PROCESS GAS APPLICATIONS WHERE API 619 SCREW COMPRESSORS REPLACED RECIPROCATING AND CENTRIFUGAL COMPRESSORS

by

Takao Ohama

President

Yoshinori Kurioka

Application Engineering Manager

Hironao Tanaka

Project Manager

KOBELCO EDTI Compressors, Inc.

Corona, California

and

Takao Koga

General Manager of Sales

KOBELCO EDTI Compressors, Inc.

Houston, Texas

Takao Ohama is currently the President of KOBELCO EDTI Compressors Inc., in Corona California, a subsidiary company of Kobe Steel, Ltd. He is in charge of both oil-free and oil-flooded screw compressors for process gas and industrial refrigeration and manages the company. Mr. Ohama's previous career for 25 years was as an engineer for oil-flooded gas screw compressors and managing the screw compressor engineering group when he was with Kobe Steel Ltd., Japan. He and his staff developed the high-pressure screw compressor H series in 1997, which is the first to be applied to 60 barG in the world as a series and expanded that range to 100 barG. Mr. Ohama also participated on the Task Force for the preparation of API 619 Fourth Edition.

Mr. Ohama graduated with a B.S. degree (Mechanical Engineering, 1979) and an M.S. degree (Mechanical Engineering, 1981) from the Saga University, Japan.

Yoshinori Kurioka is currently the Application Engineering Manager of KOBELCO EDTI Compressors Inc., in Corona California, a subsidiary company of Kobe Steel, Ltd. He is involved in proposals for both oil-free and oil-flooded screw compressors. Mr. Kurioka's previous assignment in his 15 year career with Kobe Steel Ltd., was as an engineer for API 619 type bare shaft oil-free screw compressors, R&D engineer for air packaged type oil-free screw compressors, and application engineer for both oil-flooded and oil-free screw compressors. He recently served on the Task Force for the revision of API 619 Fourth Edition.

Mr. Kurioka graduated with a B.S. degree (Mechanical Engineering, 1989) and an M.S. degree (Mechanical Engineering, 1991) from the Tohoku University, Japan.

Hironao Tanaka is currently a Project Manager of KOBELCO EDTI Compressors Inc., in Corona California, a subsidiary company of Kobe Steel, LTD. He is involved in engineering the execution of oil-flooded and oil-free screw compressors for various process gas applications. Mr. Tanaka's previous assignment in his 12 year career with Kobe Steel, Ltd., has been a system engineer and a project engineer for oil-flooded compressors.

Mr. Tanaka graduated with a B.S. degree (Mechanical Engineering, 1992) and an M.S. degree (Mechanical Engineering, 1994) from Kobe University, Japan.

ABSTRACT

Oil-free screw compressors have been used for process gas application since the 1970s. Oil-flooded screw compressors have been used in many process related applications since the 1980s. Oil-flooded screw compressors are covered in the latest edition of API Standard 619 issued in 2004. Both oil-free and oil-flooded screw compressors have been expanding into process gas compression applications. It is therefore of interest to present the authors' recent experiences and share the acquired knowledge by comparing features with reciprocating compressors and/or centrifugal compressors.

High reliability, low maintenance costs, simple foundations, low operational costs, low initial costs, low consumed power at unloaded condition, and suitability for process fluctuation such as gas composition and pressure are some of the basic attributes of the rotary screw compressors. These attributes have resulted in a significant demand for such machines, primarily as an alternate to reciprocating compressors.

INTRODUCTION

The purpose of this paper is to present the experience acquired in the use of oil-flooded screw compressors in certain process gas compression applications and highlight the key points as compared to other types of compressors. In recent years rotary screw compressors have been applied at higher pressure and larger capacity than before. This paper presents the special features of screw compressors and provides data from actual applications highlighting those features.

HISTORY

In the late 1950s, a Swedish company developed the oil-flooded technique in a screw compressor and perfected the rotor profile to achieve higher volumetric and compression efficiencies. They then licensed compressor manufacturers in the USA, Europe, and Japan to manufacture these compressors and collected royalties.

Since the screw compressors have characteristics of both rotary (centrifugal) compressors and positive displacement compressors (reciprocating), such machines found rapid acceptance in petrochemical and gas processing industries. In 1975, API 619 (2004) was introduced to specify a screw compressor. This first edition of API 619 (2004) looked only at oil-free screw compressors. During this period, the oil-free screw compressor was applied in many unique applications such as butadiene, styrene monomer recycle gas, linear alkyl benzene, soda ash, etc. Most of these applications are subject to dust and liquids that are likely to be present in the gas stream. In many cases, water injection was used to control the compression process.

In the 1980s, oil-flooded screw compressors started appearing in process gas applications. Around the same time, cogeneration started to take off with gas turbines becoming necessary in more and more applications. Also, oil-flooded screw compressors were finding their way into light gases such as helium and hydrogen. Less sensitivity to changes in molecular weight made such compressors particularly suitable for hydrogen pressure swing adsorption (PSA) compressors. On helium and hydrogen feed compressors, stringent oil carryover requirements made it necessary to introduce activated charcoal absorbers in the oil management system. Carbon dioxide compressors for the beverage industry switched to oil-flooded screw compressors with an oil removal system down to 10 parts per billion (ppb) by weight.

In the 1990s, the demand for higher volume oil-flooded and oil-free screw compressors resulted in compressor manufacturers designing and building machines in large frame sizes.

By the mid 1990s, high pressure oil-flooded screw compressors started to find their way into fuel gas boosters and many petrochemical and refinery applications. At the same time oil-free screw compressors were finding strong acceptance as vapor recovery compressors in both offshore as well as onshore applications.

GENERAL DESCRIPTION OF THE THREE TYPES OF COMPRESSORS

Before introducing actual applications, one needs to understand the compression mechanism and typical mechanical limitation for centrifugal, reciprocating, and screw type compressors.

