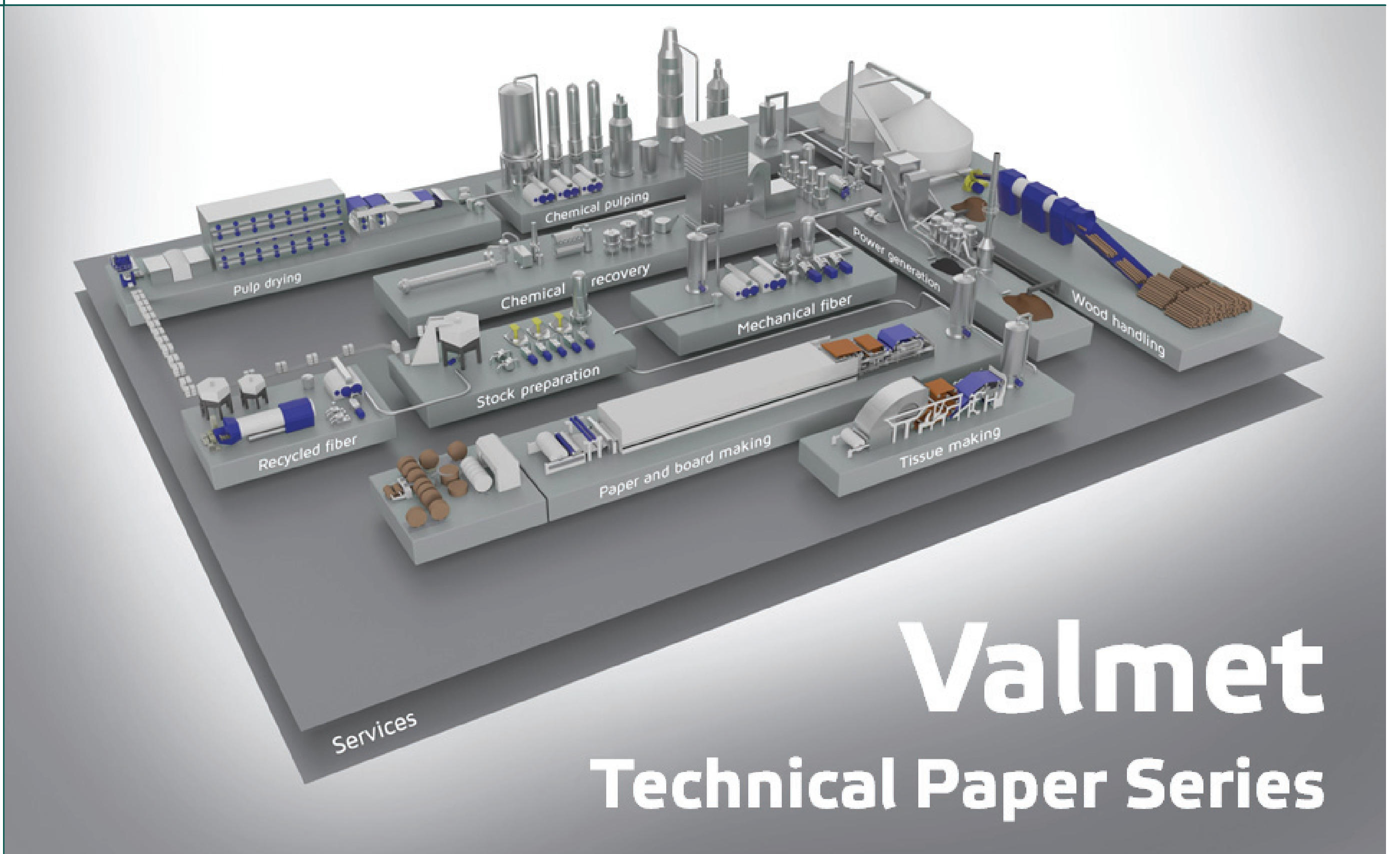

State-of-the-art Developments to Save Energy in Coating Drying

Executive Summary

Coating drying is expensive. A great deal of energy is needed to effectively evaporate sufficient water to dry the coating. In production of coated paper or board, the amount of water evaporated in the coater dryer section is typically 0.1 to 0.2 ton H_2O per ton of produced paper or board. In terms of the operating costs of coating drying there are two important factors; 1) the specific energy consumption in the drying and 2) the price of the energy source used in the dryers. The specific energy consumption in the coater dryer section can vary from 4,500 to10,000 kJ/kg evaporated water, depending on the drying concept, dryer adjustments and other operating parameters. Different energy sources, for example natural gas, LPG gas, medium or low pressure steam and electrical power are generally used in the coater dryers.

