INTRODUCTION

The large number of variables that determine performance of the dryer section of the paper machine require constant monitoring and evaluation. To effectively improve the operation and achieve optimal performance in the dryer section, a systematic approach must be given to the optimization process. Sheet properties, felt permeability, felt design and tension, pocket ventilation, hood air systems, dryer surface scale and condensate removal are among the multitude of factors that affect dryer performance.

Maximizing the runnability and efficiency of the dryer section requires a holistic view that considers the dryer section as a single unit and not separately as individual components (e.g. dryer cylinders, air systems, syphon design, drainage system, etc.). Condensate removal and air systems account for more than 65% of the variables that effect the overall performance of the dryer section. Because the dryer section is heavily influenced by these two elements, serious consideration must be given to these areas as well as those areas that are directly impacted by condensate removal and the air systems in the dryer section. This article presents a framework for optimizing the performance of the dryer section using a four-step process which utilizes key dryer performance measurements. Special attention is given to syphon selection and its relation to machine runnability and maximum system flexibility.

FRAMEWORK FOR DRYER SECTION OPTIMIZATION

The four-step process for optimization of the dryer section involves: 1) Can-by-Can® steam flow analysis, 2) syphon selection and design, 3) steam and condensate system analysis, and 4) energy balance analysis.

Can-by-Can Analysis

The machine operating conditions such as speed, steam pressures, moisture content of the sheet, furnish, size of cylinders and grade of paper are among the key inputs used in the Can-by-Can steam and condensate flow analysis. There are three measurements that are generated from this program to diagnose current conditions and then evaluate dryer section performance prior to defining and implementing a solution. These dryer performance measurements include: 1) drying rate, 2) heat transfer coefficient and 3) dryer surface temperatures.

The drying rate is defined as the amount of water evaporated per hour for a given area. Drying rates are used to benchmark the actual machine performance against industry standards. The higher the condensing rate for a given sheet, the higher the performance of the dryer section. If the drying rate is relatively low, dryer section operating variables such as poor condensate removal must be identified and addressed. Other factors that impact the drying rate include the steam pressure, moisture content of the sheet, pocket ventilation systems and fabric design.

The second dryer performance measurement, heat transfer coefficient, examines the thermal efficiency of the dryer section. Since the efficiency of the dryer section includes the flow of heat, the heat transfer coefficient ‘U’ establishes a performance measure that can be compared to machines producing similar grades. The greatest resistance to heat transfer is the layer of condensate inside the dryer cylinder. Additional variables that have an effect on the heat transfer coefficient include: felt design and tension, dryer scale, dryer shell thickness, non-condensable gases inside the dryer, and dryer section air systems. Maximizing the condensate removal process creates a highly efficient operation in the dryer section. A high U-factor indicates good heat transfer and efficient removal of condensate while a low U-factor suggests room for improvement in the dryer section.
### Steam to Dryer Temperature Differences

The third dryer performance measurement used to optimize dryer section performance is dryer surface temperatures. High differences between steam temperature and dryer surface temperature suggest poor condensate removal. The differences between the two temperatures are dependent on machine speed and drying rate. However, any deviation greater than 33°C (60°F) indicates problems with the condensate removal. Charting the difference between the steam temperature and the dryer surface temperature allows for the machine operator to target flooded dryers or dryers not evacuating condensate properly. This measurement gives the operator a tool to troubleshoot and identify areas for improvement in the dryer section.

From the Can-by-Can analysis, equipment sizing can also be reviewed. The key factors determining rotary joint and syphon sizes are the flow rate, steam pressure, and desired flow velocities. It is important to have the Can-by-Can figures available to make the calculation for the proper size of equipment. Often the syphon and joint sizing process is thought of as little more than an exercise in choosing the right diameter pipe. In actuality, however, it is here where much of the actual design of the entire syphon system is determined and the required components selected.

### Syphon Selection & Design

The second step of the optimization framework utilizes the results of the Can-by-Can analysis to consider the most crucial aspects of effective dryer section performance: syphon selection and condensate removal. The optimization of the dryer section can and should begin with properly designed and selected syphons for the paper drying cylinders. The primary criteria used in selecting a syphon system is machine operating speed. Figure 1 shows the various syphon designs available and the recommended design according to machine speed. Other factors such as steam and condensate system design and machine design also play a role in syphon selection. However, machine speed is the key determinant in syphon selection.

