■ At the heart of Invista's hexamethylenediamine (HMD) process are two 5000 hp (3729 kW) Cooper-Bessemer LM-4 hyper-compressors that compress hydrogen from 300 psig to 5000 psig (20.7 to 344.8 bar). These 14 in. (35.5 cm) stroke, three-stage, reciprocating compressors operate at 327 rpm.

DEDICATED O&M TEAM OPTIMIZES PERFORMANCE OF MATURE PROCESS EQUIPMENT

Application of New Technology and Attention to Detail Keeps Invista's Equipment Performing Reliably in Demanding Nylon Intermediates Production Process

By Norm Shade

Most of the chemical industry's plant equipment was installed decades ago. Nevertheless, through the ongoing efforts of dedicated plant operators, engineers and maintenance technicians, the majority of this machinery continues to operate reliably and efficiently. Such is the case at Invista's plant in Orange, Texas, U.S.A. Formerly known as Dupont Textiles & Interiors; Invista reported that it is the world's largest integrated fibers and intermediates company with more than $6.3 billion in revenue, 18,000 employees and a presence in 86 countries. The Orange plant produces nylon intermediates used to make nylon 66 for a wide range of end use products including carpeting, apparel and home interiors.

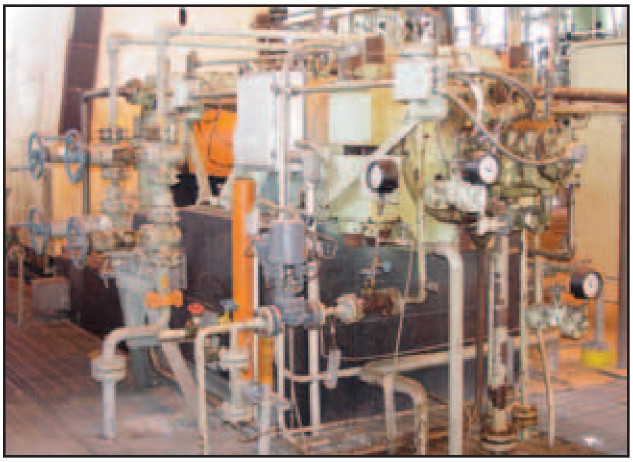
The Orange plant's production includes large volumes of adipic acid, a white crystalline powder that's shipped out in rail hopper cars, and hexamethylenediamine (HMD), a liquid that is shipped from the plant via tank cars and barges. Hydrogen, liquid adiponitrile (ADN), and ammonia are delivered to the plant by pipelines, tank cars and barges, and then pressurized to above 5000 psig (344.8 bar), mixed and passed through a proprietary catalytic reaction process. Next, the ammonia, which is used as a moderator in the process, and nonreacted gas are separated from "crude" HMD and recycled, while the separated HMD goes to a refining unit in another section of the plant. The refining unit removes impurities that might affect strength or "dye-ability" of the nylon fibers that are made from the intermediates.

A number of compressors and pumps are used in the HMD production process. At the heart of the process are two 5000 hp (3729 kW) Cooper-Bessemer LM-4 hyper-compressors that compress hydrogen from 300 to 5000 psig (20.7 to 344.8 bar). These 14 in. (35.5 cm) stroke, three-stage, reciprocating compressors operate at 327 rpm. The ADN is injected into the hydrogen stream by a large slow-speed Aldrich plunger pump, and ammonia is injected by a 7200 rpm, 12-stage Bingham centrifugal pump.

A 1250 hp (932 kW) Cooper-Bessemer JM-2/1 compressor recycles unreacted hydrogen and ammonia back into the process for reuse. This 14 in. (35.5 cm) stroke, single-stage reciprocating compressor also operates at 327 rpm. Ammonia is recovered from various points in the process and compressed to 575 psig (39.6 bar) by an 800 hp (597 kW), 514 rpm, three-stage Cooper-Pennjax HOE-3 reciprocating compressor. The ammonia is then fed back into the suction of the Bingham pump for reuse. A 500 hp (373 kW), 514 rpm, single-stage Cooper-Pennjax HOF-2 reciprocating compressor serves as a catalytic reduction unit that handles two different process gases. All pumps and compressors in the HMD plant are electric motor driven.