Recent developments have taken the coater drying process to a new level; offering substantial savings never before available. Case studies are presented to illustrate examples of two state-of-the art technologies used today in coating drying, and the significant benefits these new components provide in reducing energy and carbon footprint, and improved quality, efficiency and profitability.

Introduction

Air floatation or impingement coating drying is not a new concept. The operation and benefits of impingement drying are well understood; to the point where air drying is very much the norm in the industry. In the simplest terms, hot dry air is simply blown onto the wet coating thus raising the coating temperature to a point where water is evaporated from the sheet, leaving a relatively dry coated finish. The basics are simple. The challenges however are significant when one considers the many variables and influences that must be considered; which include:

- machine performance, geometries and limitations (draws, wrap angles, trim, speed)
- base sheet properties (basis weight, moisture, furnish, porosity, pre-coating, etc.)
- coating properties (chemistry, solids, coat weight(s))
- sheet/coating quality (CD and MD uniformity , marking, mottle, etc)
- energy
- runnability and machine efficiency
- maintenance and service
- cost (capital, operating, maintenance)

Recent developments in air dryer technology have significantly enhanced dryer performance. Specifically, new nozzle designs have dramatically improved drying effectiveness, namely doing more (better) drying using less energy.

Foil nozzle ***Float nozzle*** ***High performance nozzle***

Figure 1. Nozzle development

Early nozzles were relatively simple foils with a single air slot. Later nozzles typically included a double slot (float) arrangement to improve sheet floatation and drying performance. The most recent, and state-of-the-art designs include a much larger nozzle profile that supports and dries the sheet over a greater area. This improved design has a significant effect on the dryer's ability to deliver energy to the sheet, more effectively; thus saving energy. **Figure 2** illustrates the comparison between traditional double slotted nozzles, versus a new high performance design.

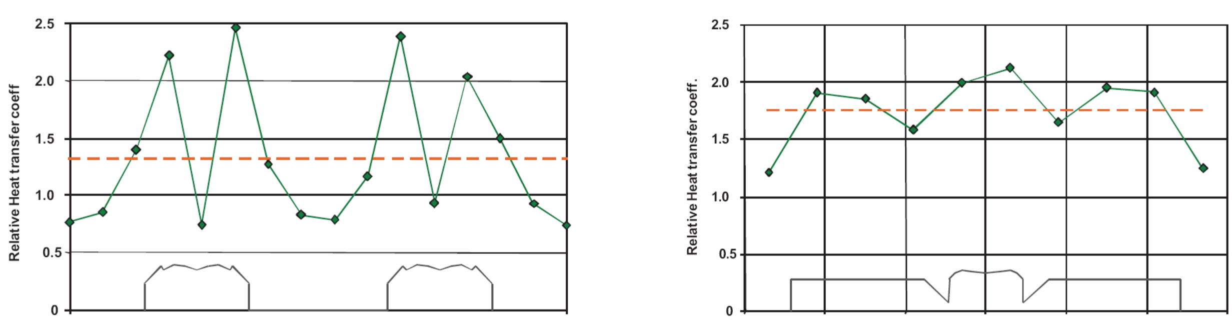

Figure 2. Nozzle comparison – (left) double slotted nozzle and (right) new nozzle

Over approximately the same (MD) cross sectional area, with the nozzles operating at the same temperature (200 ° C) and blowing velocities (50 m/s), the new nozzle design performs much better (approximately 32%) in terms of average heat transfer coefficient. This improvement in heat transfer translates into significant savings in terms of energy and operating costs. In addition, the more uniform air distribution across the nozzle face offers significant advantages, namely:

- better sheet support (runnability, less marking)
- more even drying (sheet quality)
- reduced maintenance (less coating buildup)

This new nozzle design provides significant benefits and new opportunities in coater drying.

Case study #1: Air bar development background

The true test of any new design is in a production situation. A side-by-side or on/off test is best, in order to demonstrate and quantify the performance of new technology relative to existing alternatives. For the purposes of this study, an existing machine was (partially) retrofitted with new dryer nozzles, thus providing the opportunity to do a true "before/after" comparison. The machine in question is a production capacity offmachine coater (OMC):

Machine	Coater #1 (bottom)	Coater #2 (top)	Coater #3 (top)	Coater #4 (bottom)
Fine Paper (LWC)	Coat wt: 7.97#/ream @ 63% solids	Coat wt: 7.97#/ream @ 63% solids	Coat wt: 7.97#/ream @ 63% solids	Coat wt: 7.97#/ream @ 63% solids
3700 fpm	Gas IR	Gas IR	Gas IR	Gas IR
150" trim	2 Air Dryers	2 Air Dryers	1 Air Dryer	1 Air Dryer
67.95#/ream	2 steam cylinders	2 steam cylinders	4 steam cylinders	7 steam cylinders
3.28% moisture (base)				5.35% moisture (final)

Table 1. Machine data

In order to quantify the nozzle performance, baseline data was compiled for the existing machine prior to the rebuild. Similar data was then recorded post-rebuild for comparison.