There are eight basic designs of syphon systems to select from. Each design has its benefits and advantages, as well as its disadvantages. In most applications, there are at least two syphon design alternatives that will provide for optimal condensate removal. Syphon system applications should be reviewed on an individual basis to identify all possible syphon design options. Using a one-design-fits-all approach will inevitably lead to a narrow definition of alternatives and will not provide for dryer section optimization. Considering machine operating speed as the only variable, there is one syphon design that is recommended for all machine speeds -- the cantilever stationary syphon.

The cantilever stationary syphon was designed with two considerations in mind: reliability and runnability. The operating variable that has the greatest effect on long term performance and success of the stationary syphon is vibration. Because all mechanical components have an inherent natural frequency and resulting vibration, it is important that the syphon design minimizes vibration. In addition, the natural frequency of the syphon equipment should not be within ±25% of the natural frequency of the dryer cylinder. If the natural frequency of the syphon equipment is within this range, or the second or third harmonics of the natural frequency of the cylinder, serious amplitudes in vibration will occur and premature failure of the syphon is possible. For this reason alone, all syphon manufacturers should analyze the natural frequency of the cylinders as well as the stationary syphon equipment to avoid catastrophic failure of the syphon.
<table>
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<td>Low Differential Rotary</td>
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Figure 1: Syphon Selection Guide

Many paper machines today are rebuilding the dryer section and including cantilever stationary syphons as a technology to simplify the design of the steam and condensate system as well as improve efficiency of the dryer section. The constant differential pressure of 0.20 bar (3 psig) will adequately evacuate the dryer under any operating condition. This low differential pressure requirement also permits better control in the wet end where the operating pressures can be sub-atmosphere and creating high amounts of differential pressure is difficult. The minimized blow-through steam rate of 10% to 12% results in potential steam savings and permits smaller return line sizes and valves due to the lower volume of blow-through steam in the system.

Cantilever stationary syphons are generally applied to machines operating at medium to high speeds due to the fixed and minimal differential pressure and blow-through steam requirements. Felt driven dryers are also a prime candidate for cantilever stationary syphons as it is difficult to stop the dryer with the syphon always in the six-o-clock position. If the rotary syphon is not in the six-o-clock position when the machine is stopped, some condensate will remain in the dryer and may cause additional strain on the drive system as more amps are required to turn the dryer with condensate inside the dryer. Another advantage of stationary syphons is the motive steam usage is lower compared to a rotary syphon. This is due to the fact that rotary syphons will always require a higher operating differential pressure than stationary syphons. Higher motive steam pressure is required to create this larger differential with a thermocompressor system.

A well supported cantilever stationary syphon can successfully operate at a clearance of 3mm (1/8”). Because the syphon clearance determines the level of condensate inside the dryer, the goal is to minimize the syphon clearance to maximize heat transfer and cross machine temperature profile. A traditional rotary syphon clearance is factory set at 1.5mm (1/16”) while the stationary syphon clearance can vary according to the syphon design. Turbulator bars are highly recommended when a stationary syphon system is used due to the higher clearance requirement of the stationary syphon.

Turbulator bars re-introduce the turbulence inside the rotating dryer to improve the heat transfer and create a level cross machine temperature profile. When rotational speed increases, so do friction and centrifugal forces which carry condensate in the direction of rotation up the side of the dryer drum, eventually rimming the entire inner circumference of the dryer. In the rimming stage, gravity causes deceleration of condensate moving upward and acceleration of condensate moving downward. This variation in speed causes oscillation and produces turbulence in the condensate that reduces the condensate’s resistance to heat transfer.
When rotational speed continues to increase, oscillation decreases, the condensate flow becomes more laminar, and is more resistant to heat transfer. When this laminar rimming stage occurs, Turbulator bars can be placed inside the dryer to break up the rimming condensate's laminar flow. Turbulence is reintroduced into the condensate, heat transfer rates increase, and dryer efficiency is improved.

Turbulator bars can make significant contributions to improved dryer efficiency and paper quality when they are used under the proper conditions. The effectiveness of Turbulator bars is determined by an interrelationship between dryer speed and condensing load. As the machine speed or condensing load increases, improvements can be found in the heat transfer rate and in moisture profile. At speeds below the laminar rimming stage, where sufficient turbulence is already present in the condensate, bars are usually less effective at increasing the heat transfer rate. However, the decrease in cross-machine temperature deviation resulting from the Turbulator bars will provide for a level moisture profile across the sheet at any operating speed.

