The Vacuum System Survey – Its Contribution to Papermaking

Doug Sweet, P.E.
Doug Sweet & Associates, Inc.

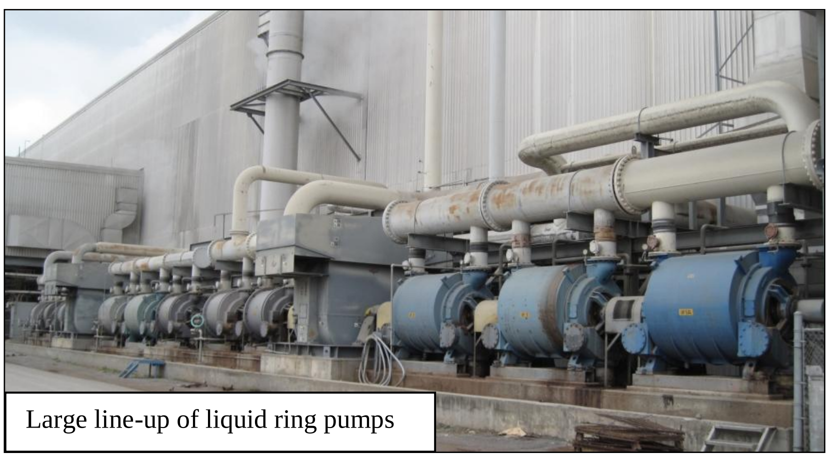
ABSTRACT:

Papermaking consists of many interrelated subsystems, including stock cleaning, refining, wet end chemistry, forming, pressing, drying, and others. Another important, but often misunderstood, system is the vacuum system. Why is this system misunderstood and how do problems with the vacuum system operation impact sheet dewatering and paper machine performance?

Vacuum System Surveys, with proper data collection and analysis, are important in the paper machine optimization process. Every system could be studied as early as 2-3 years following start-up, before small unidentified issues become big and costly problems. As the paper machine processes evolve and age, the vacuum survey can identify limitations which have been created. These problems cause limited dewatering, poor vacuum control, added operating power, and vacuum pump wear. Early and thorough process examination can minimize the impact of these problems. Vacuum surveys require much more than calculating vacuum factors for each vacuum element. Every survey will acquire its own objectives and outcomes, as well as focusing on problems uncovered during the survey process. The following presentation will address the suggested scope of the vacuum survey, important vs. unnecessary data, analysis and recommendations needed to provide useful action steps for the continuous improvement effort.

DISCUSSION:

The vacuum system affects formation, sheet dewatering, felt conditioning, and press performance and these all impact overall machine efficiency and production rates. Over time, operation of the vacuum system often transforms into an improperly operated and inefficient process. Generally, the vacuum pumps are forgiving and require little maintenance. This statement is true for most liquid-ring and many multi-stage centrifugal exhauster systems. This also means the vacuum system receives little attention, which can have good and bad effects.



Large line-up of liquid ring pumps

A favorite phrase used in my 2009 TAPPI presentation titled, "Ten Myths about Paper Machine Vacuum Systems", stated an important rule. It was: You can get the sheet to the reel with a really screwed up vacuum system. The following rule in the list said, "If you think there is nothing wrong with your vacuum system, then refer to the previous rule." Studies of over 200 vacuum systems, following a career of designing, selling, and starting up these systems qualifies one for making these bold remarks.

Place a group of papermakers, engineers and machine tenders in a room and ask about typical processes where pressure is measured or controlled. About everything in the process is intended to operate at a necessary pressure. These include systems such as steam, hydraulic, stock prep, stock cleaning, fabric showering and compressed air. But, the vacuum system operates at a negative pressure. Next, consider process equipment creating fluid flow and pressure and these are typically centrifugal pumps. But, the majority of vacuum systems are using positive displacement pumps. Combine negative pressure, or vacuum processes, with positive displacement pumps and the misunderstandings begin. Bring papermakers and engineers from a mill with liquid-ring vacuum pumps and take them to a mill with a centrifugal exhauster system and the situation is not much different. This is because liquid-ring pump principles, even with limited understanding, are often being applied to a completely different kind of vacuum system.


Vacuum system issues also apply to exhauster systems

Components of a Good Vacuum Audit:

At this point the need for a vacuum system audit is clear. A vacuum survey can vary from a minimal overview to an extensive system analysis requiring several full days on site. Below, the system is separated into areas of study during a vacuum system audit.

