OPERATING SAFETY AND DEPENDABILITY WITH DRY-RING COMPRESSION

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The carry-over of oil vapors from the cylinder lubricating system of lubricated reciprocating compressors into the down stream process equipment always has been a serious problem in air separation plants, ammonia plants, or any of the many other processes that require clean, oil-free gas compression.

One of the major safety hazards in many air separation plants is created by the inherent nature of lubricated reciprocating compressors. Oil vapor, when present, will eventually settle out in the down stream equipment to such an extent that solvent washing and, in the case of low temperature equipment, deriming will be required. Further, the high compression ratios that are frequently used may result in local hot spots which can crack the lubricant, forming low molecular weight gases. We have, then, two very undesirable sets of conditions: First, the certainty of eventual costly shut downs for solvent washing and/or deriming; and second, the very possible accumulation in the process system of highly explosive compounds. The presence of collected oil in separators and filters presents the additional hazard of fire.

Oil vapor carry-over has been reduced successfully in a number of ways. The use of lower compression ratios, where possible, may tend to decrease the cracked material by reducing the heat of compression, but this does not insure the complete elimination of the hazard of gas formation. Compressor discharges have been cooled to below ambient temperature in attempts to further the removal of oil vapors. This method is quite effective since the oil vapor will tend to coalesce, and be carried off with the condensed moisture from down stream knock-out drums. It follows, therefore, that when dry gases are being compressed, discharge cooling is not appropriate.

Oil vapor removal

The use of desiccant beds or filters beyond the compressor is a highly recommended method of oil vapor removal. A well designed and adequately maintained removal system of this sort usually can eliminate enough of the contaminant to allow safe operation for fairly long periods; however, since no filter is completely effective on oil vapor service, shut down and solvent wash will be a periodic necessity.

The use of phosphate-ester lubricants is considered by many to be a partial solution to the problem. Certainly, the use of lubricants of this type to the cylinders of reciprocating compressors materially decreases fire hazard; it should be kept in mind, however, that, while they are far less combustible than ordinary lubricating oils, phosphate-ester lubricants are not fireproof. It is a matter of record that fires have occurred in systems where they were in use. In addition, their lubricating qualities tend to be poorer than those of ordinary oil. A final disadvantage is the fact that phosphate-ester lubricants are not as readily removed in down stream desiccant beds and filters as are ordinary lubricants.

In view of the foregoing, it becomes obvious that the only really effective method for the prevention of oil carry-over is to eliminate all contact between the lubricating oil, and the gas stream. This has been a fundamental factor in the selection of centrifugal feed air compressors for air separation plants. Very often, however, the pressure and flow requirement of a particular process may preclude the use of this type of equipment, but may simultaneously demand oil free gas compression. Optimum conditions in such cases would seem to be obtainable only through the use of a reciprocating compressor requiring no lubricating oil whatsoever to the cylinders. Carbon rings have been used in unlubricated reciprocating compressors with a measure of success in special applications but such compressors have usually been small in size, and have had poor maintenance records. Further, it is considered almost impossible to use dry carbon rings successfully in bone dry gas service. Their success has been limited to operations in which moisture could be introduced as a lubricant. The introduction of moisture, however, presents special difficulties in cases where the compressed gases subsequently enter low temperature equipment.

Use of Teflon

The relatively recent application of Teflon as a compressor ring material has been of great interest to plant operators who have been beset by the many problems of removing lubricating oil vapor from gas streams. The development of Teflon in this service is of great significance to the safety of operation of all process plants in which lubricating oil vapors in gas streams cannot be tolerated. Its use can eliminate the hazard, and maintenance generally associated with oil vapor removal. Teflon is a trade name for a material developed by du Pont technically known as polytetrafluroethylene. It has a high degree of lubricity, and, when properly installed, eliminates, in most cases, the need for lubricants in the cylinders of reciprocating compressors. The Mingo Oxygen Company is currently operating a large reciprocating machine, using dry rings of Teflon which has been running successfully for just under 7000 hours to date. It is believed that this machine may go to 10,000 or even 12,000 hours before these dry rings will have to be replaced.