Centrifugal compressors are continuous flow machines in which one or more rotating impellers accelerate the gas as it passes through the impellers, which are shrouded on the sides. The resultant velocity head is then converted into pressure. This occurs partially in the rotating element and partially in the stationary diffuser.

Reciprocating compressors are positive displacement machines with a piston compressing the gas in a cylinder. As the piston moves forward it compresses the gas into a smaller space, thus raising its pressure. There are two types of reciprocating compressors, called "lube" type with oil injection and "nonlube" as oil-free.

Screw compressors are also positive displacement machines but rotating twin rotors act as pistons that compress the gas in a rotor chamber (casing). Compression is done continuously by the rotation of the twin rotors. There are also two types of screw compressors: the "oil-flooded" type with oil injection, and "oil-free" with no oil injection.

Pressure, flowrate, and gas composition are the major factors to be considered in selecting the type of compressor. Table 1 shows comparison of three types of compressors with respect to pressures, flows, and gas compositions, etc.

Table 1. Comparison Table of the Three Types of Compressors.

Compressor Type		Reciprocating		Screw		Centrifugal
		Lube	Non-lube	Oil Flooded	Oil Free	
Pressure	Maximum Discharge Pressure	4500psiG (300barG)	1500psiG (100barG)	1500psiG (100barG)	600psiG (40barG)	3,000psiG (200barG)
Pressure	Maximum Pressure Ratio by Single Stage	3 : 1	3 : 1	> 50 : 1	4 : 1 ~7 : 1	1.5 : 1 ~ 3 : 1
Flow rate	Maximum Actual Inlet Volume	8800 ACFM (15000 m3/h)	8800 ACFM (15000 m3/h)	15000 ACFM (25000 m3/h)	41000 ACFM (70000 m3/h)	240000 ACFM+ (400000 m3/h+)
Flow rate	Turndown accomplished by:	Suction valve unloaders (step and stepless) Clearance pockets Bypass	Suction valve unloaders (step and stepless) Clearance pockets Bypass	Slide valve (15-100%) step less Bypass	(None) Bypass	Inlet guide vane Speed control (70-100%) Bypass
	Polymer gas	Difficult	Difficult	Difficult	Possible	Difficult
	Dirty Gas	Possible	Difficult	Possible	Possible	Difficult
	MW Change	Possible	Possible	Possible	Possible	Difficult

(*1) Two stage tandem arrangement maybe adopted in actual high pressure ratio application due to better efficiency.

Generally, reciprocating compressors are suitable for high pressure ratios, low flow, and low megawatt (MW) applications. Centrifugal compressors are suitable for large flowrates. Screw compressors are suitable for the following conditions.

- *Pressure ratio limitations*—Since it is a positive displacement type compression, and has no valve movement, a high pressure ratio can be achieved. On oil-flooded screw compressors, there is no mechanical limitation for pressure ratio. The only concern is efficiency.
- *Capacity control*—Oil-flooded screw compressors have an unloader called a slide valve and can provide stepless turndown (typically 100 percent to 15 percent) with corresponding reduction in power.
- *Impact of molecular weight of gases*—There is almost no impact of molecular weight of the gases upon the performance of an oil-flooded screw compressor. Injected oil is a sealant and leakage is controlled. Therefore these compressors are highly efficient for even the lowest molecular weight gases.
- *Gases containing dust and polymers*—In oil-free screw compressors, any type of gas can be compressed. This is practical because compression is done by displacement with continuos rotation, the rotor shaft is rigid so that effect of unbalance is limited, and there are no internal valves to hinder the operation from dust and polymers.
- *Availability*—High reliability resulting in compressor availability is the same as centrifugal machines and allows single machine operation without a spare in critical services.

GENERAL DESCRIPTION OF OIL-FREE SCREW COMPRESSORS

A cutaway drawing of a typical oil-free screw compressor is shown in Figure 1. There are two rotors inside the casing of the screw compressor. One rotor is referred to as male, and the other rotor is the female. The male rotor and the female rotor maintain a small clearance and do not contact each other. To keep phase with each other, a timing gear is furnished to drive the other rotor.

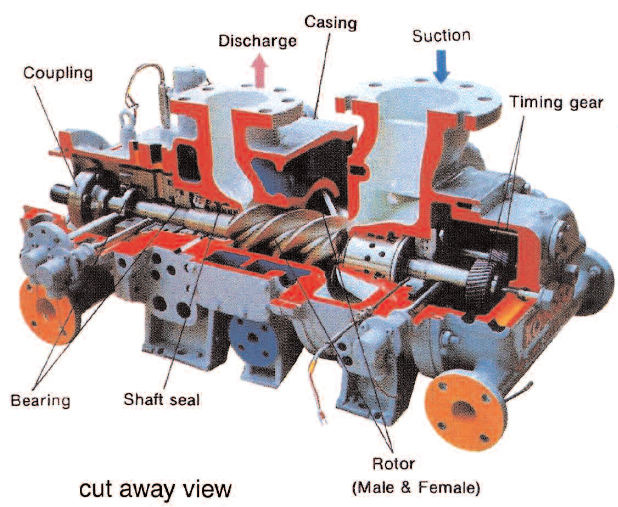

Figure 1. Typical Cutaway Drawing of Oil-Free Screw Compressor.

To isolate the rotor chamber from the bearing with an oil atmosphere, seals are furnished next to the rotor lobe on each end of the machine. There are journal bearings outside the seal area, which are typically sleeve type hydrodynamic bearings. Thrust bearings are located on the outer side of the journal bearings, and tilting-pad type is typically used.

The following are the major characteristics of the oil-free screw compressors:

- Process gas is completely free of oil, there is no contamination, and therefore any gas can be handled. In oil-free screw compressors, due to the positive displacement compression, even polymer gas or dirty gas can be compressed.

- The rotor speed is higher than with oil-flooded screw because of no oil turbulence in the rotor chamber, but does not exceed any critical speed since the rotor shaft is to remain rigid. Rotor speed is typically higher than an oil-flooded screw machine so compressor frame size can be smaller than the oil-flooded type.