Simulations

Prior to the rebuild, extensive computer modeling was done to simulate comparative drying performance. This provided an opportunity to project the expected savings and verify the project feasibility.

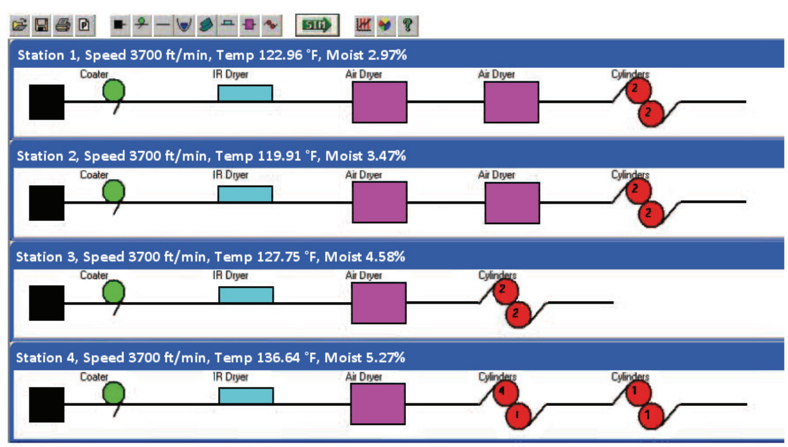

Figure 3. OCM computer model

In simulating the drying, it is important to consider the entire drying process and all of the associated variables. Changing the drying at one point will have a ripple effect through the entire process, thus

Energy Calculation Summary -- Simulation projection - All Dryers with Existing Air Bars Based on production data taken April 2009

Speed	3,701 ft/min	1,128 m/min	Operating days per year 350	
Trim	152.8 in	3,881 mm	% Operating efficiency 85	

Gas Cost $8.00 / million BTUs
Electrical Cost $400 / HP / year

Coater 1

Gas IR			Dryer 1			Dryer 2		
Abs. Energy	792 MBH	232 kW	Abs. Energy	2,065 MBH	605 kW	Abs. Energy	1,993 MBH	584 kW
Evaporation	238 lb/hr	108 kg/hr	Evaporation	1,217 lb/hr	552 kg/hr	Evaporation	1,655 lb/hr	751 kg/hr
			Imp Temp	498 F	259 C	Imp Temp	511 F	266 C
			Imp Vel	9,820 ft/min	49.9 m/s	Imp Vel	9,940 ft/min	50.5 m/s
Gas Cons.	1,898 MBH	556 kW	Gas Cons.	3,430 MBH	1,005 kW	Gas Cons.	3,404 MBH	998 kW
			Elect Cons	86 HP	64 kW	Elect Cons	86 HP	64 kW

Coater 2

Gas IR			Dryer 3			Dryer 4		
Abs. Energy	793 MBH	232 kW	Abs. Energy	1,939 MBH	568 kW	Abs. Energy	1,768 MBH	518 kW
Evaporation	325 lb/hr	147 kg/hr	Evaporation	1,114 lb/hr	505 kg/hr	Evaporation	1,699 lb/hr	771 kg/hr
			Imp Temp	505 F	263 C	Imp Temp	519 F	271 C
			Imp Vel	8,840 ft/min	44.9 m/s	Imp Vel	8,070 ft/min	41.0 m/s
Gas Cons.	1,898 MBH	556 kW	Gas Cons.	2,973 MBH	871 kW	Gas Cons.	2,846 MBH	834 kW
			Elect Cons	71 HP	53 kW	Elect Cons	57 HP	43 kW

Coater 3

Gas IR			Dryer 5		
Abs. Energy	443 MBH	130 kW	Abs. Energy	1,488 MBH	436 kW
Evaporation	201 lb/hr	91 kg/hr	Evaporation	967 lb/hr	439 kg/hr
			Imp Temp	463 F	239 C
			Imp Vel	8,720 ft/min	44.3 m/s
Gas Cons.	1,253 MBH	367 kW	Gas Cons.	3,006 MBH	881 kW
			Elect Cons	59 HP	44 kW