The Mingo Oxygen Co. has been in production for somewhat less than a year. It was designed and constructed by Hydrocarbon Research, Inc., and is jointly owned and operated by Hydrocarbon Research and the Wheeling Steel Corp. Products include high purity vapor oxygen which is sold to Wheeling Steel and delivered through a three and one-half mile pipe line; and high purity liquid oxygen and very high purity liquid argon both of which are sold to National Cylinder Gas Co., and delivered by highway and railroad tankers. The requirement was for a 400 ton per day facility, for which two 200 ton/day low pressure units were built to provide maximum operating flexibility. Each unit is fed by a separate electrically driven Clark No. 5H4 centrifugal compressor. Vapor oxygen product from each plant is compressed to 200 lbs./sq. in. gauge in separate, two case, diaphragm cooled, centrifugal booster compressors which are also of Clark design. Refrigeration for each plant is provided by centripetal expanders supplied by Rotoflow. The additional refrigeration required for liquid oxygen production is provided by a medium pressure nitrogen recycle circuit with cascade forecooling, and a high pressure centrifugal expander, also by Rotoflow.

The compression requirement in the nitrogen recycle circuit could be met only by a reciprocating type machine, therefore, after careful consideration, Hydrocarbon Research selected for this service a Clark

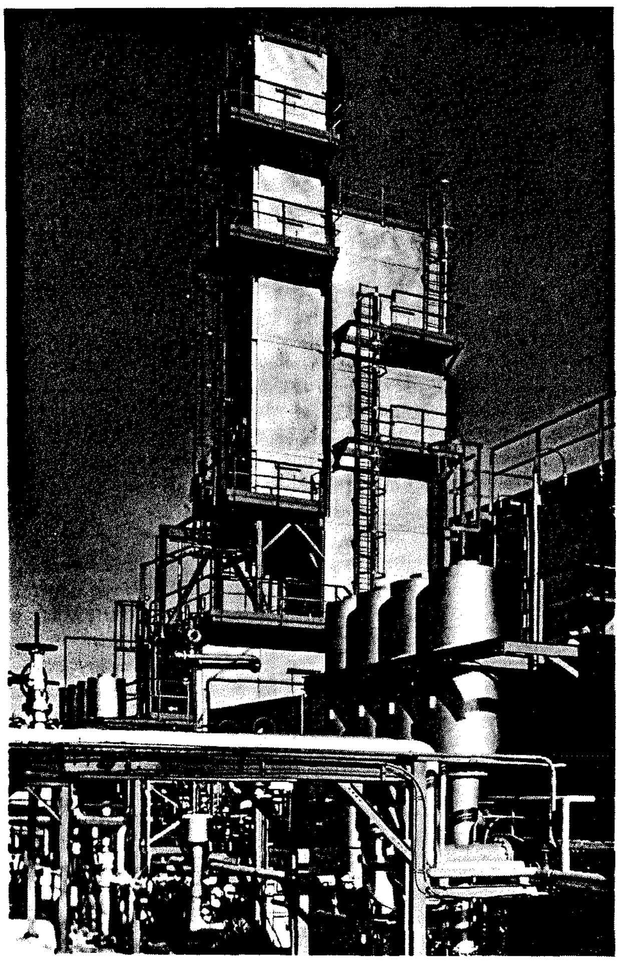

Figure 1. Cold box for one of two air separation units at Mingo Oxygen Co.

six throw, multi-stage, compressor with compression rings and rider rings of glass filled Teflon. At the time this selection was made, there were few, if any, compressors in completely dry ring service having piston diameters greater than six inches. In contrast to this, the machine that was selected for the Mingo Oxygen Company has twenty-nine inch pistons in three of its cylinders, with the other three pistons sized somewhat smaller. In order to insure that every possible engineering advantage would be afforded the proposed dry ring operation, Hydrocarbon Research worked very closely with Clark Brothers in developing the design criteria for this machine. The following factors were among those considered in establishing the frame size:

1. Discharge temperatures were to be limited to approximately 250 F., which dictated a low compression ratio per stage.

2. Low piston speeds in the range of 500 ft/min were specified resulting in a requirement for larger frame and cylinder sizes. Conventially, piston speeds of 800 to 900 ft/min are used on machines of this size.

Mechanical design

The following are some of the mechanical design features specified:

1. Special treatment of piston rods and cylinder liners with stringent surfact finish specifications.

2. An effective cooling system for the Teflon rod packing.

3. Glass filled Teflon compression and rider rings were selected, based on a study made to determine the potentials of this material in such service.

4. Clearance pocket installations suitable to maintain relatively low discharge temperatures in all stages at part load operation.

5. The use of extra long distance pieces to prevent crankcase oil from entering the cylinders; and the installation of oil slingers on the rods to prevent oil creepage along the rods.

6. Pulsation snubber installations adequate to control operating vibration.

7. The use of a fouling factor in the design of the intercoolers that would insure low suction temperatures even after continued operation.

