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Prevent startup compressor failure

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Measurement of condenser response to air ingress and exhauster operation

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Condenser performance can be impacted negatively by a wide range of factors, including air in-leak, air venting efficacy, vacuum equipment capacity and other factors related to plant operating conditions.

The importance of continuous measurement of air in-leakage (AIL) and vacuum equipment capacity is recognized and is now beginning to be addressed by installing multi-senor flow instruments into condenser-to-vacuum equipment off-takes. This article describes the history and uses of important monitored parameters in improving the understanding of steam surface condenser performance.

The Heat Exchanger Institute (HEI) provides guidelines and tables for air removal equipment sizing, venting capacities and recommendations for condenser pressures to maintain performance at various levels of air in-leak. Recommended venting equipment capacities are based on total steam flow and the number of main turbine exhaust openings of all the shells. It can be reasonably deduced from these tables that keeping air in-leakage below the look-up value will result in the condenser operating free from air in-leak related issues. However, this approach is not based on a measurable parameter to indicate why any given value of air in-leak is too high, nor does it consider degraded exhauster capacity or inefficient tube bundle designs.

Conventional industry wisdom holds that air in-leakage (AIL) should be kept as low as possible. A commonly used industry rule of thumb was 1 SCFM per 100 MW of power generation. This rule originates from Westinghouse but does not account for sizing of original equipment or efficiency in bundle design to guide and remove noncondensables. [1] [2] [3] However, conditions vary greatly from condenser to condenser. In many cases these guidelines may be misleading, resulting in excessive resources being committed to reducing AIL when it might not be sufficiently warranted.

Historically, periodic readings using a variable area type flow meter – such as a rotameter – located downstream of the air removal equipment were the accepted method for monitoring AIL to the condenser. However, a measurement at this point in the venting system does not provide enough information to determine if the observed level of air in-leak is causing condenser performance degradation. Data from hundreds of installed instruments covering numerous condenser designs over the past 25 years has led to a new understanding that AIL is not a problem unless it exceeds the air removal equipment's capacity to extract it at the operating exhauster suction pressure dictated by condenser pressure, or that proper tube bundle venting is not being achieved. Therefore, a complete understanding of the effect of air in-leak on condenser performance must take into consideration any relative degradation in the capacity of the air removal equipment and effects of condenser design or construction deficiencies. As a result, it is imperative that in addition to continuous monitoring of AIL, the exhauster capacity also must be continuously monitored along with other parameters that track condenser performance. A new approach is defined by monitoring the water-to-air mass ratio (W/A).

The water-to-air mass ratio is the ratio of water vapor density to air density of the gas mixture in the air removal vacuum line. This ratio can be used to gauge exhauster performance relative to the measured air in-leak and determine whether the air in-leakage exceeds exhauster capacity. A threshold point can be found (typically around W/A=3) that identifies the onset of excess condenser pressure due to the forming of stored air around the air removal section; that is, the formation of a stagnant air rich zone around tubes in the condenser. The outlet water box stratification also is an indicator of air binding within the tube bundle, which is a configuration issue that can be remedied by reconfiguration of steam flow through the bundle.

The value of the water-to-air mass ratio has significance in determining the vacuum system adequacy for a given operating condition. This mass ratio depends not only on the amount of air in-leakage being removed, but also on the total exhauster capacity. The capacity can be a function of the number and type of exhauster used, operating conditions (environmental or motive), suction side pressure (condenser pressure), discharge pressure (generally atmospheric), and mechanical condition (wear) of the exhauster(s).

It has been shown through testing and observance of plant data that as air in-leak is reduced, the total pressure decreases until the W/A reaches a value of approximately 3. After reaching this value, the pressure remains relatively constant as further reduction of AIL is made. However, as the pressure remains relatively constant with declining AIL, the mass ratio continues to increase. Therefore, an acceptable level of air in-leak is that which results in a W/A mass ratio above 3 with only one exhauster pump running.

