \times (1/0.978) \times 10^6 \text{ g/tonne} = 0.8405 \times 10^6 \text{ g/t} = 0.8405 \text{ tonne water per tonne of paper made}$$

Over a 6 month period, **steam use on a particular UK two-ply board machine** was found to average 1.7 tonnes steam per tonne of paper made. If the steam was saturated (not superheated) and if the dryer was 100% efficient, the enthalpy associated with 1 tonne of steam would be completely transferred to the water in the sheet and 1 tonne of steam would be evaporated. Steam supplied to the board mill dryer is close to saturated so the board mill dryer efficiency can be approximately assessed (by the just-defined measure of dryer efficiency) as:

$$(0.8405/1.7) \times 100\% = 49.44\%$$

Over a recent two month period, **steam use on a UK newsprint machine** averaged 50.73 tonne/hr and the production rate averaged 40.29 tonnes/hour. Steam supplied was superheated: on average it was supplied at 3.478 bar and at a temperature of 156°C; it therefore had about 18°C of superheat. Thus each tonne of steam supplied had about 1.372 times the enthalpy required to evaporate 1 tonne of water. Factoring dryer steam use by this amount, an adjusted dryer steam use figure can be calculated (to estimate steam use as if saturated steam were supplied to the dryer):

$$40.29 \text{ t/hr} \times 1.372 = 69.62 \text{ t/hr.}$$

Therefore, factored dryer steam use averaged 69.62/40.29 = 1.728 tonnes steam/tonne paper produced. Using the same measure of dryer efficiency as defined above the newsprint dryer efficiency is approximately:

$$(0.8405/1.728) \times 100\% = 48.64\%$$

1.2 Four Possible Ways to Reduce Dryer Steam Use

Recent six-month data sequences from a UK board machine have been collected and analysed. They show that:

- the sheet is consistently over-dried - the finished sheet moisture content is 0.32% less than target.
- the sheet is heavier than its target weight by an average of 1%

In this section, the implications for energy use are considered of improving sheet drainage, of reducing the incidence of over-drying the sheet, of making it to target weight rather than heavier, and of improving dryer efficiency.

Improve Drainage

Taking headbox consistency as 0.9%, let us again consider the fate of 100g of thin stock laid onto the wire at the headbox. Suppose that sheet moisture is 88% at the couch roll, 50% at the entry to the dryer and 8% at the reel. Let us consider an alternative operating regime in which a drier sheet is presented to the dryer: sheet moisture is 45% instead of 50%. Table 2 shows the weight of solids and of water that remains associated with the original 100 gm of thin stock laid onto the wire.

	At the headbox	At the couch	Into the dryer	Better dryer feed	At the reel
Sheet moisture	99.1%	88%	50%	45%	8%
Water in sheet	99.1g	6.6g	0.9g	0.736g	0.078g
Solids in sheet	0.9g	0.9g	0.9g	0.9g	0.9g
Water removed		92.5g	5.7g	5.86g	0.822 (0.658)g

Table 2: Solids and Water Weights Through the Machine

	Into the dryer	At the reel	At the reel (increased moisture)
Sheet moisture	50%	8%	9%
Water in sheet	0.9g	0.078g	0.089g
Solids in sheet	0.9g	0.9g	0.9g
Water removed		0.822g	0.811g

Table 3: Solids & Water Weights for Increased Reel Moisture Content

Notice that:

- the wet end drains over 92% of sheet water, the press section drains less than 6% of sheet water, and the dryer removes less than 1% of sheet water.
- if it possible to reduce sheet moisture to the dryer by 5%, the weight of water to be removed in the dryer reduces from 0.822g to 0.658g. That is, a 5% reduction in sheet moisture implies a 20% reduction in dryer load. (This substantiates the well known maxim that "A 1% reduction in sheet moisture to dryer results in a 4% reduction in dryer load".)

An obvious way to present a drier sheet to the dryer is to provide better control of drainage, aimed at reducing the sheet's moisture content. The material so far presented in this section thus establishes that better control of drainage will be a key means of reducing the energy used in paper making.

Eliminate Over-Drying of the Sheet

In relation to the energy cost of over-drying the sheet, consider the steam benefit of raising the reel moisture target by 1%, in relation to the 100 gm of stock laid onto the wire, as described in Sections 2.1 and 2.2.1. See Table 3. By raising the moisture target by 1%, when the dryer feed moisture was 50%, the dryer steam demand would diminish by (1 - 0.811/0.822) x 100 = 1.34%. That is, a 1% increase in moisture target results in a 1.34% reduction in dryer steam demand. There is not the same amplification in benefit as there is with improved drainage.

