THE APPLICATION OF SCREW COMPRESSORS FOR PROCESSES IN THE CHEMICAL AND PETROCHEMICAL INDUSTRIES

by

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INTRODUCTION

The name of the event that has kept us all in suspense for three days is "Turbomachinery Symposium." We have been fed a wealth of interesting information on turbines and turbo compressors—mostly radial machines but also axial compressors. The machines referred to were, without exception, flow machines which transform kinetic energy into potential energy (or vice versa), machines that is to say that work dynamically. I have been asked to give you an account of the uses screw compressors are put to in the processes met with in the chemical and petrochemical industries. Screw compressors are not turbo machines: they do not compress dynamically but by positive displacement, exactly like the piston compressor. Nevertheless it would appear reasonable to discuss screw compressors like these within the context of a symposium otherwise devoted exclusively to the subject of turbo machines. Of all known rotary piston machines the screw compressor surely represents the best attempt at uniting the advantages of a turbo and a piston machine while at the same time eliminating their disadvantages. The speeds, for example, with which the rotors do their oil-free compression work are in the range otherwise reserved for turbo machines.

This is perhaps why even today—almost 20 years after the screw machine made its way on to the compressor market—we still occasionally come across users with the notion that the screw compressor is similar in its characteristics to the flow machine.

To avoid misunderstandings of this sort and to explain as clearly as I can the workings of the screw machine as a process gas compressor, I shall, with your permission, briefly deal with the peculiarities of this machine's modus operandi—even at the risk of covering familiar ground once again.

THE SCREW COMPRESSOR'S OPERATION

There are two sorts of screw compressor—the classic, oil-free compressor that was originally invented by the late Professor Lysholm, and the oil-flooded machine now so widely used in pneumatic and cryogenic systems.

We are concerned here with the "dry" machine, which was already known in Europe and especially in Germany as a process gas compressor at a time when oil injection cooled machines were unheard of.

The screw compressor really does possess the advantages of the purely rotating turbo machine (its capacity for high-speed performance and the consequential small and simple design, the absence of inertia forces and the undesirable vibrations these set up) alongside the straightforward and stable handling characteristics of the piston machine. Compression is oil-free and there is no contamination of the gas, while neither impurities already in the gas nor liquid elements contained in it can do much to upset the screw machine.

The screw compressor is constructed for throughputs of between 200 and 27,000 cfm and for pressures between a few Torr and approximately 600 psig. The higher volume figure will perhaps cause some to raise their eyebrows and remark: "But that's already up in the turbo compressor range!" To which the answer is of course "Yes, for 'normal' gases like air and nitrogen there are already turbo compressors for throughputs of down to around 1700 cfm.

If, on the other hand, the gas is pure hydrogen or if it has a high hydrogen content, it is possible with the displacement machine to make do with a single stage, whilst there would be no way round giving the turbo machine a multi-case design to accommodate the numerous stages it requires. Fig. 1 conveys an idea of the size of such 25,000 cfm machines.

The position is much the same with crude gas mixtures that are polluted or tend to polymerize, especially cracking gases with an acetylene content. It must be

Figure 1. Screw compressor rotors, 630 mm diameter.
clear that the screw machine has all the trump cards here with its general resistance to contamination and its in-built facilities for monitoring and limiting gas deposit build up. However low a delivery temperature may be selected, the pressure ratios per compression stage can be high. The water injection system takes care of that, cooling, flushing and preventing polymerization or other even more undesirable, premature reactions.

Fig. 2 shows the crude gas compressor station of an acetylene plant with two-stage screw compressors, each handling 10,000 cfm and compressing it up to 160 psig. The station pictured is in the open.

Here, however, we have already touched on rather extreme fields of screw compressor application. The fact that we are dealing with special designs here should be apparent from the machine arrangement with the inlet at the top and outlet at the base. The injected water can thus be passed through the machine so that the force of gravity takes it right through, removing on its way any incrustation and deposits that might otherwise find their way back from the outlet nozzle to the rotors.

The stuffing boxes are fed with sealing water; we can see the feed and the leakage water lines with their sightglasses, but not the special steps that have been taken inside the machine to obviate erosion and corrosion. Here the right choice of material and, if need be, the cladding of the casing walls play a major part. Yet even these special machines are in essence no more than fast running, oil-free compressors of the GHH standard range depicted in Fig. 3.