Vacuum Control: I am often asked, "What is the most common problem found with paper machine vacuum systems"? My answer is, "Poor vacuum control". Note, the second most common issue is poor vacuum measurement.

The most need for control of vacuum levels is found around the former. This can be a fourdrinier or new twin wire gap former, but all will have a few or several vacuum elements requiring some means of limiting or maintaining the level of vacuum. Control, or lack of control, will include valve selection (size and type), maintenance issues preventing valve operation, design errors concerning the vacuum control scheme, and poor vacuum measurement causing incorrect control. Additionally, if a DCS displays this information, many screens show vacuum schematics which are out of date, incorrect, difficult to follow, or have mis-labeled vacuum elements. Some mills still are referring to a series of flatboxes or a tri-vac, as the Flo-Vac.

Often, brand new flatbox, tri-vac and quad-vac systems are installed and vacuum levels are limited because vacuum piping and valves are undersized, or control is poor because throttling valves were greatly oversized and must operate in nearly closed positions. Sometimes the need for a valve was not recognized and it is missing from the process, such as a vacuum inbleed valve.

Problems resulting from inadequate vacuum control can include or cause:

- Excessive vacuum system energy consumption
- Vacuum pump motor overloading
- Inconsistent vacuum levels leading to MD dewatering variations
- Sheet formation problems and sheet sealing, which limits dewatering

Vacuum gauges may not be accurate

Vacuum Measurement: Accurate vacuum measurement at the pumps and paper machine is required. Do not assume DCS values are correct. Do not rely on local gauges unless they are high quality and/or relatively new. Well designed systems should have less than 1" Hg of vacuum differential between the paper machine and vacuum source, no matter how long the piping run may be. Further investigation is needed when vacuum measurements reveal significant losses.

Vacuum Piping: Time should be spent in a general review of vacuum piping, assuming an accurate system drawing is available. Guidelines have been established for recommended velocities to use for dry air (after separators or for applications without liquid water) and for wet air (containing liquid water before separators).

- Wet Air: 3500 – 4000 fpm
- Dry Air: 5500 – 6000 fpm

Vacuum level measurements at the pumps and paper machine elements will indicate if vacuum losses exist. While taking these vacuum measurements, do not rely on existing gauges and transmitters. If possible, take all measurements with a single, accurate, vacuum gauge. As mentioned earlier, well designed systems should have no more than 1” Hg of vacuum loss.

An easy estimate of ideal pipe size is to observe the pipe sizes at the vacuum pump. If connected piping is smaller, there can be a problem. In a recent review of uhle boxes on a tri-nip press, a 10,000 cfm vacuum pump was used for the two uhle boxes on each felt. The vacuum pump had two 14” diameter vacuum inlets. However, the uhle boxes were 10” and 12” diameter, where they both should have been 16” (handling liquid water, not dry air). Not surprisingly, uhle box vacuum was 12” to 15” Hg while the vacuum level at the pumps was 17” Hg. Besides requiring the vacuum pump to operate at higher horsepower, vacuum losses of several inches of mercury consumes a portion of the available vacuum capacity necessary for specific dewatering operations. Observed systems can lose 10 to 25% of connected vacuum airflow due to these vacuum losses.

It is surprising how many paper machines are operating with 8, 10 or 12 (and more) vacuum pumps, requiring 3000+ horsepower, and an accurate vacuum system schematic does not exist. An accurate P&I drawing is required.

Having a well designed vacuum system is only useful when every component works properly, consistently, and continuously. Enhancing the system with correctly labeled vacuum pumps, piping, valves, and auxiliary components will assure ease of troubleshooting, good maintenance and system analysis. You cannot study a vacuum system unless you can be sure of what connects to what. Consider color coding the lines on a P&I or a simple schematic used by operators and stuck on the control room wall. This makes it easier to understand the system.

Vacuum Separators: Air/water separators can come in all sizes and shapes. Square and rectangular designs are more common to the forming section where the required cross sectional area fits in limited spaces better than with a cylindrical design. Tangential inlets on cylindrical separators may be more common for uhle boxes and larger flatboxes. The shape isn’t as important as the working area required to achieve reduced velocity within the separator and allow entrained liquid water to fall from the vacuum airflow. Internal velocities of 500 – 1000 fpm are recommended for most separators.