- Discharge temperature is typically high because of compression heat. To avoid excessive heat deformation, cooling is required. Some applications utilize a process compatible fluid such as water or solvent to cool the gas directly by injection into the rotor chamber inlet.

- Due to its longer rotor span for seal area, rotor clearance, and limits on discharge temperature, pressure ratios are limited for the oil-free screw compressors.

- Because of its high rotational speed, noise is rather high so that silencers on suction and discharge nozzles are typically required. Expansion and/or absorption type silencers are typically used in combination or separately. Frequency of the noise is high because its main frequencies are pocket passing frequency (rotational speed*lobe number) or its harmonics. The major noise is measured at discharge piping. In the authors' experiences it is apparent that the expansion is good for several discrete frequencies. The size of the expansion type silencer can be optimized by using a simulation to target the specific frequencies, i.e., pocket passing frequency and its harmonics. To absorb this high frequency noise, internal absorption type silencers are considered to be more effective than external absorption type. Absorptive method is effective in abosorbing pulsation energy of frequencies ranging from 500 Hz to several thousand Hz. Further experience confirms the use of a combination of absorption and expansion type silencers to be more effective in noise reduction. By expansion type, 15 to 20 dB of sound pressure level inside the piping can be reduced whereas, by internal absorption, 25 dB of sound pressure level inside the piping can be reduced. In addition to the silencers, a noise enclosure enclosing just the compressor and gearbox is typically required if there is a sound requirement of 85 dBA at 1 m (3 ft) from the compressor skid edge.

GENERAL DESCRIPTION OF OIL-FLOODED SCREW COMPRESSORS

A cutaway drawing of a typical oil-flooded screw compressor is shown in Figure 2. There are two rotors inside the casing as with the oil-free screw compressors. However, here they contact each other at lobe surface via an oil film.

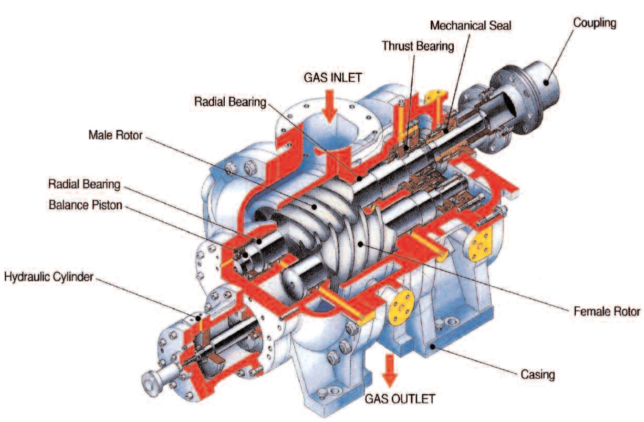

Figure 2. Typical Cutaway Drawing of Oil-Flooded Screw Compressor.

Oil is supplied not only to the bearing and seal, but also to the rotor chamber directly and oil will act as lubricant, coolant, and sealant in the rotor chamber. Typically, the male rotor is driven by a directly coupled two-pole or four-pole electric motor and drives the female rotor. An external gear unit is typically not used since the tip speed of the oil-flooded screw compressor is in the proper design range when driven at motor speed. Since oil is injected into the rotor chamber, the seal area between the lobe and bearing is no longer necessary. There is one mechanical seal located at the drive shaft end. There are typically sleeve type journal bearings on either end of the rotor lobes. Thrust bearings are typically tilting-pad type and are located on the outer side of the journal bearings.

The oil and gas mixture is discharged through the compressor discharge nozzle into an oil separation system located downstream of the compressor. Oil separated in the oil separation system is circulated in the compressor lube system.

An unloaded slide valve is located in the compressor just beneath the twin rotors and is used to adjust the inlet volume. The inlet volume of the compressed gas can be adjusted by moving the slide valve, which is actuated by a hydraulic cylinder. A typical schematic diagram for an oil-flooded screw compressor is shown in Figure 3.

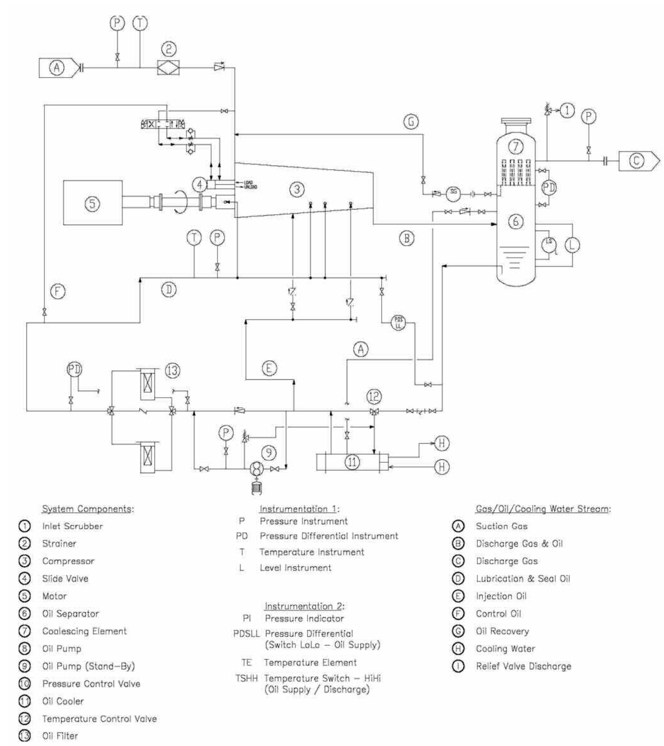

Figure 3. Typical Schematic Diagram for an Oil-Flooded Screw Compressor.

