DEVELOPMENT AND APPLICATIONS OF NONLUBRICATED RECIPROCATING COMPRESSORS

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The increased complexity and more stringent requirements of gas process work and gas handling in general have greatly extended the need for methods of gas compression which eliminate or reduce the contamination that is caused by conventional, lubricated type, reciprocating compressors. While synthetic lubes of many types have been proposed and used, with some success, the nonlubricated and minimal-lubricated compressors appear to be a more proper approach to the problem. More specifically, Teflon equipped compressors, operating both nonlubricated and minimal-lubricated appear most feasible.

Filled Teflons have been selected because of their wide assortment of desirable characteristics, and their complete compatibility with many gases and mating materials. Teflons have the advantage over carbon of being nonbrittle. Because of carbon's brittle characteristic, the problem of chipping and cracking, and a resultant scoring of the mating metal parts, makes the operation of compressors equipped with carbon somewhat hazardous. Teflons, on the other hand, when properly selected, have the capability of wearing out or being destroyed, due to some adverse situation, without destroying the mating metal surfaces. Compressors equipped with Teflon further have the advantage of a simpler and less expensive maintenance program. Although Teflon parts by themselves are quite expensive, the compressors equipped with Teflon utilize to greater advantage the bearing and ring materials than does a compressor equipped with carbon parts.

Nonlubricated operation

Before entering into a discussion on nonlubricated and minimal-lubricated compressors, it will first be necessary to define or describe exactly what is meant by these two terms. We can say we have a nonlubricated compressor when we have a cylinder that is designed to operate completely without the addition of lubricants of any kind. When we speak of lubricants, we mean a lubricant in a liquid form. Some people consider Teflon equipped compressors dry lubricated. For the purpose of this discussion, however, we will describe such compressors as being nonlubricated. Further, they will only be nonlubricated when the pistons are equipped with Teflon piston rings, Teflon wear bands, and when the piston rods are equipped with a seal that contains a Teflon packing, preferably a floating-type packing similar to that used in lubricated compressors. In addition to these requirements there must also be, between the driver and the compressor cylinder, a suitable means of preventing oil carry-over from the crankcase of the driver. The oil stop usually takes the form of a collar or slinger on the piston rod and most generally one such collar is sufficient. In ex-extreme situations, as encountered in the operation of oxygen compressors, it is very desirable to have a secondary stop. This stop may be either in the form of a second collar and/or an auxiliary wiping packing which is capable of absorbing any minute particles of oil that may be carried over either in vapor or liquid droplet forms.

Oxygen and air compressors

The use of completely nonlubricated compressor is required when normal lubricating oils are hazardous or when special lubricating oils are very expensive. Two good examples of this situation are oxygen compressors and air compressors. The operation of nonlubricated compressors is desired when the lubricating oil would contaminate the final product or the catalyst that is involved in producing the final product. Low temperature gas compression also makes nonlubricated compressors very desirable. Without the need of lubricants, deriming or shutdowns for removal of oil from the process system are unnecessary. Nonlubricated compressors are practical only in those processes which permit the presence of absolutely no oil in the gas stream. Because of the limitation of Teflons that are available today, the nonlubricated compressor is much larger in size than its lubricated counterpart This quite naturally means that the nonlubricated compressor will be more expensive to install and operate than would be the equivalent lubricated machine.

Minimal lubricated operation

To bridge the gap between nonlubricated compressors and fully lubricated compressors, one may wish to consider the use of minimal-lubrication compressors. Generally speaking, the size of a minimal-lubricated compressor will fall between that of a lubricated machine and the nonlubricated machine when handling a given quantity of gas. The reduction of the size of the machine is made possible by the admission of small quantities of oil into the cylinder and/or the compressor piston rod packing. One would generally consider the use of such compressors when lubricating oils would tend to contaminate the process stream or when it would cause fouling in the heat exchangers. Minimal-lubricated compressors may also be used in some hazardous situations such as air compressors where high discharge pressures may occasionally cause combustion of the lubricating oils. All minimal-lubricated compressors differ from the nonlubricated compressor in that they do not have the provision for preventing oil carry-over from the crankcase of the driver. Cylinder construction may lie anywhere between the designs of lubricated and nonlubricated machines, the exact construction depending on the quantities of oil admitted to the cylinders.

