COMPRESSOR FOULING

CRACKED GAS COMPRESSOR FOULING AND ANTI- FOULING TECHNOLOGIES

BY PALLAVI BADDAM

Ethylene plant capacities in recent decades have increased well beyond 1.5 MMTPY (million metric tons per year) and are now around 2.0 MMTPY. The Cracked Gas Compressor (CGC) is one of the most critical pieces of rotating equipment present in modern ethylene plants.

The purpose of the CGC is to compress gases from the cracker for separation in downstream units within the process plant. The compressor handles process gas, which is a complex mixture of cracked gases containing substantial quantities of high molecular weight hydrocarbons, such as C_4s, C_5s and C_6s.

Therefore, any reduced capacity or unscheduled downtime of the CGC negatively impacts overall production and plant economics. Fouling is one of the typical causes for reduced capacity or performance deterioration in CGC operation.

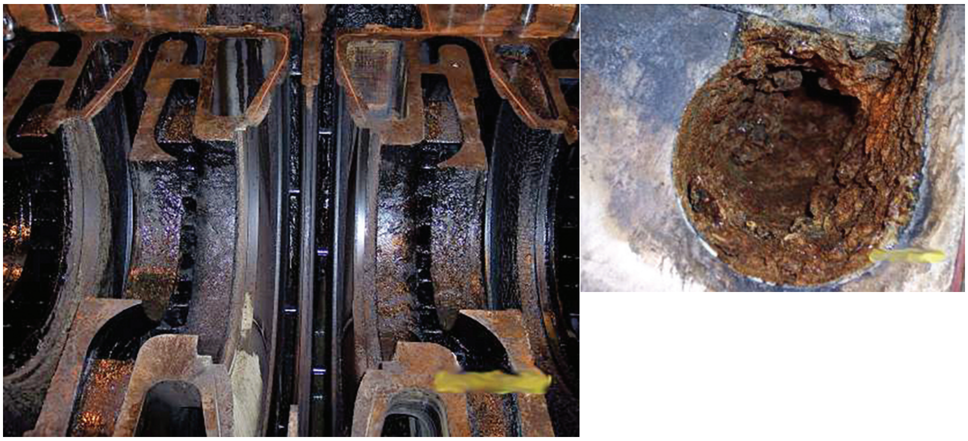


Figure 1. Cracked gas compressor fouling: CGC LP casing after operation (left), and HP casing (right). As a result of fouling, the accumulation of polymers on the internal surfaces adversely affects overall performance. Changes in feedstock or cracking severity can change or shift the dominant fouling mechanism.

Typically, a CGC train consists of two or three bodies of multistage compressors driven by steam turbines (STs). Fouling that occurs in a single multistage cracked gas compressor has a crippling effect on the overall performance of the train.

Fouling is caused mainly by three different mechanisms: free radical polymerization, condensation and thermal degradation to coke. Polymerization occurs when two or more unsaturated monomers with reactive double bonds (or consisting of the same elements in the same proportions by weight but differing in molecular weight) react to form another compound having higher molecular weight and different physical properties.

Compounds, such as ethylene (C_2H_4), Propylene (C_3H_6), Butene (C_4H_8) within the gas stream may react with heavier molecular weight (i.e., C_6, C_7, C_8 hydrocarbon compounds) resulting in polymer formations. These polymer formations and fouling rates tend to increase exponentially with temperature.

As such, the polymer chain grows, and the molecular weight of the polymer increases until it becomes insoluble and clings to the metal surface. With time, these polymer deposits reduce to a coke-like substance on internal parts of the compressor (Figure 1).

Fouling and performance

Surface roughness has a major impact on compressor performance. Impeller and diffuser performance depends on the presence of a smooth surface finish. Fouling aggravates the degree of surface roughness and affects the component efficiencies at individual and collective levels. Additionally, this fouling reduces the fixed volume of the internal components, ultimately decreasing the gas-pass area within the impeller (Figure 2).

In a two-stage impeller compressor the performance of the first-stage impeller has a significant effect on the performance of the second-stage impeller. Decreased flow area due to fouling, lowers the efficiency and discharge pressure of the first impeller (Figure 3).

Therefore, the predicted suction pressure of the second impeller is no longer the same as the actual suction pressure. As a result, the pressure, temperature and flow to the second stage also change, thereby lowering second-stage efficiency.

