Simulation Aided Control of Drying Process

Summary

The project “simulation aided control of drying process” was carried out from February 2020 to March 2022. A reduction of specific energy for paper drying by 5% was the principal objective of this project. This energy reduction was achieved by utilising Hi-Tech process control.

The Simulation Aided Controller takes advantage of well-known and frequently published drying physics, measured process information and equipment technical data. Non-measured or difficult-to-measure process variables are displayed on a dedicated operator screen and used for process control. This technology identifies energy losses and optimises the transition from one operating set point to the next.

This new technology was proven at the Smurfit Kappa Townsend Hook mill in Snodland (Kent), on a recently updated Paper Machine (PM9) capable of producing over 235,000 tonnes per annum (tpa) of Lightweight Containerboard. The project was split into seven phases:

1. General fact finding, data gathering and investigation of any anomalous characteristics.

The Industrial Energy Efficiency Accelerator (IEEA)

The IEEA programme supports the development of innovative technologies that will help industry reduce energy consumption and cut carbon emissions. It focuses on innovations with large potential cross-sector energy and carbon reduction impact - either new technologies or established technologies applied to new sectors. Over £15 million in public and private funding has been committed to develop solutions through partnerships between technology developers and industrial companies willing to test technologies on-site. The programme is funded by the UK government (BEIS) and managed by the Carbon Trust, with support from Jacobs.

2. Assembling a simulation model of the drying process according to the PM9 technical documentation.
3. Testing and validation of simulation model parameters results in a digital twin of the real process.
4. Connection of the ‘digital twin’ online to the Distributed Control System (DCS). Testing and validation of communication interfaces.
5. Open loop phase; the simulation aided controller started to simulate remote set-points, however the remote set-points were not active.
6. Closed loop phase; the simulation aided controller started to control the process using remote set points.
7. Controller evaluation added to simulation, learning of process limits, evaluation control results, and documentation.

As the drying section is split into two distinct sections (pre-dryers (PD) and after-dryers (AD)), it was possible to progress the project in the different sections to differing schedules.

The project target of 5% energy reduction was exceeded. An energy reduction of more than 7% was achieved.

Introduction

A paper machine represents a huge complex of mutually influencing processes consuming nearly 80% of the energy consumption of paper mills. The usual machine construction is about 100m long, 10m high and 8m wide. A paper machine consists of 4 main sections: wire, press, drying and heat recuperation. The paper is drawn from the beginning of the wire section until the end of the drying section. A major challenge for all control systems is the process dwelling time (the time between set point change and measured process result). The measured response (e.g., final web dryness) to a control action (e.g., change of steam pressure in the drying section) takes minutes, and so a change in operating conditions at the wire section will usually only be measured at the end of the drying process after several minutes. In addition, some important process values cannot easily be measured at all because of difficult ambient conditions (100% air humidity, high air temperature, strong vibration, splash water, etc.). These factors complicate control management substantially. The controller’s reaction to any changes must be cautious to avoid risking any destabilisation of the manufacturing process.

Figure 1. A modern paper machine.

The main target of a conventional control system is to control the quantity and quality of the paper. Little attention has been paid to energy historically. The conventional control system is generally equipped with no more than two steam flow meters, which provides too little information to optimise process control and avoid unnecessary energy use. There are two main reasons for unnecessary energy losses:

- Insufficient information from the process for energy efficiency control.
- The control loops generally work independently of each other, which extends the time for process stabilisation.

Simulation aided control technology combines process values from field instrumentation with a framework of physical equations and equipment parameters creating a digital twin to model real processes. The control system does not only work with process data, but also with well-known and established physical dependencies and machinery parameters. This improves the information flow and transparency to obtain higher efficiency as well as paper quality. This new approach provides an opportunity to optimise process control and outperform existing advanced control technics (i.e., Model Predictive Control, or MPC).

Paper web leaves the press section with a moisture content of c. 50%. This means that one tonne of paper entering the drying section contains 500 kg of water, the majority of which has to be evaporated. To produce one tonne of paper, the paper machine needs about 1.6 tonnes of steam. A standard paper machine producing around 200,000 tonnes of paper per year consumes over 320,000t steam/yr. This corresponds to heat energy of 240 GWh or more than 4 TWh/yr across the UK paper industry, offering significant potential for material energy savings.

About the innovation

The drying process is broken down into elementary physical processes and they are described using physical formulae. Each model of the elementary process is an object, with machinery and process parameters. Individual models are brought together to assemble a digital twin of the real process, running as a software program. This program is connected to the existing control system. The real and virtual processes run in parallel, but the results of the virtual processes are available much more quickly. This enables the simulation aided controller to optimise the process, providing optimised remote set points to the underlying control system.

In order to control production, the current control systems use process values from field instrumentation. The efficiency of the control system depends on the quality of the information sent by this instrumentation. However, many important process variables are difficult to measure or cannot be measured at all (e.g. web dryness after press section, temperature of drying cylinders, MD evaporation rate, MD moisture profile, air moisture in the paper machine hoods, efficiency of drying aggregates etc.). This is a limiting factor of existing modelling and control techniques (i.e. PID and model predictive control systems).

