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# Advantages of Non-lubricated CNG Compressors


by Tingrong Ren, PhD and Jacobus Neels, P.Eng

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**Abstract**

This paper discusses the advantages of non-lubricated compressors when used in compressed natural gas (CNG) service. The features of non-lubricated CNG compressors will be illustrated and explained. The maintenance schedule for a non-lubricated CNG compressor is also presented.

## 1. Introduction

As an alternative fuel, CNG has a number of advantages: lower cost, higher efficiency, lower emissions, lower engine noise level and longer engine life. CNG technology has been developed and applied for decades and is becoming a mature, applicable technology. With the development of the vehicle industry and higher standard requirements of environmental protection, this clean alternative fuel will be extensively used.

As the heart of a CNG fuelling station, compressor performance has significant influence on the overall system operation. There are also some special requirements for CNG compressors. Natural gas vehicle fuel systems and engines, as well as CNG stations, require CNG with very low oil carry-over. More and more non-lubricated piston compressors have been developed and applied in CNG stations, especially for low- and medium-capacity CNG stations. It has been demonstrated that non-lubricated compressors have a number of advantages versus lubricated compressors in CNG applications.

This paper will discuss the advantages of non-lubricated compressor when used in CNG service. The features of non-lubricated CNG compressors will be illustrated and explained. The maintenance schedule for a non-lubricated CNG compressor is also presented.

## 2. The influences of oil carry-over

Oil carry-over (aerosol and oil gas) in CNG has a significant negative influence on natural gas vehicles, engines, and the maintenance and operation of CNG stations [1 ~ 3].

- The oil vapor and small aerosols will accumulate in fuel tanks. Fuel storage capacity is therefore diminished, the vehicle dead weight increased, and fuel economy diminished by carrying this additional weight.
- Oil aerosol affects the compressor heat exchanger surfaces, resulting in hotter discharge gases that reduce the storage capacity and consume more compressor power.
- Oil carry-over increases vehicle emissions during engine combustion.
- The maintenance and replacement of oil separators and filters will affect the CNG station maintenance costs and overall downtime. This will also increase the

> Oil carry-over increases vehicle emissions during engine combustion

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accumulation of waste oil which is a toxic substance and must be disposed of properly (often at a significant cost).

- Inside a CNG vehicle, onboard CNG stored at 20 MPa is regulated to 0.7 MPa by a regulator and then injected into engine. There are many examples of oil soaking the regulator diaphragm, affecting its accuracy and, in some cases, causing a rupture of the regulator internals if oil clogs the regulator.
- The area most sensitive to oil contamination is the engine itself. The sensors of the engine system are extremely sensitive to any contamination.

## 3. Selection of a CNG compressor

As the main component of a CNG fuelling station, compressor dynamic characteristics, thermodynamic performance, operation availability, and reliability have significant influence on CNG station operation. The selection of compressor type is one key step in investigating and building a CNG station.

In order to maximize the vehicle tank capacity (and resultant driving range), you require a multiple-stage compressor to compress low-pressure natural gas from available pipeline pressure (0.05 ~ 2 MPa for example) to high pressure (approximately 25 MPa). The required compressor flow rate is also high. In addition, because of the low gravity and flammable properties of natural gas, the compressor requires a very high sealing efficiency. In such applications, the reciprocating piston type compressor is the most suitable type of compressor for CNG stations. So far, there are mainly three different types of reciprocating compressors serving the CNG industry.

- **Non-lubricated compressor** – The lubrication system only provides lubrication to crankshaft bearings, crank pins, cross head pin and cross head guides. The piston rings and packing rings are not lubricated by oil, but only by using self-lubricated materials. Compressor major constructive parameters (speed, stroke, cylinder, piston and piston rod) are specially selected and designed to enhance ring life and ensure compressor performance.
- **Low oil compressor** – The lubrication system only provides lubrication to crankshaft bearings, crank pins, cross head pin, cross head guides, and packing rings. Piston rings are non-lubricated. Compressor design is the same as a lubricated compressor. In some cases, the only difference with lubricated compressors is the absence of an oil injector for the cylinders.
- **Lubricated compressor** – The lubrication system provides direct lubrication to the crankshaft bearings, crank pins, cross head pins, cross head guides, packing rings, and piston rings.

