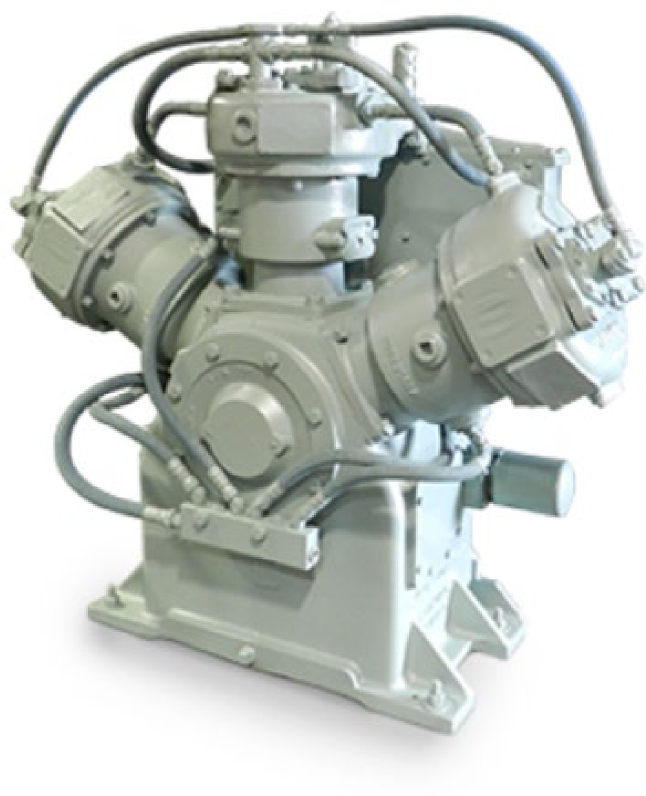
U.S. Department of Transportation

Federal Railroad Administration

Office of Research, Development and Technology
Washington, DC 20590

Oil-free Air Compressor Research for Freight Locomotives



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14. ABSTRACT

The Federal Railroad Administration (FRA) contracted Ensco, Inc. to evaluate oil-free air compressor technology for potential applicability in freight rail locomotives. Oil-free air compressor technology is technically feasible as an alternative to oil-lubricated compressors for freight locomotives. However, additional development of the technology is required to ensure oil-free compressors meet the operational requirements for freight locomotives, and to increase interest in the potential use of oil-free technology by freight railroads.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

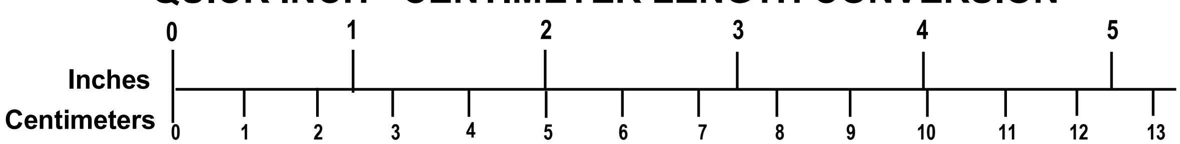
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Contents

Illustrations

Tables

Executive Summary

The Federal Railroad Administration (FRA) contracted Ensco, Inc. to evaluate oil-free air compressor technology for potential applicability in freight rail locomotives. Oil-free air compressor technology is technically feasible as an alternative to oil-lubricated compressors for freight locomotives. However, additional development of the technology is required to ensure oil-free compressors meet the operational requirements for freight locomotives, and to increase interest in the potential use of oil-free technology by freight railroads.

Rail vehicles are equipped with air compressors for operation of the brake systems. Traditional designs for locomotive air compressors are oil-lubricated, reciprocating compressors. Researchers investigated the baseline compressor performance by comparing a range of different existing locomotive air compressor designs.

The research team collected data from industries that use air compressors to determine the current state of technological readiness of oil-free air compressors. The team found that oil-free air compressors:

- tend to have a high upfront cost which may be offset over time by the relative lack of required maintenance
- tend to have shorter operational lifespans than comparably sized, well maintained oil-lubricated units
- tend to experience worse performance in high temperature environments and better performance in low temperature environments than oil-lubricated units
- tend to be noisier during operation
- present a simpler and potentially less expensive method to produce high purity compressed air when compared to an oil-lubricated system

Researchers identified different types of commercially available oil-free air compressors, separated them into different use cases, and compared their technical capabilities. The team concluded that existing oil-free compressors intended for use in a railroad environment do not have a sufficient capacity for freight locomotive use. Oil-free air compressors for stationary applications can generate sufficient capacity, but there is insufficient information available to determine if those designed for stationary applications could operate in a railroad environment.

Researchers compared the capabilities of the oil-free air compressors with several oil-lubricated locomotive air compressors to understand the differences in technical performance. The team then contacted a locomotive air compressor manufacturer and discussed the requirements for air compressor systems and the prospects for development of an oil-free version.[1] Researchers found that while the manufacturer developed oil-free air compressor technology for freight locomotive use, the technology was not developed sufficiently to meet the needs of the freight rail industry.