Simulation aided control technology uses physical dependencies to substitute for missing process data. This enables more efficient control of all dewatering sections and decreases energy losses to a physical minimum. It combines measured values together with process physical dependencies and equipment functions creating a simulated virtual drying process. Unmeasured drying variables are derived from a virtual process and visualised in combination with real data that is available, to increase both the quantity and quality of information available to the process control system.

The simulation model

To build the simulation model, the process is mathematically described by physical formulae in a first principles model in order to simulate and assess real process dependencies. This is innovative over the MPC approach, where the mathematical function is derived from measured signals. The first principles model represents the behaviour of the paper machine at all working points with precision equal to that of the best instrumentation installed. The biggest advantage of the first principles approach over the MPC approach, is that it is based on technical and geometrical parameters of the paper machine and does not depend on the operating parameters or fibres used.

The simulation model contains individual models representing real components, such as the steam box, cylinder, heat exchanger, ventilator and other relevant units. Just like real equipment, these individual models are connected with energy and mass flows in the form of physical equations. The model functionality is independent of processes running on the real machine, forming a digital twin; a mathematical representation of physical, technical and technological parameters and functions of the real equipment. As the architecture of a digital twin allows for easy extraction of any process variable from the model, one of its big advantages is transparency.

It is rare that all the necessary technical parameters of paper machine equipment are available to construct the model, so unknown parameters are derived from technical publications and historical process information. The model must then be validated which is initially performed offline using historical process data. Real set points and process input values are entered into the model. The model simulates the drying process, and the results are compared with the results of the real machine. The term "results" includes all measured process values. The model reads data, simulates the drying process and writes results back automatically. This procedure usually needs only several seconds to process data from a period of one month's operation. Differences between simulated and real results lead to the correction of corresponding model parameters. The model with the new parameters is then proven with the same data set and again corrected until eventually all simulated results match the measurements.

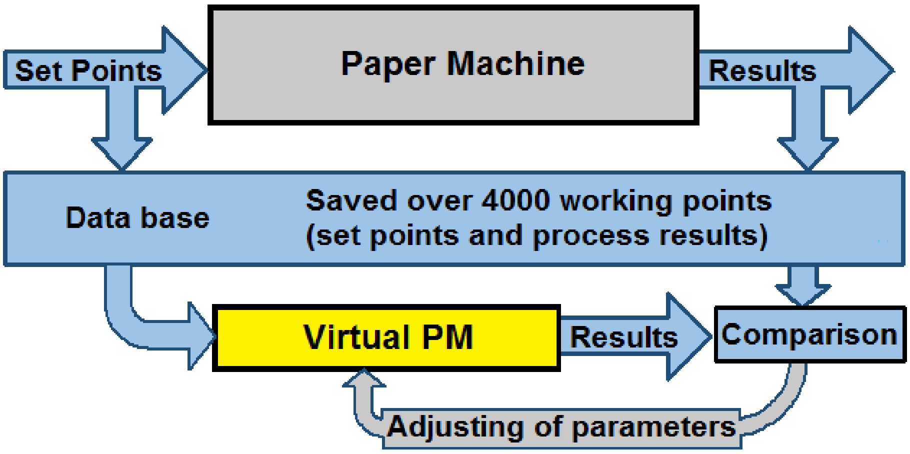

Figure 2. Validation of simulated drying process is performed offline. The identical set points must generate the same results. Deviations are only in scope of instrumentation accuracy.

The validated model is subsequently checked with another process data set. Only after this procedure can the model be confidently known to represent the real process (digital twin). The precision of simulated results will be very similar to the precision of the best measurement instrumentation installed on the paper machine.

The demonstration

The new technology was tested at the Smurfit Kappa Townsend Hook mill in Snodland (Kent), on the recently updated Paper Machine MP9 producing 235,000 tpa of Lightweight Containerboard. The project was split into seven phases:

1. General fact finding, data gathering and investigation of any anomalous characteristics.
2. Assembling a simulation model of the drying process according to the PM9 technical documentation.
3. Testing and validation of simulation model parameters results in a digital twin of the real process.
4. Connection of the 'digital twin' online to the DCS control system. Testing and validation of communication interfaces.
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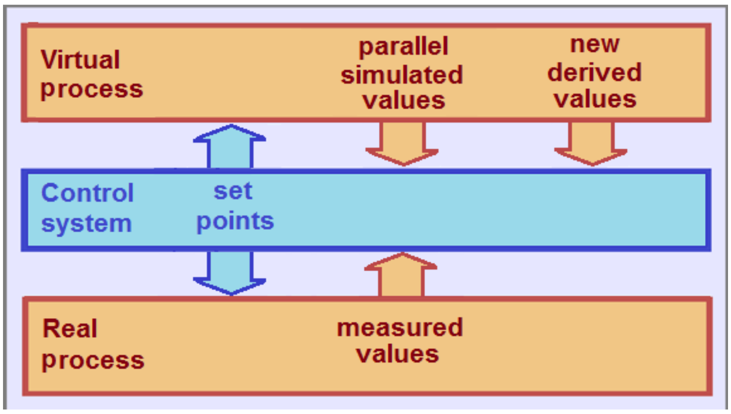


Figure 3. The phase 2, model on-line connection of instrumentation accuracy.