One may basically break down the descriptions of the various minimal-lube compressors into four different categories. The first would be a cylinder which had the full complement of Teflon seals and wear bands; that is, it would have Teflon piston rings, wear bands, and packing rings. A compressor so equipped, but without provision for lubrication, would have only a bare minimum of carry-over of lubricating oil into the gas stream. This oil would be represented by the carry-over from the crosshead or driver frame into the compressor cylinder. The carry-over is so small in quantity that, for some applications, this method of operation challenges a full nonlubricated machine. It has the further advantage of greatly reduced rod packing problems.

Higher degree of carry-over

A second form of minimal-lubricated construction would have Teflon piston rings and Teflon wear bands but lubricated packing. It is obvious that a cylinder so equipped would have a higher degree of carry-over than the aforementioned cylinder.

A third degree of minimal lubrication would be that which was represented by a compressor cylinder equipped with Teflon piston rings only. It is obvious, in this case, that there must be a considerable quantity of carry-over in that the piston must be supported by an oil film. In this situation as in the previous one, the packing would be lubricated.

The fourth degree of minimal-lubrication operation would be a plunger-type cylinder. Such a cylinder could be equipped with lubricated packing or with a packing equipped with Teflon rings and no provision for direct lubrication. Some people refer to compressors of the plunger family as being nonlubricated. In the strict sense of the word they are not, but rather minimal lubricated. Each of these various arrangements of minimal-lubricated compressors has a purpose and is capable of delivering gas with smaller than normal quantities of oil carry-over in the gas stream.

In each of the minimal-lubricated operations the quantity of oil carry-over must be carefully considered. There is a rate, at present unknown, at which the oil will tend to mix with the debris from the wearing of the Teflon to form an abrasive paste. Under such conditions wear is greatly accelerated and, if not detected immediately, can result in serious damage to piston rings, wear bands, and packing. Under these conditions it is also possible to score piston rods and liners as well.

The more abrasive is the filler of the Teflon, the more rapid will be such wear. When properly used, Teflon will operate successfully nonlubricated as well as lubricated. There are many instances where Teflon piston rings and packing rings are very desirable for lubricated services. This is brought about by the fact that Teflon is inert in the atmosphere of many gases.

General piston design

In considering the application of Teflon to the compressor cylinder, we will first look at the piston assembly in the low to moderate pressure cylinders. These remarks will generally be applicable to the minimal-lubricated as well as the nonlubricated compressors. Wear bands may generally take one of two forms on the piston. First is the split band and second the continuous band. The split band generally requires a heavier piston because of the need of a deeper groove. However, these split bands are much easier to install either in the field or as original equipment by the compressor builder. To prevent these bands from acting like piston rings, they must be balanced. This balancing takes the form of slots on the vertical sides of the wear bands themselves. The slots are intended to permit an easy bypass of the gas around the band so as to present a balanced condition from one side of the band to the other. In practice this balancing proves to be fairly effective. However, there are instances that have occurred where, in spite of balancing, the wear bands have insisted upon acting like piston rings. A means of combating this situation is the continuous or rubber band-type wear band. These bands are stretched over the piston and into a groove where they remain absolutely tight. These bands are generally smaller in cross section, and, therefore, require shallower grooves. There is, however, the disadvantage of requiring special assembly tools. The distinct advantage to these bands is the fact that when a piston is rotated, the band turns with the piston. This means that it is very easy to pick up a new wearing surface on a given wear band. Such rotations extend the life of a band and, therefore, bring the operating cost of a compressor down. These bands, because they cannot be pressure energized, leave the job of sealing solely to the piston rings.

Wear band grooves

With either type of band it is generally advisable to have wear band grooves at either end of the piston. With this arrangement the tendency for rocking or cocking of the piston is greatly resisted. In order to maintain uniform quality throughout the cross section of a piece of Teflon, reasonable proportions of depth to width must be maintained in a given cross section. To meet this requirement and the requirement of low bearing pressures, it is sometimes necessary to use a multiplicity of wear bands on a given end of a piston.