Separators are important in all vacuum systems

The necessity of these separators will often need to be reviewed because not all vacuum applications require separators. First, determine the type of vacuum equipment in use. Centrifugal fans for low-vac elements should all have a “secondary” separator just prior to the fan. During the audit, look for signs of whitewater carryover to the centrifugal fans causing them to operate out of balance. All vacuum systems using centrifugal exhausters need separators for all vacuum services. These can be a combination of tangential inlet/cylindrical body units often used for uhle boxes and large concrete chambers located in the basement. Any stationary vacuum element requires a separator. These include flatboxes, uhle boxes and transfer boxes.

Suction rolls all require separators when machine speeds are below 1500 fpm. Higher speeds will allow most of the water extracted from the sheet to sling out rather than be pulled into the suction box. Suction rolls handling high volumes of water such as a forming roll, or suction breast roll on a tissue machine should have a separator. Some vacuum systems are designed with once-through seal water systems where fresh water is used for seal water and flows through the vacuum pumps, is collected, then returned to the source (river). A turbidity or conductivity meter is used to measure significant changes in seal water quality as it is discharged from the pumps. This gives an indication of contamination due to carryover from a vacuum process. These systems will have separators on every vacuum service to greatly minimize the possibility of contamination. The seal water is then treated as non-contact cooling water.

The auditing issue is related to getting the water out of the separator. When these are properly elevated with well designed barometric drop leg piping and seal tanks, they are usually trouble free. Problems develop when long horizontal runs of piping are used for drop legs, or when a lack of elevation requires an extraction pump.

Separators located in the basement and requiring extraction pumps are often troublesome. It is difficult to pump from a vessel which is under vacuum and the simplest recommended feature would be using a weir tank to allow confirmation that the centrifugal pump is even working. Selection of the type of pump is made where consideration of suction piping details and positive shaft sealing are important features. Adding instrumentation and automatic level control often leads to problems where transmitters quit working, and pumps quit pumping. It would require a couple more pages to describe all of the possible scenarios found to be wrong with these separator/pump systems, but at a minimum, understand that a shaking separator means it is likely full of water. This is only a symptom indicating a significant problem of water carryover to the vacuum pumps.

Bottom felt separator pumps need to be reviewed for flows and pump performance. This includes installation details, types of pumps, and most importantly seal water. Often, flows are observed from these pumps, at the weir, but seal water is discovered to be turned off, or there is a plugged supply line. Restoring seal water often results in significant flow increases.

These separator/pump issues often go unnoticed, or when observed, are not corrected. The reason for this is that when the extraction pump stops working, water just passes to the vacuum pump and the sheet still gets to the reel. Unless the extra water causes the vacuum pump to overload, the problem is usually not addressed. Consider water from uhle boxes containing acid or caustic felt cleaning chemicals which can carry over to the vacuum pumps during felt washes.

Vacuum systems with centrifugal exhausters or Roots-Connersville (rotary lobe) pumps will be the exception where extraction pump and separator issues will be quickly resolved, or vacuum pumps will be damaged. Liquid ring systems will slowly deteriorate with constant carryover of whitewater or uhle box water. A serious issue for liquid ring systems with carryover is when seal water is cascaded or recirculated and cooled with a cooling tower. A continuous flow into these systems will only concentrate and eventually cause problems with every vacuum pump in the system. Cooling towers have caved in within 6 months from these problems and others require major rebuilding after only a few years.

Seal Tanks and Weirs: The first weirs for uhle boxes appeared over 30 years ago. At the time they were rarely seen, but offered some interesting information about felt dewatering. Since then, they have become more common. Today the best paper machines include felt water flow measurement, with DCS displays indicating and trending all water flows from the press. Even without automatic measurement, weirs provide a visual indication for operators. This information is useful especially for bottom felt uhle boxes and separators requiring extraction pumps. Flow measurement from all felts and press nips is essential for optimizing press performance. Be sure to note which uhle box and which felts are flowing into a weir tank.

Weirs are useful to analyze vacuum dewatering performance

During the audit, weirs and flows should be observed. Flow rates are related to showering, felt age, production rates and felt positions so one must be aware of where the other end of the pipe is connecting to.