Compressor lubricant oil is present in the process side, so the lube oil selection is very different from other types of machines. The bulk of the oil is separated in the primary oil separator, but a secondary coalescing oil separator may be used as an additional separator. Separation of oil is one of the important factors for oil-flooded screw compressors. Typically, a combination of demister mesh pad and coalescing elements are used. For example, 0.1 parts per million by weight (ppm wt) level can be achieved by combination of a demister mesh pad and two stages of coalescing elements. Charcoal absorbers are occasionally used for more severe applications. Borocilicate microfiber is a typical material used in coalescing elements and submicronic particles of oil can be separated from the compressed gas. Unlike reciprocating compressors, oil from the compressor has no deterioration by piston rubbing so oil can be recirculated in the

Table of Contents

system as lubricant for longer life. The lube oil circulation system consists of compressor lube lines, oil cooler, oil filters, and oil pump. The oil pump may be double or single configuration. The design of a single pump system may be used when the pump is required only during startup. In such case, after the compressor starts and discharge pressure is established, oil can circulate in the system by utilizing gas differential pressure between suction and discharge.

A slide valve is used to load and unload the compressor to maintain suction pressure or discharge pressure. There is a spool valve actuated by air with solenoid valves to switch over the oil lines to pressurize the slide valve cylinders to the load side or the unload side. A typical control range by slide valve is from 15 percent to 100 percent stepless by inlet volume.

Below is a list of some of the major characteristics of the oil-flooded screw compressor:

• *Power consumption savings by a built-in slide valve*—The slide valve as unloader adjusts the inlet volume of the compressor, and this equates as power savings. Figure 4 shows the basic principle of the slide valve mechanism. The slide valve is located just beneath the rotors and moved in the axial direction. The slide valve is moved typically by hydraulic cylinder with oil utilized from the compressor lube oil line. Moving the slide valve to the suction side attains full load, and unloading is achieved by moving the slide valve toward the discharge port. At full load position, the entire length of the rotor is utilized to draw the gas so that inlet volume of the compressor can be maximized. By moving the slide valve to the unloaded position (i.e., discharge side), the length of the compression chamber is shortened. As a result, inlet volume of the compressor is reduced. Compression is done with less inlet volume of the compressor so that theoretical brake horsepower is reduced.

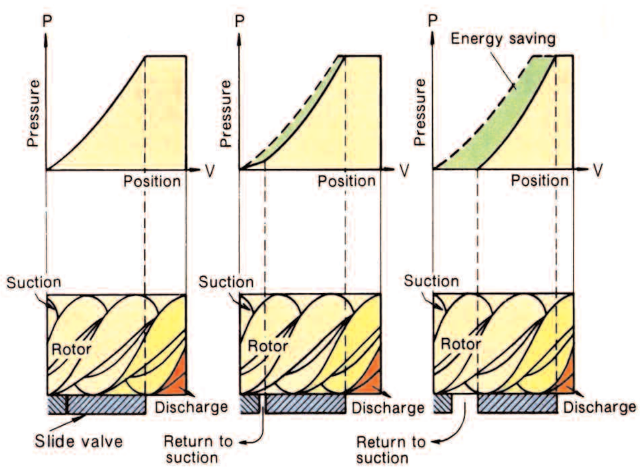

Figure 4. Basic Principle of the Slide Valve Mechanism.

• *High compression ratio limitation*—Since the oil acts as a coolant and sealant the limit on compression ratio is very high. Discharge temperature can be adjusted by oil flowrate, i.e., oil can be injected into the rotor chamber to absorb the compression heat in the oil-flooded screw compressors.

When a very high pressure ratio is required, a tandem arrangement of two stage compressors combined in one casing is available. Typically, this tandem arrangement is used when the pressure ratio is larger than 7:1, and can be applied to ratios of more than 50:1. A typical cutaway drawing of a tandem arrangement oil-flooded screw compressor is shown in Figure 5. Since oil will act as a coolant at the intermediate stage, an external intercooler with piping for intermediate stage is unnecessary.

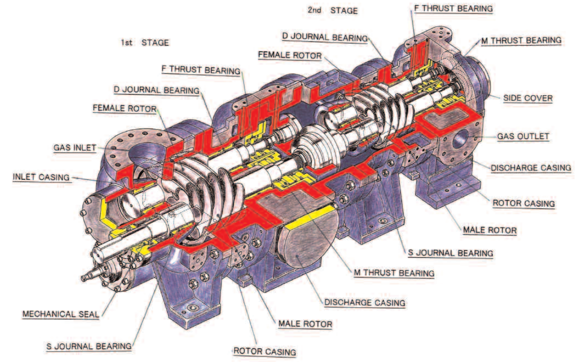

Figure 5. Typical Cutaway Drawing of a Tandem Arrangement Oil-Flooded Screw Compressor.

• *Low maintenance cost*—Due to the lube oil system the rotors and many other parts of the compressor have an oil film on their surface. The life of the rotors is long enough so that a spare set is not required. The mechanical seal is typically one per casing, so maintenance and replacement cost for the seal are typically reduced.

• *Single skid arrangement*—The compressor and lube oil system are integrated and packaged on a single skid. Thus, transportation and installation are completed in a short period.

• *No cooling water jacket/no gas bypass cooler*—Since oil acts as coolant in the compression process, discharge temperature can be controlled by the oil injection flowrate so that the casing structure is made simpler by elimination of a cooling water jacket. The gas bypass cooler can also be eliminated by oil cooling.

• *Selection of oil is driven by the need to be compatible with process gas.* Not only mineral-based oil, but synthetic oil has recently been used to expand the application range of oil-flooded screw compressors. Hydrotreated mineral-based oil has typically been used, but recently many are changing to synthetic oil. There are two kinds of synthetic oil: one is polyalphaolefin (PAO), and the other is polyalkylene glycol (PAG). With PAG there are several kinds of oil that differ in ratio of propylene oxide (PO) and ethylene oxide (EO). For a process with a heavy hydrocarbon, both mineral-based oil and PAO are subject to dilution; however, less dilution can be expected with PAG. There is no difference for dilution ratio by process with heavy hydrocarbon between mineral-based oil and PAO; however, less dilution can be expected for PAG.