This also leads to high temperatures within the compressor internals. To meet the predicted discharge pressure, then, the compressor has to work harder. As a result, the speed and power of the compressor increases. This rise in power results in higher than expected operating expenses

As mentioned earlier, surface roughness contributes to compressor performance. The effects of surface roughness within the gas passage due to fouling can be estimated using ICAAMC Reynolds Number correction formulas.

If surface roughness is worse than the impeller design condition, losses can be expected at the impeller surface resulting in a lower pressure coefficient. Therefore, a shift in the operating point from the design point brings about a change of predicted polytropic head, flow coefficient and impeller efficiency (Figure 4).

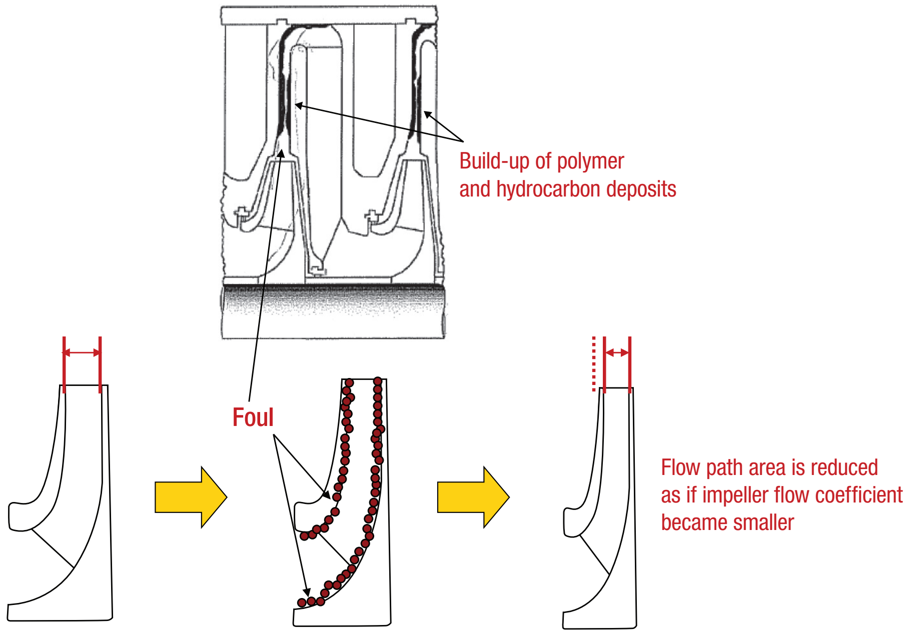


Fig. 2. Volume reduction due to narrow passage within the impeller as a result of fouling. This is equivalent to using an impeller with a smaller flow coefficient. As a result, the efficiency of the impeller decreases.

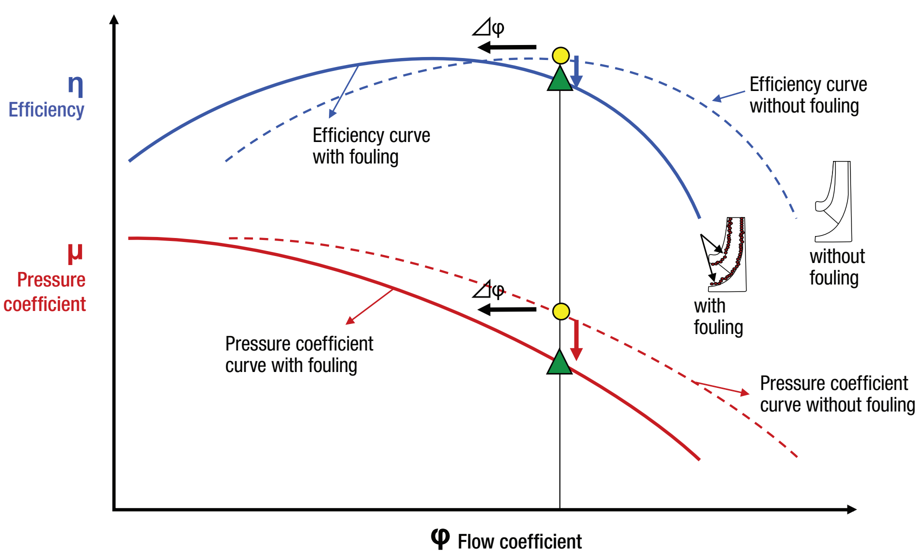


Fig. 3. Stage 1 Aerodynamic performance with and without fouling. As can be seen, fouling causes a reduction in the gas passage area which impedes the impeller. As the impeller design was optimized for a particular flow coefficient, fouling means a drop in impeller efficiency.