Vacuum System Horsepower: Audits of vacuum system audits often neglect to compare operating power for each vacuum pump to expected levels from performance curves. Usually, mills do not look at motor loads unless a particular motor is frequently overloading and tripping out. Typically, any vacuum pump will have a specific operating power based on the vacuum level and speed (rpm). This comparison of measured vs. expected power will indicate problems caused by whitewater carryover, excessive or inadequate seal water, and vacuum pump conditions.

Calculation of Vacuum Factors: Vacuum factors are typically in units of cubic feet per minute, per square inch of open area (cfm/in²). It is also referred to as vacuum density. These factors are essential in the initial design of a vacuum system, selecting vacuum pumps and piping design. With an existing system, the factors can be calculated by knowing the connected vacuum capacity and suction element open area. This is often part of the scope of a vacuum audit. However, it is usually given too much emphasis and results can lead to incorrect conclusions and recommendations. TAPPI TIP 0502-01 provides vacuum factors for most vacuum applications on most grades. Another important document, TAPPI TIP 0404-47, provides commonly observed values for sheet consistency leaving the former and press section, with observations for sheet solids on the top quartile of paper machines.

While the vacuum factor calculation is worthwhile, more important data is knowledge of existing couch and press solids, and verification of how this information was obtained (gamma gauge, grab samples, trim samples, or wild guess). Many paper machines achieve excellent sheet consistency values exiting the former even though the couch vacuum factor (for example) is 20 – 30% below the recommended level, according to the TAPPI document. Even the TAPPI document states that the suggested vacuum factors are "guidelines".

Can vacuum airflow be accurately measured? Methods for measuring vacuum system airflows through a pipe do not appear to be consistently reliable and accurate. Various forms of velocity measurement devices have been used, including pitot tubes and hot wire anemometers. Evaluating the data presented with this equipment suggests an accuracy of ±20 – 30%. Yes, the devices may indicate that a vacuum pump is 20% higher capacity than it really is, which is not a practical situation.

So, if you cannot directly measure vacuum airflow, the next best thing is to track operating vacuum and even vacuum pump horsepower on a daily basis. Knowledge of vacuum pump conditions and maintenance frequency can help to fill in the blanks for estimating vacuum airflow.

Vacuum pump condition: Complete understanding of the network of vacuum piping and assurance of which pump, or pumps, connect to every vacuum service is a critical step during the audit. This knowledge allows the vacuum factors to be calculated. But, recall the vacuum factors are in units of airflow per unit of area (cfm/in² is typical in North America). Therefore, the numerator value of vacuum pump capacity is important.

Some vacuum studies are presented with an across the board estimate that all pumps are only 80% of new pump performance. Some studies take this further and try to calculate saturated vacuum airflows based on inlet temperatures and seal water temperature. Whichever assumption or calculated value is used, this should be stated. However, an effort should be made to establish the condition of the vacuum pumps. Many years ago, vacuum pumps were only performance tested, on site, to determine their condition. This could require several hours during a shutdown just to test one pump. Even then, measured data could easily be inaccurate and result in incorrect performance estimates.

Today's technology of using fiber optics and experienced pump service personnel to examine the critical regions of vacuum pump internals allows relatively easy estimates of vacuum pump conditions. The fiberscope inspection should be made with the newest digital equipment allowing photographs to be taken of the pump internals. Although an accurate measurement of capacity can be provided with physical testing of the pumps, the cause of poor performance is likely to be unknown. Visual images will show critical clearances, points of wear, internal scale build-up, and other conditions which affect pump performance.

This information can now be plugged into the vacuum factor calculations, which we recall are to only be used as guidelines. The fiberscope inspection is useful and should be considered at least every other year so pump conditions can be tracked and maintenance can be planned.

Seal water systems: Although appearing at the end of this paper, seal water quality and control are essential to vacuum system performance for liquid ring pumps. Unfortunately, seal water is generally ignored, and pressures often are not monitored. Many times the pressure gauges are located following the orifices and therefore are indicating vacuum rather than a recommended pressure.

Early in this discussion, two items were described as the first and second most common vacuum system problems (vacuum control and vacuum level measurement). The third most common problem relates to seal water systems. They often are not well controlled (pressure and flow) or managed. When seal water is discussed by mill personnel, it usually is a question about the temperature of the supply. A more significant issue concerns the amount of water actually flowing to each pump.