These machines have to be run with high tip speeds in order to keep internal leakages to a minimum. In addition to their timing gear, therefore these machines need an independent gear unit, they need precision bearings for the rotors (in both axial and radial direction) with forced-feed oil lubrication, and lastly they need silencing arrangements to cope with the high frequency noise set up by their operation.

The importance of the high tip speeds for dry running machines like these is shown in Fig. 4.

Our diagram illustrates the volumetric efficiency of a screw compressor as a function of its tip speed and the width of the gap between the rotors and between the rotors and the casing wall. It can be seen that any deviation from the rated gap width for manufacturing reasons has but little effect by comparison and does not jeopardize adherence to a certain guaranteed delivery tolerance, whilst with the slow running machine not only the volumetric efficiency in the design point is poorer but also excessive gap widths play a significantly greater role in lowering the real volumetric efficiency. In certain circumstances this factor can render operation impossible on account of the overheating and the consequential thermal expansion of the rotors that goes hand in hand with sagging volumetric efficiency levels.

This effect is explained more clearly in a somewhat different and generally valid manner in the next figure (Fig. 5).

The drop in volumetric efficiency, expressed as a percentage of the rated volumetric efficiency when the gap width differs from the design value, is plotted against the Mach number, i.e. against the ratio of the male rotor tip speed to the speed of sound in the gas on the suction side of the machine.

It will be apparent that even greater attention has to be given to the observance of running clearances when
manufacturing machines that are going to handle very light gases, i.e. those in which the velocity of sound will be high and the Mach numbers low.

The following can be taken as a general rule: the fast-running machine is cooler and therefore safer than the slow-running machine.

Needless to say there is a limit to the speed at which these machines can operate, a limit that is dictated by economic considerations.

In Fig. 6 the losses of a screw compressor are plotted against the tip speed as a percentage of the purely adiabatic compression. One can see the effect of the internal seepage losses, which diminish as the tip speed increases. Their curve corresponds to the tendency shown by the volumetric efficiency level in the previous figure. On top of this frictional and flow losses begin to make themselves felt. These grow as the tip speed rises. In our diagram we have lumped them together under the general heading of dynamic losses. The cumulative curve of all the losses indicates a clear, albeit shallow, minimum at a tip speed that is optimal for the conditions prevailing in the relevant circumstances, those in other words under which the machine attains its greatest efficiency.

![Figure 5. Volumetric efficiencies with varying gap widths as a function of the Mach number. $M = \frac{u}{a}$.](image)

![Figure 6. Losses compared with total power consumption of a screw compressor.](image)

The flat character of the efficiency curve is not only valid for efficiency as a function of the tip speed or the rotational velocity but also as a function of the pressure ratio during operation.

Fig. 7 shows the PV diagram of a screw compressor on the left. On the right we have the volumetric efficiency and the adiabatic total efficiency curves as functions of the working pressure ratio for a machine running at a constant speed and with a specific, firmly installed, internal pressure ratio.

The compression line reaches the pressure corresponding to design point at the outlet control edge, which is fixed in the casing. If the network pressure is at the same level, exhaust operation follows immediately. As the machine does not have any dead space, there is, in contrast to the piston compressor, no back-expansion. The theoretical PV diagram has the simplest almost ideal form.

If the machine has to work against pressures that do not correspond to the so-called installed pressure ratio, one of two things happens when the outlet control edges have been reached: either there is expansion to the lower line pressure with subsequent exhaust at this pressure, or there is full compression to the higher pressure in the line, again with subsequent exhaust.

The exhaust work is always carried out at the correct back-pressure. The small hatched triangles indicate the extra work that has to be done by a machine with fixed outlet control edges as against an ideal compression. The amounts are small. The diagram shows the flat path of the efficiency curve against the working compression ratio. The efficiency peak is seen to be located where the installed pressure ratio and the working pressure ratio coincide.

We can also see from our diagram how slight the volumetric efficiency level drop is when the pressure ratio rises. Here again we have the screw machine betraying typical piston compressor characteristics. It is because of the fast speed at which these machines run that many people still regard them as a sort of turbo compressor and a dynamically compressing machine. They expect characteristics with high throughputs at low pressures and low throughputs at high pressures, just as is usual for turbo compressors.
Such temperature ceilings are shown in the form of curves on the QH diagram. We can see that if our machine's speed and throughput are on the low side we cannot have it running at quite such high pressures as would be possible if the speed were higher.