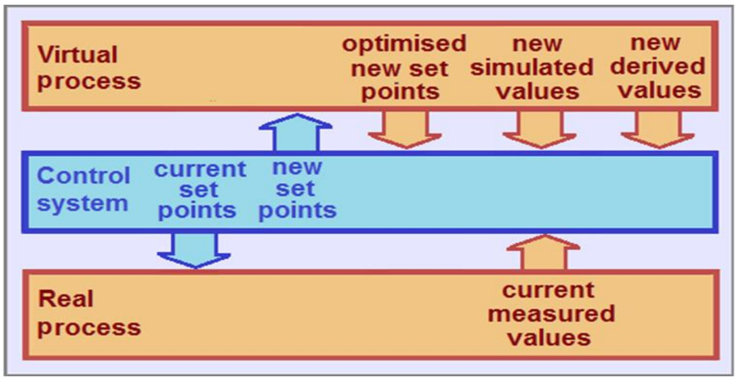
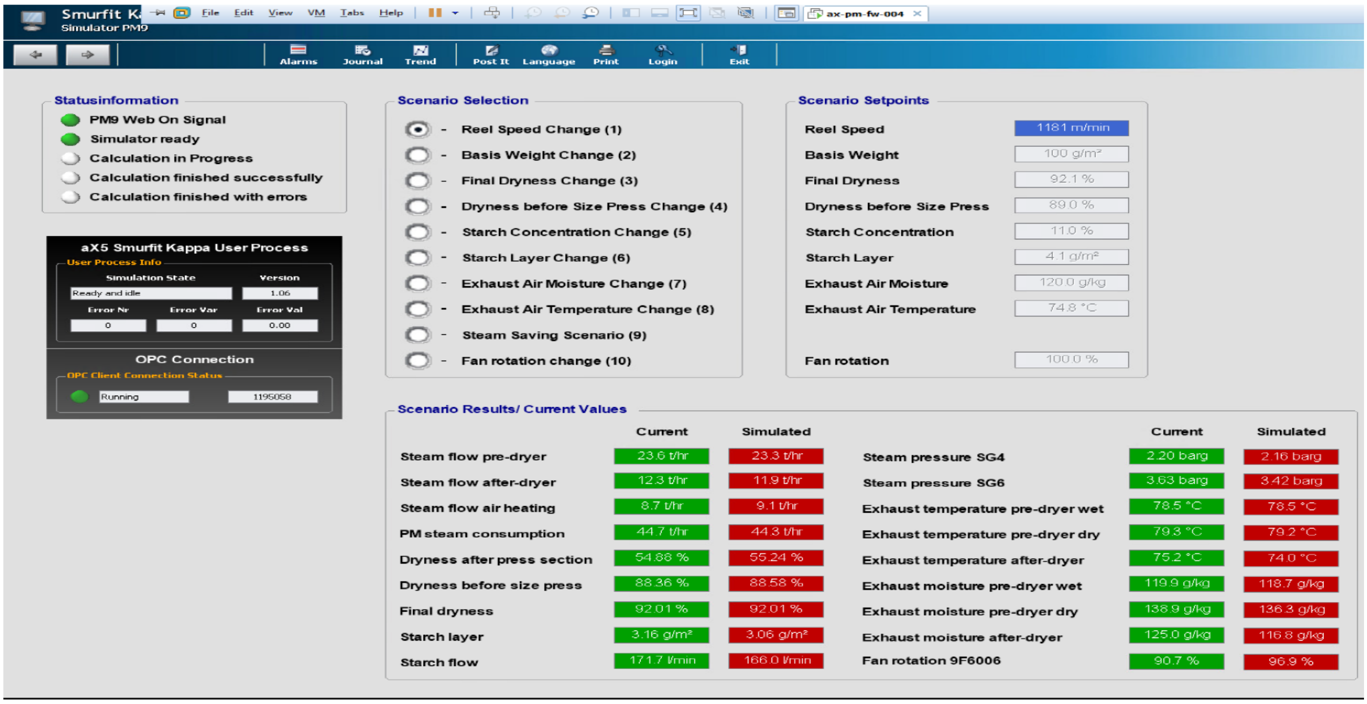


Figure 4. Phase 3 and 4, open and closed loop regime.

The new control technology is based on 2 identical processes (real and virtual) running in parallel. Set points are identical for both processes. There are two main control modes in the control algorithm. Mode 1 is active during stable production conditions. The digital twin simulates measured process values and additionally derives difficult-to-measure process variables such as air humidity, paper dryness after the press section, the temperature of the cylinder shell surface and many others. The simulation aided controller uses this information to predict future process behaviour to increase the stability, precision and speed of control reactions.

Mode 2 is active during a production change. First, the impact of new set points are predicted into the future, so that deviations are corrected before they occur in the real process. The optimised set points from the predicted future then simulate the best process route to reach the new targets. The new production conditions are stabilised in the physically shortest time. Broke (paper waste) is reduced to a minimum and energy consumption is significantly decreased.



