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Design Considerations for High-Pressure Reciprocating Compressors for Refinery Services

S. N. Dwivedi
Bharat Pumps & Comprs. Ltd.

DESIGN CONSIDERATIONS FOR HIGH-PRESSURE RECIPROCATING COMPRESSORS FOR REFINERY SERVICES

S. N. DWIVEDI
Manager-Compressor Design
Bharat Pumps & Compressors Ltd.
(A subsidiary of Bharat Yantra Nigam)
Naini,Allahabad-211 010.
INDIA.

ABSTRACT

Reciprocating Compressors are used for a vide variety of applications in the Refinery services. The refinery environment necessitates some special considerations by the compressor designer so as to result in a smooth trouble free operation of the machine installation.

The present paper brings out some practical design considerations required for a successful design of the compressor besides following the suggestions covered in API Standards. These considerations include a thorough analysis of the gas and its properties selection of suitable metallurgy for the wetted components, provision of suitable dynamic seals, type of lubrication as well as adequate designing of dampners, intercoolers and separators or knock-out drum to take care of the condensates, sludge, etc. The whole design process culminating into an analog study results in the safe and reliable operation of the machine as well as the refinery plant.

The paper concludes with specific suggestions for the users for what they should look for while making specifications for the compressor meant for the refinery service.

INTRODUCTION

Refineries involve a variety of services requiring use of compressors for handling a wide variety of gases, ranging from hydrogen, methane,ethane to a mixture of various hydrocarbons. Many of these applications involve Reciprocating compressors and most of these now-a-days are horizontal balanced p opposed compressors.

Reciprocating compressors, due to their inherent design, are capable of achieving the highest pressures involved in any service. In fact, the highest pressure that can be achieved by a reciprocating compressor is limited only by the physical properties of the materials employed for its construction. In addition these machines have the advantage of high flexibility to operate at varied operating conditions involving a broad range of capacities and pressure that may be required during various phases of a process.

Applications do vary, but the sole aim of the compressor designer is to endeavour to achieve the required operating parameters by a judicious combination of designs, materials and processing for individual compressor components so as to ensure highest economically and practically feasible, trouble-free working life for the compressor. This ultimately helps the reffinery maintain or even increase their processing capabilities over a longer duration.

REFINERY APPLICATIONS

Refinery applications involve compressors for handling 'Crude Over-head' gas containing a complex mixture of hydrocarbons including petroleum cuts. Compressors are also required for handling a mixture of hydrogen and hydrocarbons in varying proportions. Large high pressure Reciprocating compressors are required for the hydrogen-make-up service for hydrocracker plants intended to enhance the yield of middle distillutes from a refinery.

These services normally involve hazardous environment in which the compressors are required to operate. API Standard 618 'Reciprocating Compressors for General Refinery services' now running in the Third Edition of February 1986 is based upon the accumulated knowledge and experience of manufactures and users of reciprocating compressors and intends to establish the minimum mechanical requirements. This standard has been universally accepted for Reciprocating compressors, in general and refinery service compressors in particular.

A designer, however, would look in the minutest details of the service, gas handled and the operating conditions for deciding upon the best suited design of the compressor and all its components so as to match the expectations of the user.

APPLICATION CONSIDERATIONS

It is important that all the operating parameters involved in the particular service are well specified in the beginning itself, indicating the minutest details as accurately as possible. The design is normally based on the following parameters:

- Gas to be handled.
- Suction & Discharge pressures & temperatures.
- Capacity required indicating capacity control requirements
- Lubrication conditions
- Drive arrangement and Prime mover
- Location & environment

thorough knowledge of the properties and behavious of the gas to be handled is most essential for the proper application of a compressor. The user should specify the exact gas composition (or the range of composition, in case of a variation at various operating stages of the refinery) enumerating the mole percentages of the individual constituents of the mixture including pseudo-cuts in case of complex hydrocarbon mixture. Based on this, by means of a computer program using Soave-Radlick-Kwang and UNIFAC methods, the thomo-physical properties of the gas can be determined, as well as flash calculations are done to estimate the amount of condensate to be taken out of gas stream after each cooler. This data is used further for the sizing of the cylinders of various stages as well as the design of separators.

It is also important that any components causing corrosion, condensation or polymerisation should be identified and the design of compressor should take care of these.

ased on suction and discharge conditions and the capacity required, the number of stages and power requirements for compression are calculated. This leads to frame selection and design of cylinders for the various stages. Cylinder sizing is also affected by lubrication conditions, viz. mineral oil lubricated, synthetic oil lubricated, or non-lubricated, which depend upon the process. In general, however, an optimum lubrication is the best recommended condition.