Eliminate Over-Weight Making of the Sheet

If the weight target was reduced by 1%, the finished grammage of total solids from the original 100g of headbox stock would be 0.99 x 9g = 0.891g. This would mean that a sheet moisture content entering the dryer of 50% would contain just 0.891 g water; this is to be reduced in the dryer to 0.07747g (assuming target moisture of 8%), ie 0.8135 g water are to be removed in the dryer per 100g of headbox stock. The resulting reduction in the dryer steam demand is (1- 0.8135/0.822) x 100 = 1.034%. That is, a 1% reduction in the weight target results in a 1.034% reduction in dryer steam demand. Though this is a useful benefit, there is not the amplification factor that there is with better control of drainage.

Improve Dryer Efficiency

Given that dryer efficiency is typically 50%, as already noted in Section 1.1, the question arises as to whether this might be improved. Given the nature of paper machine drying, and the simple definition of dryer efficiency adopted in Section 1.1, it is very unlikely that efficiencies approaching 100% will be achievable, though the contention of this work is that they can be improved. Considering the nature of performance improvement that APC can offer, attention focuses on:

- the dryer hood: many paper dryer hoods are operated without closed loop controls, much less is there any consideration of the optimisation of energy flows in or out of the dryer hood.
- the possibilities for using all the variables available for controlling the dryer: differential pressures and condensate recovery rates, as well as steam pressures, in each of the controlled sections of the dryer. Typically, existing practice involves a single closed loop operating on a measurement of sheet moisture and adjusting a dryer steam pressure signal which is cascaded across each section of the dryer. If differential pressures are regulated in closed loop it is very uncommon for the setpoints of these loops to be adjusted in machine operation, much less optimised.

There is a body of published work aimed at modelling various aspects of paper dryer operation and presenting some approaches to control, for example [4] – [12], but none of this work appears to quantify the benefit that could be provided by multivariable optimising control, incorporating all the available manipulable dryer variables, listed above. In order to better understand and quantify these opportunities for improving dryer efficiency, the authors are involved in two projects in which data is being gathered from and controllers are being designed for full scale commercial paper machines. Some preliminary results from these projects are reported in Section 4.

1.3 Two Prime Focii for Reducing the Energy Used in Paper Making by Better Control

The operation of a paper machine requires electrical energy, for example, to run drive motors, to operate pumps that move stock and to generate vacuums. Though on many machines, there may be opportunities to reduce this electrical energy use, there will be well-defined limits to the reduction in energy that can be achieved using this approach. The published work already referred to points to dryer steam use as by far the largest culprit in the consumption of energy in paper making; thus, reducing dryer steam use should be a prime target in seeking to reduce the energy used in paper making.

The material in Sections 1.1 and 1.2 has established that once the excess use of energy in over-drying and over-making the sheet have been eliminated, there are two main ways to reduce dryer steam use:

1. **Improve sheet drainage** to reduce the moisture content of the sheet entering the dryer: the 4:1 magnification factor described in Section 1.2 makes this appear to be an attractive option.

2. **Improve the efficiency of the dryer**, by optimisation and better control of:
    - The means of evaporating moisture from the sheet into the dryer hood environment: for each section of the dryer, make optimal use of the differential pressures and, where separately available, condensate recovery rates, as well as dryer steam pressures.
    - the dryer hood: there are opportunities to energy-optimise the hood by adjusting the temperatures and flow rates of fresh air entering the hood and the air humidities and flowrates of moist exhaust air leaving the hood.

For all these tasks, Advanced Process Control (APC), providing a multivariable optimising approach to the operation of the dryer, appears to offer very appropriate tools. Work in this direction is under way. This paper presents some case studies of paper machine APC application projects which had energy reduction as one of several performance improvement objectives. These encouraging results heighten interest in the potential for further energy reduction using this approach.

2. ADVANCED PROCESS CONTROL

A robust Advanced Process Control (APC) application requires a toolset that offers a wide range of APC technologies. Perceptive Engineering Ltd's APC software toolset includes the core technology of most APC toolsets, Model-based Predictive Control (MPC), along with modelling and control approaches using Artificial Neural Networks, Adaptive Control, Inferential Estimation and Fuzzy Logic. All of these tools are available in the ControlMV package, developed and used by Perceptive Engineering Ltd (PEL).

MPC, the core technology of most APC toolsets, is now overviewed. Much more complete descriptions of APC techniques can be found for example in [13] and [14]. The objective of the MPC controller is to determine a sequence of control moves, starting with the current control move and continuing with control moves that would be applied in the future. This series of 'ideal' control moves is calculated in such a way as to ensure that one or more controlled (output) variables move to their setpoints in an optimal manner.