**Dryer Drainage Analysis**

The third component in the framework for optimization of the dryer section is the analysis of the steam and condensate system. A well designed steam and condensate system will efficiently remove condensate, allow for maximum control of steam pressures, and minimize steam use. A poorly designed system will cause dryer flooding, limits on drying capacity and excessive energy consumption. In addition, the quality of the sheet will be effected due to problems encountered with poor moisture profiles, cockle and wrinkling of the sheet due to poor steam pressure control and varying shell temperatures. Various designs of drainage systems are available and should be applied according to the machine design and paper grades being produced. A first class system will include the ability to graduate wet end steam pressure, prevent sheet picking, wrinkling, cockle and maximize control of the blow-through and differential pressures for optimal condensate evacuation.

To properly design the steam and condensate system, accurate information regarding the operation of the paper machine is necessary. Data such as condensing loads and blow-through steam rates are crucial to the proper design of the system. These calculations must account for unorun dryers, pocket humidities, felt arrangement, sheet moisture, dryer diameter and existing or recommended syphon flow characteristics among other inputs. As presented earlier, a Can-by-Can analysis will provide this data and allow the system designer to properly design the optimal drainage system.

**Energy Balance**

The final consideration of the framework for optimization is the energy balance as it relates to hood exhaust, air flows and pocket ventilating systems. Because air flow systems can impact the efficiency and performance of the dryer section, it is presented as the fourth and final component in the framework for optimization of the dryer section. A key performance factor to be measured for identifying proper air flows is hood air balance. Hood air balance is defined as the ratio of units of dry air supplied to units of dry air exhausted. Recommended hood air balance values are 0.25 to 0.35 for an open hood, and 0.60 to 0.70 for a closed hood. If the hood air balance is too low, edge lifting, sheet flutter, humidity variation and condensation in the hood can result. When the value is high it can signify high energy use and create sheet instability in the unorun section. For these reasons, optimization of the dryer section must include a review of the hood air balance to ensure maximum efficiency.

Figure 3

Pocket humidities must also be reviewed to ensure good performance of the dryer section. This dryer performance measurement can be used to benchmark against “good performance” standards in order to identify areas for improvement within the dryer section. With good pocket ventilation values, the drying rate can be enhanced significantly. However, too much pocket ventilation can cause system control problems as the steam pressures are reduced to compensate for the over drying capacity of the system.

The pocket of a dryer section is created by the draws of the sheet, the dryer shell and the felt draws and roll. Pocket humidities serve as an important factor when considering dryer section optimization and water evaporation from the sheet. Pocket humidity values vary over a wide range and are defined as the amount of water vapor per unit of dry air. Peak pocket humidities can be as high as 1.3 units of water per units of dry air. However, at this condition the
pocket air is saturated at 90°C (195°F) and no moisture can evaporate from the sheet until the absolute humidity of the pocket is reduced to approximately 0.65 units of water per units of dry air. A good target level which is also the industry standard is 0.25 units of water per unit of dry air. If there is a wide variation between the center and edge humidities, the moisture profile of the sheet is effected and quality suffers.

**PYRAMID OF OPTIMIZATION**

A pyramid of dryer section optimization is created when we consider the framework for optimization of the dryer section four components. The basis for beginning the optimization process is the analysis of the drying rates, heat transfer coefficient, and dryer surface temperatures. All of these measurements can be made with the Can-by-Can steam and condensate flow analysis. The second level of the pyramid is syphon selection and design. Because condensate removal accounts for such a large portion of variables effecting dryer section performance, this level must be analyzed in detail prior to moving to the next level of dryer drainage system design. The information generated by Can-by-Can analysis and equipment analysis provides the basics for evaluating the drainage system design and gives insight into what can be improved for maximum efficiency. The fourth level of the pyramid closes the loop in the dryer section by examining the energy balance of the dryer section. Although it is the last step proposed in this framework, it is certainly not any less important to the overall strategy of considering a holistic view to dryer section optimization.

**CONCLUSIONS**

The large number of variables that effect dryer section performance require a systematic approach to optimization that considers all aspects of the dryer section. A simplistic view of only one area will not provide the operator enough information to accurately define a solution to the inefficiencies of the machine. Using the framework presented above allows the user to take a holistic view of the dryer section performance and considers the most crucial areas as building blocks to optimization. With the goal of dryer section optimization, papermakers can take confidence in knowing that a holistic view will address the most serious performance issues and provide results beyond expectations.