According to the requirements for gas quality, using non-lubricated compressors is a better and more reasonable choice

In the early days of CNG applications (normally with low flow capacity), small single-acting lubricated compressors were more commonly used in small dispensing stations. This is partially because the negative influences of oil carry-over were not recognized, but the major reason is because the high-pressure, multiple-stage non-lubricated compressors were not yet available.

As the carry-over of lubricated oil aerosols and vapor became a big problem for both vehicle fuel systems and engines, more and more non-lubricated compressors (where the rings are self lubricated) have been developed and applied in the CNG industry. According to the requirements for gas quality, using non-lubricated compressors is a better and more reasonable choice. In practice, since the self-lubricated material has been developed and compressor designs optimized, acceptable performance and life of self-lubricated seal rings have been achieved. This ensures the non-lubricated CNG compressor operation reliability and eliminates the oil carry-over problem.

As more and more large fleets and public transportation companies turn to the use of CNG, the requirement for higher compressor flow rates has increased. Large compressor packages are required in many cases. Some users may consider the equipment capital cost (for a given flow capacity, non-lubricated compressor cost is typically higher than a lubricated compressor) and worry about the ring life of a non-lubricated compressor. Choosing between a lubricated or non-lubricated compressor for a CNG station is becoming a critical decision.

To solve the oil contamination problem in CNG stations, the most reasonable method is to eliminate the problem at the cause, i.e. avoid using oil to lubricate the compressor cylinders. All those factors affecting the CNG station equipment cost, operation, and maintenance cost have to be taken into account during the selection of a CNG compressor. Reference [1] provides a cost comparison between two similar CNG stations. Both stations installed two 2400 Nm3/hr (280 kW) compressors, but one uses non-lubricated compressors and the other uses lubricated compressors. It clearly shows the large maintenance savings due to the application of non-lubricated compressors.

## 4. The features of non-lubricated CNG compressors

A CNG compressor system is normally designed and manufactured as a single skid mounted within a weatherproof enclosure. Some cases require a movable mobile station (Mobile Refuelling Unit). For designing a non-lubricated CNG compressor, the following points have to be considered to ensure the best compressor thermodynamic and dynamic performance as well as adequate piston ring, packing ring, and valve operation life time.

- **W or V style –** Angle mounted cylinders and pistons benefit piston ring and packing ring operation life. These kinds of compressors have excellent dynamic force balance. First order reciprocating inertial force and rotation inertial force, as well as second order reciprocating inertial force can be balanced by using counter weights. When it is designed as double-acting, the total resistance torque curve is even. These compressors run very smoothly. This also benefits cylinder cooling. This kind of compressor utilizes a very simple foundation and can be designed as an air-cooled, movable compressor package. It is well suited for CNG stations, particularly low to medium capacity applications, standard stations, daughter stations, and mobile stations.
- **Cross head design –** Natural gas (predominantly methane) is a flammable gas and a greenhouse gas. It is required that gas leaking to atmosphere is eliminated or at least limited during compressor operation. Compressors with crossheads benefit by sealing gas from leaking between the cylinder and the crankcase. Using a seal carrier and seal ring assembly can easily limit leaking gas to less than 0.1% of the gas mass flow rate. Compressor crankcases can then be designed to be non-pressurized, making it unnecessary to install special sealing gaskets or to use high-pressure oil systems.
- **Double-acting cylinders** – Double-acting cylinders increase cylinder utility and compressor flow rates, reducing the compressor's physical dimensions and weight. It also benefits piston ring life.
- **Lower piston speed** – Limiting piston speed (<3.5 ~ 4.0 meters/second) can improve seal ring and valve life-time. Using the modern self-lubricated materials, 5000+ hours ring life for non-lubricated compressor pistons has already been achieved. Under optimum conditions, ring life has been shown to be able to exceed 8000 hours.