In the case of the split wear band, it is generally conceded that one band per groove is more desirable. In this situation the end clearance per groove is kept to a minimum and wear band slap is also kept to a minimum. This means, that in some instances, it is quite possible and very probable to have as many as four wear bands per piston. In this situation each band would be in a separate groove. In the case of the continuous band, however, a multiplicity of bands may be placed in a common groove because the band is shrunk to the groove and is not free to slap back and forth during the operation of the piston. Although very high bearing pressures may in some cases be tolerated, the most conservative values are generally considered more satisfactory. For example, a wear band bearing pressure of 10 lb./sq. in. will generally result in more than twice the wear rate of a bearing loading of 5 lb./sq. in. Thus the life or operating time of a given cylinder can be extended through the reduction in bearing pressures. This means lower cost per operating hour.

One does not wish to infer that loadings as high as 10 lb./sq. in. and higher cannot be tolerated in special cases. There are instances where piston rings have been made to do double duty and, in fact, supported the piston as well as perform the function of sealing the head end of the piston from the crank end. Higher bearing loadings, however, are also more susceptible to failure as a result of debris and dirt carry-over and will fail in a shorter time than will units equipped with wear bands designed for the lower unit loadings.

Snap variety piston rings

Teflon piston rings most generally are the snap variety and may be purchased in butt-, angle-, or step-type joints. Because of Teflon's notch sensitivity and its tendency to deform under load, some people choose not to use the step-type joint for piston ring applications. With the angle and butt cut ring one must, of course, expect more ring blow-by. Even with the possibility of failure one finds it advisable to use the step-joint ring. In situations where failures were experienced, we have never experienced any damage to the cylinder or the piston proper. This fact coupled with the better sealing capability of the step joint makes its use very desirable.

In all compressors and at all pressures except atmospheric suction, one can obtain very satisfactory operation without the use of piston ring expanders. The significance of successful operation without the use of expanders is, of course, protection. With the loss of piston rings, as a result of excessive wear, there is always a danger that expanders, when used, will move out of the piston ring groove, and wedge between the piston and the cylinder bore. Such a situation can very readily result in excessive cylinder bore scoring or piston scoring, or even piston seizure in the bore. In handling some gases such as oxygen, such a situation could also be fatal. Regardless of the gas being handled, however, it is advisable to operate, whenever possible, without the aid of piston ring expanders. When it is necessary to operate with expanders, it is suggested to use a special expander spring that is made out of a plastic or other synthetic material. It is important that the material selected by generally softer than the bore and not of an abrasive nature. Unfortunately, the assortment of materials that are available for use as expander springs today are generally not compatible with oxygen.

Piston rod packing arrangements

The following remarks concerning piston rod packing will apply to the minimal-lubrication, as well as nonlubricated compressors, at the low to moderate pressure loads. Piston rod packing is classified by packing style and also by packing case construction.

Basically, the ring style is differentiated by the use of standard-type packing rings with, and without, antiextrusion rings. By standard-type packing rings, one simply means the use of a radial tangential combination ring. The function of the antiextrusion ring, when used, is to prevent, as a result of pressure, the extrusion of the packing ring between the annular space formed by the packing case and the piston rod. It also affords the additional benefit of more effective cooling through the more intimate contact of a heat conducting material with the piston rod and the cooled packing case. Such antiextrusion rings are generally made of a bronze-type material or in some cases cast iron or babbitt. The alternate materials are generally used where bronze is not compatible with the gas being handled.

In the lower pressure ranges or whenever possible it is advisable to use a packing set without the antiextrusion ring. The antiextrusion ring, because it is metal and in direct contact with the piston rod, and without the benefit of lubrication, is subject, in some instances, to excessive wear. In these situations the antiextrusion ring then proves to be more of a liability than an asset. For this reason, the operation with the standard tangential radial combination without the antiextrusion ring is a preferred assembly.

The various combinations of Teflon ring styles that are used in conjunction with the antiextrusion rings generally serve to reduce the total amount of Teflon in contact with the rod. While such rings may be successfully accomplishing their job, there may be other features to these rings which make them somewhat undesirable. In any given application the specific type packing rings or combination of packing rings that will be used will depend upon the particular conditions encountered.