[1] The discussion did not provide specific information about designs and capabilities for oil-free locomotive compressors.

1. Introduction

The Federal Railroad Administration (FRA) contracted Ensco, Inc. to evaluate oil-free air compressor technology for potential applicability in freight rail locomotives and determine their cost and ability to reduce emissions. The research was conducted between March 2023 and August 2024 at the Transportation Technology Center (TTC) in Pueblo, CO.

1.1 Background

Railroad freight trains use compressed air to activate on-board brake systems. Compressed air provides the force needed to apply and control train brakes. The locomotive air compressor system provides a sufficient supply of compressed air to operate the brakes on every car in a train.

Oil lubricant used in existing air compressors is carbon-based and creates contamination and waste oil. Oil-free air compressor technology represents an opportunity to eliminate the emissions, contamination, and waste products from oil-lubricated compressors.

1.2 Objectives

The objective of this effort was to evaluate the efficacy of oil-free air compressor technology, and to better understand the potential environmental and operational benefits of oil-free compressors for use in locomotives.

1.3 Overall Approach

The research was broken down into two related areas of concern: 1) an evaluation of current oil-free air compressor technology and 2) a comparison of oil-free and oil-lubricated air compressor capabilities.

1.3.1 Technology Evaluation and Assessment

The team identified different types of oil-free air compressors available for locomotives, and compiled technical and economic data on currently available technology both through contact with manufacturers and research of publicly available literature.

1.3.2 Comparison of Oil-free Compressors

Researchers used information generated in the technology evaluation and assessment to compare oil-free compressor technology and oil-lubricated air compressors currently used in locomotives. The comparison included the impacts on air, water, and ground contamination, fuel efficiency, performance in weather extremes, operation and maintenance requirements, life-cycle costs, safety, and applicability and availability of oil-free air compressors for freight rail use.

1.4 Scope

The scope of the study was limited to a literature review of publicly available information regarding air compressor designs or capabilities and information obtained during a discussion with a single railroad air compressor manufacturer.

Researchers did not receive any input from railroads or other locomotive operators regarding either existing locomotive air compressors or the potential use of oil-free air compressors. No testing or physical evaluation of oil-free or oil-lubricated air compressors was conducted under this effort.

1.5 Organization of the Report

Section 2 provides background information about the need for compressed air on freight trains and existing types of oil-lubricated locomotive air compressors.

Section 3 provides an overview of how oil-free air compressors are designed and operate.

Section 4 presents research on available oil-free air compressors and examines their suitability for use in freight locomotives.

Section 5 compares oil-free air compressors with oil-lubricated freight locomotive compressors. This section also discusses attempts to adapt oil-free technology for freight locomotive use.

Section 6 summarizes the report and provides concluding remarks.

2. Air Compressors for Railroad Use

This section discusses conventional oil-lubricated air compressors used in North America rail operations and background information on automatic air brake systems. In North America, freight railroads operate in a wide variety of conditions, ranging from extreme heat and humidity to frigid arctic temperatures to desert areas with blowing sand. The freight rail industry establishes environmental range standards for equipment in a locomotive engine compartment where temperatures may range from -40 degrees Celsius to 140 degrees Celsius in a tunnel [1]. Humidity may range from 40 to 95 percent [1]. These standards also specify endurance for unique conditions such as exposure to salt fog from coastal areas or sand and dust in environments where those particles may become airborne [1]. Locomotive air compressors must be capable of prolonged operation in all these environments.

2.1 Railroad Air Brakes

Freight trains in North America use compressed air for several different purposes. The most important function of compressed air on freight trains is to provide power and control for the train's braking system.

Both locomotives and freight cars are equipped with brakes that are actuated by compressed air. Freight cars receive compressed air via the brake pipe, a pressurized line of both rigid pipes and flexible hoses that runs the entire length of a freight train. Compressed air in the brake pipe is generated by air compressors onboard one or more locomotives. North American freight railroads generally operate with brake pipe pressures at approximately 90 psi [2]. Air reservoirs are storage tanks on each car that are supplied with compressed air via the brake pipe. When the lead locomotive in a train consist applies the brakes, the pressure in the brake pipe on subsequent rail cars decreases. This loss of pressure causes brake valves located on each car to send pressure from a car's air reservoir into a piston, applying brake shoes against the wheels to decelerate the rail car. When the lead locomotive brakes are released, compressed air from the locomotive is fed back into the brake pipe to raise the pressure. This increase in pressure releases the brakes on each car in a train and recharges the air reservoirs, ensuring sufficient air pressure is available to apply the brakes again whenever necessary. In this manner, compressed air generated by locomotive air compressors provides both the power and means of control for brake application on a freight train.

A simplified layout of a train brake system is shown in Figure 1. Note that the Driver's Brake Valve in the figure refers to the train operator's brake control in the locomotive cab.