Statusinformation

- ● PM9 Web On Signal
- ● Simulator ready
- ○ Calculation in Progress
- ○ Calculation finished successfully
- ○ Calculation finished with errors

aX5 Smurfit Kappa User Process

User Process Info

Simulation State	Version
Ready and idle	1.06

Error Nr	Error Var	Error Val
0	0	0.00

OPC Connection

OPC Client Connection Status

● Running 1195058

Scenario Selection

- ● - Reel Speed Change (1)
- ○ - Basis Weight Change (2)
- ○ - Final Dryness Change (3)
- ○ - Dryness before Size Press Change (4)
- ○ - Starch Concentration Change (5)
- ○ - Starch Layer Change (6)
- ○ - Exhaust Air Moisture Change (7)
- ○ - Exhaust Air Temperature Change (8)
- ○ - Steam Saving Scenario (9)
- ○ - Fan rotation change (10)

Scenario Setpoints

Reel Speed	1181 m/min
Basis Weight	100 g/m²
Final Dryness	92.1 %
Dryness before Size Press	89.0 %
Starch Concentration	11.0 %
Starch Layer	4.1 g/m²
Exhaust Air Moisture	120.0 g/kg
Exhaust Air Temperature	74.8 °C
Fan rotation	100.0 %

Scenario Results/ Current Values

	Current	Simulated		Current	Simulated
Steam flow pre-dryer	23.6 t/hr	23.3 t/hr	Steam pressure SG4	2.20 barg	2.16 barg
Steam flow after-dryer	12.3 t/hr	11.9 t/hr	Steam pressure SG6	3.63 barg	3.42 barg
Steam flow air heating	8.7 t/hr	9.1 t/hr	Exhaust temperature pre-dryer wet	78.5 °C	78.5 °C
PM steam consumption	44.7 t/hr	44.3 t/hr	Exhaust temperature pre-dryer dry	79.3 °C	79.2 °C
Dryness after press section	54.88 %	55.24 %	Exhaust temperature after-dryer	75.2 °C	74.0 °C
Dryness before size press	88.36 %	88.58 %	Exhaust moisture pre-dryer wet	119.9 g/kg	118.7 g/kg
Final dryness	92.01 %	92.01 %	Exhaust moisture pre-dryer dry	138.9 g/kg	136.3 g/kg
Starch layer	3.16 g/m²	3.06 g/m²	Exhaust moisture after-dryer	125.0 g/kg	116.8 g/kg
Starch flow	171.7 l/min	166.0 l/min	Fan rotation 9F6006	90.7 %	96.9 %

Figure 5. Phase 3 and 4. Operator interface to the model.

Monitoring

The main objectives were to ensure alignment between measured and simulated values to a sufficient level of accuracy. 15 process variables were monitored and statistically evaluated.

During normal operating conditions (figure 6), the simulated temperature values of exhaust air meet the measured ones. In cases where the model does not have important process information (such as open hood), or during extremely unstable working conditions, the simulated values slightly differ from the measured temperature. The deviations are within the scope of instrumentation accuracy.

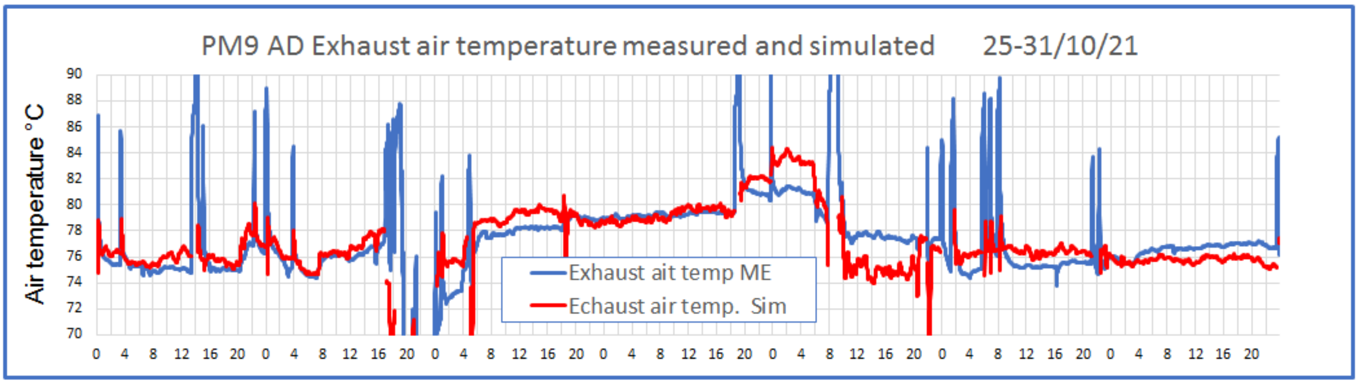


Figure 6. PM9 AD Exhaust air temperature measured and simulated 25-31 October 2021.

The histogram (figure 7) shows a deviation distribution of over 17,000 working points. The simulator calculations for steam consumption are mostly within 1% of measured values. This represents a steam flow deviation of less than 0,6 t/hr. 99.92% of all simulated values are inside of the defined tolerance band of 2.5%. The process variable “total steam flow” therefore passed the test for required accuracy.