Coater 4

Gas IR			Dryer 6		
Abs. Energy	221 MBH	65 kW	Abs. Energy	1,635 MBH	479 kW
Evaporation	157 lb/hr	71 kg/hr	Evaporation	1,348 lb/hr	611 kg/hr
			Imp Temp	517 F	269 C
			Imp Vel	8,050 ft/min	40.9 m/s
Gas Cons.	633 MBH	185 kW	Gas Cons.	3,831 MBH	1,123 kW
			Elect Cons	45 HP	33 kW

Total Energy Consumption from Gas	*25,173 MBH*	*Gas Cost*	*$1,437,858 /year*
Air Dryer Gas Consumption	*19,490 MBH*	*Electrical Cost*	*$161,405 /year*
Total Water Evaporated	*8,922 lb/hr*	*Total Cost*	*$1,599,264 /year*
Gas Energy Consumption per lb Water Evap.	*2,821 BTU/ lb H_2O*		

Figure 4a. Drying simulation results – pre-rebuild

Energy Calculation Summary -- Dryers 5 & 6 with New Hi Performance Nozzles (From Simulation)
Based on production data taken April 2009

Coater 1

Gas IR			Dryer 1			Dryer 2		
Abs. Energy	792 MBH	232 kW	Abs. Energy	2,065 MBH	605 kW	Abs. Energy	1,993 MBH	584 kW
Evaporation	238 lb/hr	108 kg/hr	Evaporation	1,217 lb/hr	552 kg/hr	Evaporation	1,655 lb/hr	751 kg/hr
			Imp Temp	498 F	259 C	Imp Temp	511 F	266 C
			Imp Vel	9,820 ft/min	49.9 m/s	Imp Vel	9,940 ft/min	50.5 m/s
Gas Cons.	1,898 MBH	556 kW	Gas Cons.	3,430 MBH	1,005 kW	Gas Cons.	3,404 MBH	998 kW
			Elect Cons	86 HP	64 kW	Elect Cons	86 HP	64 kW

Coater 2

Gas IR			Dryer 3			Dryer 4		
Abs. Energy	793 MBH	232 kW	Abs. Energy	1,939 MBH	568 kW	Abs. Energy	1,768 MBH	518 kW
Evaporation	325 lb/hr	147 kg/hr	Evaporation	1,114 lb/hr	505 kg/hr	Evaporation	1,699 lb/hr	771 kg/hr
			Imp Temp	505 F	263 C	Imp Temp	519 F	271 C
			Imp Vel	8,840 ft/min	44.9 m/s	Imp Vel	8,070 ft/min	41.0 m/s
Gas Cons.	1,898 MBH	556 kW	Gas Cons.	2,973 MBH	871 kW	Gas Cons.	2,846 MBH	834 kW
			Elect Cons	71 HP	53 kW	Elect Cons	57 HP	43 kW

Coater 3

Gas IR			Dryer 5		
Abs. Energy	443 MBH	130 kW	Abs. Energy	1,355 MBH	397 kW
Evaporation	201 lb/hr	91 kg/hr	Evaporation	1,010 lb/hr	458 kg/hr
			Imp Temp	311 F	155 C
			Imp Vel	8,720 ft/min	44.3 m/s
Gas Cons.	1,253 MBH	367 kW	Gas Cons.	2,159 MBH	633 kW
			Elect Cons	80 HP	59 kW

Coater 4

Gas IR			Dryer 6		
Abs. Energy	223 MBH	65 kW	Abs. Energy	1,474 MBH	432 kW
Evaporation	151 lb/hr	69 kg/hr	Evaporation	1,337 lb/hr	607 kg/hr
			Imp Temp	342 F	172 C
			Imp Vel	8,050 ft/min	40.9 m/s
Gas Cons.	633 MBH	185 kW	Gas Cons.	2,753 MBH	807 kW
			Elect Cons	54 HP	40 kW

Total Energy Consumption from Gas	*23,248 MBH*	*7.6% Decrease*	*Gas Cost*	*$1,327,909 /year*
Air Dryer Gas Consumption	*17,566 MBH*	*9.9% Decrease*	*Electrical Cost*	*$173,206 /year*
Total Water Evaporated	*8,947 lb/hr*		*Total Cost*	*$1,501,116 /year*
Gas Energy Consumption per lb Water Evap.	*2,598 BTU/ lb H_2O*			

TOTAL SAVINGS PER YEAR: $98,148 ***CONSERVATIVE ESTIMATE: $90,000***

Figure 4b. Drying simulation results – post-rebuild estimate

it is critical to look at the process as a whole and not in isolation. This also provides opportunity to look at shifting drying from higher cost dryers (e.g. IR) to more efficient air dryers to realize the full potential of the dryer section. As illustrated above, the projected air dryer savings was 9.9%. Overall however, the dryer section savings were predicted to be slightly lower (7.6%) due to the machine configuration and shifting of the drying within the dryer section.