The ownership and pride of the HMD operations and maintenance personnel were apparent as they explained the nu-

■ A large slow-speed Aldrich plunger pump injects adiponitrile into the hydrogen stream in Invista's HMD process.



■ **Ammonia, used as a moderator in the Invista HMD process, is supplied by a 7200 rpm, 12-stage Bingham centrifugal pump.**

■ **A 1250 hp (932 kW) Cooper-Bessemer JM-2/1 compressor recycles unreacted hydrogen and ammonia back into the HMD process for reuse. This 14 in. (35.5 cm) stroke, single-stage reciprocating compressor operates at 327 rpm. The ammonia is then fed back into the suction of the Bingham pumps for reuse.**

merous improvements made to keep their mature equipment operating at peak performance. "We have a very proactive team," said Martin E. (Buck) Stephens, predictive and preventive maintenance technician. The maintenance team does most of the compressor valve repair at the plant and has made significant improvements in valve mean time between failures (MTBF). Its work area includes a clean room and a lapping machine that is complemented by a well-equipped machine shop in another part of the plant.

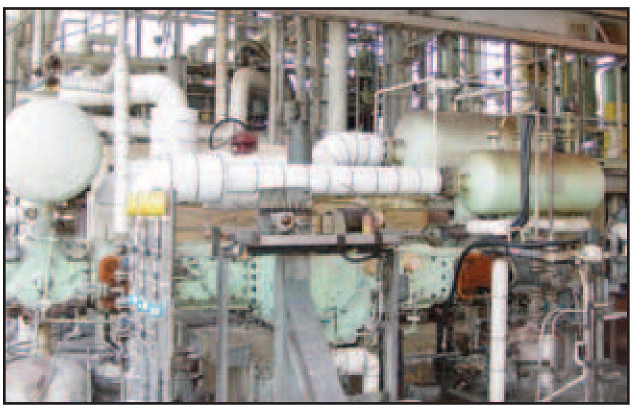
One of its successes involved improving valve life and performance in the hydrogen compressors. Previously, the third-stage valve seats were limited to about eight months. Working with Cook Manley, they fitted the compressors with Manley valves having PEEK plates and with lift and springing optimized for the high-pressure hydrogen application. They now report consistent valve service in excess of one year in all three stages, while achieving 14% more flow than before the conversion. Another valve improvement success involved the Pennjax HOF-2 catalytic reduction unit, which has hot and cold swings during its duty in the process. Valves in this compressor are also exposed to liquid upsets. After a BETA analysis indicated what was happening with the valves, a change to thicker PEEK plates improved the MTBF of the original valves to one year.

The compressors currently achieve three years of service life on cylinders, pistons, piston rings, piston rods and packing. "We adhere to very stringent rod run-out checking procedures and limits," said Lonnie Turple, maintenance supervisor. "We measure all cylinder bores to ensure roundness and we take good care of alignment, both hot and cold, to keep the rods centered in the crosshead guides within less than 0.015 in. (0.4 mm). We use optical alignment and have permanent targets on all crosshead guides to check thermal growth." The HMD team also found that converting to PEEK piston rings and rider rings in most of the cylinders, along with using relatively high lubrication rates, increased service life on both the rings and the cylinders.