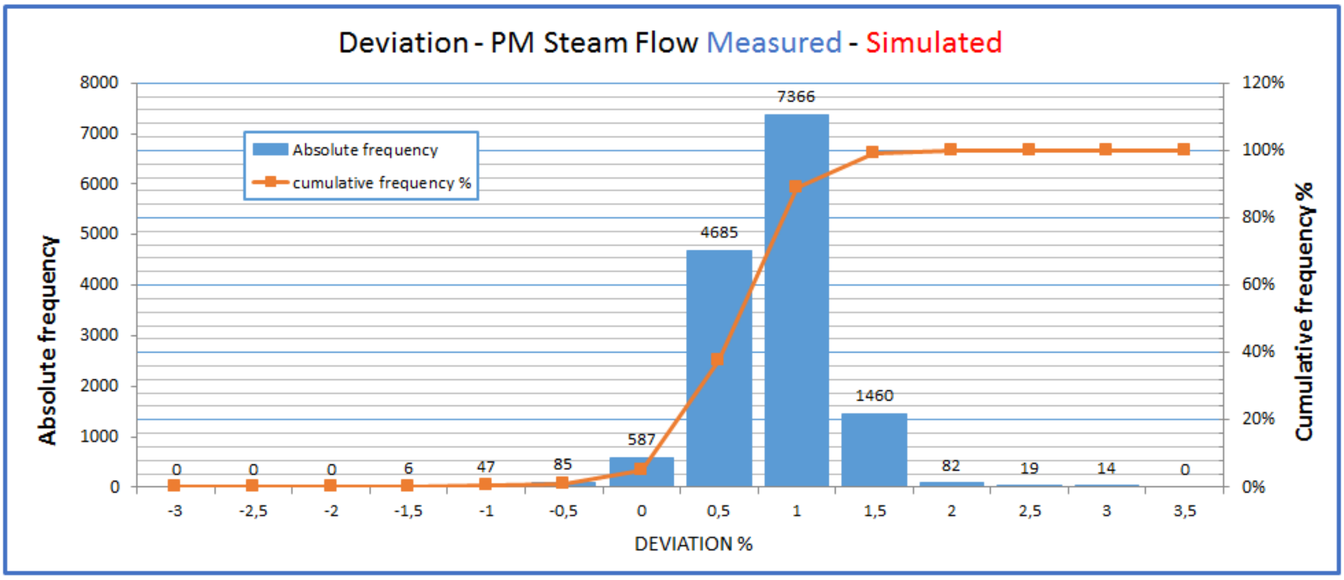


Figure 7. Deviation – PM steam flow: measured vs. simulated.

Results

Through this project, the control system technology has demonstrated reduced steam consumption by up to 2% in the press section, up to 3% in the drying section and up to 3% in the heat recovery area. The main objective of this demonstration project was to reduce the average steam consumption on the paper machine at least by 5%.

Due to mill equipment reconstructions over the project duration of two years, during which there were changes in fibres used, chemical components and other conditions, a simple before and after comparison of steam consumption would have limitations. Nevertheless, the original drying conditions two years before could be replicated. These “old” drying conditions can be stabilised in four hours and then the process can be controlled by the PM simulator with the new proven set points.

Not all process variables are measured. For instance, the steam flow for PM9 is measured in two places for medium pressure and high pressure steam. The measured steam flow is a summation of steam for the pre-dryer, after-dryer and steam for air heating.

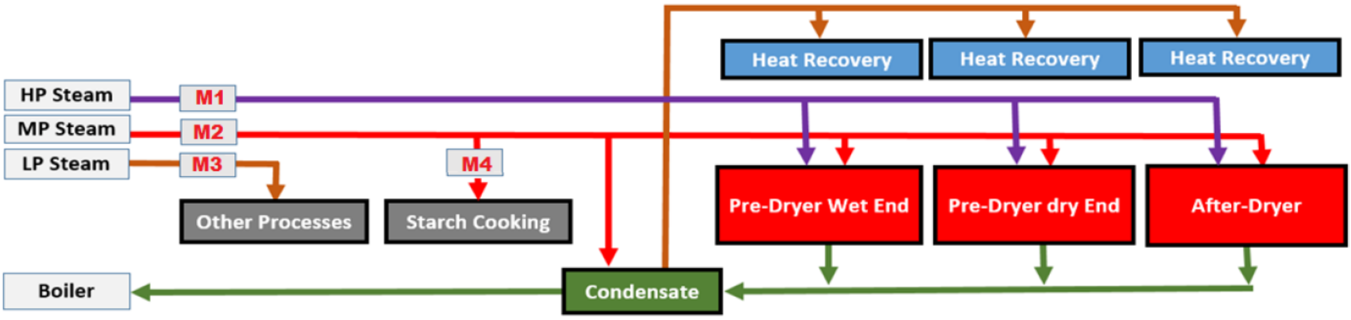


Figure 8. Rough steam distribution around PM9.The steam consumption for the drying process is the sum of high pressure (HP) and medium pressure (MP) steam flow. The steam for starch cooking must be subtracted from this sum. Steam for drying = M1 + M2 – M4.

In order to assess the steam saving contribution of Simulation Aided Control, the set point of the controlled/ manipulated variables must be set according to the pre-project conditions and, following the stabilising time, the simulation aided controller can be started according to the new proven safety limiting values.

Table 1. Planed trial set-points.