**SCREW COMPRESSOR APPLICATIONS**

*Air and Clean Gases*

The initiators of the screw compressor, Lysholm and the other engineers of the company now known as Svenska Rotor Maskiner AB, naturally tried the machine out as an air compressor. It should not surprise anyone therefore to hear that its first use was as a supplier of compressed air. The air it delivers is, after all, free of oil and that is of particular value in the chemical industry.

Here we see the compressor station of a detergent production company known throughout Germany. This firm needs "clean" air at numerous points along the production line, e.g. for pneumatic transport, and has therefore gone over to screw compressors for its entire supply of compressed air. (Fig. 9)

The picture is the same in the foodstuffs industry, where flour and sugar etc. have to be pneumatically handled, and in the brewing trade, where the absolute absence of oil contamination has been welcomed as a great improvement.

It goes without saying that these properties have earned equal acclaim in pharmaceutical circles. I am thinking of ball mills and microbe cultures for penicillin production. These cultures have been doing particularly well at the establishments run by an American firm with a world-wide reputation since it adopted an oil-free ventilation system for them. Once this firm switched to screw compressors the yield rose abruptly.

The intricate and extensive measuring and control installations used in today's chemical plants and refineries represent yet another demand for clean air in particular. These need special instrument air systems and it is in the field that screw compressors driven both by

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Figure 8. Characteristic curves for various types of compressor.

Fig. 8 therefore shows the characteristic curves of screw compressors, radial and axial turbo compressors in a QH diagram of the customary type for the latter machines at a variety of speeds.

Whereas there is always a typical interdependence between pressure and volume in the case of turbo compressors and whilst these machines have an unstable zone when the throughput falls below a certain value, the so-called surge limit, the volume the screw machine compresses is governed practically by the speed alone and the pressure it can work to is not a primary function of speed.

Our diagram illustrates the position with a single-stage machine; the slight reversal tendency of the throughput curves exactly corresponds to the marginal volumetric efficiency drop against the pressure depicted in the last diagram. With two-stage and multi-stage machines the throughput characteristic curves follow a perpendicular path, since the compressor's delivery pressure influences the intermediate pressure between stage 1 and stage 2 only to a small degree, with the first stage then operating with what is virtually a constant pressure ratio and consequently an unvarying throughput.

In connection with the screw compressor too, however, we find there is a limitation to the characteristic that appears especially in the lower speed ranges.

We have already established that a low tip speed will be accompanied by a deterioration in the volumetric efficiency of the machine. The internal seepage losses, which within any given period remain constant, nevertheless increase relatively speaking. The gas that has already been compressed and returned to the inlet side of the machine is hot and thus it heats the fresh intake of gas with the result that compression temperatures rise as the speed of the machine falls.

At this point increased thermal dilatation sets in in the rotors as well. At a certain temperature and given a certain cold clearance between the rotors contact would be sure to follow. This would put the machine out of action. So, it is plain that there is a certain compression temperature that must not be exceeded, a temperature of course that will vary depending on the size of the machine, cold clearances, materials and on whether the rotors are specially cooled or not.
electric motors and steam turbines have proved to be so dependable. (Fig. 10)

In many instances drying plants are connected up downstream so that the hot oil-free air is first used to regenerate the saturated dryer before being cooled and dried itself. This process takes place without the need for any additional power from other sources.

Naturally, even in the early days people turned their attention to the possibilities of compressing clean gases. In air separation plants both the oxygen and the nitrogen have to be compressed apart from the air itself. Oxygen demands absolutely oil-free compression, and nitrogen too has to be completely clean, whether for example, it is to be used as a sealing gas in other machines or in plants set up to obtain heavy water, where screw compressors have established themselves as nitrogen vacuum pumps.

In our picture (Fig. 11) you can see a number of nitrogen compressors in an air separation plant for a B.O.F. steel works. Of special interest is the relative size of the two screw compressors on the one hand and the high-pressure piston compressor machines arranged downstream of these. You can imagine how large these piston machines would have to be if they had to cope with the lower pressure range from 35 to 170 psig as well. The combination of the two types of machine here is a happy one, with the fast-running, compact screw machine dealing the large volumes at low pressures and the piston machines handling the smaller throughputs and high pressures.

**Light Gases**

Very light gases have always been difficult to compress. Hence, a turbo compressor handling pure hydrogen requires about 15 times as many stages as it would for air to attain the same pressure increase. For a machine that operates with a positive displacement characteristic the specific weight of the gas is virtually insignificant. All the same, even a screw compressor notices something of the increasing internal leakage losses when it is pure hydrogen that is being compressed. It then requires 2 stages where one would have sufficed for air and it must operate with tip speeds as high as possible.