Dryer rebuild

By maintaining the same dryer air volumes and temperatures (or less) all of the existing ancillary equipment (e.g. ductwork, fans, burners, instrumentation, etc.) could be reused, saving considerable cost and downtime; thus providing a very attractive return on investment. Based on the projected return (e.g. energy savings <3yr ROI), plus the opportunity to improve sheet quality and runnability (e.g. machine efficiency), the decision was made to rebuild the two (2) oldest dryers (#5, 6), by using the latest generation air bar technology.

The two existing air flotation dryer hoods were modified to accommodate the new air bar technology. New return air screens were also installed between the air bars and around the internal perimeter of the dryers as shown in **Figure 5**. To fully optimize the two (2) dryers, additional repairs were also made to the dryer's air supply and exhaust systems. The entire dryer rebuild process, for both dryers, took less than 72 hours.

Figure 5. Dryer rebuild –Before slotted bars (wide spacing) and large screens on left and after new bars and return screens on right

Conclusions

Figure 6 illustrates the initial results of actual production conditions measured before and after the dryers were rebuilt with the new air bars. Post rebuild testing confirmed savings due to improved nozzle performance in the order of 10% (compared to 7.6% predicted). An additional 5% savings was realized principally due to the refurbishment and optimization of the existing equipment, controls and air systems (e.g. rebalancing, dryer cleaning & alignment, etc.).

This next generation of air bar technology provides significant benefits in terms of:

- Superior heat transfer resulting in greater operating efficiency
- Improved sheet runnability
- Relatively simple retrofit (minimal investment, little down time)

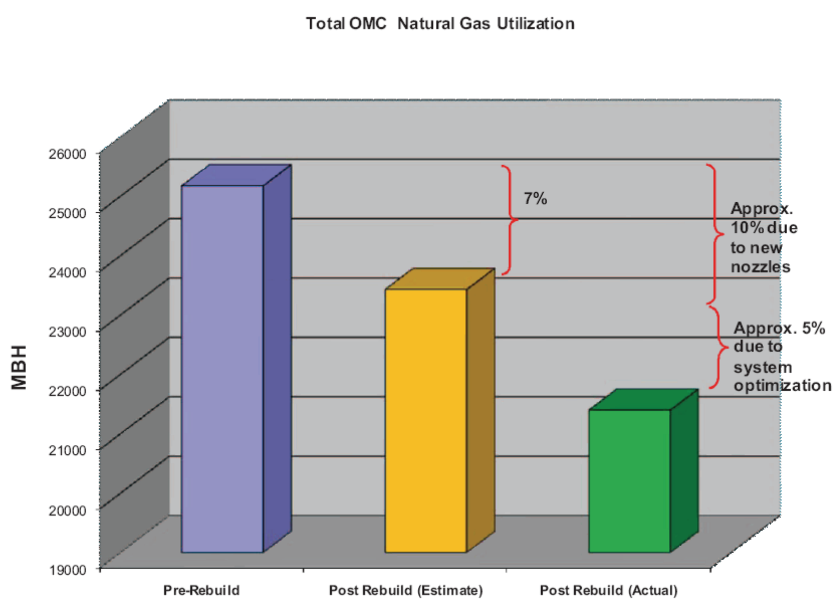

Figure 6. Energy savings

Case study #2: Drying strategy background

Drying is a critical part of the quality formation process of coated paper. In support of this, many studies have been undertaken to look at how drying strategies affect quality, and to confirm the best drying strategy to use. The most common drying strategy used today is the so-called "high-low-high" theory. The consensus of these earlier studies has been that the drying rate during the "critical" drying phase is the main factor contributing to mottle (e.g. unevenness of the print surface). Uneven binder migration has been assumed to be the reason for uneven surface properties, leading to non-uniform printing. No conclusive evidence however for this has been found in surface binder content analysis. Unfortunately, many of the earlier studies were limited due to the layout of the pilot coaters. Generally the pilot machine configurations included an infrared (IR) dryer, free draw, and air dryer. If part of the coating has been consolidated in the IR dryer or free draw, the rest of the coating has to be consolidated in a similar fashion (low evaporation rate) in order to reach the same coating structure. This leads to a failed conclusion, e.g. that the best strategy is that a low drying rate has to be maintained in the later part of the drying section (high-low-high strategy) in order to maintain coating structure.