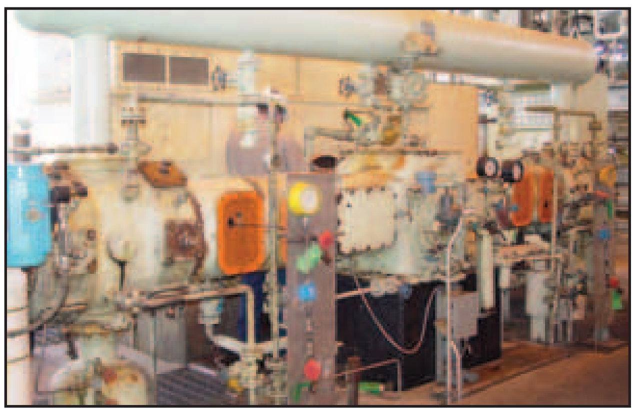
When the current team took over responsibility for the compressors, it found that the piston rods were of unknown pedigree. It now require use of traceable material in all rods, document all rod heat treatment and limit procurement to only two sources, one of which is the compressor manufacturer. Serial numbers, heat numbers, dates and sources are all stamped on the rods for traceability.

The team has also tightened specifications for piston rod coatings. "Previously, failures were numerous and most were ultimately traced to poor application of coatings by vendors. We now coat almost all of our rods with LW15 tungsten carbide coating applied by Praxair with a D gun," explained Stephens, who has more than 25 years of experience at the facility. The maintenance crew checks run-out on the piston rods as received, then again after attachment of the piston. It completes a final check of rod run-out in the compressor after installation.

The maintenance team also



■ **Ammonia is recovered from various points in the HMD process and compressed to 575 psig (39.6 bar) by a 800 hp (597 kW), 514 rpm, three-stage Cooper-Pennjax HOE-3 reciprocating compressor.**



■ **A 500 hp (373 kW), 514 rpm, single-stage Cooper-Pennjax HOF-2 reciprocating compressor is a catalytic reduction unit that handles two different process gases in Invista's HMD process.**

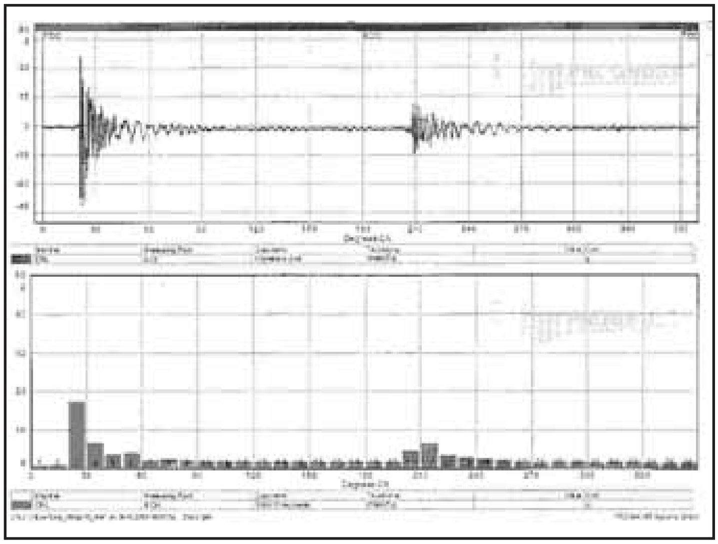
repairs all packing cases and ring stacks in its repair shop. The compressors use mostly PEEK packing rings, along with some carbon-filled Teflon rings, supplied by C. Lee Cook and France. “We worked with these suppliers to tighten the tolerances and dimensional consistency of the packing for our compressors. We also made the back-up rings softer. We made mandrels for every rod size in our plant and we check every packing ring for ‘light-tight’ close clearance before we approve them for use in rebuilding a packing assembly,” said Stephens.

Stephens also attributes the addition of coolant to the packing cases to the extension of packing life as a result of reduced operating temperatures. He indicated that propylene glycol coolant worked well, but posed an environmental problem if a leak developed, so a change was later made to Envirogard, which is an environmentally safe antifreeze. “With these improvements, we have been able to completely eliminate packing break-in runs, which allows us to get the process on line faster after a rebuild,” added Stephens.