8. Adequate rust inhibitor inside the cylinders prior to start up, to maintain the special finish.

9. Meticulous cleaning of all intercoolers, interconnecting piping, and process piping, prior to start up.

10. Strict adherence to a special break-in formula for initial start up and operation.

Much of the success experienced with this compressor is attributable to the above listed features. Moreover, the extreme care exercised by Mingo Oxygen in the operation and maintenance of all mechanical equipment contributes substantially to the satisfactory operation of compressors. The case history of this unique machine proves the wisdom of this policy. During an inspection shutdown, at 5500 hours, it was found that the Teflon compression and rider rings indicated a wear of slightly less than twenty thousandths of an inch. Correspondingly, the cylinder liners showed no wear whatsoever.

A recapitulation of all contributing factors indicates that properly engineered, carefully installed, and intelligently operated dry Teflon ring reciprocating compressors, even in large piston sizes, eliminate

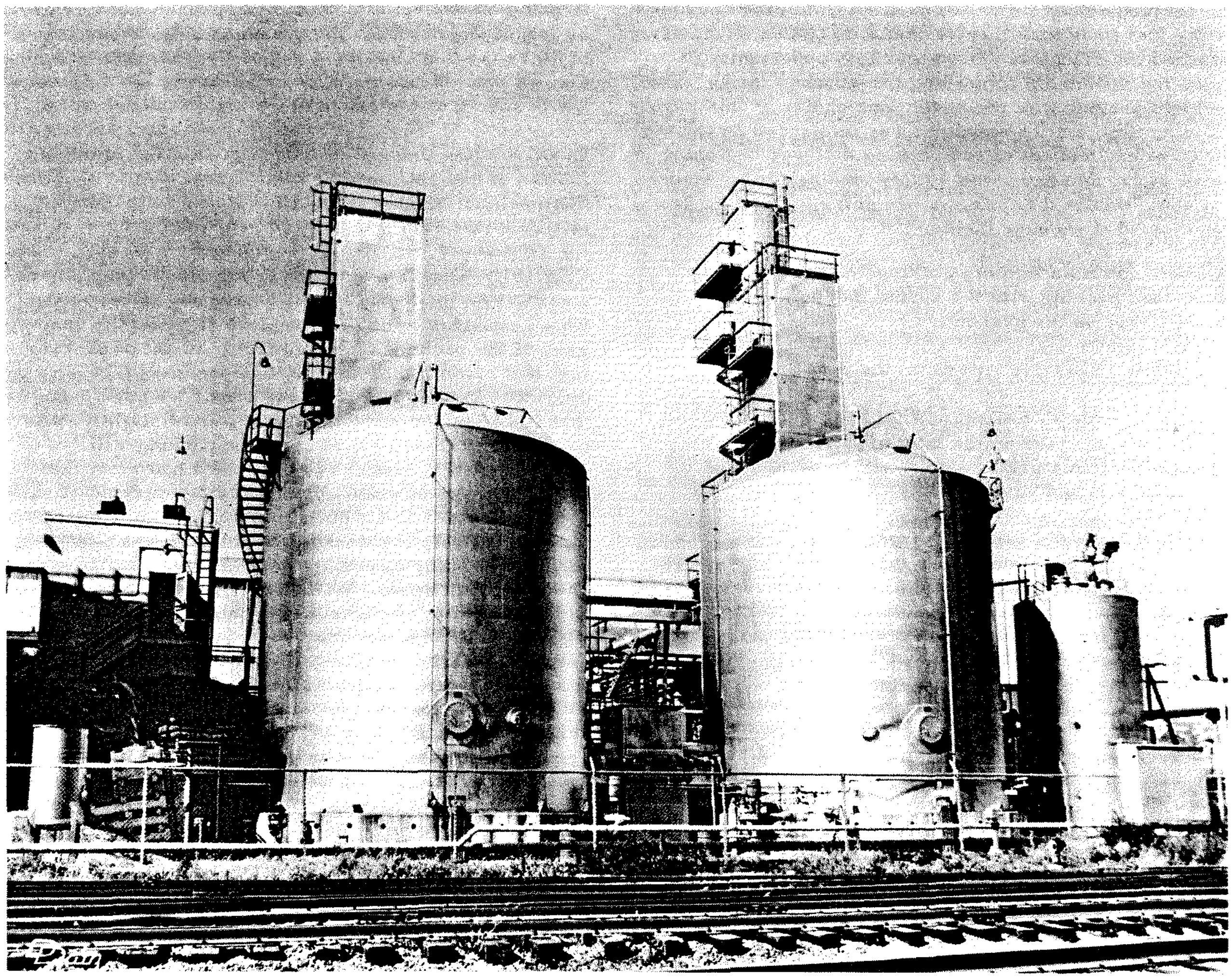

Figure 2. New $6 million air separation plant at Mingo Junction, Ohio.

the hazard once thought to be inevitable in the application of such compressors to processes, such as air separation or ammonia plants, in which the presence of oil vapors in compressed gas streams is intolerable. Simultaneously, it is believed that the dependability of the dry Teflon ringed machine is at least as good as that of oil lubricated equipment, and that the over all plant dependability and availability are greatly improved by the elimination of the need for oil clean up in the process gas stream.