A well-known Canadian firm uses extremely large screw compressors to compress hydrogen containing nickel dust.

Hydrogen screw compressors can also be found in a number of European detergent and hydrogen peroxide production plants. The compression of helium makes great demands upon the tightness of machines, in particular their stuffing boxes. In one plant where extremely low temperature have to be created 3-stage screw machines are teamed up with downstream helium expansion turbines.

**Process Gases**

GHH made an early start—some 17 years ago now—on designing and refining screw compressors to handle all kinds of gases in the chemical, coal and petrochemical industries and associated fields.

In the course of this work the screw machine was found to possess a number of special features that must be accepted as substantial advantages over the traditional models, the reciprocating and the turbo machines. With piston compressors dirt in the gas can lead to wear of sliding components, valve clogging, and deposits in dead spaces that can cause damage due to blockages.

On turbo machines there is always a risk of erosion and consequently damage to the thin blade edges and the impeller and cover discs. Dirt can also lead to deposits in swiftly rotating parts. This restricts the machine's efficiency and the surge limit on one hand while inducing imbalance such as can hazard operation itself on the other.

On the screw compressor it is the running clearances that determine the extent to which any layer of dirt forms on the rotors and casing walls. All excess is dealt with by the screw machine's self-cleaning effect: it is simply passed through the compressor into the discharge line. The volumetric efficiency of rotors that automatically "fill out" like this is appreciably higher than that of new machines. We are faced with the remarkable fact that where we are given equal power consumption the fouled machine will deliver a greater throughput at lower discharge temperatures than the brand new counterpart that has just come off the production line. In other words, the volumetric efficiency of the used machine is superior to that of the new one. In this
Figure 12. Five 3-stage screw compressors, each for 14,000 cfm of unscrubbed coke-oven gas, at an Indian steel works.

Figure 13. Five screw compressors at a station run by a Belgian gas supply company handling 85,000 cfm.

Figure 14. Screw compressor with automatic idling device at an Italian coke-oven plant.

Figure 15. Two-stage compressors at a station for lime cyanamide.

respects then, we can see that the screw compressor's behaviour is exactly the reverse of the turbo machine's.

With the screw compressor there is no need for the regular opening up and cleaning routine that can, depending on the nature of the gas, become so inconveniently frequent in the case of the classical machines.

It was actually not until the screw compressor came along that it became possible to compress unscrubbed coke-oven gas. The by-product plants in coke oven installations which clean the gas can do this job more easily if the gas scrubbing is done under pressure, e.g. under grid gas pressure. What is more, these units are then much smaller and cheaper.

The five 14,000 cfm machines in our picture for example (Fig. 12) compress the gas in them up to 200 psig. Only after this pressure has been reached does scrubbing take place before the gas is then dispatched to a fertilizer factory where it is required at this pressure for ammonia synthesis.

Municipalities and rural districts also make a big call on gas supplies, hence the need for hefty compressor units. One Belgian station for example is fitted out with 7 sets handling no less than 85,000 cfm. Our picture shows 5 of them undergoing erection. (Fig. 13)

A Spanish city too has decided to incorporate our largest screw compressor models for 16,000 cfm in their gas production modernization scheme. In the modern cracking plants that now occupy a fraction of the land previously taken up by coking plants they recover from oil many times the quantity of town gas that used to be produced.

To prevent rotors from sticking when sets like these are shut down it is a common practice today to fit an automatic idling device as standard equipment. You can see such a unit in the next picture, flanged on to the set. It is provided (Fig. 14) with a free-wheeling system so as to give a smooth transition from run down to idling. This piece of equipment, which is connected to an emergency power supply, has proved particularly worthwhile wherever (e.g. in developing countries) there is a fair likelihood of frequent mains supply failure.

A gas that is similar to coke-oven gas as far as its dirtiness goes comes from carbide furnaces. A South German lime cyanamide works conveys this gas in a pipeline that simultaneously serves as a gas reservoir from one of its works to the other. The pressure for this is supplied by a screw compressor station, part of which you can see in our picture. (Fig. 15).
Another example of screw compressors being used to compress dirty gases is furnace top gas.

The very fact that these compressors do operate with such gases indicates how robust they are. It is not only possible to compress moist gases and vapours, but also to inject almost any amount of liquid into them.