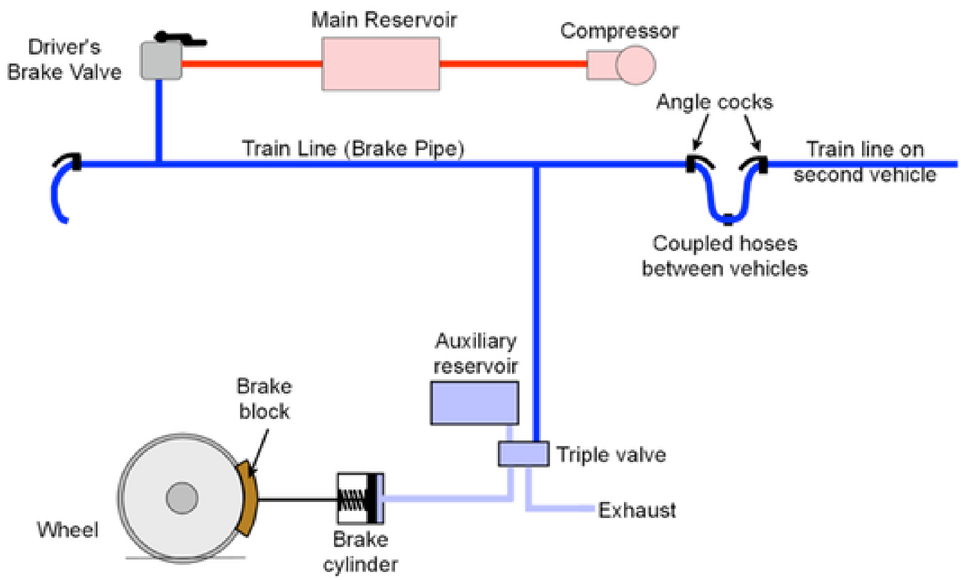

Figure 1. Diagram of Freight Train Air Brake System [2]

2.2 Freight Locomotive Air Compressors

Mainline locomotives must be equipped with air compressors capable of generating a sufficient supply of compressed air to operate the brake system on the entire freight train. The safety critical nature of the air brake system require air compressor designs which are robust, easy to maintain, and well suited to a wide variety of operating environments. While there are many different types of air compressors, most freight locomotives rely on a compressor design which has remained mechanically similar for several decades. Most diesel electric freight locomotives are equipped with an oil-lubricated reciprocating air compressor, which is a positive displacement type of air compressor. In this air compressor design, pistons move back and forth within one or more cylinders. When a piston moves down within a cylinder, air is drawn in. When the piston moves up within a cylinder, the volume of the air is reduced and the pressure increases [3].

Reciprocating air compressors for locomotives often share certain common features, even across different designs and manufacturers. These compressors commonly contain between three and six compression cylinders that are water or air cooled. The pistons in these cylinders are driven by a rotary crankshaft, powered by either an electric motor or a drive shaft connected directly to the locomotive's diesel engine. It is common for locomotive air compressors to have an output pressure of 140 psi, although the output air capacity in cubic feet per minute (CFM) may vary by design. A common style of three cylinder locomotive air compressor is shown in Figure 2.

These types of air compressors are designed to be robust. Oil lubrication on all moving parts both prevents excessive wear and assists in dissipating heat. The heat dissipation provided by lubrication and either air or water cooling enables these types of compressors to operate more effectively in the extreme heat environments that can be encountered in many parts of North America.

