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Avoid refrigeration compressor damage

Online monitoring helps prevent liquid injection and operating in choke

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Every rotating equipment engineer knows that the number one priority is to keep the machinery rotating. While it is important to keep the machinery running efficiently, mechanical issues take precedence. In today's world of limited resources, efficiency projects take a back seat to mechanical projects. There are, however, some good preventive maintenance reasons to monitor compressor performance.

Scheduling of maintenance outages and preventive maintenance based on field performance testing is a relatively new practice. Many users are doing continuous online monitoring to keep on top of compressor performance for this and other reasons. Not only can field performance analysis be helpful for predicting when maintenance is needed, but also knowing where the compressor is operating on the curve can be beneficial in preventing failures. Knowing the compressor performance details is the first step in considering a rerate, and online monitoring can help the operators make efficiency adjustments to the plant by giving them instant feedback. And having a good compressor performance history can aid in resolving compressor problems.

Impeller failures. Because of the nature of refrigeration systems, they can damage compressors by ingesting the liquids that are inherent in the system. When the plant is originally designed, precautions are taken by the designer to assure liquid ingestion is avoided. These precautions include designing components like evaporators and knockout drums properly to avoid liquid carryover into the compressor suction. High-speed turbomachinery can withstand only limited amounts of liquid ingestion. Typical limits are in the 3–5% by weight range. During high market demand periods it is easy for plants to push the capacity well beyond normal design limits with no immediately apparent distress to the equipment. The increased capacity results in velocities beyond the design limits of the evaporators and knockout drums making liquid ingestion and operation in overload very possible. Continued operation under these conditions can result in impeller fatigue and eventual impeller failure.

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Case in point. Naphtachimie in Lavera, France, has been having multiple impeller failures on the last stage of a propylene refrigeration compressor. The

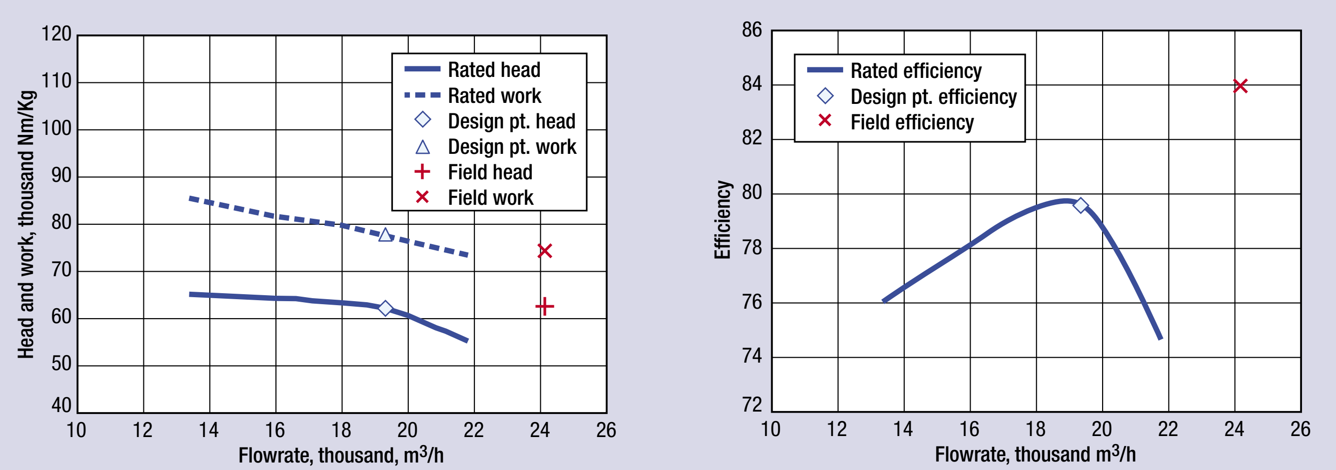

FIG. 1 Performance curve for the third section of the refrigeration compressor. Results are fan-law corrected to a 7,060-rpm design speed.