DISCUSSION

STOCKBRIDGE—Southern Nitrogen: Did you have any replacement for your Teflon rings during start-up? In polishing inside your liners, did you have to replace any rings or anything of this nature?

PENROD—Hydrocarbon Research: At 5,500 hours, we replaced two rider rings. Those are the only rings that have been replaced in the machine since the start-up, including the initial break-in. The two rings that were replaced were changed not because of excessive wear, but due to having been slightly damaged during the removal of the piston from the cylinder, and due, also, to a desire on the part of our mechanical people to have these representative rings examined under laboratory conditions. As far as the condition of these two rings at the time that the machine was shut down is concerned, I can say without hesitation that they could have been continued in service, just as were the balance of the Teflon rider and compression rings that were in use in the machine.

STOCKBRIDGE: Whose rings were these? Did Clark develop them?

PENROD: They were provided by Clark, from Koppers Company, Inc.

TIXHON—Brockville Chemicals: I would like to know what was the discharge pressure?

PENROD: Five hundred and fifty pounds. This is a relatively low pressure. The machine is on bone-dry nitrogen.

MASON—Dow Chemicals: You mention that you had specified a high polish. Do you have the specific identification?

PENROD: It is a high micron finish, and I do not at present.

CULP—W. R. Grace: I believe you mentioned you have Teflon packing on the rods. What was the condition of this packing after 5,000 hours?

PENROD: We considered this 5,500 hour shutdown the annual turn-around. We had been wondering, as had a great many people who had been following the operation, just what condition we would find when we finally opened the machine. So we took this opportunity to give the machine a complete turn-around, during which all rod packing was replaced. Our choice of this particular time for the shutdown was influenced by the fact that we had one set of rod packing that was beginning to give us trouble and I was simply looking for an excuse to say, "this is the time, we are going to open the box and see what we have inside."

CULP: Is this a floating packing? I am thinking of the pressure packing with the spring loading, but it would float freely on the packing.

PENROD: Yes, this type is on the rods.

MACKAY—M. W. Kellogg: What special precautions, if any, did you take on the inlet side during start-up, and immediately prior to start-up, to prevent the ingress of grit and scale?

PENROD: We did two things; we were extremely careful, as is our practice in any case, to have the suction lines completely and thoroughly clean, and we placed strainers in them.

MACKAY: They were effective?

PENROD: I think you would have to say that they were. As a matter of fact, in this particular instance, we got almost nothing out of the strainers. We had some people who did a fine job on our pipe cleaning.

JENKINS—U. S. I.: Would you go through the break-in procedures again? You ran at "no load" for a considerable period of time?

PENROD: We ran at "no load" for a considerable period of time and, of course, during that period we constantly monitored the machine to see that we were not getting undue heat from friction. Then, when we loaded the machine, we permitted our temperatures to build very gradually to the point presumed to be normal for a new, tight machine, subsequently inducing additional temperatures commensurable with the requirement of our break-in system for Teflon. There are many schools of thought about the use of Teflon. There have been cases where Teflon ringed machines have developed a fairly heavy accumulation of Teflon powder on the rods and in the distance pieces during the early hours of operation. I think that when this is true, the break-in has been possibly too fast and/or too cold. In the last analysis, what you have on even the highest of high micron finishes is a metal surface having a certain porosity, and I believe that the success of running dry Teflon depends not simply on having Teflon running on a high micron finish, but, rather, Teflon that is running on a high micron finish that is impregnated with Teflon. This, I say again, is simply a theory that I have which is based on some relatively elementary surface friction experiments, and on the fact that we have had outstanding success with machines that were broken-in in a way that we feel produced these conditions.

JENKINS: Our mechanical people feel that if you break in at no load or if you run for great periods at "no load," you get "packing slap" and this deteriorates your packing. We have had better luck breaking in at higher pressures than we have at lower pressures.

PENROD: I think a lot of that would depend on how true your rods were running, would it not? If you have a true machine, the rod packing won't really know what is going on, except that it is being pushed to a greater or lesser degree from the pressure side, depending on whether the machine is, or is not, loaded. The machine that we are discussing runs at relatively low pressure. We believe that we can go much higher on dry Teflon.