Capacity control, in stepped or stepless manner as required for plant starting and operation as also in view of energy conservation, can be suitably incorporated into the design, depending upon user's requirements.

The compressor can be driven through a 'V' belt for low power ranges, a gear box in moderate/high power ranges or directly through a flexible or rigid coupling for almost any power range. The prime mover could be Electric motor, diesel engine, gas engine, gas turbine or steam turbine. The compressor-driver system is examined thoroughly for compatibility of drive elements, by conducting torsional analysis by means of a computer program.

The location and environment of the plant alongwith data on available utilities must be furnished by client so as to enable the designer design a suitable compression system.Climatic conditions may necessitate suitable preventive measures to avoid any mal-functioning, while availability of utilities dictate the limitations, within which the heat exchangers, etc. are to be designed. Environmental area classifications based on NEC or other standards specified by the client, are necessary in order to make a proper selection of Electric motors, instruments and control panel to suit the hazardous area classification.

COMPRESSOR COMPONENTS DESIGN

While for compressor frame, crankshaft,connecting rods, cross-heads etc. standard designs and metallurgies are used, cylinder components are designed to withstand the pressures and forces involved and their metallurgy is selected based on their compotability with the gas to be handled. Cylinders in Cast Iron, SGCI,Steel casting as well as forgings are used depending upon the pressures to be handled. Piston rods and valves in stainless steel(13% Cr) metallurgy are employed for normal non-lube or corrosive services, while for gases involving H_2S the piston rods made of 17-4 PH precipitation hardening stainless steels are used. While the normal 13% Cr stainless steel rods are surface hardened to 50 HRC or more in the packing zone, the 17-4 PH rods are through hardened to upto 33 HRC which is the maximum hardness level allowable for this material in H_2S environment. Most other materials while being used in H_2S environment are not recommended for hardening above 22 HRC, which is insufficient to provide necessary strength for the rod.

While dealing with gases involving high percentages of hydrogen it is important to provide a very good finish for achieving a perfect seal at all metal to metal sealing contacts, such as those between the cylinder head, liner and cylinder, valve sealing faces, stuffing box packing cups, etc.

DYNAMIC SEALS

The reciprocating compressor functions by sucking gas through suction valves into the cylinder during the backward stroke of the piston and compressing the gas and delivering it through the discharge valves to the discharge manifold during the forward stroke of the piston. Thus the efficiency of the compression cycle depends to a large extent on the effectiveness of the dynamic seals, viz piston rings, packing rings and valves. This is the area which should and actually does receive maximum attention from the designer particularly while designing a compressor for handling refinery gases containing good percentages of hydrogen which has a higher tendency to deceive these seals due to its low molecular weight.

set of piston rings, provided on the piston, sliding on the inside surgace of the cylinder liner, provide the seal between the suction and discharge ends of a double acting cylinder. The number of piston rings required for an application depends on the pressure differential, the type of gas and various other factors such as speed and cylinder size.

For most of the refinery applications, with lubricated or non-lubricated cylinders, filled PTFE piston rings, in two-piece construction can be considered ideal upto moderately high pressure differentials. This is because of the fact that PTFE while rubbing on a metallic surface initially wears fast so as to form a thin layer of PTFE powder on the counter surface so that subsequent sliding takes place between PTFE and PTFE, for which the coefficient of friction is extremely low. This ensures considerably longer life for the piston rings as well as the liner.

For higher pressure applications, however, PTFE may be subject to extrusion through the gap between the piston and liner and as such bronze piston rings are used, which must be adequately lubricated. Bronze piston rings can be used for the highest pressures involved in refinery services.

Two-piece balanced design as shown in Fig.1, serves well in most refinery application. While the two-piece design with parallel angle cuts at both ends results in an ideal contact and flying action, the presence of pressure balancing grooves results in considerably low net radial force on the liner and almost uniform load shearing between all rings, so as to result in reduced wear of ring as well as liner.

So as to eliminate the possibility of piston rings taking the dead weight of the piston, a pair of rider rings mostly in filled. PTFE material is mounted on the piston. The rider ring (fig.2) has an angle cut for expanding it over the piston for asse bly and a suitable number of pressure-relieving grooves on the outer surface so as to ensure that the rider ring does not perform the work of piston rings.