Generation of heat

Regardless of the style of ring used, the result of the sealing forces upon the piston rod is the generation of heat. Such heat, when it becomes excessive, will cause the accelerated wear of the packing rings and also of the antiextrusion rings. When pressure conditions and the subsequent heat build-up becomes significant, a cooled packing must be employed. If possible, it is advisable to have every cup of the case cooled. The coolant grooves in each cup should be such that they are located as close as is physically possible to the packing rings themselves. With the benefit of such cooling, however, comes the hazard of the possibility of water leakage into the packing case proper and, therefore, into the main gas stream. With such gases as ammonia and carbon dioxide the results can be quite hazardous. In such instances special design techniques must be employed to the packing case so as to prevent any possibility of leakage of coolant water into the gas stream. These arrangements also make it possible to completely drain the packing case prior to disassembly. The added benefit to this type of packing case design is the prevention of rust on the internals of the compressor cylinder and also of the piston rod when a standard carbon steel-type piston rod is used. In nonlubricated applications it is advisable to use the coolest water available for cooling the packing case.

Cylinder construction

In the low to moderate pressure level the double-acting pressure cylinder is generally standard. When acceptable to the customer or to a particular process, the cylinders are equipped with liners. The purpose of the liner is twofold. It first provides a surface which may be removed without destroying the entire compressor body, and second it provides a surface that is more properly compatible with the Teflon rings and/or the gas being handled. With the replaceable liner it is possible to provide various types of coating materials in the cylinder bore without drastically increasing the over-all price of the compressor unit.

As one moves above the moderate pressure level into the higher pressure compressor cylinders, one departs from the standard double-acting construction to a single-acting type cylinder design. In such a design there is no piston rod seal, but rather a special piston head seal which is responsible for sealing the compression space from the low pressure end of the assembly. Such single-acting cylinders are generally used in conjunction with a low pressure single-acting cylinder that is placed inboard. The inboard cylinder must have a piston rod packing seal. This, of course, is only possible in the situation of a multistage unit. Such arrangements make the job of sealing the piston rod much simpler. One may also introduce, between the inboard and outboard piston assemblies, an intermediate pressure which will act as a back pressure for both the inboard and outboard piston assemblies. This will reduce the differential pressure which each assembly must face. Even if the outboard single-acting cylinder were required to seal the same differential as would a packing case on a double-acting cylinder, one benefits more from satisfactory cooling of piston rings running against the cylinder liner than one would with packing rings against the piston rod. When properly designed, the single-acting cylinder will give a better relationship of cooled surface to the piston ring area than will the packing case to piston rod arrangement. Much of the success of a nonlubricated machine depends on the ability of the coolant to absorb the frictional heat that is generated by the seal elements.

Single-acting piston design

The construction of the piston in a single-acting high pressure cylinder assembly must limit running clearances to a very minimum to prevent the tendency of piston ring extrusion. At the same time these clearances must not be so small as to provide an inadequate amount of wear band projection beyond the surface of the piston for a reasonable wear life. When one is so severely limited on the projection of wear band one must use even more conservative wear band loadings to reduce wear rates. One must use very low bearing pressures to resist, to the utmost, the tendency of settling of the piston as a result of wear band wear. The tendency for the outboard piston to settle may further be reduced by using the inboard piston as a crosshead. As in the case of the outboard piston, the inboard piston wear bands must be very adequate to insure a minimum wear band loading.

As would be expected, the piston ring design on such high stage cylinders becomes a very critical item. Special attention must be given to the joint design, proportion of ring, and the number of rings required to adequately seal the pressure involved. In the single-acting applications at the higher pressure levels, it is easier to arrive at a ring joint design that will resist breakage completely. In some situations where the loss capacity or excessive blow-by is not critical, a butt-type joint may be used. It is generally desirable to seal as completely as possible the gas being compressed because any leakage represents a loss in horsepower. With improperly designed rings, and/or an improper number of rings for a given pressure application, excessive heat will be generated. Such heat will only lead to the ultimate failure of the rings. Only when the proper number is used will the maximum or optimum life be obtained from piston rings.