ROCKWOOD—Union Carbide: You said the imminent failure of rod packing was what caused you to shut down the machine for check-up. How did that breakdown manifest itself?

PENROD: That is a question that I cannot factually answer at this moment because I have not as yet gotten what I consider to be the complete story on the analyses of the packing segments from the set of packing that had become increasingly bothersome. There is one point that I would like to inject here. We have found that if Teflon rod packing starts to blow slightly, this need not necessarily mean that the packing will go, or even that it will continue to blow. We had a set that blew intermittently and very lightly for periods of an hour or two at a time, but which sometimes stopped blowing entirely for weeks at a time. It was this particular set which caused us to finally inspect the machine at 5,500 hours. We believe that this is sometimes caused by changes in the degree of trueness with which a particular rod may be running. Dry Teflon rings move circularly in their grooves and, since it is unlikely that the ring wear would be completely even, it follows therefore, that under certain conditions the centering of both piston and rod could be slightly changed, and that this change is reflected directly on the contact between rod and rod packing. We would expect that deveations as slight as this would be absorbed by the spring loaded, segmented packing, but it appears that such is not always the case.

ROCKWOOD: Did you have any rod wear against the packing?

PENROD: Little rod wear. Not enough to be significant. However, we did have marks on our rods which, frankly, I can't account for. When the machine was down from time to time for process reasons, it was our practice to check the clearances between packing cups and rods very carefully. When we first did this, we found marks on some of our rods which no one, including the Clark representative who was there could account for. They did not bother us.

POWELL—DeVoe Corp.: You mentioned "no load" operation of the compressor. Do you mean that there is no gas flow through the compressor? If so, how do you prevent overheating of the valves?

PENROD: We were operating with the valves removed. We were simply mechanically operating the machine at no flow as the first step in breaking it in.

POWELL: On this Teflon packing and rings, you mentioned glass-filled Teflon. Have you ever used carbon filled?

PENROD: I have not.

CULP: The rings that reached the twenty thousandths wear. Are these a floating ride on the piston or are they fixed on the piston?

PENROD: They are floating.

GARRICK—M. S. A.: There seems to be a lot of emphasis on cleaning up all the lines. This is prior to start-up and I assume that there would be dirt in the pipe lines, etc. I wonder whether there has been any thought given or whether you have any means of cleaning up dirt and particulate matter in the intake. It seems to me that this could be a factor in the life and wear of the rings.

PENROD: I probably did not make myself clear enough on the exact service of this machine. It is in ideal service. It is pumping bone-dry nitrogen which is utterly clean. The only chance of contamination would have to be from the process lines, and, since the entire system was chemically washed and carefully blown prior to start-up, this seems most unlikely.

STOCKBRIDGE: You stress the fact that it is on nitrogen. With this experience behind you, would you hesitate to use this on air?

PENROD: I don't think I would. I think that if I were to be doing it, however, I would make it mandatory that every advantage be given the machine by cleaning everything up that goes into it. I say that simply as a matter of common sense rather than from knowing just how badly particulate matter might affect glass filled Teflon rings. We have a machine that is pumping oxygen with which we had poor success when the machine was first set up. It lasted about three weeks. Then we took the machine down and put new Teflon in it, and broke it in by the method that we feel is the proper one. It has been running ever since last January, eight months, I believe.

SHANER—Linde: What purity was the nitrogen that you were recirculating?

PENROD: Not more than three percent oxygen.

KEITH—Hydrocarbon Research: A gentleman over here asked the question, "would we be confident using a machine of this type on air?" We have had a lot of conversations with the machine manufacturers, and I think that the same comments can apply to Teflon on any saturated air service as applied to carbon rings. I don't think we would have any compunction at all about putting in a Teflon machine. As a matter of fact, we would prefer it to carbon for non-lube air service. Now we would, as Jack has pointed out, take special precautions with regard to filtering the air intake. But we would expect a minimum of 8,000 hours on saturated air service. With regard to our confidence in pumping bone-dry nitrogen, we have placed an order for a 1,500 pound machine and, I believe, five or six stages, which we will be running on bone-dry nitrogen.

MILLER—DuPont: To what did you attribute the failure in oxygen service?

PENROD: We think that it was because the machine was broken in too fast and without proper regard for the temperature control that we feel is necessary for dry Teflon. We did not supervise the original breaking in of this particular machine. In any case, we know that since we replaced the Teflon, using the break-in method that we prefer, we have had no trouble, and this was done eight or nine months ago.