- **Lower rotational speed (<900 RPM) and longer stroke (>100 mm) –** This ensures the flow capacity and reduced rod loading. It also benefits cylinder cooling, reducing power consumption and discharge temperature, while increasing piston ring life. With lower rotation speeds, the valve open-close frequency is much lower than that of a high speed lubricated compressor. This substantially increases the valve life.
- **Lower pressure ratio** – This decreases heat of compression. The major factor which affects PTFE (Teflon®) ring life is high temperature; therefore the discharge temperature of each stage has to be limited. Some new self-lubricated materials can handle higher temperature, e.g. PEEK ring material can be used up to 180° C temperature. In a non-lubricated compressor, using PEEK rings in some stages with higher temperatures can enhance the piston ring operation time even further.
- **Longer piston body** – Extending the piston body length allows one or two more piston rings to be mounted, plus rider rings are used to separate the piston and cylinder wall. In this manner, the piston ring sealing efficiency and operational life can be increased.
- **Longer piston rod** – In order to further avoid oil carry-over, besides using an oil wiper ring for a non-lubricated compressor, it is necessary to increase the piston rod length by one stroke. This ensures that the section of the piston rod (crankcase end) that contacts the oil cannot enter the cylinder.

> …the heat exchanger of a non-lubricated compressor has less fouling effect inside the tubing that is caused by accumulated oil film

Compared with a lubricated compressor, the heat exchanger of a non-lubricated compressor has less fouling effect inside the tubing that is caused by accumulated oil film. These (non-lubricated compressor) heat exchangers can run with higher efficiencies for a longer time and ensure the maximum use of available storage capacity. CNG compressor stops and starts are controlled according to pressure signals from the storage assembly. If the heat exchanger cannot cool the high temperatures of the compressed gas, it will cause this higher temperature gas to go into the next stage and then into storage. This will affect the compressor performance and storage capacity. In fact, after an inter-stage cooler, every 3° C rise in temperature approach will result in 1% higher power consumption in the next stage. After the after-cooler, every 3 ° C rise in temperature approach will result in a 1% reduction of storage capacity.

Some lubricated compressor manufacturers, in order to address the oil carry-over problem, simply remove the cylinder oil injector and change the metal piston rings to PTFE rings, packaging these as oil-less compressors. In fact, since lubricated compressors normally have a shorter piston rod, lubrication oil can still be easily introduced into the cylinder by the piston rod.

As mentioned above, for a non-lubricated CNG compressor, there are some special design features that ensure better performance and longer ring and valve life. It is not easy to get a good quality CNG compressor by simply using the same design as a lubricated compressor.

## 5. Methods of sealing in a non-lubricated CNG compressor

Since the specific gravity of natural gas is less than air, it is more difficult to seal. It requires a very high sealing efficiency compressor. Fig 1 shows a typical non-lubricated compressor cylinder assembly, including packing rings and seal carrier. The sealing between the piston and cylinder, as well as piston rod and seal carrier is a dynamic sealing issue. The most common sealing method used in reciprocating compressors is the combination of clog sealing and labyrinth sealing, but mainly clog sealing.

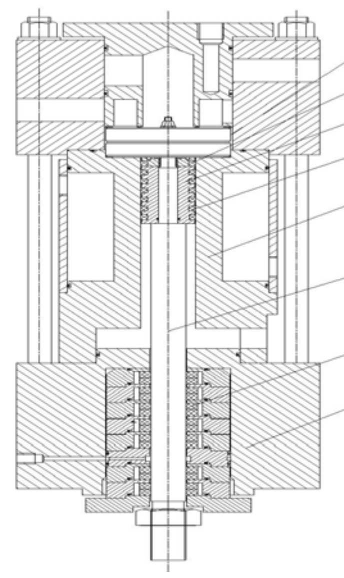


Fig 1 – Non-lube compressor cylinder

Fig 2 shows the difference between lubricated and non-lubricated compressor piston structures. As mentioned above, a non-lubricated piston has a longer body, more piston rings are mounted, and one or two rider rings are used to separate the cylinder and piston. Normally, PTFE or/and PEEK material rings are used as the sealing rings in CNG compressors. These materials have excellent self-lubrication properties under non-oil conditions. The hardness is lower and this allows the rings to touch the cylinder surface to achieve better sealing.

Between piston rings there are several encircled spaces. They have considerable sealing results. Similarly, the packing rings have the same function.