• Dilution rate

Mineral oil = PAO > PAG(PO)>PAG(EO+PO)>PAG(EO)

PAG with EO = 100 percent is hygroscopic; however, it has no dilution for heavy hydrocarbon. By using PAG oil, oil-flooded screw compressors are now able to be used for heavy hydrocarbon applications as in refinery services.

GENERAL COMPARISON BETWEEN DIFFERENT TYPES OF COMPRESSORS IN SOME APPLICATIONS AND RECENT SITUATIONS

Hydrogen Service

Hydrogen is widely used in oil refining processes and many processes in petrochemical fields. Hydrogen is typically generated in pressure swing absorption, membrane, or electrolyzing systems. Hydrogen generated by the above methods is usually produced at atmospheric pressure and then compressed typically up to 30 barG (435 psiG) by compressors.

Due to the very low molecular weight of hydrogen and high pressure ratio needed, centrifugal compressors or oil-free screw compressors are rarely used for such applications. Reciprocating compressors have been typically used in this service. Due to the advantage of low maintenance cost, oil-flooded screw compressors are increasingly being applied for this application. Table 2 shows comparison for oil-flooded and reciprocating compressors in typical hydrogen service.

Table 2. Typical Comparison Table for Hydrogen Service.

		Oil-injected Screw	Reciprocating
Gas Composition (by volume)	H2	99%	
	CO+CO2	0.1%	
	CH4	0.78%	
	N2	0.1%	
	O2	0.02%	
	Relative Humidity	0%	
Model		Tandem-type	5 stage
Suction Condition	Pressure	0.4 (bar G) / 6(psiG)	
	Temperature	32 (degC) / 90(degF)	
	Inlet Volume	14960 (m3/h) / 8804(ACFM)	
Discharge Condition	Pressure	23 (bar G) / 334 (psiG)	
	Temperature	100 (degC) / 212 (degF)	140(degC) / 284(degF)
	Temp. at after cooler	40(degC) / 104(degF)	
Flow Rate		18500 (Nm3/h) / 11511(SCFM)	
Speed		2540 (rpm)	330 (rpm)
Total BHP		100%	90%
Required installation area	For one unit	100%	120%
	Includes spare unit	not required	200%
Cost	For one unit	100%	85%
	Includes spare unit	not required	170%

As shown in Table 2, the reciprocating compressor has an advantage of total brake horsepower (BHP) due to multistage compression with an intercooling system. However, the oil-flooded screw compressor has the slide valve to save power at the unload condition. Figure 6 shows the typical package for hydrogen service with an oil-flooded screw compressor.

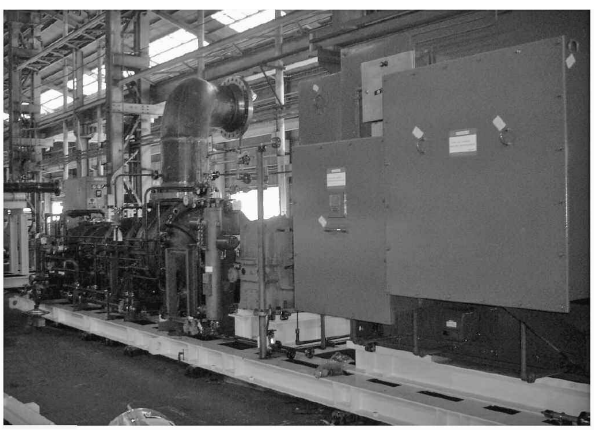

Figure 6. Typical Package for Hydrogen Service Using Oil-Flooded Screw Compressor.

Oil-flooded screw compressors have an advantage due to the smaller amount of installation area needed and less weight to support. In the case of a tandem arrangement, which is two stage compressors arranged in one casing, compact skid arrangements can be adopted on oil-flooded compressors. Another advantage of the oil-flooded screw compressor is longer times between maintenance. The typical maintenance period for a reciprocating compressor is one to two years, while an oil-flooded screw compressor is two to four years. Reciprocating compressor applications typically require a spare compressor, so investment and installation costs are doubled.

The gas industry field requires a longer maintenance period such as two to four years. Equipment demands require continuous operation, and the oil-flooded screw can meet this demand. Oil carryover from the oil-flooded screw compressor is managed by oil coalescing systems, which can reduce carryover to 1.0 ppm—in some applications by adding charcoal absorbers. Less than 50 ppb carryover by weight is achieved.

Vapor Recovery Unit (VRU)

In most offshore platform applications, crude oil or natural gas drilling produces vapor gas as a by-product. This vapor by-product needs to be recovered for environmental reasons. As a result, vapor recovery units together with compression systems are used. The typical gas composition and operating condition is shown in Table 3.

Table 3. Typical Gas Composition and Operating Condition for VRU.

Gas Composition (by volume)	N2	0.1%
	H2O(VAPOR)	12.0%
	CO2	3.0%
	H2S	0.3%
	CH4	34.0%
	C2H6	11.0%
	C3H8	15%
	i-C4H10	4.5%
	n-C4H10	10.0%
	i-C5H12	4.0%
	n-C5H12	3.0%
	C6H14 Plus	3.0%
Suction Condition	Pressure	0.7(barG) / 10(psiG)
	Temperature	60(degC) / 140(degF)
	Inlet Volume	4697(m3/h)2764(ACFM)
Discharge Condition	Pressure	3.8(barG) / 55(psiG)
	Temperature	128(degC) / 262(degF)
Flow Rate		6652(Nm3/h) / 4139(SCFM)

Gas composition of the recovered vapor can change due to well location and the age of the well. Even from the same well, the vapor gas composition and flowrate can fluctuate. Centrifugal compressors have difficulty in this application because of unsteady gas composition and flowrate. In recent years, lower costs have increased the use of oil-flooded and reciprocating compressors in this application.