The control calculation at each point in time is based on the current value of each controlled variable, as well as a prediction of the future values of each controlled variable. This approach differs from the classical PID approach to control, in which only the current control move is calculated, based on the current setpoint error. The prediction of the future values of each controlled variable is based on an explicit model of the process. This model encapsulates all of the multivariable 'cause and effect' dynamic relationships between controlled variables, manipulated variables (control inputs) and feedforward variables (measured disturbance variables arising in upstream process elements).

The control algorithm typically uses a Receding Horizon approach. In this approach, the future variation of the controlled variables is predicted up until a finite time in the future (called the 'prediction horizon'). A sequence of control moves is calculated for each manipulated variable, at each execution interval from the current time up to the control horizon, which may be the same as or shorter than the prediction horizon. Only the first move in this sequence is actually implemented, and at the next execution interval, the entire control calculation is repeated using the latest measurements of process variables. The repetition of the control algorithm at each execution interval provides a 'negative feedback' mechanism which minimises the effect of unmeasured disturbances and inaccuracies in the model. Generally MPC is applied to multivariable systems having a number of manipulated (control) variables each affecting more than one of the controlled (output) variables. However, for a system involving a single manipulated variable and a single controlled variable, the following diagram illustrates the methodology behind most MPC-based controllers.

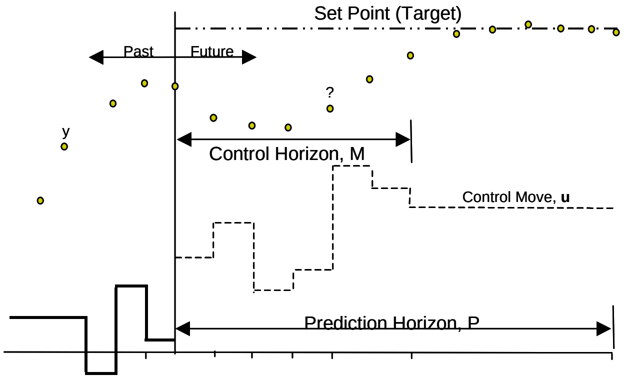

Figure 2. Control Strategy of Most MPC Controllers

MPC is a particularly advantageous control strategy for processes having any of the following characteristics:

- Processes whose system dynamics are highly coupled and multivariable; that is, processes in which moving a particular input variable affects more than one controlled variable. Because of the multivariable process model at its centre, MPC is ideally suited to multivariable problems and is able to provide optimal control for almost all situations.
- Processes whose system dynamics are long or complex and in particular, when they have long dead times, and/or inverse (that is, non-minimum phase) responses. Plants with characteristics like these are hard to control using PID techniques - PID controls usually need to be detuned. However using MPC, the explicit process model can predict the effect of complex process dynamics and calculate control moves accordingly.
- Processes where for optimum operation, the controlled variables need to be kept close to operating limits. With MPC, controlled variables can be maintained either at a setpoint (in the same way as with traditional PID control), or they can be kept within defined upper and lower constraint limits. Constraint control allows a controlled variable to move freely unless the variable is predicted to move outside of its constraint limits within the prediction horizon. If a constraint violation is predicted, the MPC will re-calculate control moves to ensure the controlled variable is maintained within limits in an optimal manner.
- Processes having feedforward disturbances that can be accurately measured. The use of an explicit process model means that the effect of measured disturbances from upstream processes can be used to predict the subsequent future variation of one or more controlled variables. Given this prediction, the MPC controller will calculate control moves in order to minimise the effect of this disturbance.
- Processes in which it is desirable to control to a variable that is measured intermittently, often by lab measurements. Often variables that are critical to quality can only be measured in this offline way. By using model-based inferential sensors, it is possible to control to the inferred quality value in between lab measurement updates. This can considerably reduce the standard deviation of critical-to-quality variables.

In general, if any one of the above process conditions exists, then there are good grounds for considering MPC as a process improvement tool.

The controller design process is typically based around an investigation of the process, taking into account a number of factors including:

- The economic benefit associated with the tighter control of key variables.
- Bottlenecks and limitations in the process equipment, including safety requirements.
- The state of current process instrumentation.
- The performance of the existing regulatory control systems.
- The knowledge and problems experienced by operators and process staff.

The investigation of the process will typically also involve process tests in order to determine the dynamics of the process. The final design of the advanced control system should encapsulate all of the factors listed above.