The packing rings, provided in suitable housing cups forming part of the stuffing box assembly, are usually a three-piece segmental design kept together with the help of a garter spring. The packing ring configuration for most high-pressure refinery applications consists of a pressure-breaker ring on the pressure side, followed by a suitable number of Radial-Tangential (RT) pair of seal rings and one or two Tangential-Tangential (T-T) pair of seal rings in the last one or two cups (Fig.3). Either filled-PTFE or bronze or a combination of both are used depending upon the nature of application.

The suction and discharge valves are known as the 'heart' of the compressor, thus signifying the importance of their functioning. For sych a seemingly simple device, there is no single piece of hardware on the compressor that has a greater influence on its efficiency. This is the reason why utmost care is required in the design of compressor suction and discharge valves so as to ensure desired performance.

Valves of ring type or plate type can be used depending upon the gas and the operating conditions. The valves are designed so as to result in a smooth operation with minimum of pressure drop, which in turn results in optimized power consumption. Losses in the valves may assume large proportions particularly in recycle service compressors. In applications involving variation of suction pressure a double-mechanical damping plate type valve (Fig.4) results in optimum performance. This is due to the fact that use of comparatively lighter working springs on the main valve plate allows valve opening at a slight differential pressure, while the presence of damper plate which joins the working plate after a part of its movement, ensures lower impact velocity at the guard.

LUBRICATION CONSIDERATIONS

There are two independent lubrication systems employed in a reciprocating compressor, one for the crank gear lubrication and the other for the cylinder and stuffing box lubrication. While the crank-gear lubrication system is a must on all compressors, the cylinder and stuffing box lubrication system is eliminated in case of non-lubricated compressor applications.

Petroleum based lubricants of suitable grades have been conventionally used for compressor lubrication.

However, in some of the applications very good results have been achieved by using diester based synthetic oils which have resulted into following advantages:

- Extended crank-case drain intervals due to better thermal oxidation stability of these oils.
- Extended valve maintenance intervals due to the absence of carbonaceous deposits.
- Reduced oil consumption due to low volatility.
- Improved safety as a result of higher flash point and autoignition temperature combined with low volatility and absence of carbonaceous deposits.
- Extended life of wearing parts due to the lower coefficient of friction and high film strength.
- Lower sump temperatures resulting from the better thermal conductivity and greater heat capacity.

DESIGN CONSIDERATIONS FOR AUXILIARIES

The compression system consists of auxiliaries, such as the suction and discharge pulsation dampners on each stage cylinder, intercoolers and after-coolers, oil/condensate separators and interconnecting piping.

The pulsation dampners are designed, with or without internals to dampen the flow and pressure pulsations generated by the reciprocating motion of the piston. Proprietary techniques are used to make effective designs which reduce the pulsations at the outlet flange of the dampeners to a considerably low level. When required to operate against a wide variation of gas characteristics the dampeners are suitably designed to be effective over a wide range. These vessels are designed in accordance with ASME Section VIII div.1 or div.2 so as to handle the pressure to which ehese are subjected during operation.

The heat exchangers are designed, in most of the cases, as shell and tube heat exchangers in accordance with TEMAC or TEMAR based on the availability of cooling water. The metallurgy of tubes and the shell is selected in view of the nature of gas handled and the quality of water available. Duplex stainless steel tubes and tube sheets have been used for a number of applications. The mechanical design conforms to ASME Section VIII Div.1 or 2, as applicable.

The separators or knock-out drums, could either be plain vertical vessels with a demister pad on top and oil collecting portion at the bottom or could be high efficiency vane pack type separators of proprietary designs, depending upon the gas characteristics and the process requirements.

Inter-connecting piping of suitable metallurgy and pressure rating is provided between the stages so as to couple the various auxiliaries to the comoressor cylinders. ANSI standards are followed for the piping design and flexibility analysis is conducted as required.

PULSATION AND VIBRATION CONTROL CONSIDERATIONS

Flow and pressure pulsations generated by the reciprocating compressor may sometimes get coupled to the piping, producing vibrations and even fatigue faitures. On the other hand, pulsations also result in decreased operational efficiency of the compressor on account of significant deviations in indicated cylinder horsepower and capacity with consequent overloads and loss in efficiency.

Pulsation and vibration control is achieved by suitably designed pulsation dampners which are finally checked by conducting an Analog/Digital pulsation study and mechanical response study in accordance with Design approach 3 of API 618-1986. This study indicates any acoustical or mechanical resonances that may result in excessive vibrations and stresses leading to failure and suggests necessary modifications in the vessels and piping so as to eliminate these problems. As all this evaluation can be done at the design stage itself without actually building the plant, necessary changes/modifications can be readily incorporated into the system so as to obtain an optimum performance.