In comparison with reciprocating compressors, oil-flooded screw compressors are more widely used due to their gas flow adjustment capabilities, which can be adjusted by the internal slide valve. However, the "unpredictable" gas composition sometimes contains serious amounts of sulfur, tar, or other unknown corrosive components as well as heavy hydrocarbons that are always present. Also, there are some difficulties in using oil-flooded compressors due to serious dilution of oil.

Oil-free screw compressors are being increasingly used where the specific heat coefficient (k value) is rather small and the discharge temperature is lower for higher pressure ratios. A typical package with oil-free screw compressor for VRU is shown in Figure 7. As shown in the picture, the skid needs to be very compact due to restriction of space, which is also a very important factor on VRU.

Figure 7. Typical Package for VRU Using Oil-Free Screw Compressor.

Lube oil does not come in contact with process gas within oil-free screw compressors. Therefore, there are no dilution problems. In addition, heat insulation and electronic heat tracing are required to avoid condensation of gas in oil-flooded screw compressors when the compressor is not running. During operation, process gas temperatures need to be kept higher than dew point to avoid dilution of oil in oil-flooded screw compressors. In the case of an oil-free screw compressor, there is no concern due to condensation of gas. Therefore the overall system is simple.

Regarding the gas flow change, oil-flooded screw compressors have an advantage with adjustment by the internal slide valve and power savings. However, the rate of change of the gas flow is very slow, typically 20 to 30 years of operation, and generally changes over the life of the field. Oil-free screw compressors can accommodate this change by adjusting the operational speed. Replacement of gear and pinion combinations in a speed increasing gearbox makes this procedure possible. These parts are interchangeable and can be replaced and maintained. A comparison table between oil-free screw compressors and oil-flooded screw compressors is shown in Table 4.

Table 4. Comparison of Screw Compressor Features for VRU Between Oil-Free and Oil-Flooded Types.

(Bold with underline denotes advantageous feature)

Description	Oil-free Screw	Oil-flooded Screw	Remarks
Suitable use	- Low press. & large capacity - Smaller press. Ratio - Water/hydrocarbon mist **Entrainment-containing gas**	- Middle - high press. & small-medium capacity - Larger press. Ratio	
Compressor Size	**Smaller**	Larger	Difference in speed
Max. Differential Pressure & Pressure Ratio	Smaller	**Larger**	Discharge temperature limitation to oil-free type.
Turndown Control	- Variable speed - Bypass	**Slide valve** +Bypass	
Limitation of Components In Handled Gas	**Smaller**	Larger	Oil-flooded type requires compatibility of oil with gas components (Heavy hydro carbon, Water, H2S).
Pre-treatment of Gas	**Less**	More	Oil-flooded type requires pre-cooler & knock out drum to prevent oil contamination.
Noise Level	Higher	**Lower**	Silencers are required for oil-free type.
System Complexity	Comparable	Comparable	Complexity due to: Oil-free: Shaft seal system Oil-flooded: Oil treatment & separation system.
Package Space & Weight	**Smaller**	Larger	Oil-flooded type requires additional equipment for gas pre-treatment, oil separation and oil purification.
Total Initial Installation Cost	Comparable	Comparable	Depends on flow rates, pressures and gas components
Spare Parts	More	**Less**	Recommended spares for oil-free type: shaft seals & bearings
Risk In Operation	**Lower**	Higher	**Oil-free: mechanical issues only** Oil-flooded: mechanical + process issues. Uncertain factors remain.

Fuel Gas Booster for Gas Turbines

Recently, the efficiency of generating electrical power by gas turbines has been significantly improved. High efficiency type gas turbines are used in many power plants utilizing natural gas as fuel. Many gas turbines require higher supply pressure of the fuel at typically 30 barG to 50 barG (450 psiG to 725 psiG) and natural gas pressure coming out from the pipeline is low. To boost the fuel gas to the required pressure of the gas turbine, a fuel gas booster is required. For the fuel gas booster application, reciprocating compressors and centrifugal compressors have been used primarily.

In the 1990s, high pressure oil-flooded screw compressors were developed and started to be used for fuel gas booster applications. The oil-flooded screw compressors are very suitable for these applications, since the requirement of the fuel gas booster fits very well with characteristics of oil-flooded screw compressor, i.e.:

- Suction pressure fluctuations
- Gas turbine load fluctuation, i.e., flowrate fluctuation
- Unstable gas composition (typically pipeline quality natural gas)

Also, this fuel gas booster application requires economical operation and the oil-flooded screw compressors with a slide valve as an unloader can provide significant power savings.

Because of suction pressure fluctuations, the compressor needs to be sized according to the design point, which is the lowest suction pressure in specification. However, the actual suction pressure is typically higher than the design point so that the compressor is always operated in a partially unloaded condition. A typical unload performance curve is shown in Figures 8 and 9.

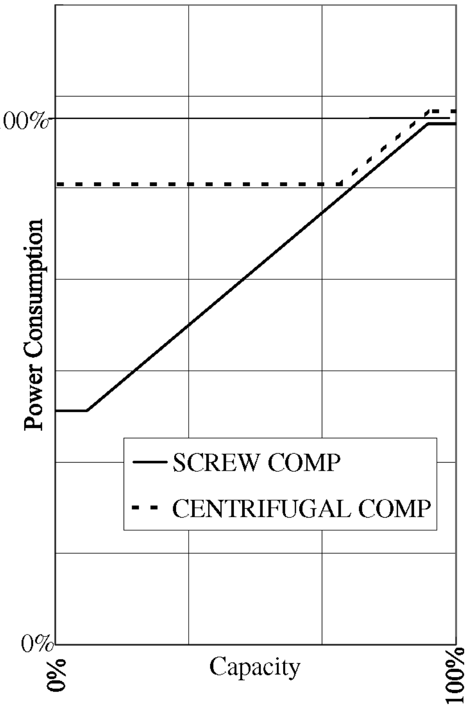

Figure 8. Typical Unload Curve When Mass Flowrate is Constant with Suction Pressure Change.