Figure 4. A rough surface inside a compressor due to fouling

Anti-fouling technologies

A certain amount of fouling is, inevitable; however, it can be controlled. Several anti-fouling mechanisms have been used by operators. As the fouling mechanism changes, the effectiveness of the mitigation method may also shift. It is usual for process licensors and end users to dictate the type of anti-fouling mechanism needed.

Anti-fouling technologies can broadly be divided between conventional and unconventional techniques. One example of an unconventional approach involves the use of chemical treatments or anti-foulants within the process gas.

Its main function is to prevent fouling by inhibiting chemical reactions. These formulations contain an inhibitor and antioxidant. The inhibitor reacts with monomers before they can form insoluble polymers. The antioxidant reduces oxidative polymerization. Researchers are constantly coming up with anti-foulant formulations that can prevent polymerization at its initial phase.

Conventional anti-fouling technologies used by ethylene producers include:

CGC COMPRESSOR COATINGS

Compressor internals are coated to avoid corrosion and foulant deposition on the surfaces. Use of coatings has a minimal efficiency decrement. They are generally applied to diaphragms, inlet guide vane (IGV) and rotor assemblies (Figure 5). Process licensors, purchasers and OEMs mutually agree upon the compressor components that need coating based on the type of service and the process gas used.

Mitsubishi Heavy Industries Compressor Cooperation (MCO) uses SermaLon coatings if requested, typically a three-layer coating. The foundation is a tightly adherent layer of sacrificial aluminum–filled ceramic.

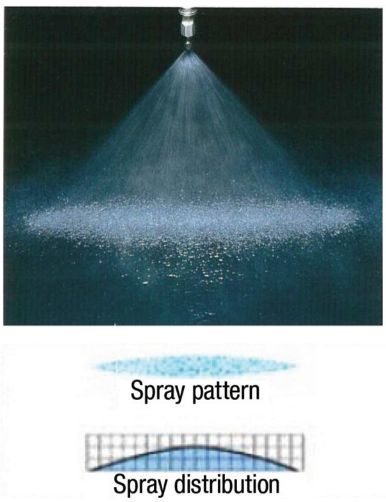
This galvanic coating prevents corrosion of structural hardware. The intermediate layer in a SermaLon is an organic coating containing metalo-compounds, which prevent corrosion by modifying the chemistry of environmental corrodants. The outermost layer is an organic material containing PTFE. It acts as a barrier against corrodants in the environment and limits fouling. This incurs a nominal drop of compressor efficiency.

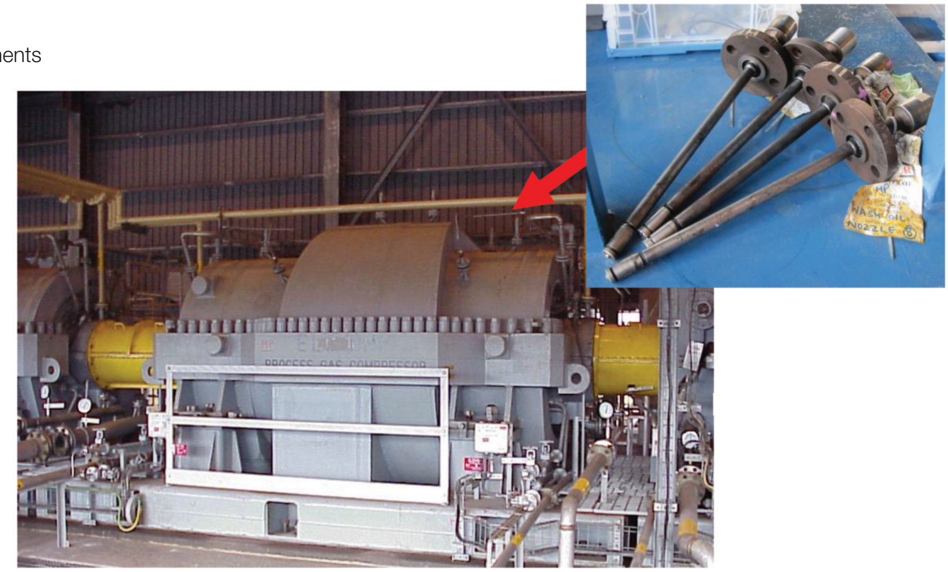
CGC COMPRESSOR WATER INJECTION

Ethylene producers typically add water to the process gas compressor to lower the gas discharge temperature. Water vaporizes in the compressor stage, absorbing some heat of compression and lowering stage discharge temperatures.

