Case Study

Detecting Vacuum Leaks in a Multi Effect Evaporator Using Ultrasound Detection

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The amplitude of a vacuum leak is less in comparison to a pressure leak so proper shielding and positioning techniques are paramount to successful leak detection. Most manufacturers of ultrasound equipment continue to innovate, new methods for finding vacuum leaks are resulting in more successful and less frustrating project abandonment.

One such innovation is the improvement of contact sensors. That’s right; contact sensors can play a huge role in finding vacuum leaks. Most of us when we think of leak detection draw our point of reference to airborne sensors only. If you only rely on airborne sensors for leak detection you will miss potential wins. Think about it. In a vacuum leak much of the turbulence is contained inside the vessel. A contact sensor, if closable and repeatable, and super sensitive within a confined bandwidth can be a very effective tool. One area where vacuum leak detection improves efficiency and throughput is applied to multiple effect evaporators used in the processing of sugarcane, the desalination of water, and the production of black liquor in the pulp and paper industry to name just a few applications. The case study focus of this paper addresses significant wins for black liquor production at a large Pacific Northwest pulp and paper maker.

In the pulp and paper industry vacuum leaks serve a key role in several processes, not the least of which is the production and recovery of black liquor. Black liquor is a by-product of the Kraft process which is the stage in the production of pulp where wood is digested into pulp cellulose. The black liquor contains a majority of the energy potential of the wood so its recovery and reuse has value for pulp mills. They use recovery boilers to burn the black liquor they produce, generating steam while reclaiming spent chemicals that can be re-purposed by the digestion process. During wood digestion chemicals and heat are used to cook the wood into cellulose fibres. Lignin pieces and chemical agents are recovered through evaporation.

Evaporators are large vessels used to produce black liquor and recover cooking chemicals. Steam is fed through tubes inside the calandria. Water is boiled out of the black liquor and removed as condensate. The condensate is sent to the boiler for reuse after purification. Meanwhile the liquor is further concentrated and becomes more viscous at each stage of the evaporation.

**Multi-Effect Evaporator**

In the pulp process multiple effect evaporators provide more efficiency than single effect for production of black liquor. Multiple Effect Evaporators are more efficient than single-stage evaporators because that additional energy in the first effect is re-used in the preceding effects. The temperature in the steam chest is higher in the second effect than the second effect and so on. So in order for the steam provided by first effect to boil off liquid in the second effect, the boiling temperature point in the second effect must be lower. For this to happen, the second effect must be under lower pressure than the first effect. Each preceding effect will be at a lower pressure than the previous effect. In some cases the first effect may be above atmospheric pressure so the second effect could be at atmospheric pressure. Usually the third and later effects must be put under vacuum. In a forward feed evaporator the vacuum serves two purposes. The first purpose is to keep the boiling temperature of the condensed steam lower than the previous effect. The second purpose is to move the condensate leaks on the 4th effect stack of Clearwater’s black liquor evaporator, these properties challenged the team. The challenge here was that the entire stack was insulated with 4” of fiberglass insulation and then wrapped in steel. Any ultrasound produced by vacuum leaks was muffled by the insulation and not detectable with airborne methods. Structure borne contact ultrasound probes are used to detect the presence of friction inside structures, especially metallic ones. Bearings, steam traps, valves, hydraulic and a whole host of other equipment are evaluated using ultrasound structure borne contact probes.

A vacuum leak pulls air into the vessel so the turbulent flow is occurring inside the vessel. This makes the contact ultrasound probe the best sensor choice for surveying the 4th effect stack and locating any vacuum leaks. The sound heard in the ultrasound detectors headgear will intensify, and the measured dB(A) levels will rise as the contact probe nears the source of the leak.

Prior to November 2009, conventional contact ultrasound probes were not sensitive enough for this inspection. They were more than adequate to monitor bearing friction levels and troubleshoot steam traps and by draulics, but not for the application needed for the detection of vacuum leaks in a large vessel like a black liquor evaporator. After nearly five years of research and testing, SDT released its new RS-1 needle sensor. This contact sensor is a great advance over what was previously available.

The RS-1 is shielded and insulated so any airborne ultrasound will not contaminate the detected signal through the needle tip. The optimum length to diameter of the contact probe was researched to eliminate artificially induced resonance while transmitting the greatest amount of structure borne ultrasound.

The RS-1 contact sensor is more sensitive than any conventional contact probes currently available. It is this advance in contact sensor technology that made the discovery of small vacuum leaks in a large vessel possible. All the while improving throughput and saving money.