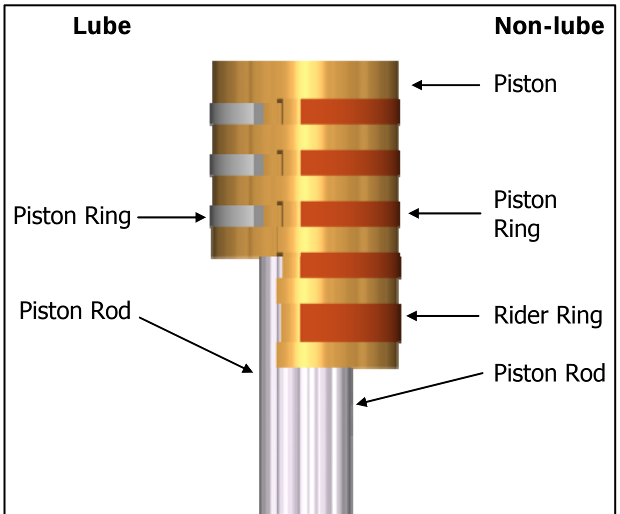


Fig 2 – Lube and non-lube piston

Fig 3 illustrates the principle of labyrinth sealing method. The gas pressure drops when the gas is passed through the leaking path and gets into the next encircled space. The gas expands and its volume is increased. Since the leaking gas mass through every space is equal, for the same leaking path section area, larger velocity, therefore more pressure difference is required since the gas volume is expanded. This makes the gas more difficult to pass through. For a non-lubricated compressor, since more sealing rings are mounted and rings are able to touch the cylinder (or piston rod) surface, better labyrinth sealing results can be achieved.

For the cylinder surface final finish, one might think that it requires much better finish for a non-lubricated compressor than for a lubricated compressor, and continuous operation condition must be very hard for non-lubricated piston ring and packing ring life. However, this is not true. Improved surface smoothness is not necessarily better. Actually, when the surface is too smooth, it is not easy for the PTFE molecule to adhere to the cylinder surface. This is not beneficial for self-lubrication. Normally, the adequate cylinder surface finish is Ra 0.25 ~ 0.5 µm, the piston rod surface finish is Ra 0.20 ~ 0.40 µm, and the hardness is about 50 HRC. The sealing ring wear also depends on the compressor operation time. Continuous operation can increase the sealing rings actual operational lifetime. This is because the PTFE molecular film adhering to the surface will continuously provide the lubrication function. Once the compressor shuts down, the film tends to disintegrate. Next time the compressor starts, the lubricating film will be established again.

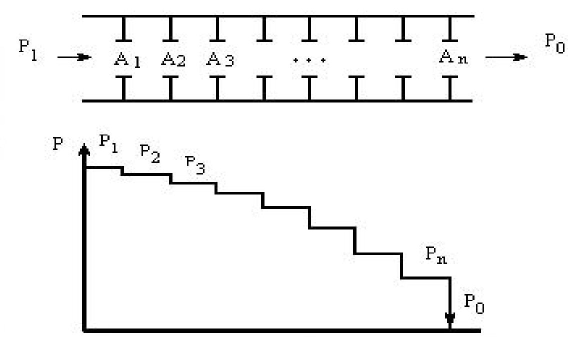


Fig 3 – Function of Labyrinth Sealing

The lower hardness of self-lubricated rings is the primary reason for their shorter lifetime; however, the resulting reduction in wear to the cylinders and piston rods extends the life of these expensive components considerably.

Compressors used in time-filling applications can operate within a large range of discharge pressures. Certain compressors must operate above a specific minimum discharge pressure to ensure the proper operation and sealing of the piston rings. Without sufficient backpressure, the rings will not seal adequately against the cylinder wall and, in some lubricated compressors, oil consumption will increase as oil is drawn into the compressor cylinder. To address the problem, a backpressure regulator is installed at the compressor discharge and set to the manufacturer's minimum required pressure. This requirement increases power consumption unnecessarily. Non-lubricated compressors easily avoid this kind of problem and therefore can handle a wider range of discharge pressures.