Were this to be tried with piston machines the result would be "hammer," while with screw machines and their high tip speeds erosion damage could easily ensue. The screw compressor on the other hand can digest gas/liquid mixtures in which, spatially speaking, there is a high proportion of incompressible matter.

In numerous instances the liquid injected into the screw machine is used for internal cooling. This is of particular value with gases that must be kept below certain temperatures during compression. Furthermore, in this way very high compression ratios can be achieved in one stage. In other instances injection obviates premature polymerization. (Fig. 16)

Solvents too can be used continually or administered when conditions demand it. This can be done automatically for example when the power supply fails so as to prevent coats of dirt adhering to the machine during undesired shutdowns of this sort.

From natural gas and crude oil, carboniferous and all manner of other basic materials modern chemistry is producing new materials, plastics and synthetic fibres in an ever widening range. A major process in the creation of these new products is the compression of crude, pure and return gases and it is here that, remembering what has been said about the properties of the screw machine, we find a typical field of application for these machines, one in fact for which they would appear to have been predestined.

The compression of gas mixtures with an acetylene content has become a special field of application peculiar to screw compressors and screw vacuum pumps.

Here temperatures over 160°F must be avoided at all cost during compression. This is done by copious water injection. When serving as a vacuum pump the screw machine can be operated with a pressure ratio of up to 15 in one stage at temperatures below 140°F. Such figures are possible only if water is injected at the rate of up to 3½ gallons/100 ft³ of gas. To give (Fig. 17) 100% sealing tightness water-fed stuffing boxes are employed; the water that makes its way into the machine is then used again, this time for flushing and cooling. The injection point for the water is at the inlet nozzle directly upstream of the rotors. It is unnecessary or to be more precise, undesirable to distribute the water especially evenly, since it is a good flushing action that one is after here. Condensate is used for injection purposes. With so much water going into the machine during compression normal materials are prone to severe erosion (cast iron for the casing and carbon steel for the rotors). This can be avoided by making the rotors out of 13% chromium steel and cladding the cast iron casing end walls with plates of the same 13% chrome steel composition. Our picture shows these (Fig. 18) plates being mounted in the casing of a screw machine to handle crude gas with an acetylene content.

However, when it comes to lime kilns used in the production of soda it is not sufficient to clad the inside of the screw compressor in this way. This time rotors and casing must be of the same chromium steel so as to prevent the formation of electric elements owing to the aggressiveness of the gas and water mixture.
The plating of casings by spraying on non-rusting metals has not proved successful. Too much depends on the quality of the workmanship and the task itself is not made any easier by the unfavourable shape of the casings with their sharply intersecting edges. The risk of a blockage caused by pieces chipping off and lodging in the rotors is too great.

There can hardly be any hydrocarbon gas or gas mixture that is not passed through or compressed by a screw machine during the creation of a synthetic material.

The polyethylene production sector is another quarter in which one can expect to encounter screw compressors in common use. The same goes for the PVC field. Most of the big west European chemical works have opted for screw machines for both crude and pure vinylchloride gas.

Some of these compressors operate dry, some use water injection, and yet others have fuel oil injected into them prior to shutdown to prevent coalescence.

In the production of synthetic rubber too, difficulties that arose in the compression of butadiene, particularly recycle gas mixtures of butadiene and styrene, were resolved with the introduction of screw machines service either as vacuum pumps or as compressors. The injection of liquids is calculated to keep compression temperatures down and prevent premature polymerization. Water is the medium selected for recycle mixtures and liquid butadiene for pure butadiene compressors.

Screw machines with water injection are also operated as vacuum pumps for hydrocyanic gas, which is employed as a starting product in the fabrication of synthetic fibres on an acryl-nitril basis.

The highest pressure attained by a GHH process gas screw compressor is that achieved by a set in use in Italy for synthetic rubber. Properly speaking, this comprises two (Fig. 19) three-stage sets compressing a propylene gas mixture firstly from 14 to 240 psig and then from 70 to 600 psig. The client specified absolute gas tightness, a condition that was met by the combination of a carbon ring and oil seal. Propylene is also handled by screw compressors in refrigeration circuits: here, where the entire oil circuit is subjected to the inlet pressure of the gas, it is the contact ring seal that has provided the best solution. Because of the low temperatures special oils have to be used.

