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Liquid Injection Oil Cooling of Frick® Screw Compressors

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Liquid Injection Oil Cooling of Frick Screw Compressors

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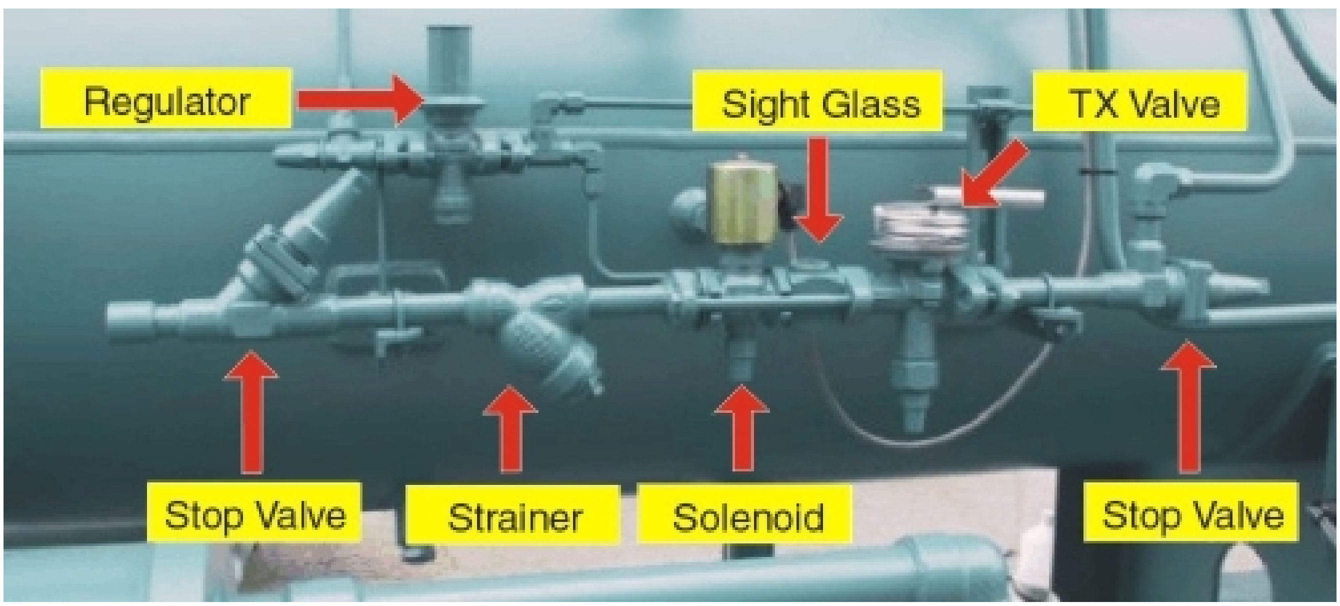
One of the primary advantages of screw compressors over reciprocating compressors is the inherently low discharge temperatures achieved with screws due to oil injection into the gas stream during compression. This allows screws to run at high compression ratios without approaching temperatures which could shorten the life of the oil or materials of construction of the compressor.

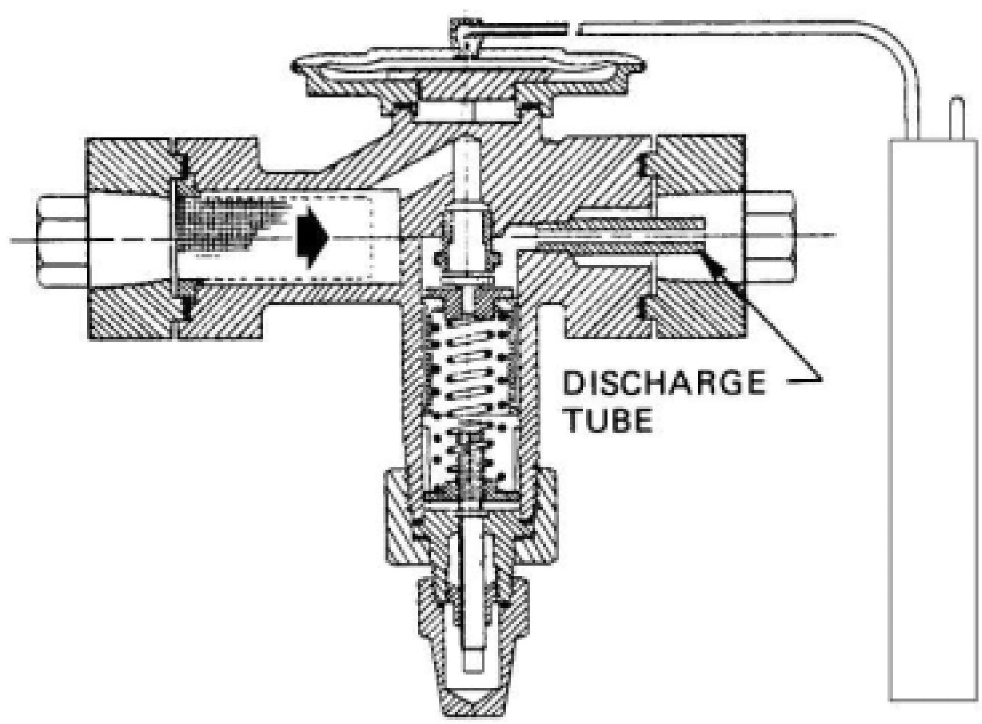
The use of oil injection does however shift a portion of the heat of compression from the discharge gas to the oil circuit, requiring that oil cooling of some type be used to reject the heat.