In addition to careful attention to parts quality, installation and alignment, the HMD team makes special efforts to ensure that pump-to-point lubricators are working properly at all times. Every point on every throw is routinely checked the first thing every morning. “Also we have been gradually upgrading the lubricator boxes on our compressors with a new design supplied by Premier,” added Stephens.

The plant’s ISO certification requires effective preventive maintenance and lube oil analysis programs. With improvements in MTBF, the plant has been able to establish a rigorous preventive and predictive maintenance program. Using a three year accumulation of comprehensive and detailed maintenance history, they are now forecasting and planning all preventive maintenance five years into the future. Plant compressor and pump lubricants are routinely checked for wear particles, total-acid-number, water and additives condition.

“From time to time the analyses have shown bearing problems that were developing due to water and process fluid leaks,” said Turple. “This caused us to hunt down the sources and eliminate them before they led to serious problems. We work constantly to avoid the ingestion of process material into our compressor and pump crankcases.”



Invista’s Prognost monitoring and diagnostic system shut down a Pennjax HOF-2 CRU compressor after an accelerometer mounted on one of the compressor cylinders recorded vibration in excess of the 8g RMS trip setting. A review of this stored data by plant technicians led to a rapid and correct diagnosis that the nut holding the piston to the rod had loosened. The state-of-the-art system prevented serious damage and allowed the compressor to be returned to service with minimal downtime.

Another success story was the addition of a PROGNOST intelligent monitoring system to the plant’s reciprocating compressors. This is a self-learning system that Invista said provides convincing “information” instead of raw “data” as a base for well-founded decisions. Crank-angle related analyses refer to the special characteristics of reciprocating machines.

The system monitors accelerometers mounted on the crossheads on all throws of each major reciprocating compressor and pump in the plant and provides alerts to problems. It provides an FFT plot, which is used as a diagnostic tool along with the process signal to focus on problems and equipment condition. “It can tell us where in the 360 degree crank cycle there’s a problem with valves, rod reversal, etc., all relative to TDC of the 1st cylinder,” explained Don Easterwood, technical associate for electrical and instrumentation and a certified Six Sigma Green Belt. “We use a conservative safety factor on trip settings so that shut-down only occurs in the event of a major problem and the system has not caused a spurious trip to date,” he added. “It also saves data on either side of an event to allow analysis.”

“We got the PROGNOST system for safety reasons, but it has saved on preventive maintenance costs too,” said Stephens. First installed in June 2001, the system passively collected operating data until December 2001 when the shutdown interlocks were enabled. Soon thereafter the system showed its value by minimizing damage during major events in mid-2002, when there were two shutdowns on the hydrogen compressors related to second stage piston failures. “The captured data showed that the compressors were stopped in 13 revolutions, so damage was mitigated and the compressor was quickly repaired each time,” said Stephens.

Analysis of the failures led to a change in assembly procedure to eliminate a stress riser that had been caused by piston rod flange bolts bottoming in the tapped holes in the piston. Invista personnel now carefully measure the depth of each tapped hole and the length of thread insertion. Then they use Loctite to keep the bolts tight without bottoming them in the holes.

In another event, the catalytic reduction unit had a vibration spike that shut down the unit. After looking at the captured data and applying his past experience, Stephens had a good idea where the problem might be. Inspecting the compressor subsequently confirmed his diagnosis that the nut holding the piston to the compressor rod had loosened. “The system tells us where to look and cuts down on the time to find problems,” explained Stephens. “It has more features and capability than we are using so far,” he added, “and we hope to use more of them in the near future.”

“Learning from past failures has allowed us to reduce the MTBFs from one year to the next,” said George C. Russell, Ph.D., P/M/T area superintendent. “Our goal is to be able to run three years with no unscheduled shutdowns and we are achieving that already on most of our equipment. The collective accomplishments of our people are just amazing.” ■

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