Types of filler materials

To this point we have only mentioned filled Teflons and have made no specific reference to any one given type of filler material. We have, however, dwelled very heavily on design aspects and rightly so. Through experience we have shown that design techniques will ultimately lead to the maximum improvements in wear life rather than depending upon the selection of filler materials only. Filler materials with Teflon, however, do have their place and should be properly selected for a given application. The three most common materials in use today as fillers for Teflons are carbon, bronze, and glass. Wherever possible, carbon filled Teflons are used for the seal and bearing elements in a compressor cylinder. The reason for the selection of this material is that the carbon filled Teflons have the least abrasive characteristics of the filled Teflons that have been introduced to date. They do, however, have the disadvantage of being rather soft, and more subsequent to cold flow than the bronze and glass materials. When properly utilized, this disadvantage is readily overcome at the low and moderate pressure levels and the full benefit of the less abrasive carbon filled material is then gained. This material, through experience, has shown to be a generally good performer in most applications.

Bronze filled Teflon

The bronze filled material is a rather new addition to the filled Teflons, and has been shown to be a very good performer in the more difficult applications. It appears to have excellent heat conductivity, good wear resistance, and a very good resistance to cold flow. Although it is somewhat more abrasive than the carbon filled Teflon, the tendency to erode the mating metal surfaces can be reduced through proper mating material selections and design. At the present time bronze filled Teflons are giving a good account of themselves at the 4,000 lb. level on single-acting machines. These machines are in operation in the field and are completely nonlubricated.

The third filler material—glass—is probably the oldest one that has been used in conjunction with Teflon. As might be expected, however, glass is an abrasive material and, if not properly used, can be a very hazardous material. Glass filled Teflons are very stiff and resist cold flow to a high degree. They must be handled very carefully in the minimal-lube applications where slight amounts of liquids or lubricants may enter the air or gas stream. When glass fibers are mixed with the lubricants or liquids, in the proper proportions, an abrasive compound similar to that of a lapping compound may be formed. The result is excessive and usually disastrous type wear. It is generally difficult to detect this type of wear and as a result major failures may occur without warning.

Combination filler materials

Along with these three basic filler materials, are other materials that are used in conjunction with the prime fillers. For example, combinations of glass and carbon in Teflon, combinations of bronze and molydisulfide, and also combinations of glass and molydisulfide. Actually, the list is endless. Many people have been working to develop new filled materials to solve the problem of nonlubricated compressors. While one filler may have specific advantages over another type of filler, the base material must be Teflon. As long as the filler material will allow the composition to retain a plastic characteristic, then one can only hope to reach certain almost predictable maximum physical characteristics. If, for example, the quantity of bronze filler were allowed to get out of hand, one would be more properly speaking about a

Teflon filled bronze material. The result would be a loss of the self-lubricating qualities of the basic Teflon material. The extreme of this, of course, would be a bronze ring with no Teflon filler of any amount. Such rings have been tried in completely nonlubricated service and have proven to be highly unsuccessful. The final selection of a proper filled Teflon is made by a careful study of the nature of the gas being compressed, and the mating materials that will be used in the construction of the compressor cylinder.

Liner materials

Some of the most popular materials being used for liner materials are Meehanite grade cast irons, nodular irons, ni-resist irons, and basic iron liners with chrome or other surface coatings. The specific selection will depend, as mentioned before, much upon the type of gas that is being compressed. As one gets into the more corrosive type gases one will go to the ni-resist or chrome type liners. There are some reasons for using nodular iron liners in place of the Meehanite. The latter, to date, has proven the most satisfactory type material used in conjunction with any filled Teflon. The selection of a liner material is based on the nature of the gas itself which will, to a great extent, determine the type of filled Teflon that will be used for piston rings and wear bands.

Piston rod materials

A few of the materials which may be considered for piston rods are 1050 and 4140 steels, 17-4PH, K-Monel, Colmony coated 1020 steel rods, and also flame plated rods. The flame plate rod is a tungsten carbide material plated over virtually any basic type piston rod material. When noncorrosive gases are being handled the 1050 or 4140 steels are generally used. These materials are capable of attaining high surface hardnesses, with very good micro-finishes for the long wear lives that are desired of piston rod packing rings. However, when encountering corrosive gases one will choose one of the stainless materials such as those that we have already mentioned. The 17-4HP stainless has proven to be a very good material for use in compressor piston rods because of its ability to attain a reasonably high hardness. The Colmonoy coated rod is a very hard material but it has the disadvantage of causing a reduction in rod load capability on a given size rod. This results from the fact that the Colmonoy coated rod cannot be heat treated to increase physical properties of the base material once the Colmonoy has been deposited on the rod. In many instances, however, this is of no serious consequence.