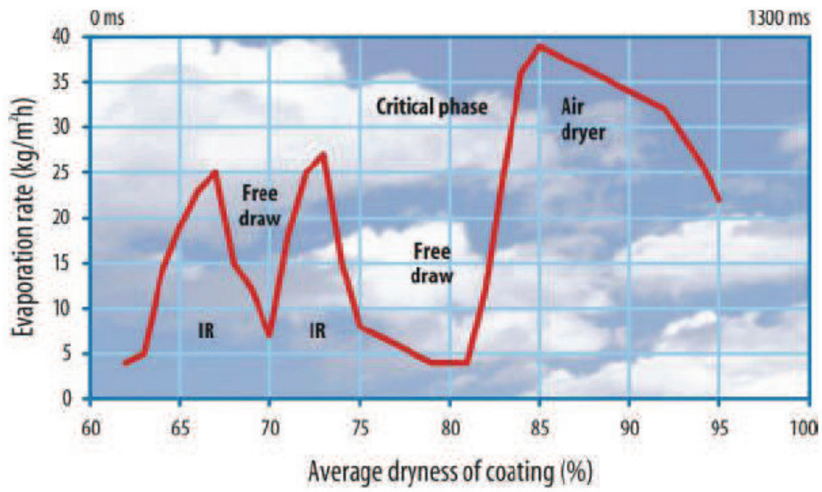

Figure 7. Traditional "high-low-high" drying strategy

Hi-intensity air dryer

Given the limitations associated with the earlier studies, a new study was undertaken to see the effects in coating quality and binder gradients if the coating is dried using a single-sided high intensity dryer. Utilizing newly developed nozzle designs (see Case Study #1), and a hi-intensity dryer system, it was possible to test the "all-high" drying hypothesis using an all air dryer, in place of traditional IR.

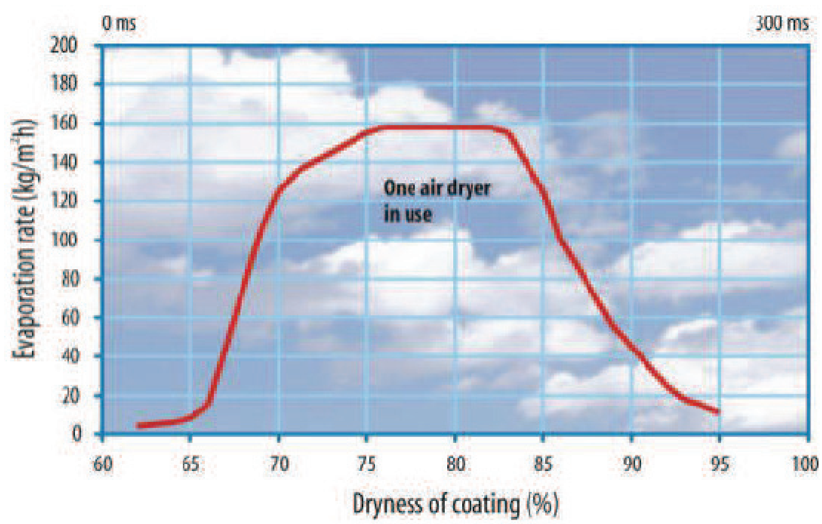

Figure 8. New "all-high" drying strategy

Paper grade	Base paper	Precoating (g/m^2)	Top coating (g/m^2)	Top coat color	Speed (m/min)
Triple coated WF	WF1 80 g/m^2	8+8+12+12	12+12	2	1500
Double coated WF	WF1 80 g/m^2	8+8	12+12	2, 3	1000
LWC	LWC1 40 g/m^2	none	12+12	2, 7	1000
LWC	LWC2 45 g/m^2	none	12+12	8	1000
Double coated board	Board 190 - 215 g/m^2	10 (TS)	12 (TS)	5, 6	500

Color	2	3	4	6	7	8
Fine clay (HG 90)	70	70	30	70		
Ground fine carbonate (HC 90)	30	30	70	30		
Delaminated clay (Astraplate)					100	100
SB latex A, Tg +10	12		12		12	6
SB latex B, Tg +15						
SB latex C, Tg +0		12				
VinAcetAcrylic latex D, Tg +15				14		
CMC	0.8	0.8	0.8	0.8	0.8	0.8
Oxidized Starch						6
Hardener	0.1	0.1	0.1	0.1	0.1	0.1
Lubricant	0.5	0.5	0.5	0.5	0.5	0.5
Optical brightener	0.2	0.2	0.2	0.2	0.2	0.2
Solids	62	62	62	63	60	60

Figure 9. Trial conditions

A broad cross-section of grades and coating colors were tested as part of the coating/drying trials.