It should be recognized that a mass ratio of 3 is a rule of thumb value based on observations from hundreds of instrument installations. The true value for a particular unit will be condenser design dependent. It is recommended to perform air in-leak testing to develop a curve for each unit being evaluated. If the testing cannot be done or has not been completed, then a W/A mass ratio value of 3 can be used until such testing can be performed.

Reconfiguration of steam flow requires identification of the steam flow pattern by model analysis and changes in the air removal section configuration. These changes can be accomplished during a typical outage even if a retubing operation is being done.

Exhauster system performance evaluation

Poor or reduced exhauster capacity will have the same detrimental effect as excessive air in-leakage – increased condenser pressure caused by air storage as found in a stagnant zone. This relationship highlights the importance of monitoring both air in-leakage and exhauster capacity. In the absence of this type of air storage, the condenser performance curve dictates the inlet pressure of the exhauster. As this type of air storage occurs due to high air in-leak or low exhauster performance, the actual exhauster performance curve drives the condenser pressure higher.

For a liquid ring vacuum pump, a plot of exhauster capacity is obtained by evaluating vent line volumetric flow rate (or total mass flow rate of SJAEs) vs. suction pressure over time. Figure 1 shows an example of measured capacity of a steam jet ejector with the manufacture's performance curve overlaid in black. The data points are colored based on a time scale to highlight trends over time. Lower condenser pressure can be seen corresponding to winter operating months in the blue data. The ejector capacity agrees closely with the design curve below a suction pressure of 2.5"HgA. Based on this trend, the SJAE is operating as designed. The most probable cause for deviation from the design curve above 2.5" is elevated inter-condenser pressure as a result of higher condensate temperature water passing through the inter/after condenser.

Exhauster capacity, measured in mass flow rate for SJAEs or volumetric flow rate for LRVPs, is dependent on its inlet pressure. Thus, lower condenser pressure will result in low exhauster capacity. For this reason, air in-leakage might result in more air storage and lower condenser performance while meeting low pressure expectations under cold circulating water conditions (or low load) when compared to warm circulating water conditions (or high load) with higher than desirable condenser pressure. For example, A 10 SCFM leak might not cause excess back pressure at 80°F inlet water temperature, but might do so at 70°F. In other words, the water-to-air mass ratio will decrease for a given air in-leak as condenser pressure decreases due to lower exhauster capacity during periods when circulating inlet water conditions are low.

Online exhauster evaluation

Liquid ring vacuum pump capacity comparison

The value provided by the ability to perform online evaluation of exhauster capacity cannot be overstated. Historically, plant maintenance managers have waited months