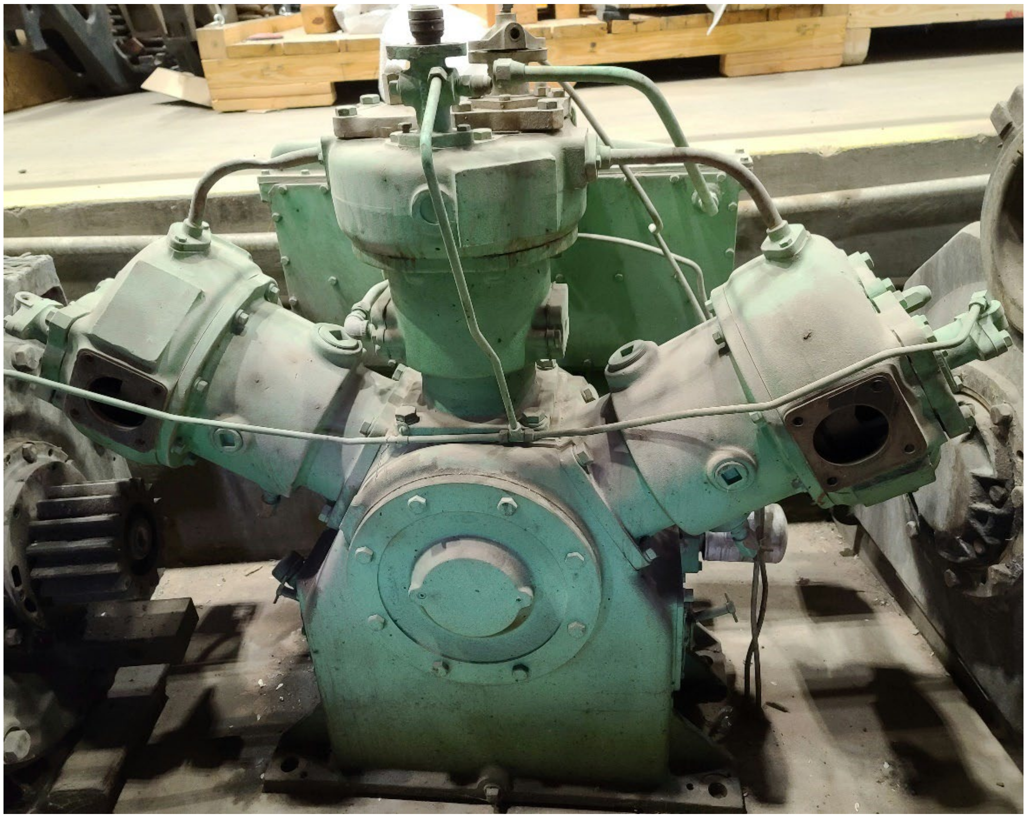

Figure 2. Three Cylinder Locomotive Air Compressor

3. Oil-free Compressor Technology

Oil-free air compressors are designed to produce compressed air in a manner similar to oil-lubricated compressors. The most significant difference between the two compressor types is how the moving parts of the compressor are lubricated. Rather than utilizing an oil coating, an oil-free air compressor minimizes friction by coating moving parts with water or replacing contact surfaces with a flow friction liner, for example, a Teflon coating.

An important benefit of oil-free air compressors is the elimination of oil contamination from the end supply of compressed air. The oil in an oil-lubricated compressor is in contact with the working gas when a volume of air gets compressed. This causes small amounts of oil to become mixed with the end supply of compressed air. In several industries, such as food processing and medical industries, oil contamination presents an unacceptable hazard to the use of compressed air. It is possible to install filtration systems which can remove oil contamination from air compressed with an oil-lubricated compressor, but this adds extra complexity to the braking and air supply systems of rail equipment. Therefore, oil-free air compressors present the opportunity to create an air supply free of oil contamination when the air is first compressed.

3.1 Oil-free Compressor Designs

Much like oil-lubricated air compressors, oil-free air compressors can utilize many different types of compressor technologies, including reciprocating compressors, screw compressors, and scroll compressors. The main differences in design between oil-free and oil-lubricated compressors are the design changes required to allow an oil-free air compressor to operate without oil lubrication. Oil-free compressors do not require oil reservoirs, oil filters, oil pumps, or the associated equipment required to power an oil pump. In addition, oil-free compressors must have moving parts and contact surfaces either lubricated with water or covered with a low friction coating. It is important to note that some air compressors which are considered oil-free actually use oil to lubricate some moving parts, but do not use oil to lubricate components which contact the working gas. These compressors are considered oil-free because there is no oil contamination in the compressed air supply.

In any compressor, as the working gas's pressure is increased, its temperature will increase as well. In an oil-lubricated compressor, the oil will absorb a portion of the heat generated during compression and dissipate it. In an oil-free air compressor, this extra heat will be absorbed by the compressor's components and must be dissipated. As such, it is common for the design of oil-free air compressors to require additional cooling capacity, especially near components in contact with the working gas during the compression process. Even with additional cooling, it is common for oil-free air compressors to struggle in high temperature operating environments.

Oil-free air compressors are commonly used to supply compressed air for many different purposes, from large stationary facility compressors to portable compressors. This wide range of uses combined with different compressor technologies means oil-free compressors are suitable for a wide range of capacities and operating environments.

3.2 Technology Status of Oil-free Compressors

As part of this research effort, the team gathered information regarding the current level of technological readiness of oil-free air compressor technologies in the industries in which they are used and evaluated their applicability for rail application. Companies that manufacture or sell both oil-free and oil-lubricated compressors provide publicly available information about both types of compressors, and provide data on the available air compressor technologies to educate potential customers as to which option would best fit their needs. Therefore, most of the information gathered is generalized and not specific to the railroad environment.

For many applications, oil-free air compressors have a higher upfront cost than conventional oil-lubricated air compressors [4]. However, oil-lubricated compressors have additional operating costs over their lifetimes associated with changing and maintaining oil levels and oil filters. Many oil-free compressors require minimal maintenance throughout their service life which can lead to lower overall costs in some circumstances.

Over time the low friction coatings in the moving parts of oil-free compressors tend to wear and lose effectiveness. As these coatings wear, friction between moving parts increases, which can cause some oil-free compressors to become less efficient. The wear of the low friction coatings in oil-free compressors also tends to occur more quickly than wear in an oil-lubricated compressor where the oil has been well maintained over the compressor's lifetime. This tends to cause oil-free compressors to have a shorter service life than well maintained oil-lubricated units [4].