CONCLUSION

In view of the various design considerations involved in refinery service compressors, it is suggested that the compressor user while making the specifications for the compressors should specify all known and predictable gas characteristics and variations in gas composition if any expected during the operation of the plant and try to list out all operating contitions to which the compressor may be subject during start of run. End of run or regeneration conditions. The capacity control requirements, in stepped or stepless manner as required should be indicated and the area classification should be elaborated. It is also suggested that sufficient interaction between the process designers and compressor designers should be encouraged during the design stage so that the user is able to meet all anticipated requirements from the equipment.

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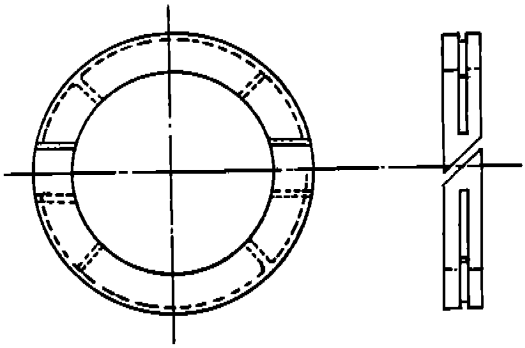

FIG 1: BALANCED 2-PIECE PISTON RING

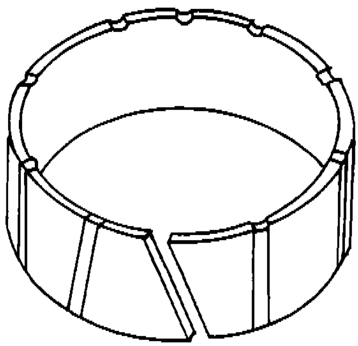

FIG 2: CUT RIDER RING WITH FULL PRESSURE RELIEF

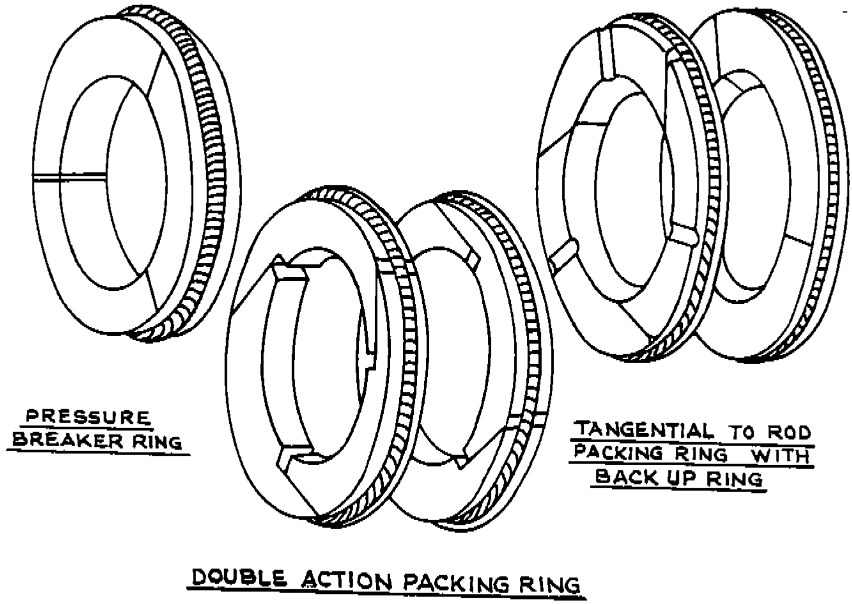

FIG. 3 PACKING RING DESIGNS

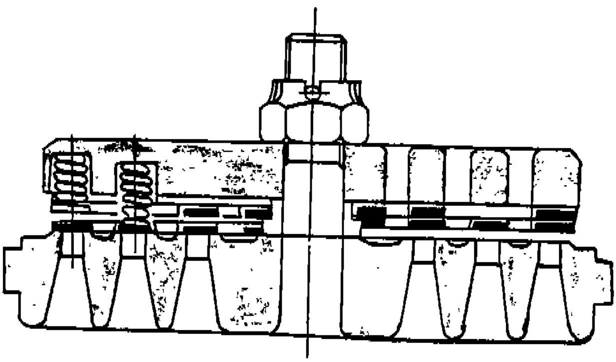

FIG. 4 VALVE DOUBLE DAMPING DESIGN