3. SOME RECENT ENERGY REDUCTION RESULTS IN PAPER MAKING

It has already been noted that 80% of the energy used in making paper is consumed in the dryer. This immediately focuses the attention of energy reduction initiatives on the use of steam in the dryer. The energy reduction results described below arise out of recent APC paper machine project work aimed primarily at improving wet end stability [15] – [18]. The energy reduction that results have sharpened focus on the energy saving potential of APC, in particular on better control of drainage.

3.1 Energy Reduction in Board Making

Many board machines are 'dryer-bottlenecked', that is, production rates are limited by the rate at which the sheet can be dried. This means that reducing the demand for steam in the dryer has at least a double benefit: it lowers the cost of making paper by reducing specific energy consumption and it facilitates greater production rates. In addition, if the demand for dryer steam can be reduced by better drainage of the sheet, a third benefit will result: better drainage will create a drier sheet; many paper makers believe that a drier sheet will improve machine runnability and also facilitate faster running. Such a range of potential benefits creates a strong incentive to seek to reduce dryer steam demand.

The first step in this direction was taken recently when PEL designed and implemented an APC system aimed at improving wet end stability on a 2-ply Australasian board machine making 100 – 220 gsm products. The resulting performance improvements included:

- **A big reduction in variation**: standard deviations of wet end parameters were reduced by between 75% and 90%. Figure 3 shows the reductions in standard deviations of top layer (TL) and back layer (BL) white water consistency compared with the previous normal baseline values: a reduction of 81.9% and 72.7% respectively. Figure 4 shows the improved stability of top layer white water consistency and wire retention, after the APC system is turned on.

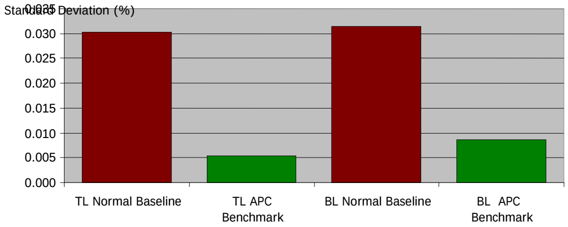

Figure 3: Reduction in SD of White Water Consistency

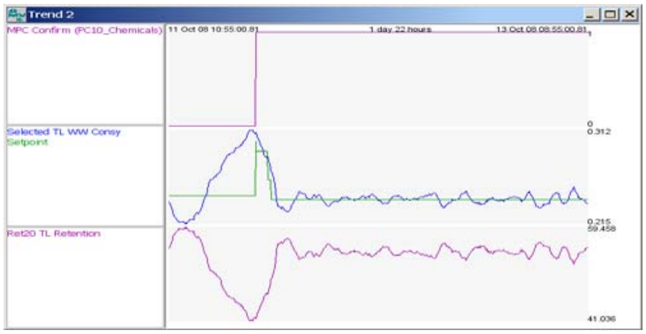

Figure 4: Stabilisation of TL WW Consistency (middle plot) and TL Wire Retention (bottom plot) under APC

- **Energy saving**: specific dryer steam use was reduced on average by more than 10%. Table 4 presents mill production data showing before- and after-APC steam use statistics across a range of grammages. The smaller percentage improvements typically resulted from shorter runs that gave less time for the steadier running under APC to be established. APC has increased drainage flowrates and reduced the variation in former drainage flowrates (see Table 5). The flowrates of retention aid and drainage aid are both used by the controller to regulate white water consistency but because drainage aid is cheaper and because of its effect on promoting drainage, the controller uses drainage aid preferentially.

Grade (GSM)	Steam Consumption (t/t) under Regulatory Control	Steam Consumption (t/t) under APC	% Reduction in Steam Use
108	2.17	2.11	2.92
115 A	2.53	2.23	11.99
115 B	2.31	1.90	17.75
120	2.22	2.00	9.93
150	2.24	2.19	2.22
140	2.24	2.01	10.02
200	2.24	1.71	23.67
		Average	**11.21%**

Table 4: Steam Consumption by Grade – Mill Production Data

Suction Box	APC SD (l/min)	Regulatory SD (l/min)	% Reduction in SD
Former Flow 1	177.2	265.1	33.2
Former Flow 2	55.7	68.5	18.7

Table 5: Standard Deviation of Former Flows by Grade

- **Reduced variation in MD weight and moisture**: though the controller was focussed on improving wet end stability alone, it has provided a reduction in the standard deviations of MD basis weight of 19.8% and of MD moisture of 14.1%.
- **Production increase**: improvements in runnability and increases in production due to reducing the dryer bottleneck because of reduced dryer steam consumption gave potential production benefits of over 5.5%.