Explosive gas mixtures, too, like those containing ethylene oxide for example can be handled by screw compressors without any fuss. One of the hardest gases to compress is without doubt chlorine. It must of course be technically dry, as (Fig. 20) it indeed normally is after it has been dessicated by treatment with sulphuric acid. It can then be compressed in screw machines constructed of the usual materials, namely cast iron and steel. We have records of these machines clocking 35,000 hours of service from one inspection to the next. Layers of dirt, some centimetres thick, made up of chlorine butter and chlorides coated suction and delivery nozzles without upsetting the operation of the rotors, which simply continued to clean themselves with every revolution they completed.

Here again care must be taken to observe a maximum admissible compression temperature. This figure should be under 210°F. In special cases liquid chlorine is injected to bring the compression temperature down. Canigenisation of the rotors ensures that the surfaces will not immediately start to corrode in the moist air once the machine has been opened up for inspection, but remain untarnished.

The compression of hydrogen chloride is yet another of the jobs tackled by the screw compressor. Here special care must be given to see that the pressure of the sealing nitrogen in the stuffing boxes is always higher than that of the gas.

Chlorinated methanes have likewise been compressed for many years now in screw machine sets. With these gases the important thing is to make sure that the throughput handled always remains constant even though the pressure in the column (which gradually freezes up) rises. This is a typical piston machine characteristic that is peculiar to the screw compressor, and it was for this reason that the turbo compressors formerly used were replaced by screw machines.

The third picture (Fig. 21) presents a typical process gas screw compressor. With a direct drive in the form

**Figure 19.** Two 3-stage screw compressors for a propylene gas mixture, 70 to 600 psig.

**Figure 20.** A 2-stage chlorine gas screw compressor.
of a steam turbine this machine compresses ammonia. The machine is kept absolutely tight by a two-fold contact ring seal downstream of a carbon ring arrangement. The leakage gas which collects in the oil tank is fed back to the inlet line via activated charcoal filters. The delivery condition of the gas is absolutely oil-free. The machine's output can be varied between 2.2 and 3.5 million kcal/h by adjusting the running speed.

The compression of ammonia for fertilizer production is one more job the screw compressor is suited for. The picture shows a set in Peru. (Fig. 22)

The most difficult gas any GHH screw compressor has had to deal with so far was a wet mixture of propylene, propane and dichloropropane with a 30 ppm content of free hydrochloric acid. Irrespective of the materials used for the rotors and casing, after every 8,000 hours of service both were so corroded that the only thing to do was to run the machine at a higher speed (with a different gear unit in order to at least obtain the original throughput again. Three or four months later, however, it became necessary to carry out repairs in the course of which the horizontal casing joint was remachined in such a way as to re-establish—at least in vertical sections—normal bore diameters. The rotors themselves were exchanged. This was sufficient to safeguard a further year's operation. So far a more satisfactory solution for this process still remains to be found, though the economic soundness of the process itself is vindicated with every further twelve months' operation.

Refinery Gases

Not quite so tough a proposition for the screw compressor is the compression of the gas mixtures met with in refinery practice. Those mainly concerned here are mixtures of hydrogen and hydrocarbon, generally with hydrogen sulphide well represented (5-25%). These gases are nearly always moist. They are: crude gas, off gas, recycle gas, flue gas, vent gas, tail gas, and strip gas.

Some of these, like the off gas, tend to polymerize at temperatures above 90°F. Here again use is made of sealing water stuffing boxes and water injection. The machines in this case are large, with throughputs of around 18,000 cfm, and they operate in styrene production plants using the Monsanto process.

Armour plating and idling devices are extras for these machines. On crude gas compressors both normal carbon ring seals with extraction arrangements and contact ring seals have proved successful. It is plain that owing to our (Fig. 23) growing concern over environmental pollution more and more preference will be given to contact ring seals in future, since there is no need to resort to flare systems to burn up the leakage gases. Many of these CH mixtures have such low K values that pressure ratios of up to 10 are quite feasible in a single stage. With recycle gases on the other hand extremely small pressure ratios, albeit at fairly high pressure levels, are not uncommon (250 to 300 or 300 to 360 psia). Here too GHH process gas screw compressors have won themselves a high reputation in Europe and overseas. Refineries in Germany, the Netherlands, Switzerland, Denmark, Sweden, Norway, the U.K., Australia, Curacao, India and—even if only few in number—in the U.S.A. as well use GHH process gas screw compressors. These machines have shown that they represent a dependable solution to even the toughest of problems.