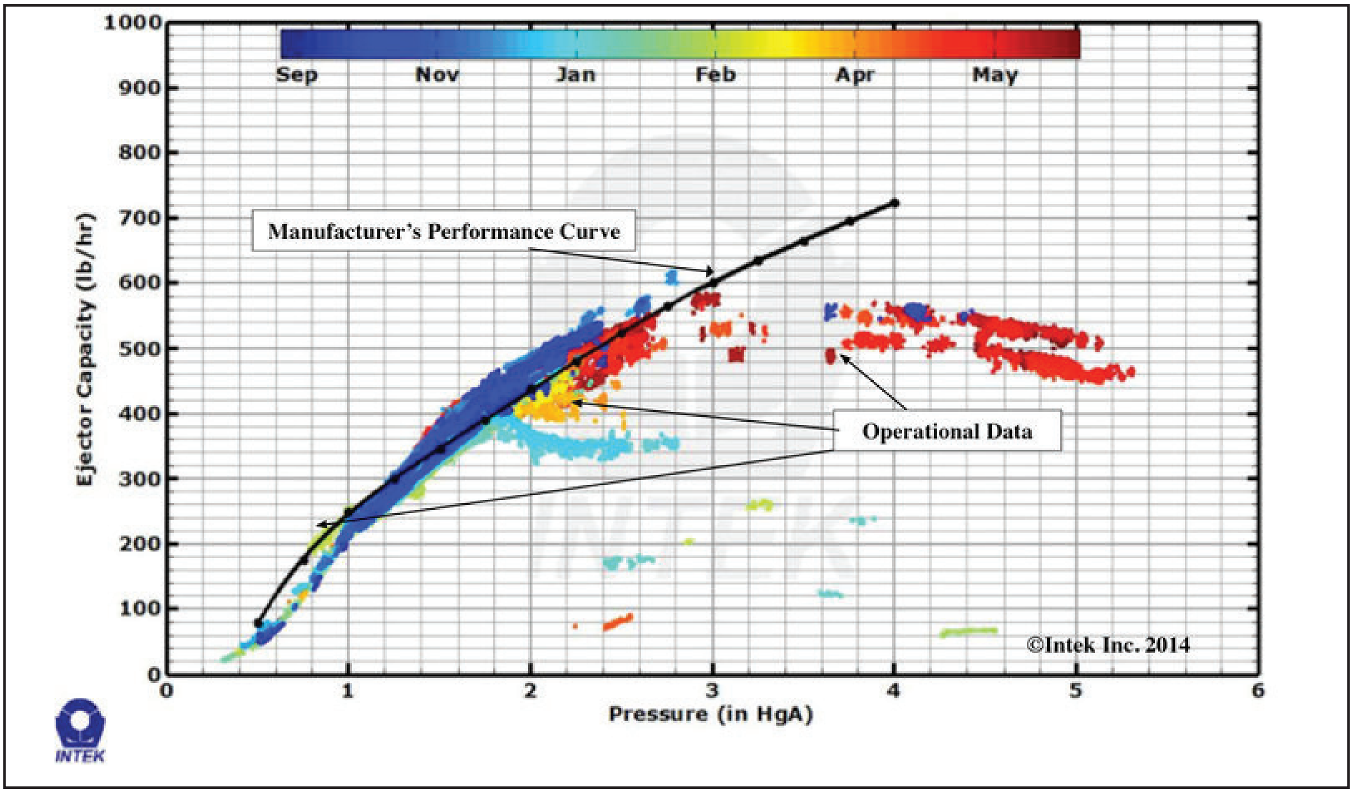

Figure 1. Exhauster design performance curve vs. operational data

for an outage opportunity that required specially assembled exhauster inlet structures, such as orifice trees, to perform exhauster capacity testing. The following example demonstrates a method whereby exhauster capacity is continuously monitored by a vent line instrument.

Summary of operator observations:

- A 0.2" Hg difference in back pressure is seen between pumps

- Pump A shows much lower capacity than Pump B

- Distinct increase in both total mass flow and W/A mass ratio

- No change in air in-leakage

Figure 2 shows the output parameters from a vent line monitor for a set of two Nash AT 1004 liquid ring vacuum pumps. Plant operators noticed a 0.2" Hg difference in back pressure between pumps and believed that one of their two Nash AT1004 exhausters was in need of maintenance. By performing a pump swap test and observing the vent line monitor parameters, operations can clearly show that Pump A is underperforming. As shown in the data above at time 12:55, Pump A is pulling less than 1/3 of the volumetric flow (ACFM) that Pump B is removing from the condenser. The result would be that excess condenser pressure will be present with Pump A in service at lower air in-leakage than if Pump B was also in service.

Note that the amount of AIL does not change with the pump change as would be expected. Also note that the vent pressures indicated by the monitoring instrument dropped 0.2" Hg, which is consistent with the plant operator's observation and, significantly, the W/A mass ratio went from near 1 to about 4. As previously mentioned, a value greater than 3 is desirable to minimize excess condenser pressure.