## 6. Maintenance of non-lubricated compressors

In general, non-lubricated compressors are relatively low maintenance machines. Some of their main advantages in terms of maintenance are as follows:

- Daily or frequent oil filling is not required
- Frequent draining of scrubbers and filters is not required
- Waste oil removal, storage, and disposal costs are greatly reduced or eliminated
- Heat exchanger surfaces do not require cleaning/removal of oil contamination film
- Discharge filtration requirement is reduced to only one coalescing filter (no oil separator is required)
- No oil lubricators/injectors are required, eliminating any related service/maintenance
- Reduced oil carry-over reduces or eliminates associated maintenance requirements on downstream equipment: station storage equipment, vehicle storage systems, vehicle fuel systems, vehicle engines

## Maintenance schedule (typical for non-lubricated compressor)

Table 1 – Recommended Compressor Maintenance Schedule

| Item | Maintenance Description | Maintenance Period | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 2 weeks | 500 hrs or 6 mos. | 1000 hours | 2000 hours or 1 yr. | 5000 - 8000 hours | 10000-12000 hours | Annual |
| 1 | Check oil levels on compressor | x | | | | | | |
| 2 | Drain interstage scrubbers and all filters. | x | | | | | | |
| 3 | Drain recovery tank sump and vent header. | x | | | | | | |
| 4 | Change oil and oil filter, and check for any unusual particles in the waste oil. | | | x | | | | |
| 5 | Change inlet and discharge filter elements, and check filter bowl/element for contents. | | | x | | | | |
| 6 | Lubricate main drive motor bearings. | | | | x | | | |
| 7 | Remove and clean compressor valves. Inspect for cracks or breakage. Leak-test with solvent, and disassemble and inspect for signs of excessive wear or leakage. | | | | x | | | |
| 8 | Remove and inspect rod packings, piston rings and compressor valves. Replace if there are signs of excessive wear. | | | | | x | | |
| 9 | Remove and inspect pistons and rods. Replace if there are signs of excessive wear. | | | | | x | | |
| 10 | Remove and/or inspect cylinders, cylinder liners, seal carriers and rod packing blocks. Replace if there are signs of excessive wear. | | | | | | x | |
| 11 | Inspect wrist pin bearings/bushings. Replace if there are signs of excessive wear. | | | | | | x | |
| 12 | Replace connecting rod journal bearings. | | | | | | **20000 Hours** | |
| 13 | Replace crankshaft end bearings, cones and oil seals. | | | | | | **40000 Hours** | |
| 14 | Winter/summer oil check. Change to suitable weight oil as required. | | | | | | | x |

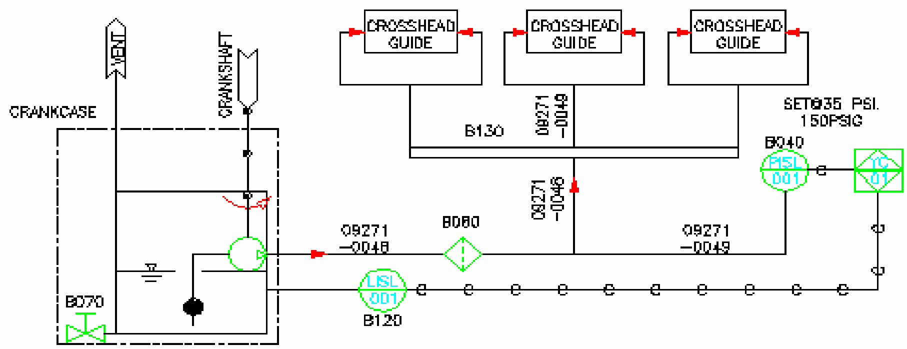
### Compressor lubrication system

The lubrication system only provides lubrication to the crankshaft bearings, crank pins, cross head pin and cross head guides.

A typical lubrication system for a non-lubricated compressor is shown in the following diagram, Fig 4 (following page).

The system is very simple and minimal maintenance is required. Lubrication to the seal carrier (piston rod packing) and piston rings is not required.

Oil consumption depends on the operational cycle of the compressor and the condition of the rod packings. Oil consumption for a non-lubricated compressor is typically 1.5 liters per 500 ~ 1000 operating hours (0.01 ~ 0.02 g/kWh) with good rod packings and up to 3 liters per 500 ~ 1000 operating hours with worn rod packings. This is extremely low compared with lubricated compressors that, at best, consume oil at a rate of 0.5 ~ 1.5 g/kWh.