Particularly interested in the potential to further reduce the energy consumed in making paperboard on this machine, the mill has recently commissioned work aimed at examining the utility of incorporating control of certain stock approach variables, headbox parameters and wet end vacuums into the APC system, to further improve drainage and reduce dryer steam use.

3.2 Energy Reduction in Newsprint Production

An APC system was implemented on a North American newsprint machine. The controller was designed to improve machine

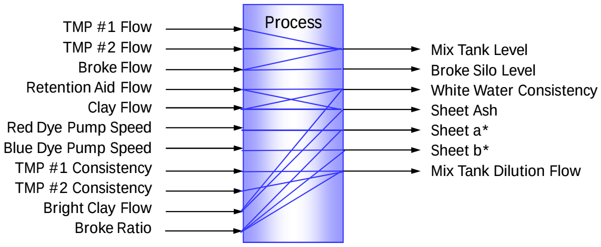

Figure 5: Structure of the APC newsprint controller

Figure 6: APC Reduces Variation in White Water

stability, reduce sheet ash variation, improve the control of colour and reduce energy use. The multivariable structure of the controller that was implemented is shown in Figure 5. Again the APC system provided a range of benefits:

- **Much improved machine stability**: the standard deviation of white (tray) water consistency has been reduced by 57%. Figure 6 shows typical patterns of variation for about 7 days before and after the APC system was implemented
- **Energy saving**: Table 6 shows that specific dryer steam use has been reduced, again by over 10%.

	Steam Consumption (t/t)		
Grade	Normal	APC	%Change
45A	1.820	1.600	12.1
45B	1.835	1.674	8.8
48A	1.858	1.613	13.2
48B	1.854	1.688	8.9
52A	1.894	1.745	7.9
52B	1.825	1.649	9.6
Averages	**1.848**	**1.662**	**10.1**

Table 6: Steam Consumption by Grade

	Standard Deviations of A* and B*		
	Normal	APC	%Change
A*	0.088	0.039	58.6
B*	0.158	0.043	73.1
Averages	**0.021**	**0.041**	**65.8**

Table 7: Improvement in Control of Colour

- **Better control of colour:** Table 7 shows that the standard deviation of colour variation has been reduced by 66%.
- **Reduced variation in sheet ash**: the APC system has reduced the standard deviation of the ash content of the sheet, as measured at the scanner, by more than 50%. This is enabling the mill to run higher ash contents and save fibre.

There is the potential to develop the controller to include better control of the dryer and sheet moisture, which will deliver a further energy saving benefit. The controller could also be extended to incorporate luminance control by modeling the effect on this of bright clay and OBA and setting the controller the task of optimising the use of the more expensive bright clay.

4. TOWARDS FURTHER REDUCTION OF THE ENERGY USED IN PAPER MAKING

Section 1.3 notes two prime foci for further efforts aimed at reducing the energy used in making paper. Some initial exploration of each these two ideas is presented respectively in the following two subsections.

4.1 The Potential for Further Improving Control of Drainage using APC

Section 1.2 establishes the pre-eminent significance of the potential for reducing energy use in the dryer, of improved sheet drainage. However, drainage is known to be affected by a range of variables, including the freeness of fresh furnish, the amount of refiner power used, the filler content of the furnish, the rate of use of chemical additives including retention aids, thin stock consistencies and flowrates, operating parameters of the headbox, the levels of vacuum applied to the sheet and press section nip pressures. Furthermore, adjusting drainage, especially close to the former, will have an impact on quality variables other than sheet moisture. Drainage should thus be adjusted only in a context in which the consequent implications for other quality parameters are known: drainage is a very strongly multivariable parameter that will benefit by being controlled within a suitably well-designed multivariable Advanced Process Control (APC) system framework, which is well suited to meeting the challenges presented by this energy optimization problem. As indicated in Section 2, in an APC system the multivariable character of a process is quantified within a model which is then used to calculate optimal controller moves. The multivariable model makes it possible to predict the effects of all input variables, control inputs and disturbances alike, on all the output variables. This allows the controller to make coherent, coordinated use of all the control variables to achieve optimizing outcomes for energy, quality and production on the machine, while maintaining the variables within their specified constraint ranges.