The pilot trials on LWC, WF and board were conclusive in confirming that a single hi-intensity air dryer, in place of IR, could net excellent results including:

- higher drying (evaporation) rates
- mottle, gloss and smoothness improved when effective air drying is included immediately following the coating station
- air drying is equal or superior to IR in terms of paper quality

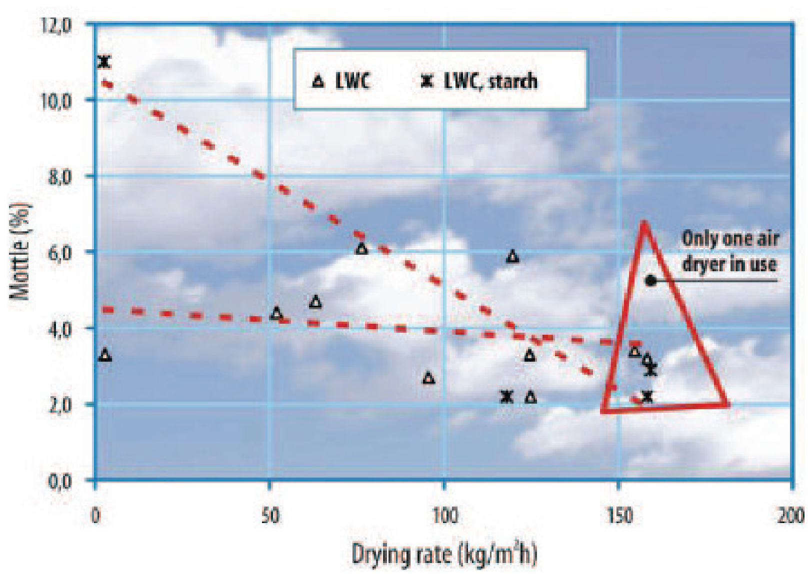

Figure 10. Test results: reduced mottle- single hi-intensity dryer

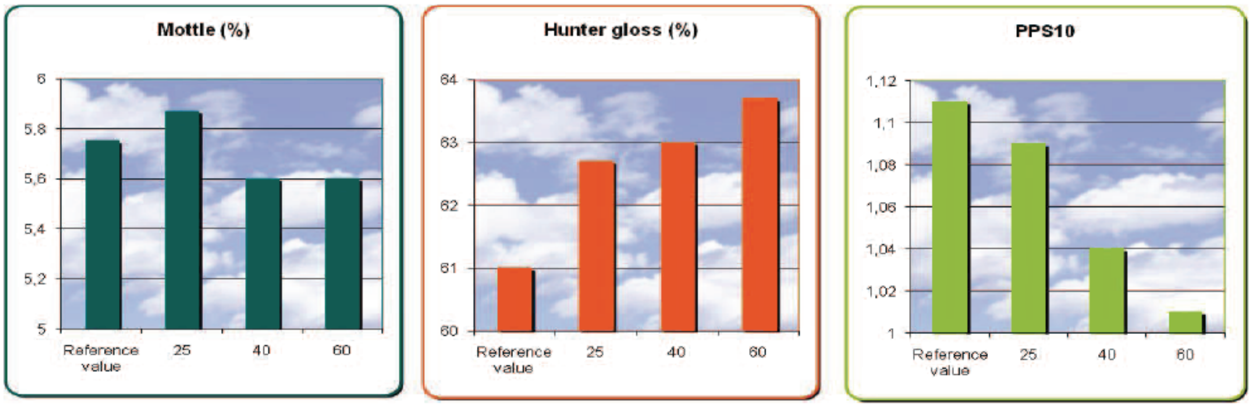

Figure 11. Test results: mottle, gloss, smoothness
"Reference Value"= gas IR; new dryer with impingement velocities 25, 40, 60 m/s

This series of pilot trials confirmed that a very uniform surface porosity distribution was possible using extremely high evaporation rates and a single dryer, resulting in better print characteristics. From this, it was possible to prove that a "high-high-high" air drying strategy could produce very even porosities resulting in less mottling, better gloss, and increased smoothness.

Dryer rebuild

Building on the success of the pilot trials, this new high-high-high drying strategy was implemented on a production machine. As part of the rebuild e.g. two (2) existing gas fired IR dryers were replaced with two (2) new hi-intensity air dryers. The new dryers fit into the exact location of the IR dryers, thus eliminating the need to reconfigure the machine and the associated costs. Utilizing new nozzle designs, the single sided hi-intensity dryer system is very similar to a traditional air dryer configuration including, a supply fan, burner, air dryer, combustion fan, make-up air and exhaust (heat recovery optional), pictures in **Figure 12**.