Air compressors generate heat both through their moving parts and due to the thermodynamics of compressing a working gas. As previously mentioned, in an oil-lubricated compressor, the oil will absorb a portion of this heat and dissipate it as it travels from the compressor's moving parts back to the oil reservoir. Oil-free compressors do not benefit from this method of heat dissipation and tend to require additional cooling to adequately control heat buildup. The tendency to produce more heat during normal operation can also lead to oil-free air compressors increasing the temperature in the surrounding area, particularly if located in an enclosed or poorly ventilated space. If adequate cooling is not provided, oil-free air compressors will not operate as well when exposed to extreme heat. Conversely, while oil-free compressors may struggle to operate as well as oil-lubricated compressors in extreme heat, they can operate more effectively in extreme cold. Oil lubricant becomes more viscous in cold temperatures and requires more energy to be pumped to a compressor's moving parts. The low friction coatings in oil-free compressors are not susceptible to this increase in viscosity at cold temperatures and tend to operate more efficiently in these environments than oil-lubricated units. However, some oil-free air compressors still use oil to lubricate certain moving parts that do not interact with the working gas. These designs would still be subject to problems with increased lubricant viscosity at low temperatures.

Oil lubricant tends to dampen noise generated by the moving parts in an air compressor. Therefore, it is not uncommon for oil-free compressors to be louder than oil-lubricated counter parts [4]. In operating environments where excessive noise cannot be tolerated, oil-free compressors may require sound proofing or isolation.

As mentioned previously, because lubricant in an oil-lubricated compressor will encounter the working gas, it is common for small particles of lubricant to be carried over into the resulting compressed air during the compression process. The amount of contamination can vary significantly depending on variations to the operating state of a compressor, but could be around 3-4 ppm [5]. It is possible for oil contamination to be removed from the compressed air generated by an oil-lubricated compressor by passing compressed air through coalescing filters and activated carbon filters to remove the contaminants. However, the introduction of additional filtration to the compression process adds complexity and increases maintenance cost, in addition to the maintenance required for the compressor's oil. Also, passing compressed air through filters to remove oil contamination requires more power for the compressor, which contributes to increased operating costs over the lifetime of the system. In the event of unanticipated mechanical failures or poor maintenance in this type of filtered, oil-lubricated air compressor, oil contamination in the end compressed air supply can rise to unacceptable levels. If the purity of a compressed air supply is paramount, an oil-free compressor can be a much more suitable alternative to filtering the air supply from an oil-lubricated compressor. Oil-free air compressors do not introduce oil contamination into the air supply, which provides a comparatively simple method of producing compressed air with high purity. Maintenance costs for such an oil-free compressor system would also be significantly lower than a comparable filtered, oil-lubricated system due to the lack of both filter and oil replacements.

4. Oil-free Compressors for Potential Freight Rail Use

In North America, all heavy freight rail locomotives are equipped with various designs of oil-lubricated, reciprocating air compressors that result in oil contamination in the compressed air supply. This contamination is released into the environment whenever compressed air is discharged from a train's air brake system or when air is discharged from any other point in the compressed air system. The total amounts of oil contamination released from brake systems on a freight train or within the railroad industry in general are not well understood and are not addressed by this research effort, nor are the potential environmental effects of the oil contamination. However, possible adoption of oil-free air compressors by the railroad industry presents the opportunity to eliminate the release of oil contaminated air, improving the environmental impact of train operations. In addition, the elimination of oil-lubricated compressors presents the opportunity to reduce or eliminate the generation of waste oil from those compressors. This provides additional environmental benefits and potential economic benefits to locomotive operators, and maintenance costs on replacing and maintaining compressor lubricating oil could be reduced.

4.1 Commercially Available Oil-free Air Compressors

There are no air compressor manufacturers offering oil-free air compressors for freight rail applications in North America even though there are a variety of oil-free air compressors available for use in many other industries. Therefore, researchers investigated oil-free air compressor designs commercially available for other industries to determine their capabilities and assess the current state of the technology.

4.1.1 Oil-free Air Compressors for Transit Rail Use

Several manufacturers of rail transit vehicle components produce oil-free air compressors, including Atlas Copco in North America and Durr Technik in Europe. Much like freight trains, these rail transit vehicles are equipped with air brake systems that require a compressed air supply. The designs of oil-free air compressors for rail transit vehicles can provide insight into the potential use of this technology for freight rail. However, these vehicles are much lighter than freight locomotives and cars and often have more efficient braking systems, such as disc brakes. These vehicles are often articulated units, with one air compressor providing compressed air for multiple rail cars. In a freight train consist the compressors from two or three locomotives must provide compressed air to 100 or more freight cars. Ultimately, this means the oil-free air compressors onboard rail transit vehicles normally have a much lower capacity than those designed for freight locomotive use. An example of a transit vehicle equipped with oil-free compressor technology is shown in Figure 3.