K-Monel piston rods may be used in special applications and specifically in oxygen service where a fire resistant material is desired. K-Monel, like other stainless steels, has the disadvantage of a rather low hardness level. A low hardness level is generally considered not compatible with Teflon. When it is desired to attain a good hard wearing surface and high physical properties in the basic rod itself, one may consider the use of flame plating. Although it is more expensive than Colmonoy coated rods, it does afford all the properties that are desired in a good piston rod. With the proper selection of the tungsten carbide coating, hardnesses approaching that of diamonds may be readily attained. As was the case with cylinder liners, the selection of a specific piston rod material will be based on corrosion resistance and compatibility with Teflon and/or the gas.

Piston speeds

Regardless of the design techniques and material selections that have been employed in a given application, piston speeds still remain as a very critical item in design. Piston speeds for given applications are generally arrived at by considering the other variables involved such as the operating pressure level, the type of gas handled, the general discharge temperature level, and the materials of construction. Each one of these variables bears on the other and plays a very significant part in determining the allowable piston speeds. Since one is guided to a great extent by allowable PV or pressure velocity levels, one may generally say that as the pressure level is increased, the piston speed must be decreased. This is considering, of course, everything else remaining equal. While gas discharge temperature must be considered, the frictional heat is generally considered to be more of a problem than that derived from the heat of compression. The discharge temperature does, however, determine a plateau from which the total load will build. The nature of the gas may be of prime consideration because of the operational hazard it presents. At a given pressure level, for example, one would be willing to operate at higher piston speeds when compressing nitrogen than one would when compressing oxygen, the reason for this being that failures of any nature are generally considered much more hazardous in the presence of an oxygen atmosphere.

Condition of gas

Control of the gas being handled is an essential part of the compressor design itself. If one is dealing with a basically dirty gas, then steps must be taken to clean up the gas stream prior to its admission to the compressor cylinder. Proper filters should be installed ahead of the suction valves and the filter equipment should be capable of removing all particle sizes larger than 5 to 10 microns. Field and lab operations have proven this to be essential.

Design factors verified

It would indeed be naive to attempt to set design parameters or to list limits of operation for general nonlube gas compression here. Because of a complete interrelationship of all variables, it is necessary to study each proposed application as a separate and distinct problem and weigh each factor influencing the operation of the compressor with the other variables which are involved. At the present time, these studies can best be made as a result of experience only and not through text book approaches to the problem.

The validity of the previously mentioned techniques and considerations have been borne out by many hours of operation on various machines in the field, compressing virtually every type of gas that is commercially used. They have resulted in success on air machines running from the standard air pressure levels up to the 4,000 lb./sq. in. level for use in wind tunnels. During the many hours of field and lab operation, the variables previously mentioned have been manipulated to promote and to extend the life of the various elements which constitute the seal and bearing surfaces of the compressor cylinders. Above and beyond the air machines, machines handling ethylene, carbon dioxide, oxygen, nitrogen, helium, and many other gases, further validate the design factors that have been mentioned and also further prove the full value of nonlubricated compressor operation.

Extension of nonlubricated performance

For the extension of operating life at all pressure levels and especially at the higher levels one must expect to deviate from the standard designs that are now used for seals in both the piston and rod packing assemblies. At the present time and with the present types of materials that are available the biggest gains are to be made in the design of the seal elements. Although one must not give up on materials, it does appear that a new material that will out perform the available filled Teflons of today is not going to be available for some time. Neither route should be rejected in preference to the other, but rather these two fields of investigation should be studied in parallel. The greatest gains of studies of this sort have not been made in the laboratory but rather have been made in the field. They have been made in joint ventures with the customer and the compressor builder entering into some very low risk type experiments with new materials and/or designs. With cooperation of this type the greatest advances in compressor technology will be made in the shortest possible time and to the greater benefit of the ultimate user of the compression equipment.

The rate of promotion and extension of the capability of the nonlubricated compressors by the compressor builder depends upon the need or the demand that is made by the compressor users. A closer working relationship between these two groups with a free transfer of information will ultimately result in the more rapid development of the nonlubricated and minimal-lubricated compressors for the process industries.