BILL OF MATERIALS

| ITEM | QTY. | DESCRIPTION | MATERIAL/SPECIFICATION |
|---|---|---|---|
| B040 | 1 | GAUGE SWITCH PRESSURE | MURPHY P/N 20PE-150 |
| B070 | 1 | VALVE BALL | TOYO P/N 5044A -B0DWOG-1/2" |
| B080 | 1 | OIL FILTER | KRAULIMINATOR P/N L1 |
| B120 | 1 | GAUGE SWITCH LEVEL | MURPHY P/N L-971 |
| B130 | 1 | MANIFOLD | IMW P/N 1805-00 |

Fig 4 – Lubrication system for a non-lubricated

The packing assembly on the piston rod is designed to prevent oil from being transferred to the cylinders. Oil wipers are used to scrape any oil from the piston rod as it moves through the packing. There is always some minor oil transfer; however, a large portion of this oil residue will be removed in the scrubber provided for each compressor stage.

Since the piston rods are sealed, gas leakage is limited and the complication of a pressurized crankcase is not necessary. Leak rates through the rod packings are minimal and compare well with rotary shaft seals required for pressurized crankcases. There is the added advantage that with a non-pressurized crankcase, the oil leakage from the oil shaft seal is negligible compared to the oil leakage from a pressurized crankcase gas shaft seal.

For lubricated compressors, oil management is a very crucial part of a maintenance program and, if not properly managed, can result in costly equipment damage

Since the oil transfer to the cylinders is very minute, the scrubbers only need to be drained every 2 ~ 4 weeks, which can be done manually. Oil top up can be every 1000 to 1500 operating hours. The maintenance time required for oil management is therefore minimal compared to oil lubricated compressors and there is no need for costly automatic drains on scrubbers and filters.

The non-lubricated compressor does not require an extensive oil management plan. When synthetic oil is used, oil change intervals can be increased dramatically, making the non-lubricated compressor even more attractive from a maintenance point of view.

For lubricated compressors, oil management is a very crucial part of the maintenance program and, if not properly managed, can result in significant and costly equipment damage. Oil management includes daily or frequent oil filling, draining of scrubbers, maintenance of lubricators (if used), and dealing with waste oil disposal.

When deciding on a lubricated or non-lubricated compressor, all these issues should be carefully considered and the overall operating costs compared.

### Piston rings and rod packing maintenance

Over the last 10 to 15 years, major improvements in piston ring and piston rod packing polymer materials have been made. The most common material used for non-lubricated compressors for the natural gas industry is PTFE material. Some higher temperature applications may require the use of PEEK materials. Many other materials are available for different gas applications.

Piston ring wear rates are dependant on many factors; one of them is operating temperature. When PTFE materials are used, material temperatures should be limited to the range of 130 ~ 145° C; operating above the maximum temperature will shorten the ring life.

Non-lubricated compressors use no oil lubrication for the piston rings, rider ring, and the rod packing. Lubrication is achieved by the ring materials depositing a layer of PTFE material on the cylinder walls. A smooth, polished surface finish results after a very short time of operation.

Expected operating life of non-lubricated rings may be somewhat lower compared to lubricated PTFE rings or cast iron rings. However, with careful selection of cylinder finish and ring material, an average operating life of 6000 to 8000 hours should be obtained before replacement is necessary. The rings on first and second stage pistons tend to last longer (due to lower pressure differentials) and operating times of up to 15,000 hours have been seen. For practical reasons, all rings are usually replaced when the higher stages require ring replacement. This minimizes overall downtime and duplicated labour for teardown and reassembly.

The rod packings generally last longer than the piston rings and 10,000 to 13,000 hours is common. Worn packings will cause some oil carry-over into the gas circuit and gas leakage to the atmosphere. Depending on the importance of these factors, it may be considered advantageous to replace rod packings whenever the compressor is disassembled for piston ring replacement.

A non-lubricated compressor has many advantages, and experience has shown that many years of reliable service can be expected from a well-designed and maintained machine

Cylinder and piston rods are inspected every 10,000 to 12,000 hours for wear. Cylinder life of 24,000 to 27,000 hours is not uncommon for the lower stages; however, a lower life can be expected for the higher stages.