To date, the approach to control of drainage on paper machines has not often incorporated closed loop control using single loop controls, let alone has it comprehended the multivariable character of the control problem. Furthermore, the potential for controlling drainage in an energy-optimising framework has not typically been recognized or tackled. Much remains to be learned about the characteristics of the drainage system and how best to approach the energy optimization task. Some preliminary efforts in these directions are reported briefly here, part of a current on-going project. For a particular board machine which had been fitted with online sheet solids/dryness measurement just after the former, Figure 7 shows the result of stepping the setpoint of the vacuum imposed on the sheet at the second former compartment, while running a 105 gsm product. The fourth and fifth trends in the figure show the actual vacuums imposed (the PV signals) at both the second and the third compartments and the resulting effect these had on post former (second trend) and calculated couch roll (third trend) dryness, on sheet moisture (first trend) and basis weight (ninth trend) at the scanner, as well as on former flow rates (sixth –

eighth trends) and, importantly when considering a total machine energy optimization approach, the current (tenth trend) and calculated power (eleventh trend) required to drive the former roll. Note however that other data reveals that increasing some other vacuums has a detrimental effect on machine operation.

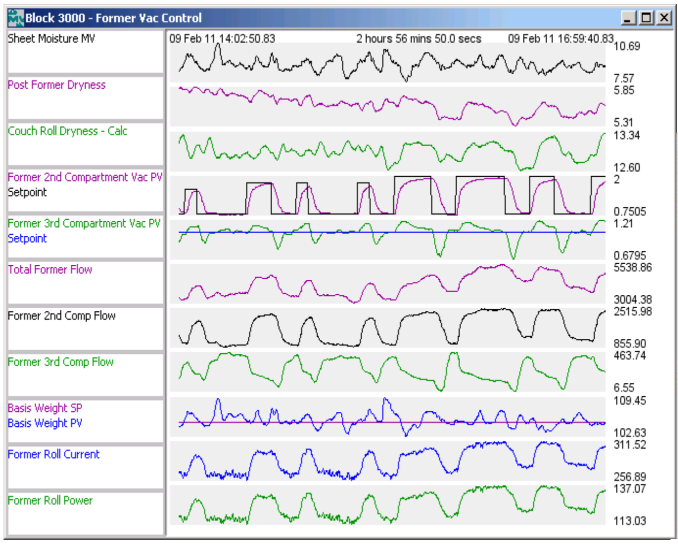

Figure 7: Effect of Variations in Vacuums on Drainage Flows, Roll Drive Power & Sheet Moisture

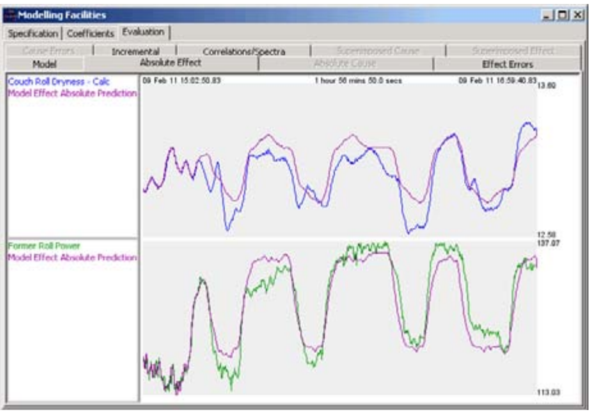

Figure 8: Preliminary Modelling from Vacuum to Sheet Solids and Former Roll Drive Power

Figure 8 presents some very preliminary models derived from the later data shown in Figure 7. More data is needed to develop models of sufficient accuracy for use within an APC system but work to date gives an expectation that the phenomena are eminently modellable. Preliminary analysis of the data suggests that large vacuums on the forming table actually reduce former flows and are detrimental to overall dryness at the couch. A possible explanation of this might be that large vacuums seal the sheet and may also starve the former of water to remove. Too much vacuum at the wrong places in the former also increases the load on the drive rolls which increases the power used in the wire section; the steady state gains of models such as those in the second pane of Fig 8 will be useful here. It is clear that online optimisation and control is required to manage the operation in such a way as to achieve a least-energy solution that also maintains sheet quality. At present it appears that the best strategy for this machine may be to minimise pre-former vacuum so as to move the wet-line to just before the former leading roll and use as much vacuum in the second chamber of the former as possible, though too much vacuum in the third chamber seems to be detrimental to sheet dryness. However the final vacuum just before the press section should be maximised.

Though there can be benefits for machine operation in having a drier sheet earlier in the machine, it is important from an energy-saving point of view to know whether the increased dryness at the couch roll persists to the dryer entry: the preliminary work to date suggests that though the press section may to some extent nullify any sheet dryness benefits that optimisation at the wet end provides, at least some of the benefit will find its way through to the dryer and result in reduced steam demand there. This and related questions, such as the possible magnitude of consequent energy reductions, are being pursued in current project work on this and two other paper machines.