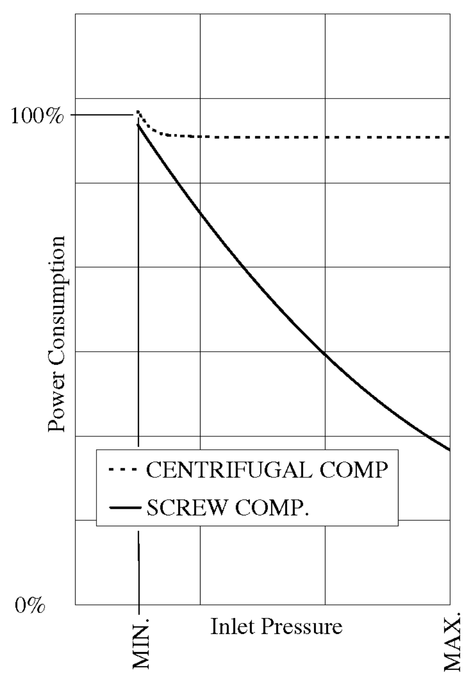

Figure 9. Typical Unload Curve When Suction Pressure is Constant with Mass Flowrate Change.

Oil-flooded screw compressors can be operated at higher suction pressures by utilizing a slide valve with less brake horsepower required in the unloaded condition. Reciprocating compressors and centrifugal compressors cannot accommodate the big fluctuation of suction pressure so a suction control valve is typically required to control suction pressure close to design point at the compressor inlet. Thus, large power energy savings cannot be acquired with these machines. The flowrate is typically rated with some range for gas turbines, since consumed fuel gas flowrate is varied by atmospheric temperature. As a result, the compressor needs to be capable of operation at lower flowrates than the rated point. The oil-flooded screw compressor can meet this demand by using the slide valve with power savings as well (refer to Figure 9).

This application typically requires a suction scrubber since unexpected water or liquid may be present in the gases. Gas turbines require very precise delivery pressure of fuel gas. Discharge pressure needs to be maintained regardless of the suction pressure swing so that a spillback (bypass line) is always required for quick load and suction pressure changes. The screw compressor slide valve control system accommodates these large changes.

In addition to the above, automatic operation is required with gas turbine operation so that a control panel with programming is typically required. Figure 10 shows a typical package for a fuel gas booster unit using an oil-flooded screw compressor.

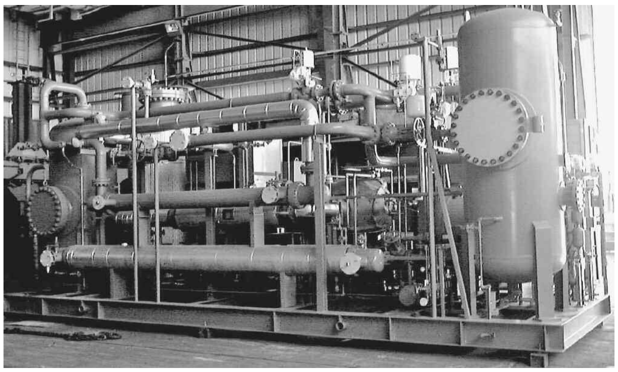

Figure 10. Typical Package for Fuel Gas Booster Service Using Oil-Flooded-Screw Compressor.

Except for large size machines, all equipment can be mounted on a single skid, including the oil separation system, suction scrubber, spillback line, and control panel. Sometimes, the compressor forward bypass line is provided when maximum suction pressure is above the discharge pressure. A typical comparison of the screw compressor features for a fuel gas booster application between oil-flooded screw, centrifugal, and reciprocating compressors is shown in Table 5.

Table 5. Typical Comparison Table for Fuel Gas Booster.

		Oil-Flooded Screw	Centrifugal	Reciprocating
Gas Composition (by volume)	CO2	0.5%		
	N2	0.7%		
	CH4	97.85%		
	C2H6	0.7%		
	C3H8	0.1%		
	n-C4H10	0.05%		
	i-C4H10	0.05%		
	n-C5H12	0.025%		
	C6H14	0.025%		
	Relative Humidity (%)	0		
Model		Single	Single	Single
Suction Condition (Rated)	Pressure	25(barG) / 363(psiG)		
	Temperature	15(degC) / 59(degF)		
	Inlet Volume	2819(m3/h) / 1659(ACFM)		
Suction Condition (Normal)	Pressure	35(barG) / 508(psiG)		
	Temperature	15(degC) / 59(degF)		
	Inlet Volume	2036(m3/h) / 1198(ACFM)		
Discharge Condition	Pressure	50(barG) / 725(psiG)		
	Temperature	-	-	-
Flow Rate (Rated)		70000(Nm3/h) / 43550(SCFM)		
Flow Rate (Normal)		65000(Nm3/h) / 40440(SCFM)		
Total BHP (Rated)		100%	100%	100%
Total BHP (Normal)		60%	96%	65%
Necessary installation area	For one unit	100%	150%	300%
	Includes spare unit	Not Required	Not Required	600%
Cost	For one unit	100	130%	100%
	Includes spare unit	Not Required	Not Required	200%

As shown in Table 5, brake horsepower at the design rated point has almost no difference among three types of compressors. However, there is a large difference at normal operation point and when the suction pressure is higher than design and less flowrate. From a cost and installation point of view, the oil-flooded screw compressor has significant advantage for such applications.

Desulfurization Compressor

Recently, demand for desulfurization of vehicle gasoline and diesel fuel is increasing all over the world. New regulations to protect the environment have forced the oil refinery industry to develop a desulfurization process. For this process, gas compression is necessary mainly utilizing a hydrogen mixture.

The oil-flooded screw compressor has been proven in this process, and demand for the screw compressor is increasing in this application. Table 6 shows a typical comparison of compressors for desulfurization process between oil-flooded screw, centrifugal, and reciprocating compressors.

Table 6. Typical Comparison Table for Desulfurization Compressors.