**Ultrasound**

Ultrasound is detected in two ways; contact and airborne. Most processes are evaluated using contact ultrasound probes to detect the presence of friction inside structures. In the case of vacuum leaks, airborne techniques are also used. High frequency sound pressure waves are low energy and short wavelength. Unlike lower, frequency audible sounds, ultrasound propagation is impeded more by its medium. Attenuation occurs over a shorter distance and absorption is more likely than reflection and production. When searching for compressing air leaks these properties are advantageous to the inspector. However when searching for vacuum leaks on the 4th effect stack of Clearwater’s black liquor evaporator, these properties challenged the team. The challenge here was that the entire stack was insulated with 4” of fiberglass insulation and then wrapped in steel. Any ultrasound produced by vacuum leaks was muffled by the insulation and not detectable with airborne methods. Structure borne contact ultrasound probes are used to detect the presence of friction inside structures, especially metallic ones. Bearings, steam traps, valves, hydraulic and a whole host of other equipment are evaluated using ultrasound structure borne contact probes.

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be unusual to see more than a seven effect evaporator in any pulping process. Each effect consists of a heat transfer surface, a vapour separator, a vacuum source, and a condenser. Multiple effect evaporators evaporate more water per kg of steam by re-using vapours as heat sources in subsequent effects. They also improve heat transfer due to the viscous effects of the black liquor as it becomes more concentrated. But they also require efficient vacuum to move the liquor on through the process and maintain differential pressure from effect to effect.

As explained above, each effect operates at a lower pressure and temperature than the preceding one. The lower pressure creates a temperature difference across each effect. Since vapours are removed from the preceding effect at the boiling temperature of the black liquor the difference in temperature cannot exist in the proceeding effect without increasing its vacuum. The operating cost of evaporation is relative to the number of effects and the temperature at which they operate, all of which hinges on the tightness of the system, otherwise expressed as its ability to pull and hold a vacuum.

It should be noted here that black liquor, for all its energy potential, is also corrosive. Stress corrosion cracking of stainless steel is more likely to occur in heavy black liquors where the solids contents are above 70%. This is due to the high process temperatures required to both concentrate the liquid solids and to also keep the viscosity of the liquor low enough for pumping. Very high service temperatures combined with corrosive products have been known to impact stainless steel tubes in heat exchangers and are now being replaced with high chromium ferrite stainless steel which provides better resistance to corrosion from liquors and high temperatures. Herein was the problem on the number four effect stack at our customer.

Black Liquor Evaporator Vacuum Leak Survey
In November, 2009 SDT Ultrasound Systems received a phone call from Clearwater Paper Corporation, Lewiston, Idaho Plant asking if our ultrasound technology could find vacuum leaks on evaporator stacks. Several leak detection service companies had been approached already but none seemed willing to risk the expense of visiting the plant with an uncertain outcome. SDT is lucky enough to have a sound technical representative stationed near the Pacific Northwest willing to embrace risk in exchange for providing customer solutions and satisfaction. Karl Hoffower, of Failure Prevention and Condition Monitoring Solutions, Inc took the call and scheduled a visit to the mill. He filed this report.

Vacuum Leak Inspection on Multiple Effect Evaporator at major Pacific North-west pulp & paper mill
By Karl Hoffower, Condition Monitoring Solutions, Inc
On December 14th & 15th a vacuum leak survey was completed on the black liquor evaporator at a major pulp and paper producer in Idaho. Evaluation of the black liquor process numbers had revealed high process pressures and temperatures requiring the most likely area of the vacuum leak was somewhere in the 4th effect piping.

Steam systems need to be checked regularly to isolate the traps which are faulty. Faulty traps waste energy and lead to poor-quality products. We also know the bad effect poor steam systems have on your evaporators.

Monitoring the condition of rotating equipment is usually done with vibrations analyzers. The question is, why analyze 100% of the bearings that are running okay? Use ultrasound as the first line of defense. Consider it a filter for your vibration department. When you have unexpected bearing failure, time its lubricate and perform vibration analysis. Since high end ultrasound data collectors now capture meaningful time signals, why not compare the ultrasound data with your vibe signatures?