4.2 The Potential for Reducing Dryer Energy Use by Using APC to Optimise the Operation of the Dryer Hood

Many dryer hoods are constructed as follows. Fresh air is drawn into the hood of the dryer at two points, one near the wet end of the sheet and the other nearer the dry end of the sheet. This fresh air is heated by heat exchange with warmed (and moist) exhaust dryer air and by heat exchange with steam. Exhaust fans remove heated, moist air from the dryer at rates that are intended to ensure that exhaust air humidity targets are maintained. The air pressure within the dryer at the height (‘zero-level’) where the dried sheet leaves the dryer should be about atmospheric pressure so as not to cause the sheet to flutter as it leaves the dryer; flutter can result in production down-time caused by sheet breaks. Nor should heated air be wasted by being lost from the dryer before it has done its requisite drying work.

Optimisation of hood operation should thus entail the determination of optimal targets for the two inlet air temperatures, for the two inlet air flowrates and for the two exhaust air flowrates, constrained by the need to maintain atmospheric zero-level pressures. These targets should be determined cognizant of the effect each variable has on the total energy use in the dryer, the sheet moisture content and on the zero level pressure. Optimal targets are likely to be a function of the grade/weight of paper being made and on the moisture target of the sheet but are also likely to change as operating conditions change. Ideally therefore, online optimisation of the dryer hood is required.

Current industry practice holds that:

- The amount of exhaust air should be just enough to carry all of the water vapour out of the dryer, with humidity a little above dew point.
- The amount of air supplied should be just sufficient to balance the air extracted, and give a sensible 'neutral point' for the zero-level pressures.
- The supply air temperature should be just high enough to maintain the air above dew point throughout the system

Not all dryer hoods are fitted with temperature and humidity sensors (though these are relatively inexpensive instruments) and are presently typically operated with little or no control. Even those hoods that do have appropriate temperature and humidity measurement and the ability to manipulate inlet and exhaust air flowrates are often operated in a fixed way, the same for each product made and for every different operating circumstance. The problem appears to be that the dryer hood presents a multivariable optimisation and control challenge that is neither properly understood nor addressed. Yet large quantities of energy are used in this aspect of dryer operation.

In order to elucidate the potential for improving the operation of the dryer hood, some experiments were recently conducted on a large modern newsprint machine:

1. Step changes were made on the steam valve heating the inlet air. The effects on relevant dryer variables are shown in Figure 9. The step signals imposed on the inlet air by heating control valve are shown in the second pane (the control loop was put into manual) and the effect on the inlet air temperature is shown in the first pane. The fifth and sixth panes show that as the inlet air temperature falls (in the latter portion of testing) an evidently wetter sheet calls for an increase in steam pressure to the dryer and hence an increase in steam flow rate. The third and fourth panes show that there was little effect on the zero-level pressure at either the wet end or the dry end of the hood.

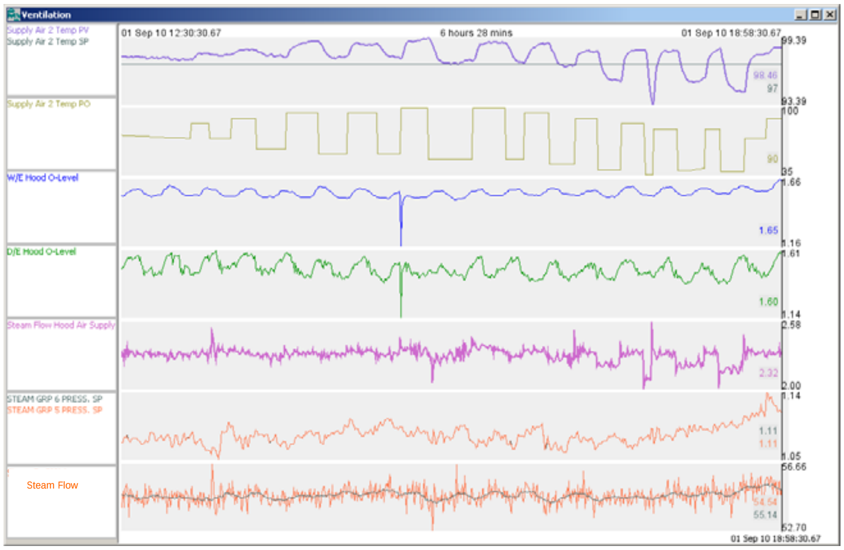

Figure 9: Effect of Hood Air Supply Temperature on Dryer Steam Use

2. Step changes were made on the exhaust fan speeds (during a period in which there was a press section break). Again the effects on relevant dryer variables were plotted, as shown in Figure 10. The steps shown in pane 3 clearly show that increasing fan speed reduces the moisture content of both stack exhaust air streams. Pane 6 shows that as expected exhaust fan speed has a strong influence on the zero-levels. Panes 7, 8 and 9 show that the exhaust fan speed affects the finished sheet moisture content, the steam pressure to the dryer and the total steam flow to the dryer: it appears that increasing fan speed causes a demand for less dryer steam, which has strong implications for the determination of a strategy of dryer optimisation.