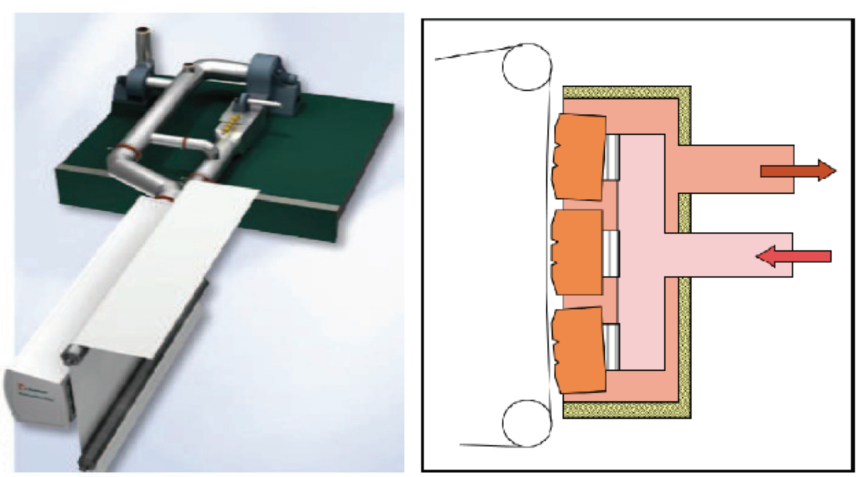

Figure 12. New hi-intensity air dryer
Typical dryer arrangement (on left) and dryer to sheet positioning (on right)

Results from the rebuild confirmed what was expected from the pilot trails in terms of sheet quality. In addition, significant benefits were also realized in terms of energy savings, and operations. **Figure 13** illustrates the comparative evaporation rates between typical drying strategies. Operating at approximately 450 ° C, 60 m/s the hi-performance dryers can deliver a significant amount of energy to the sheet. This increase results in approximately 20% more evaporation per square meter compared to traditional gas IR dryers; while maintaining runnability and sheet quality. In terms of drying efficiency (e.g. energy costs), the hi-performance air dryer operates at close to 80% efficiency, compared to traditional IR at approximately 35%.

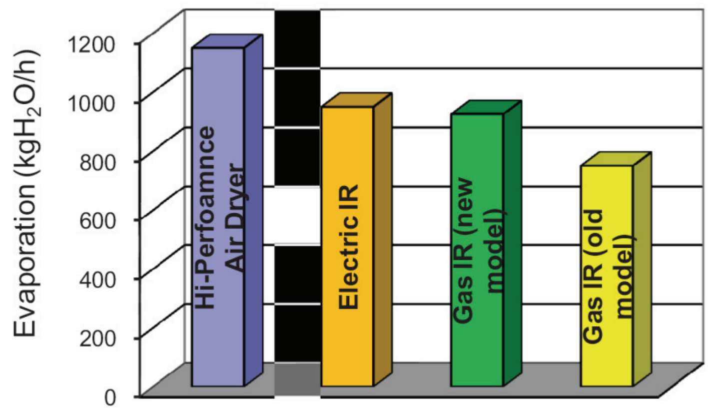

Figure 13. Relative evaporation rates

Conclusions

Based on the results from this recent rebuild, the new hi-intensity dryer concept has proven to be successful in delivering:

- Energy savings e.g. 60-80% drying efficiency with air drying, 25-40% with IR drying and reduced carbon footprint (50% less fuel burned= 50% less CO_2 formed)
- Higher drying capacity (more production potential)
- Much lower maintenance costs (approx. 0 with air dryers)
- Improved operating conditions, e.g. lower machine hall moisture and heat loads
- Equal or better paper quality (mottle, gloss, smoothness) compared to IR
    - Lower web temperature
    - Less water penetration
    - Higher binder content on the paper surface
- Low investment costs/evaporation ($/$H_2O$/$ft^2h$) compared to IR
- Greatly reduced operating hazards (e.g. fires)

Summary

The development of new dryer bars and dryer designs have opened up a number of possibilities to improve coater drying with significant benefits in reducing energy, improved finish quality, carbon footprint reduction, increased operating efficiency and improved overall Mill profitability. Compared to traditional air drying, savings are in the order of 10-15%. Compared to IR drying savings are in the neighborhood of 30-50%.

This white paper combines technical information obtained from Valmet personnel and published Valmet articles and papers.

Valmet provides competitive technologies and services to the pulp, energy and paper industries. Valmet's pulp, paper and power professionals specialize in processes, machinery, equipment, services, paper machine clothing and filter fabrics. Our offering and experience cover the entire process life cycle including new production lines, rebuilds and services.

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