Conclusions

Based on the above discussion, using water-to-air mass ratio as the primary parameter for monitoring the condenser is recommended because it takes both AIL and exhauster capacity into account. It can also be plotted vs. condenser performance to obtain useful trend data. While there might be other issues impacting the performance of the condenser, the use of W/A mass ratio provides an excellent indicator of the true impact of air in-leak. Once this is better understood, other potential factors that might be causing excessive condenser pressure can be investigated. Intek's unique RheoVac® Condenser Monitor provides continuous measurement of the water-to-air mass ratio along with several other key condenser performance parameters that aid in understanding and identifying the root causes for condenser performance degradation. ■

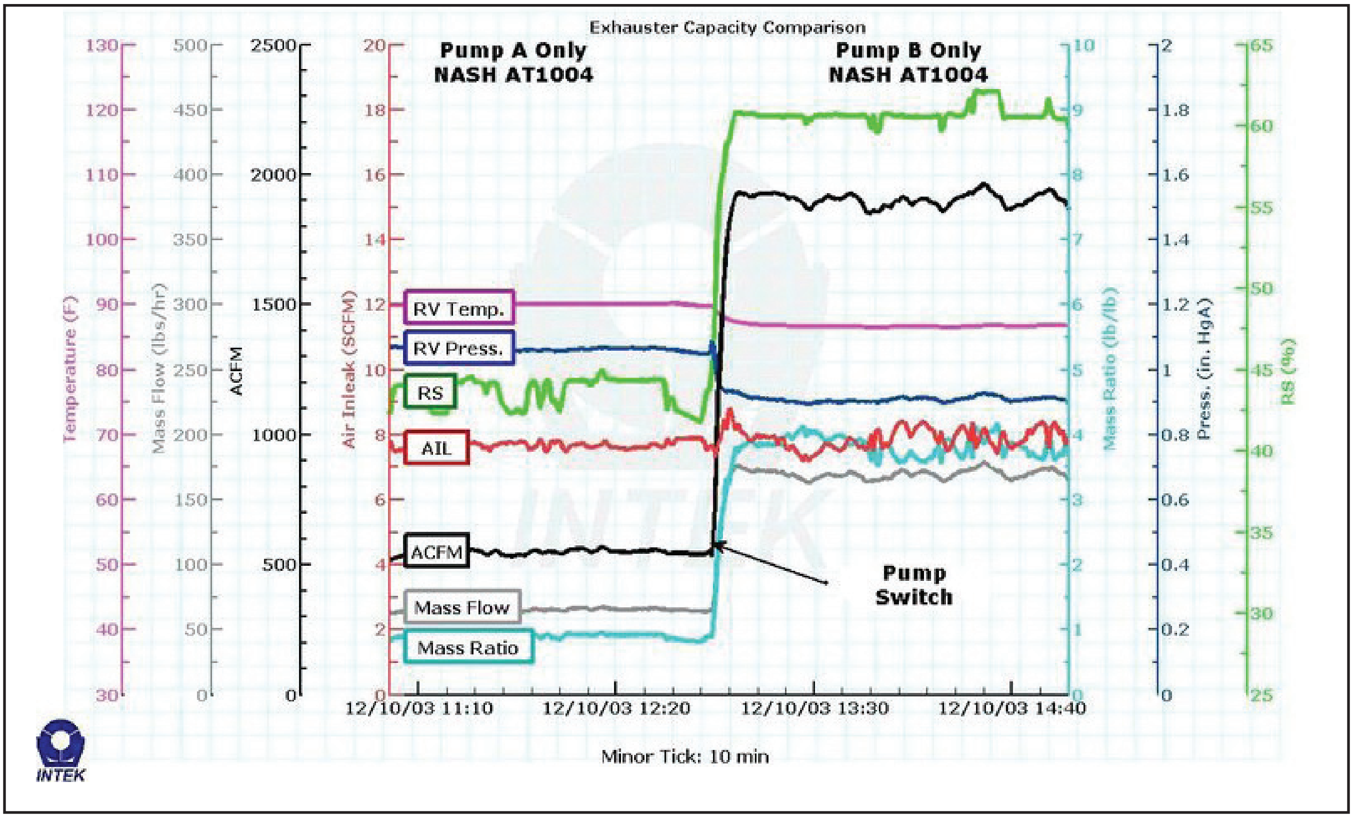

Figure 2. Pump capacity comparison, RheoVac condenser monitor data

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