Atlas Copco manufactures a range of oil-free scroll style air compressors. For this research, the team examined the Atlas Copco scroll style oil-free air compressor offered with the highest capacity. The SFR 12-50 two stage compressor has a rated pressure of 145 psi at a displacement capacity of 48.7 CFM (see Figure 4). This scroll style compressor is designed specifically for use in passenger rail vehicles and features elements intended both to increase reliability in a railroad environment and to avoid negatively affecting passenger comfort. This model of air compressor contains an integrated cooling fan which allows operation in a wide range of temperatures and a heavy-duty air filter for operation in dusty environments. The air compressor is also designed to minimize the generation of noise and is equipped with vibration dampeners to minimize the transfer of vibration to and from the unit. The technical details of this compressor are shown in Table 1.

Figure 3. An Example of Transit Vehicles Equipped with Oil-free Compressors

Figure 4. Atlas Copco SFR Oil-free Scroll Compressor [6]

Table 1. Comparison of Oil-free Compressors for Transit Vehicles [6] [7]

Manufacturer	Model	Rated Pressure	Displacement Capacity	Shaft Power	Temperature Range
Atlas Copco	SFR 12-50 2-stage	145 psi	48.7 CFM	12 kW	-40 to 122 F
Durr Technik	MC-1200	145 psi	43.1 CFM	15.8 kW	-40 to 131 F

Durr Technik manufactures several different types of oil-free air compressors for transit vehicles; this report examines the highest capacity compressor offered. The MC-1200 is an oil-free piston style compressor with a rated pressure of 145 psi at a displacement capacity of 43.1 CFM (see Figure 5). This compressor also operates in a wide temperature range and is equipped with a robust case designed to protect the unit from dust and debris. The compressor's case is designed with sound insulation and wire rope vibration dampeners to prevent excessive noise and the transfer of vibrations to and from the rail vehicle. The technical details of this compressor are shown above in Table 1.

Figure 5. Durr Technik MC Oil-free Piston Compressor [7]

The specifications of these transit vehicle compressors are similar in many ways. Both compressors are designed to generate compressed air at 145 psi and have a supply capacity of between 40 and 50 CFM. Both compressors also are designed to operate in similar temperatures, being optimized for both low and high temperature extremes to ensure a high reliability in a wide range of environments. Since both compressors are intended for use in passenger vehicles, they are also both designed to minimize noise and are equipped with vibration dampeners. It is also important to note that while these air compressors have similar capabilities, they operate based on two different types of compressor technologies. The SFR 12-50 is a scroll style compressor, while the MC-1200 is a reciprocating piston style compressor. While not definitive, this indicates a possibility that different styles of oil-free air compressors could have the potential to be scaled up to freight rail use.

4.1.2 Oil-free Air Compressors for Stationary Use

A significant application for oil-free compressors is to provide compressed air for facilities. These stationary air compressors can be designed to use a number of different styles of compression technologies. Oil-free compressors designed for stationary use usually have a larger capacity than compressors designed for use in transit vehicles. This higher capacity offers insight into the applicability of this technology for freight rail use.

Compressors for freight locomotives range in displacement capacity from 170 CFM to 296 CFM. Oil-free air compressors for stationary use have similar capacity to freight locomotive compressors. However, application of these compressors for freight rail use presents a challenge because of the difference in operating environments. Stationary air compressors are often mounted on the ground or attached to a solid structure inside a building. By contrast, the environment inside a locomotive engine compartment is exposed to the elements as well as the heat and vibration generated by the locomotive engine and other equipment. Therefore, stationary air compressors require modification before they can be adapted to the rail environment. However, an examination of their current capabilities can provide useful information.

There are numerous manufacturers of stationary oil-free air compressor systems. Researchers examined two models with similar operating characteristics which are both available in North America from Gardner Denver and Ingersoll Rand.

Gardner Denver manufacturers stationary oil-free air compressors using a variety of technologies, including reciprocating piston, scroll, and screw systems. The EnviroAire TVS55 is a type of stationary, screw style air compressor with a pressure of 150 psi at a displacement capacity of 269 CFM (see Figure 6). This model of compressor is designed with the ability to vary its speed in order to match its compressed air output with different levels of demand. While this air compressor is designed with capabilities similar to a locomotive air compressor, the housing is too large to fit in the engine compartment of most freight locomotives (81.8 inches wide by 52 inches long by 76.7 inches tall). It is also not clear that this type of compressor could be adapted for operation in the railroad environment. The technical details of this compressor are shown in Table 2.