Process variable	Unit	Controller off (Old set point)	Controller on (New set point)
Basis weight	g/m2	85	85
Rotation of PD exhaust air fan	%	100	80
Rotation of supply air fan PD dry end	%	100	85
Supply air temp. PD wet end	°C	101	85
Supply air temp. PD dry end	°C	100	85
Rotation of AD exhaust air fan	%	92	75
Supply air temp. AD	°C	105	80
Steam pressure in condensate vessel	Bar(g)	1.15	0.8

The difference between measured and simulated steam flows is about 0.5t/hr, which is in the precision range of 2.5% over the last 6 months. The blue highlighted area shows the demonstration period. The old set points in time between 9:00 and 13:00 caused roughly 4 t/hr higher steam consumption, compared with new set points documented in Table 1.

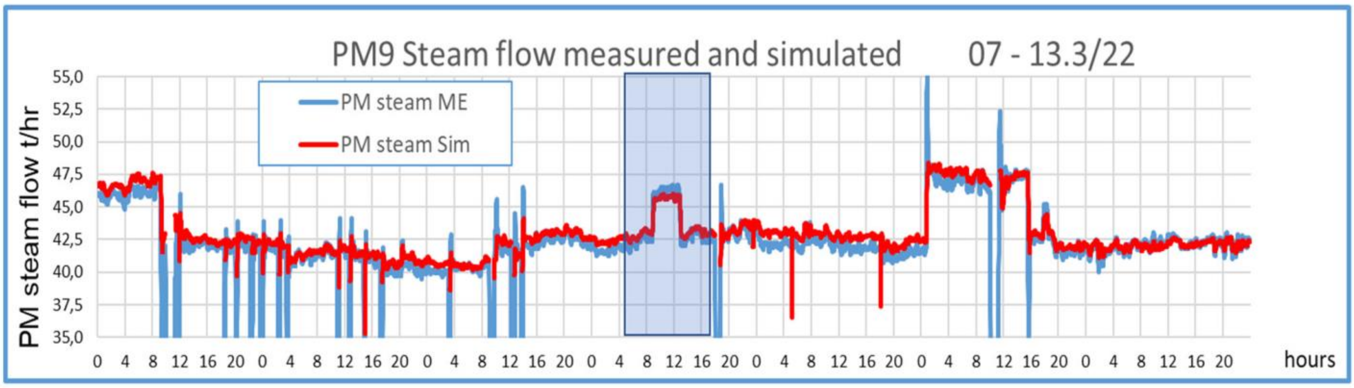


Figure 9. PM9 steam flow measured and simulated 07-13 March 2022.

The PM simulated steam flow is compiled from the drying steam flows for PD and AD and steam flow for air heating. The steam flow for drying (PD & AD) was constant throughout the trial period. The significant changes in the steam flow can be observed with the steam for air heating. This is also evidence of steam use reduction in the heat recovery area of the PM9.

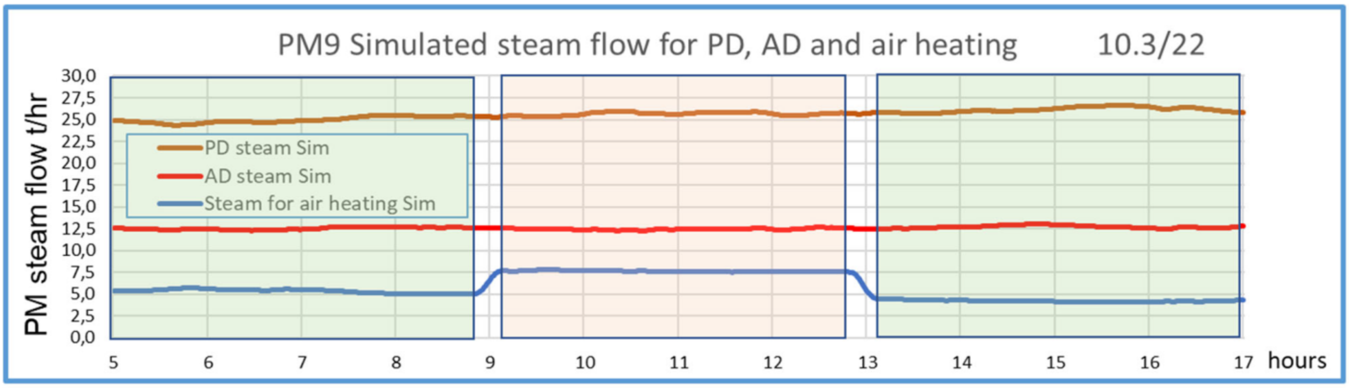


Figure 10. PM9 steam flow measured and simulated 10 March 2022 during demonstration period (blue highlighted in previous figure).