With the right tools and training, the replacement of piston rings is a relatively simple operation. A trained technician should be able to replace all compressor piston rings in 8 to 10 hours. Since the non-lubricated compressors are relatively simple in construction, many technicians are able to service the equipment with minimal training.

One important benefit of PTFE rings is that the compressor does not have to be run in when the rings are replaced (in order for the new rings to properly seat themselves and provide proper sealing).

The compressor can be put back into service immediately, which is not possible with most compressors that use cast iron rings.

A detailed inspection and maintenance program should be worked out for each installation to ensure maximum compressor availability and reduced maintenance costs. The supplier of the compressor is usually best qualified to set up and assist with a program of preventative maintenance.

### Other maintenance requirements

Many non-lubricated compressors run at relatively low operational speeds. Most applications use compressors running at 500 ~ 800 RPM up to a maximum of 1250 RPM. This is required to limit piston velocity and provide an acceptable ring life. These low operational speeds generally result in lower system noise levels as well as reduced maintenance requirements for the following reasons,

- Lower operational vibration
- Reduced compressor valve cycling
- Lower dynamic loading of components

A non-lubricated compressor has many advantages, and experience has shown that many years of reliable service can be expected from a well-designed and maintained machine. In selecting the type of compressor for CNG refuelling the points discussed above should all be considered.

## 7. Side-by-side comparison of Lubricated vs. Non-lubricated compressors

Non-lubricated compressors have many important advantages versus lubricated compressors when used in CNG service, as well as some minor disadvantages that can be managed through improved design and material use. Table 2 [4] shows the advantages and disadvantages of lubricated versus non-lubricated compressors.

| Table 2 [4] | Lubricated | Non-lubricated |
|---|---|---|
| **Advantages** | 1. increased piston ring life<br>2. higher pressure ratios and discharge temperatures allowable<br>3. longer overhaul intervals | 1. low to nil oil contamination of discharge gas<br>2. reduced lubrication requirements and costs<br>3. less filtration required<br>4. less waste oil for disposal<br>5. reduced routine maintenance<br>6. reduced noise levels due to lower speeds |
| **Disadvantages** | 1. oil contamination of discharge gas<br>2. oil deposits in pressure vessels reduce capacity to store gas<br>3. oil contamination of onboard vehicle equipment<br>4. increased vehicle emissions<br>5. higher compressor oil consumption<br>6. increased maintenance requirements on lubrication systems<br>7. increased cost for routine maintenance<br>8. increased cost for disposal of oil and filter elements | 1. increased cooling requirements<br>2. lower maximum discharge temperatures<br>3. reduced valve, piston ring, and rod packing life<br>4. lower pressure ratios required and more stages may be necessary.<br>5. shorter overhaul intervals |

## 8. Summary

There are many different types of compressors but the types that are mainly used in CNG service can be classified as lubricated, low oil, and non-lubricated, according to the method of lubrication employed in the design. We cannot conclude that one type is always better than the other, but for certain applications it is true that there are specific differences when using different types of compressors. Therefore, the key point is in the application, i.e. to select an adequate type of compressor according to the pressure range, flow rate, gas properties, and gas quality requirements.

Based on the above discussion and comparison, the following comments and suggestions can be drawn:

- For the pressure range and flow rate of CNG service, reciprocating piston compressors are the most suitable compressor to serve this application.
- From the CNG station maintenance and operation point of view, it is preferable to use non-lubricated compressors to achieve the highest quality of gas.
- Since the design and manufacturing technology of non-lubricated compressors has been further developed and there are now more advanced self-lubricated materials available, large non-lubricated compressors, up to 250 kW, are feasible for service in the CNG industry.
- Experience has shown that many years of reliable service can be expected from a well-designed and maintained non-lubricated compressor.
- From the CNG station maintenance and operation point of view, using non-lubricated compressors provides more benefits and cost reductions for the owner.
- For any other reason, if a lubricated CNG compressor is selected, it is suggested to install adequate, effective oil separators and multi-stage oil filters, and ensure comprehensive maintenance and replacement procedures are followed to minimize oil carry-over and potential damage to the CNG system and the vehicles that fuel from it.

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*oil-free natural gas*

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