Figure 6. Gardner Denver TVS Stationary Screw Compressor [8]

Table 2. Comparison of Stationary Oil-free Compressors [8] [9]

Manufacturer	Model	Rated Pressure	Displacement Capacity	Input Power
Gardner Denver	EnviroAire TVS55	150 psi	269 CFM	55 kW
Ingersoll Rand	IRN55K-OF	150 psi	275 CFM	55kW

Ingersoll Rand also manufactures a wide range of oil-free air compressors for stationary use. The Nirvana IRN55K-OF is a screw style compressor with an output pressure of 150 psi at a displacement capacity of 275 CFM (see Figure 7). This compressor is very similar to the TVS55 both in operating characteristics and its intended use. The IRN55L-OF is a stationary air compressor designed with variable speed capabilities to match its output with different levels of demand. The housing for this compressor system is 82 inches wide by 52 inches long by 77 inches high, which, like the TVS55, is also too large to fit within the engine compartment of a typical freight locomotive. The technical details of this compressor are shown in Table 2 above.

Figure 7. Ingersoll Rand IRN55K-OF Stationary Screw Compressor [9]

Stationary oil-free air compressors are available in a wide range of capacities and designs, and the compressors examined in this research do not provide a full representation of existing technology. However, the capabilities of these compressors represent an intersection of oil-free designs and traditional locomotive air compressors in terms of capacity. These compressors are good candidates for further evaluation of oil-free technology and comparison with oil-lubricated designs. However, detailed information about operating environments for these compressors was not publicly available, and it is not clear how susceptible these designs are to malfunctions due to harsh operating conditions.

5. Comparison of Oil-free and Oil-lubricated Compressors

This section presents a comparison of oil-free air compressors and oil-lubricated designs, identifying distinctions between the operating capabilities of different types of air compressors. Information is presented regarding the status of oil-free air compressor technology in the freight rail industry.

5.1 Technical Specifications

Although technical information for some air compressors was presented in previous sections of this report, Table 3 shows their specifications along with two selected oil-lubricated locomotive compressors. The power requirements for the oil-lubricated compressors are shown in both horsepower (HP) and kilowatts (kW), as these compressors can be driven from an electric motor or drive shaft connected to a locomotive engine. Table 3 is not intended to be an exhaustive list of either available air compressor models or manufacturers.

Table 3. Comparison of Oil-free and Oil-lubricated Air Compressors [6] [7] [8] [9] [10] [11]

Manufacturer	Model	Oil or Oil-free	Intended Use	Compressor Type	Rated Pressure	Displacement Capacity	Input Power
Gardner Denver	EnviroAire TVS55	Oil-free	Stationary	Screw	150 psi	269 CFM	55 kW
Ingersoll Rand	IRN55K-OF	Oil-free	Stationary	Screw	150 psi	275 CFM	55kW
Atlas Copco	SFR 12-50 2-stage	Oil-free	Transit	Scroll	145 psi	48.7 CFM	12 kW
Durr Technik	MC-1200	Oil-free	Transit	Reciprocating	145 psi	43.1 CFM	15.8 kW
Gardner Denver	WLU	Oil	Freight Rail	Reciprocating	140 psi	170 CFM	48 HP (35 kW)
Wabtec	3CW	Oil	Freight Rail	Reciprocating	140 psi	296 CFM	68 HP (51 kW)

Freight locomotive air compressors are designed to generate compressed air at 140 psi. Table 3 shows that both oil-free air compressors for transit vehicles and stationary oil-free compressors can generate compressed air at similar pressures.

Due to the variation of freight locomotive air compressor designs, the displacement capacity of these compressors also can vary. The WLU and 3CW model compressors were selected for further evaluation because they represent reasonable bounds on the required displacement for currently available locomotive oil-lubricated air compressors. The 170 CFM from the WLU compressor represents the lower end of displacement capacity and the 3CW compressor with 296 CFM represents the upper end. The stationary air compressors shown fall within this air displacement range. However, these systems are not compatible for rail use as currently designed. In addition, the displacement range of oil-free compressors for rail transit vehicles is insufficient for freight rail applications. Even though oil-free air compressor technology can deliver levels of displacement capacity suitable for freight locomotive use, more information is needed to determine if such compressors could be adapted to operate in a railroad environment.

The input power column in Table 3 shows the power which must be provided to the air compressor for regular operation. Lower input power is more desirable for freight rail use as it means the air compressor is consuming less of the limited available power generated by the locomotive engine. Although oil-free air compressors for transit vehicles have lower power requirements than oil-lubricated compressors currently designed for rail applications, the oil-free air compressors for transit applications have significantly lower displacement capacity. However, the stationary oil-free compressors are similar to the oil-lubricated compressors in both rated pressure and displacement capacity. While these stationary oil-free air compressors have input power noticeably higher than the WLU freight rail compressor, their displacement capacities are more like the 3CW freight rail compressor.

These stationary compressors have power requirements approximately eight percent higher than the 3CW compressor. This increase in required power is small but has the potential to result in a significant increase in fuel consumption over the life of a freight locomotive. More research is needed to determine if a rail-compatible compressor system with similar operating characteristics to these stationary oil-free air compressors would result in excessive power consumption over the lifetime of a locomotive.