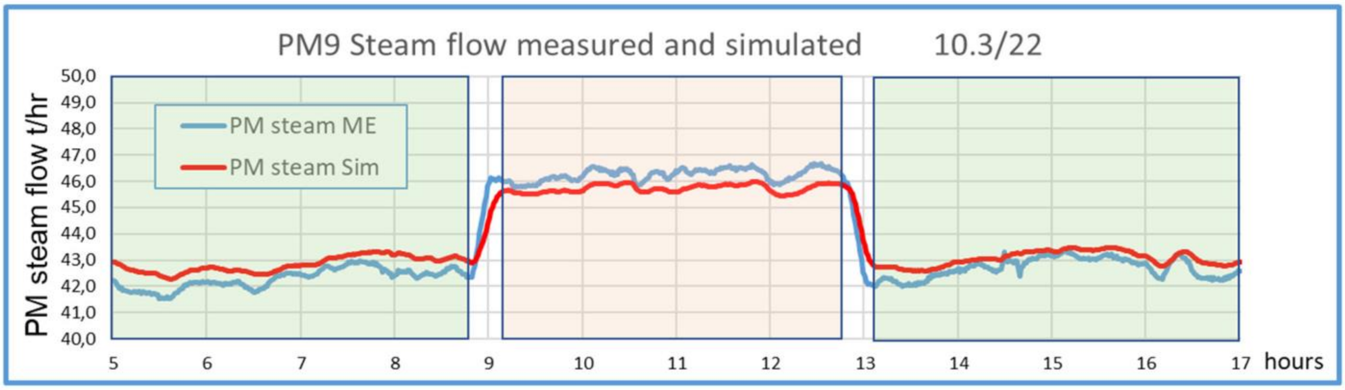


Figure 11. PM9 simulated steam flow for PD, AD, and air heating 10 March 2022 during demonstration period.

The simulated steam flow for air heating is composed of the steam for air heating in PD wet and dry end and steam for air heating in AD.

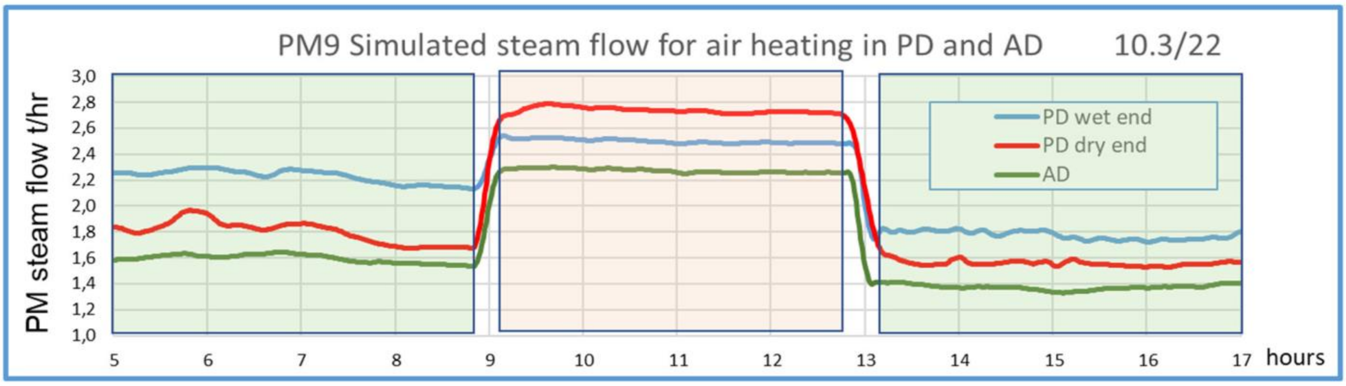


Figure 12. PM9 simulated steam flow air heating in PD and AD 10 March 2022 during demonstration period.

Table 2. Trial results. This table follows table 1 with old and new set points and documents steam consumption in the three trial periods. A slightly increased PM speed within the trial period (trend 1) is the reason for the marginally higher steam for PD drying.

		Controller Set-points			
Process variables	**units**	**ON**	**OFF**	**ON**	**saving**
Time	Hours	4	4	4	4
PD wet - steam for air heating simulated average	t/hr	2.23	2.27	1.37	0.9
PD dry - steam for air heating simulated average	t/hr	1.80	2.74	1.56	1.2
AD - steam for air heating simulated average	t/hr	1.59	2.50	1.79	0.7
PM - steam for air heating simulated average	t/hr	5.35	7.63	4.24	3.4
PD - steam for drying simulated average	t/hr	24.95	12.45	12.27	-0.3
AD - steam for drying simulated average	t/hr	12.52	25.67	26.06	0.6
PD - steam consumption simulated average	t/hr	42.83	45.74	43.05	2.68
PM - steam consumption measured average	**t/hr**	**42.29**	**46.28**	**42.69**	**3.6**
PM - steam consumption measured	**%**				**7.7**

The trial period (recorded by the mill DCS control system) shows the specific steam consumption (in tonnes per tonne; t/t) trend with very similar results. The specific consumption of 1.57 t/t was measured with old set points and the simulator control achieved a value of 1.37 t/t.