		Oil-injected Screw	Reciprocating	Centrifugal
Gas Composition (by volume)	H2	90%		
	N2	0%		
	H2O	0.95%		
	CH4	9%		
	C6H14	0.05%		
	H2S	<20volppm		
	Relative Humidity (%)	100		
Model		Single Casing	2 stage	3 Casings (24Stage)
Suction Condition	Pressure	9.0(bar G) / 130(psiG)		
	Temperature	40(degC) / 104(degF)		
	Inlet Volume	2440(m3/h) / 1436(ACFM)		
Discharge Condition	Pressure	20.0(barG) / 290(psiG)		
	Temperature	88(degC) / 190(degF)	150(degC) / 302(degF)	150(degC) / 302(degF)
Flow Rate		21000(Nm3/h) / 13066(SCFM)		
Speed		2950(rpm)	420(rpm)	11800(rpm)
Total BHP		100%	96%	125%
Necessary installation area	For one unit	100%	125%	190%
	Includes spare unit	Not required	220%	Not required
Cost	For one unit	100%	70%	200%
	Includes spare unit	Not required	140%	Not required

Hydrogen is the main gas component and H2S is typically included in the gas stream in ppm level. Gas composition is not stable due to change of desulfurization process and nitrogen operation is required at startup. Therefore the compressor needs to have the capability of operating at various conditions of gas composition.

Pressure condition is typically very low pressure. However suction pressure is higher when discharge pressure is high, which can change case by case with the process. The end users are oil refineries, so longer times between maintenance periods and high reliability are required. In the past reciprocating compressors and centrifugal compressors were typically used for this application. However, demand for the oil-flooded screw compressors has been increasing.

In the 1990s oil-flooded screw compressors suitable for high suction pressure and low pressure ratio were developed. The oil-flooded screw compressor can be suitable for gas composition changes due to positive displacement type of compression. The slide valve allows the compressor to handle pressure and flow changes with power savings.

Other than the desulfurization compressor, there is another application in the desulfurization process called “net gas booster,” which requires higher pressure ratio and larger size. Since this net gas booster contains hydrogen the oil-flooded screw compressor has started to be used for this application instead of reciprocating compressors, for longer maintenance periods. A typical package using an oil-flooded screw compressor is shown in Figure 11. A noise enclosure is not typically required for oil-flooded screw

Table of Contents

compressors due to low noise, so the accessibility to the compressor is secured, which is also a very important factor from a maintenance standpoint.

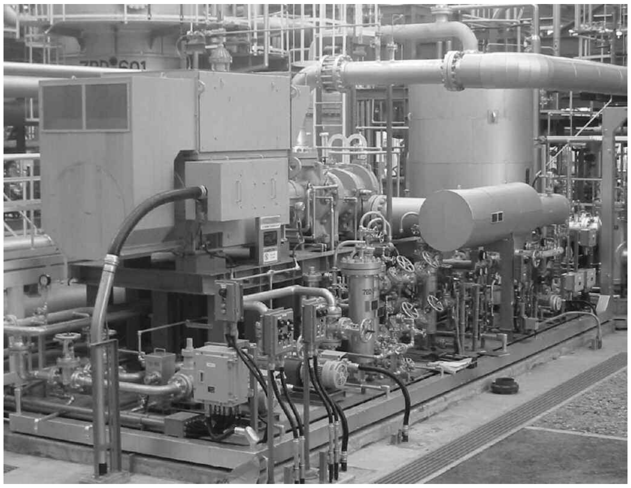

Figure 11. Typical Package for Desulfurization Service Using Oil-Flooded Screw Compressor.

Application Chart

To get a better understanding, Figure 12 shows an application chart where the applications in this paper fall with each type of compressor. Although screw compressor applicable range is confined to reciprocating compressor, and centrifugal compressor range, there are applications with ranges where screw compressors are used, as referred to in this paper because of the many advantages in using screw compressors.

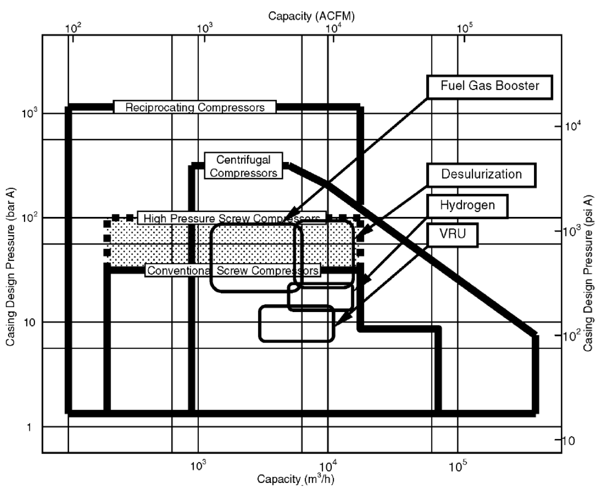

Figure 12. Application Chart with Each Type of Compressor Typical Applicable Range.

CONCLUSION

Oil-free and oil-flooded screw compressors can be applied in many applications. Some reasons for considering the screw compressor are changes in process conditions, recent progress in compressor technologies, and application range of screw compressors. There are many benefits for the customer such as high reliability, low initial cost, less maintenance cost, and power savings.

REFERENCES

API Standard 619, 2004, "Rotary Type Positive Displacement Compressors for Petroleum, Petrochemical, and Natural Gas Industries," Fourth Edition, American Petroleum Institute, Washington, D.C.

BIBLIOGRAPHY

Ohama, T., Amano, Y., and Kawaguchi, N., 2000, "High Pressure Oil-Flooded EH Series Screw Compressors," *Kobelco Technology Review,* (23).

Ohama, T., Koga, T., and Kurioka, Y., 2004, "High Pressure Oil-Injected Screw Gas Compressors (API 619 Design) for Heavy Duty Process Gas Applications," *Proceedings of the Thirty-Third Turbomachinery Symposium,* Turbomachinery Laboratory, Texas A&M University, College Station, Texas, pp. 49-56.