Seal water varies widely with respect to water quality, temperature, recovery, reuse, treatment, etc. Liquid ring vacuum systems require seal water, and most vacuum pumps will develop vacuum with 20% or 200% of the required flow rate. However, low flow will limit vacuum capacity and the resulting vacuum level, where high flow will add to pump operating power. Specific conditions at each mill will dictate the availability of relatively clean water and its temperature. Millions of tons of paper are made with vacuum systems using clarified whitewater or process water which is 120°F, or more. Many southern mills cannot economically provide seal water that is always below 100°F, while Canadian mills will question the impact when their water gets to 80°F during the summer. But the vacuum pumps still allow couch vacuum to reach 20 – 22" Hg, even with some reduction of pump capacity due to warmer seal water. Don't get too concerned about the water supply temperature if there is at least some effort to assure flows are correct for each pump and piping is not plugged.

Generally, vacuum systems have been designed to use seal water at a supply pressure of 10 psi. This is based on orifices and spray nozzles being sized for 10 psi of upstream pressure. A reasonable range is 6 to 15 psi, because these values will provide ±25% of the recommended flow rate when a target pressure is 10 psi. My old scoutmaster used to say, "Don't ever do anything and say that is close enough!" However, in this case, this really is close enough. Local (and working) seal water pressure gauges are recommended at each vacuum pump.

Accurate seal water pressure measurement is important

During the audit, each seal water connection needs to be examined for possible plugging. This is usually easy enough to just touch the pipe to determine if it is warm, hot or cold, when compared to the temperature of a pipe which is carrying water to the pumps. Finding a plugged spray nozzle automatically reduces the flow to the pump by 25%. Finding a spray nozzle and orifice plugged on one pump cuts flow by half, and is a bigger problem if both of these are on the same half of the pump.

Mills which have a lower quality of water, and cannot use orifices due to constant plugging issues, will need to verify that adequate water is getting to the pumps. At a minimum, water supply can be adjusted to achieve the highest vacuum. After this point, added water does not help.

Seal water problems are compounded when cooling towers are used to maintain the temperature. Eighty percent of liquid ring vacuum systems installed in North America since 1990 have cooling towers because once-through seal water systems were no longer practical. Additional steps are necessary to maintain seal water flows to the vacuum pumps and through the cooling tower, while preventing serious problems with the cooling tower. These problems can include plugging of hot water distribution nozzles, fouling of fill material with biological growth and/or fiber, deterioration of plastic material used for drift eliminators, and even failure of internal structures and collapse of the fill sections within the tower. Any process water carryover from the vacuum system will only be concentrating within the closed loop seal water system. All of the earlier discussions about use of separators, weir tanks and correctly designed extraction pump systems become much more important now.

Vacuum pump discharge systems: All vacuum systems must eventually exhaust out of the mill. Often, they are noisy and/or are blowing water along with the air. Noise can be difficult to resolve, but often is caused more from leaking exhaust sumps and rusted out separator-silencers. Piping direction of the exhaust can be very important and usually, straight up is the best direction to minimize noise.

Water blowing from these systems can cause problems with housekeeping to serious ice build-up on roofs during the winter. Each discharge system is as unique as the vacuum system. They can have a traditional concrete trench and sump, above-ground separators, manifolded groups of pumps exhausting into a few large separators, and many combinations of each of these options. Basically, water needs to be able to get out of the system so air and vapor can flow to atmosphere. Items limiting this include poor sump level control, excess water carryover, excess seal water flow and plugged drains on individual separators. Some of these can be investigated while the system is operating and the rest needs to be checked out while the system is down.

CONCLUSION:

Most process audits reveal opportunities for making improvements. Frequently, the audit provides the single and significant find that, by itself, makes the whole effort worthwhile. Be sure that each recommended modification is worthy. For example, do not replace piping bottlenecks unless the actual vacuum loss has a measured and negative impact on production. Be a little careful to distinguish if the audit and recommendations are actually an equipment proposal disguised as a report.

Finally, and probably most important, use the suggestions presented here and develop daily, weekly and monthly audits and incorporate them into routine procedures to be practiced by mill operators, maintenance, E&I and even management personnel. These people can observe weirs, use infrared thermometers, replace broken vacuum and pressure gauges, and make most of the necessary observations which can make that "big find" during the team audit nonexistent.