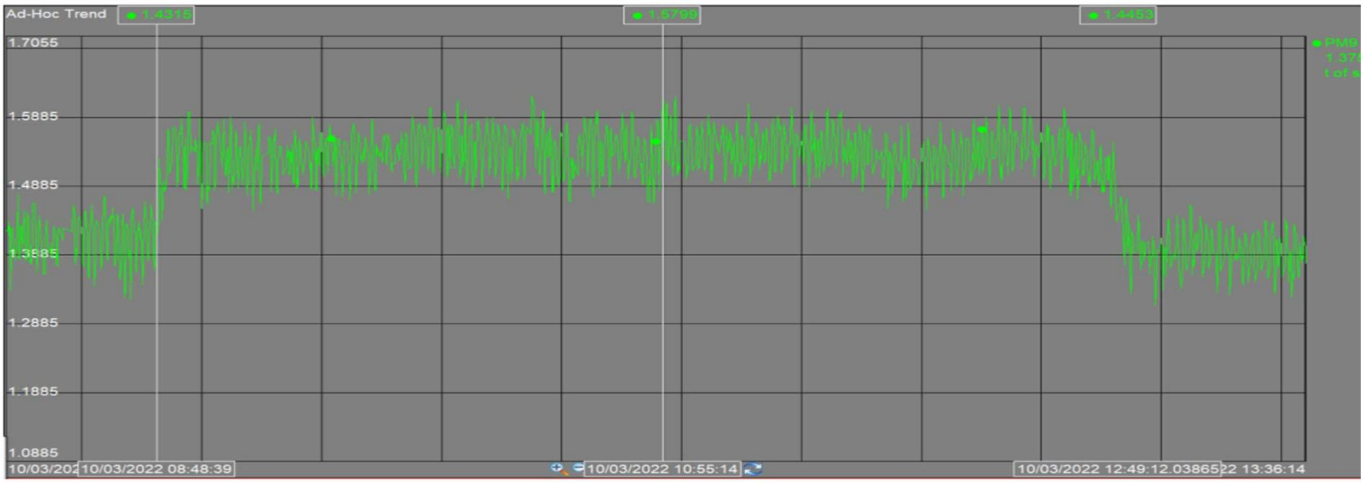


Figure 13. DCS Screenshot specific steam consumption (t/t).

In order to compare the former control technique with simulation aided control technology, the paper machine was controlled according to the set points and control loops from 2020. The new control technology was carefully activated at 12:30. The steam consumption dropped from 46.28 t/hr to 42.69 t/hr. This demonstrates steam flow reduction by 7.75%. The main project target was achieved.

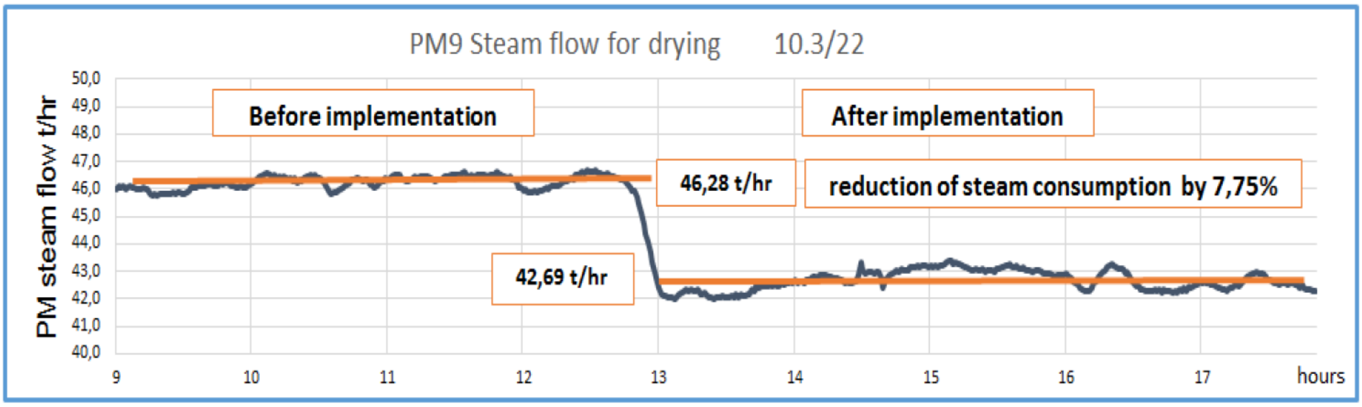


Figure 14. PM9 Steam flow for drying 10 March 2022.

Future impact

The UK paper industry produces around 4 million tonnes of paper, paperboard and tissue. This technology is immediately applicable to the majority of paper mills. According to the process complexity, a project can be realised in 6 to 8 months, and so it could take 5 to 7 years to install this technology for 70% of paper production in UK mills. It will be a challenging task, however, there are also many other processes where organic material is dried (moulded pulp, wood, cellophane, potatoes etc.). The possibilities of this new technology are to:

1. Minimise energy losses to the physical minimum.
2. Discover weak points in the drying process.
3. Quantify the efficiency of drying equipment.
4. Monitor changes in drying capacity.
5. Make visible process variables, which are difficult to measure.
6. Evaluate upgrade plans.

The control technology can also be adapted to steam production and distribution networks too. Physical modelling of boiler and steam network equipment combined with a simulation aided controller should yield:

- Minimized blow down of steam.
- Increased efficiency of turbines.
- Reduced boiler load variances.
- Minimize backup boiler usage.

Innovation lessons

Historically this technology, which offers significant potential for process improvements and process control improvements, has not been considered as being viable for large scale industrial applications.

The work at Snodland mill has demonstrated that ‘Simulation Aided Control of Drying Processes’ is a proven technology that can be applied to complex industrial applications and is capable of realising valuable energy savings and acting as a powerful problem-solving tool. Importantly, this technology can be retrofitted to operating systems with minimal disruption to the production process, producing tangible energy savings within a very short time frame and organically developed to oversee key areas of the production process.

The technology can also dramatically reduce losses (both energy and materials) during start-ups and grade changes, making further contributions to reducing overall costs. Faced with rapidly increasing energy costs, ‘Simulation Aided Control of Drying Process’ is a must-have process control tool.

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