5.2 Freight Railroads and Oil-free Compressors

Researchers attempted to gauge rail industry interest in adopting oil-free air compressor technology for freight locomotive use. An informal conversation with a North American manufacturer of air compressors for freight rail use yielded unique insight into the current state of oil-free air compressor technology for the North American freight rail industry.

The team learned that the air compressor manufacturer has been investigating potential use of oil-free air compressor technology for freight locomotives for more than a decade. While few specific details regarding this effort were shared, researchers learned that a viable oil-free air compressor for freight locomotive has been designed. In 2018 a small number of these air compressors were built and fitted to diesel electric locomotives on unspecified Class I railroads for field testing. Within six months to a year of testing, these oil-free air compressors were removed and the locomotives reverted to oil-lubricated air compressor units. The manufacturer indicated that the investigation efforts are ongoing.

The team also learned that it is currently possible to create an oil-free air compressor design that can supply the necessary displacement capacity at the required pressure but also be retrofitted to current freight locomotives. Most technical details of this design, including the type of compressor technology used, was not available. However, the manufacturer indicated that this design has a displacement capacity near 180 CFM.

The initial cost of this type of oil-free compressor for rail application could be as much as three times the relative cost of a comparable oil-lubricated air compressor. While maintenance costs for oil-free compressors are perceived to be less than oil-lubricated air compressors, this can be misleading when comparing costs over the full lifetime of a compressor. The first overhaul for an oil-lubricated compressor is usually done after 8-10 years of operation, and the second overhaul is done after roughly 6 additional years of operation. Each overhaul for an oil-lubricated compressor is a fraction of the original unit cost. In comparison, an oil-free air compressor generally requires overhaul between the first 6-8 years of operation, with a second overhaul required after an additional 5-6 years of operation. The cost for each overhaul of an oil-free air compressor is nearly comparable to the original unit cost.

The results of the 2018 oil-free air compressor field testing and specific details about how the compressors performed were not provided to the research team. However, since the railroads retrofitted their locomotives back to oil-lubricated air compressors after a period of 6-12 months of experience, it can be inferred that the railroads had sufficient reasons to revert to oil-lubricated units.

This conversation also indicated that, while railroads are concerned with reducing their environmental impact, the oil contamination from existing air compressor designs is not a significant concern. The environmental impacts of contamination from oil-lubricated compressors in freight rail use has not been studied, and the industry perception is that contamination from air compressors is insignificant compared to the environmental impact from operating the large diesel engines in freight locomotives. It was hypothesized during the discussion with the compressor manufacturer that industry interest in oil-free compression technology might be greater if alternative forms of energy (e.g., electricity and hydrogen) had already eliminated more significant sources of pollution, such as the exhaust and waste oil from diesel engines.

6. Conclusion

Researchers examined the current state of oil-free air compressor technology to determine if they would be suitable for use in freight locomotives. This research included a technological and limited economic evaluation of existing oil-free compressor technology, and identified special considerations for air compressor use in freight rail applications.

The team determined that oil-free air compressors can utilize many different forms of compressor technology, including reciprocating, rotary screw, and scroll designs. The main difference between oil-lubricated variants of these compressors and their oil-free counterparts is that the moving components of oil-free compressors use low friction coatings such as Teflon and/or water lubrication instead of oil based lubricant. Oil-lubricated air compressors generate waste oil and small amounts of oil contamination in the compressed air. Oil-free compressors eliminate oil contamination in the compressed air and can reduce or eliminate the generation of waste oil, depending on whether the oil-free design uses oil to lubricate components that do not come into contact with the working gas.

Manufacturers of oil-free compressors offer a wide variety of designs. However, the only oil-free air compressors currently available for rail use are intended for passenger transit vehicles. These compressors currently do not have the required capacity to serve in a freight rail application. Stationary oil-free air compressor designs may have the required capacity, but no information was found to determine if these designs could withstand the operative environment onboard a freight locomotive.

Discussions with a freight locomotive air compressor manufacturer revealed the existence of a program to develop and test oil-free air compressor technology. Prototype oil-free compressors were developed and field tests were conducted by installing these compressors in freight locomotives. These oil-free air compressors were removed from service by the host railroads after service periods ranging from 6 to 12 months. At the time of these discussions, development of this technology was ongoing.

Researchers found that the current state of oil-free compressor technology has the capability to generate a sufficient supply of compressed air for freight rail use. However, sufficient information does not exist to determine the reliability and robustness of oil-free compressor technology in the railroad environment. The information gathered indicates that oil-free air compressor technology generally struggles to cope with environmental extremes commonly found in the freight rail industry (e.g., high temperatures). The team found it likely that oil-free compressors would not be as cost effective to obtain or operate when compared with existing oil lubricated units. Additional research and development of the technology is necessary to successfully adapt oil-free air compressors for use in freight locomotives.

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Abbreviations and Acronyms

ACRONYM	DEFINITION
CFM	Cubic Feet per Minute
FRA	Federal Railroad Administration
HP	Horsepower
kW	Kilowatt