TABLE 1. Sidestream sectional analysis summary

Title: Propylene refrigeration
Database name: Choke.gdb

Inlet flange	Inlet	SS-1	SS-2	Discharge
Pressure, bar	1.210	2.590	4.580	
Temperature, °C	–30.0	–17.6	2.8	
Given flow, kg/hr	73,060	31,020	94,605.75	
Volume flow, m^3/hr	27,863	5,618	11,174	
Mass flow, kg/hr	73,060	31,020	104,045	
Compressibility	0.9631	0.9316	0.9046	
Flange diameter, mm	522.8	231.4	326.1	
Flange velocity, m/sec	388.2	399.6	400.2	
Discharge flange data				
Pressure, bar				14.18
Temperature, °C				82.8
Volume flow, m^3/hr				8,880
Mass flow, kg/hr				208,125
Compressibility				0.8685
Flange diameter, mm				271.3
Flange velocity, m/sec				459.3
Inlet section data				
Compressibility	0.9631	0.9515	0.9264	
Temperature, °C	–30.0	8.4	23.2	
Volume flow, m^3/hr	27,863	21,215	24,583	
Mass flow, kg/hr	73,060	104,080	208,125	
Discharge section data				
Compressibility	0.9575	0.9415	0.8685	
Temperature, °C	19.2	43.2	80.4	
Volume flow, m^3/hr	15,557	13,336	8,880	
Sectional head data				
Head, Nm/kg	38,506	31,783	65,044	
Efficiency	57	63	84	
Gas power, kW	1,382	1,460	4,470	
Total polytropic data				
Head, Nm/kg	135,333			
Efficiency	69.09			
Gas power, kW	7,311			

failures have been focused on only one of two compressors operating in parallel. While it has not been clearly identified what is causing the impeller failures, the following different hypotheses are being considered by Naphtachimie:

- Operation in choke in the third stage
- Liquid ingestion
- Both of the above.

Field data analysis shows the compressor to be operating at times in overload (Fig. 1 and Table 1). Note the exceptionally high efficiency, head and work input. This suggests liquid ingestion. The liquid (in mist form) gives the gas more density and results in a greater pressure ratio. The liquid evaporation of the liquid results in reduced discharge temperature; thus, the calculation, assuming dry gas, shows an abnormally high efficiency and work input. The evaporating liquid, due to the additional gas volume created, pushes the last stages of the compressor further into choke.

Analyses completed on other refrigeration compressors where impeller failures have occurred show similar results (high head, high work input, high efficiency and operation in overload). In another case, a rerated compressor lasted only 40 hr due to operation in deep choke.[1]

Work done by a compressor manufacturer showed a high-pressure gradient in the last-stage wheel due to the volute cutoff. This pressure gradient has the potential to excite impeller frequencies and cause eventual fatigue failures. Liquids in the gas stream generate higher flowrates as the liquid evaporates, pushing the last-stage impeller deeper into choke. The entrained liquid amplifies the pressure gradient of the volute cutoff.

Preventive measures. Resolution of the problem is two-fold:

- Keep liquids out of the compressor.
- Keep the compressor out of choke.

With the sidestreams, it is not readily apparent where the compressor section is operating on its curve, unless the proper tools are available. Online performance monitoring can not only show where each machine section is operating on the curve and show the margin to choke, but it can also keep a historical record for forensic purposes.

Discussion. While some users are taking steps to assure their compressors do not exceed the OEM choke curve limit, this is still not common practice. From the material presented, some limitations must be placed on operating in the choke area. The conservative rule is to keep the compressor operating within the OEM performance curve at all times. In other words, don't go beyond the end of the curve.

While failures due to operation in deep choke have occurred on air machines, this is rare. The more common problem is in refrigeration compressors where liquid is present as shown in Fig. 1. Monitoring the performance can show the operator not only how far into choke he or she might be operating, but also if liquid is being ingested (by the high efficiency, high head and work input).

While it may sound overly cautious to be concerned about operating in choke, this is a real concern, especially if liquids are present. **HP**

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