3. Some step changes were also made on the inlet air fan speeds. The effects on relevant dryer variables are plotted in Figure 11. Panes 2, 12, 13, 15 and 16 show that changing the inlet air flowrate (panes 8 and 9, the associated controls were placed into manual) appears to have little effect on either the exhaust air moisture content or the sheet moisture, hence no effect either on dryer roll steam pressures or steam flow rates. However the inlet air rate affects both the zero-level pressures (panes 10 and 11, the big drop in levels near the end of the data sequence was caused by the broke conveyor doors in the basement being opened for cleaning) and, as expected, the supply air temperatures (panes 4 and 6).

Figure 10: Effect of Exhaust Fan Speed on Dryer Steam Use

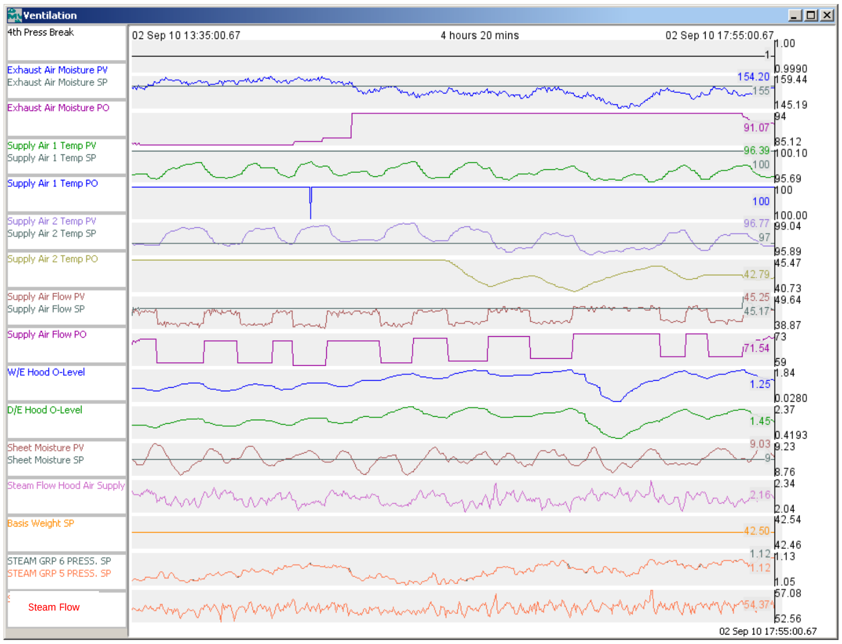

Figure 11: Effect of Inlet Hood Air Rate on Dryer Steam Use

These facts and the interactive nature of the variables that determine the amount of energy used in the dryer hood make plain the need to better understand the hood and how to go about energy-optimising its operation. APC technology provides very appropriate tools with which to acquire this knowledge for each new paper machine and to implement optimising solutions.

5. CONCLUSIONS

The magnitude of energy consumption in paper making has been overviewed. Several possible ways in which multivariable Advanced Process Control could be used to reduce energy consumption in paper making were then reviewed. Improved control of drainage, aimed at presenting a drier sheet to the paper machine dryer, has been shown to be pre-eminent among these approaches to making paper using less energy, along with the need to improve dryer efficiency.

The significant performance improvements that resulted from the implementation of APC systems on two quite different paper machines have been presented. The controller benefits have provided a very fast return on the project investment. Neither of the controllers was strongly focused on minimizing energy but they both achieved a greater than 10% reduction in specific steam consumption in the dryer. This success encourages greater concentration in future controller extensions and in new APC control system designs on one or more of the approaches to energy reduction noted in Section 1. In particular, better control of drainage and improved dryer efficiency are being targeted for the benefit these approaches can give in reducing dryer steam demand. By virtue of its inherent character, APC is able to coordinate both the short term supervisory regulation issues associated with wet end stability improvement and drainage control and the longer term optimization issues associated with steam consumption in dryers.

APC appears to have considerable potential for reducing the energy consumed in paper making. Its adoption for this purpose can be expected to develop rapidly over the next few years.

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