As fouling increases at high discharge temperatures, water injection is used in applications for more precise temperature con-

Figure 5. SermaLon coating of internal components





trol. It can either be continuous or intermittent. Typically, the water quantity is around 1% of the total process flow. When wash nozzles are requested, the purchaser or the process licensor should provide discharge temperature limits to calculate the water flow rate.

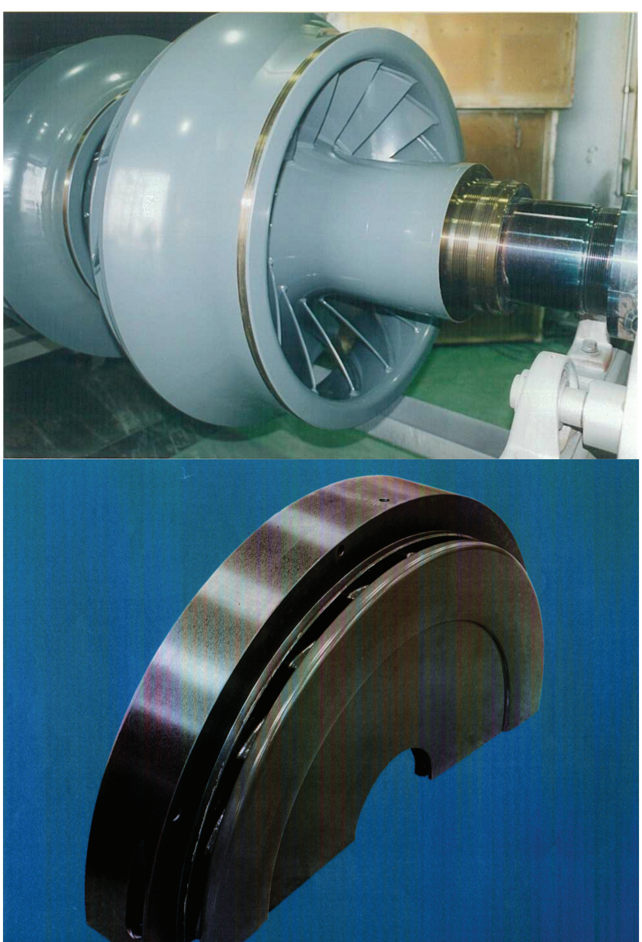


Figure 6. Water injection nozzles are located on the casing in order to be able to inject the water spray into the compressor stages.

Experience with this method had demonstrated significant decrease in temperature (~10°C) due to water injection (Figure 6).

CGC COMPRESSOR WASH OIL INJECTION

To prevent efficiency losses due to fouling during long-term operation, wash oil is injected at regular intervals in CGCs (Figure 7). Wash oil injection nozzles are usually installed on the suction piping as well as the return bend on each stage.

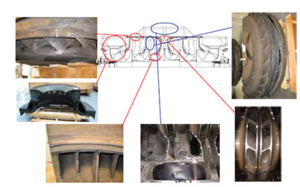
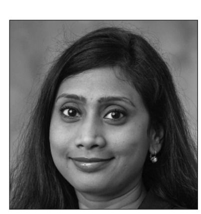


Figure 7. Compressor internals can be kept free of polymer deposits by using oil injection

Wash oil injection ensures that polymer deposits do not adhere to internal surfaces. Oil quality is important and should be free of impurities. Some of the best wash oils have aromatic contents greater than 60 % and boiling points higher than 300°C. This ensures that the oil remains liquid, allowing it to dissolve and scour polymer from the metal surfaces and minimize deposition.

OEMs have the responsibility to ensure that the droplet size is maintained to avoid erosion due to water or oil injection. The location of injection nozzles should be optimized to improve wash efficiency. CFD analyses should be used to determine the optimum oil injection location

The effectiveness of water and oil injection cannot be estimated by an OEM alone since the operating history and usage pattern is unknown. To resolve a fouling problem, collaboration is required. ■



Pallavi Baddam is the Proposal Manager for Mitsubishi Heavy Industries Compressor International (MCO). He has a Master's Degree in Mechanical Engineering. MCO is currently working with an operator to evaluate the optimum wash area and oil quantity, as well as how to mitigate erosion potential. The results will be presented in a follow-up article. For more information, visit www.mhicompressor.com/en