A vacuum leak generates friction from the turbulent flow of gas being pulled from an area of high pressure into an area of low pressure through a restriction. A vacuum leak will pull air into the vessel so the turbulent flow of gases being pulled from a vacuum leak creates an area of high pressure into an area of low pressure through a restriction. A vacuum leak will pull air into the vessel so the turbulent flow of gases being pulled from a vacuum leak creates an area of high pressure into an area of low pressure through a restriction. A vacuum leak will pull air into the vessel so the turbulent flow of gases being pulled from a vacuum leak creates an area of high pressure into an area of low pressure through a restriction. A vacuum leak will pull air into the vessel so the turbulent flow of gases being pulled from a vacuum leak creates an area of high pressure into an area of low pressure through a restriction. A vacuum leak will pull air into the vessel so the turbulent flow of gases being pulled from a vacuum leak creates an area of high pressure into an area of low pressure through a restriction.

Turbulent Flow From Vacuum Leaks
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Opening the access door allowed further probe to the airborne sensor. Ambient as we recorded contacts close to the location and investigate further. As the additional pictures below will show, there was a strong correlation between internal turbulent flow and thick. The thinnest area found on our scan, there was a strong correlation between the locations of the leaks and around 15' away from the source. Since no other points had anything higher than 51 db we decided to return to that location and investigate further.

As the additional pictures below will show, there was a strong correlation between the locations of the leaks and the thinnest of the stack. At the location of the highest ultrasound, 5 lb, the wall was found to be 0.091” thin. The thinnest area found on our initial survey.

It was decided that we would need to have a larger area opened for inspection. Mr. Storey and I went back to confer with Mr. Frei and Mr. Fleischman (sp?) about how we could gain access to the stack below the retaining ring. Mr. Storey marked out the approximate dimensions we wanted to have cut away in chalk.

We went back to the Maintenance shop and were introduced to Mr. Jim Rose, he discussed how he would cut the sheet steel away and remove the insulation to give us better access. Mr. Frei reminded us that we would need to have some type of blocking material to immediately cover the holes we expected to find. If we did not, the probability of losing the vacuum was great, thus potentially causing the entire process to shutdown.

Corrosion Damage Found: As soon as Mr. Rose removed the sheet steel we could see where the insulation had collapsed around the vacuum pull of the stack. As the insulation was peeled away, the holes were immediately visible. We placed two rubber sheets over the large holes to prevent the loss of vacuum. The sheets on the left covered the largest area of corrosion, about 8” wide. The 2nd major area of damage was about 1½” wide. Several other smaller holes were notice along the underside of the metal flange area. The exact number of holes were too numerous to count. Also many of the holes had blended together from the corrosion.

Mr. Rose recommended applying Gor-Tex™ sheets sealed with silicone to effect a strong, yet temporary repair. The decision was to strengthen and seal the holes so that the process could continue until a planned outage in March 2010. At that time a complete repair/replace-ment could be imple-mented. As they removed more of the sheet metal and insulation for the final repair, additional thickness testing was performed. The areas below where the holes were discovered clearly show how the stack is wearing out. 0.077” was the thinnest area found without actually being a hole.

Conclusion:

After the Gor-Tex™ sheets were wrapped and sealed, the process moni-toring software validated the repair. The amount of vacuum began returning to levels not seen for quite a while. The control valve also moved dramatically into the correct direction right as the repair was being finished. By 4pm on December 15th it was apparent the system had been returned to normal. The survey is considered ended and a success.

I was sent an email that noted, the “morning report” at IPD on 12/17/09 stated the following: “Vacuum im-provements on the evapo-rators resulted in the best solids throughput tons per day we have achieved on the set in the recent past.”

The report filed by Mr. Hoffower illustrates just how complex the job of locating vacuum leaks can be. The complexity in this case was magnified by several conditions including insulation material wrapping the stack, sheet metal covering the insulation, primary and secondary airs gaps between stack, isolation, and sheet metal, high elevations requiring a lift and platform, ambient noise in the ultrasound frequencies related to non-leaking turbulent flow, and of course the discomfort of high temperatures which also pose a safety risk.

The report also illustrates how rewarding the job can be. The win for this paper company is a reduction in energy costs through more efficient vacuum leakage maintenance and better thermal transfer from effect to effect. Additionally they have the best throughput of black liquor in years. Make no mistake here; it is trying times for paper makers. The difference between a profitable quarter and a losing quarter may well be decided by the efficiency of a single process such as black liquor production.

Many leak surveys are abandoned due to frustration which is the product of poor quality equipment ill suited to the task. It is also the product of training. Without ultrasound training an inspector will be overcome by the hurdles of the task. Your investment in an ultrasound programme must be threefold. Invest in quality ultrasound equipment, quality personnel to carry out the inspection, and most important, inspector training. Training must address the unique place ultrasound holds for reliability and plant maintenance, ensure good transfer of knowledge between inspector and student, and return the inspector to the field with the confidence to succeed in the most trying inspections.

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