Water or glycol cooled oil cooling is used to cool the compressor oil in a heat exchanger through contact with water or glycol circulating to a cooling tower. Thermosyphon cooling systems reject the oil heat through a heat exchanger that is evaporating liquid refrigerant and rejecting the generated vapor to the system condenser.



Liquid refrigerant injection systems cool the oil in the compressor package through direct contact of liquid refrigerant with the hot oil and gas being compressed in the screw compressor. In effect, the compressor is treated like an evaporator, with liquid sprayed directly into a trapped pocket in the compressor, part way through compression. The direct contact of the liquid droplets with the hot oil or gas will change the state of the refrigerant from liquid to vapor, absorbing the latent heat of vaporization of the liquid in the process. Because heat transfer is not instant, much of the injected liquid will travel down the discharge line while being mixed with the oil and discharge gas, giving time to vaporize the liquid refrigerant. The oil separator will come to an equilibrium temperature set by the temperature setting of the liquid expansion control device where the discharge gas, the oil, and the vapor from the expansion of the liquid are all in equilibrium at the desired discharge temperature. Any reasonable discharge temperature is achievable by the injection of a larger or smaller quantity of liquid. In general, the discharge temperature is chosen by the desired oil temperature needed for injection of oil to the compressor.

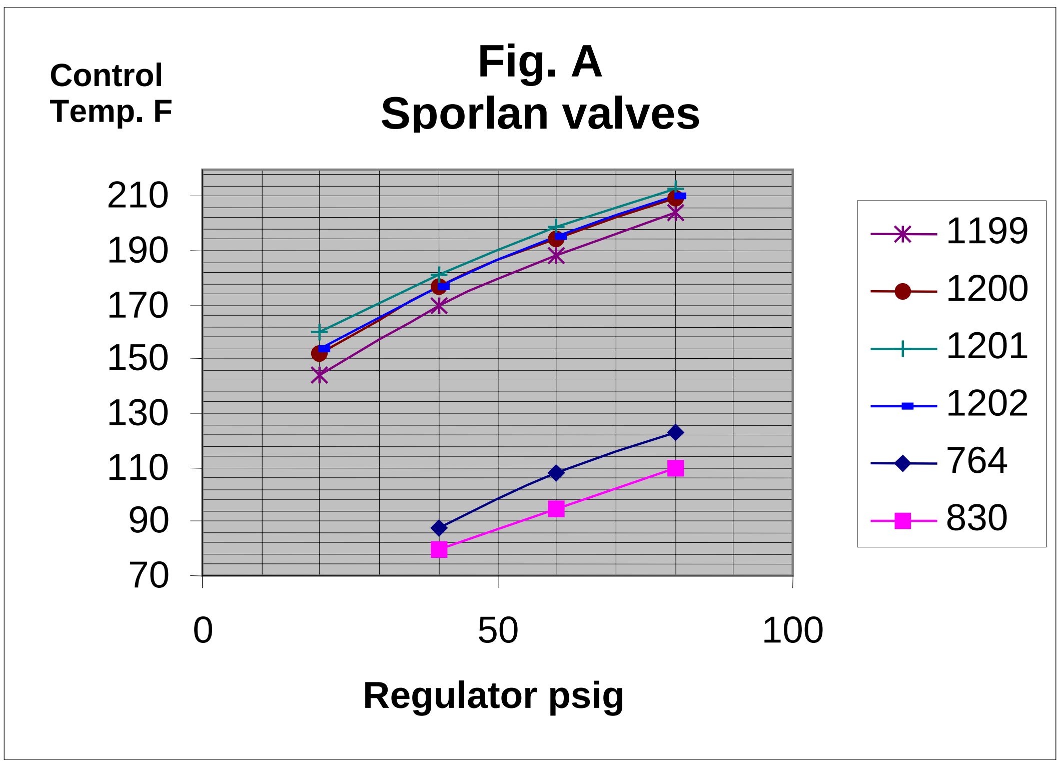
Sporlan thermal expansion valves have been used as the expansion device for liquid injection systems for many years. They are simple, durable and low in cost. They do however bring with them some inherent weaknesses that must be understood in order to have systems that function acceptably.



Cross Section of Sporlan TXV

Conventional expansion valves utilize a refrigerant liquid filled bulb attached to a capillary tube in order to sense the temperature after the evaporator. These systems are generally used to control the amount of expanded liquid based on maintaining a fixed superheat at the evaporator outlet. Screw compressor liquid injection systems are a bit different in that a fixed discharge temperature is normally desired, not a fixed superheat at the measuring point. For this reason the TXV's used for liquid injection generally use an external equalizing line that is set with a pressure regulator to establish a fixed "balance pressure" below the TX valve head, instead of the equalizing pressure being tied to the evaporator pressure as on conventional evaporator TXV's. Adjustment of the desired screw compressor discharge temperature is achieved through the setting of the pressure in the TXV equalizer line.

A particular charge of refrigerant in the capillary bulb will vaporize at the temperature outside the bulb, and establish the saturation pressure of the fluid used inside the bulb, and above the TXV head where it is connected. Sporlan offers a variety of different refrigerant charges in their standard TXV lines. The relationship between the equalizer pressure that is set and the temperature where the valve controls is quite different with the different charges. See figure A.



The valves fall into two basic families based on the refrigerant charge in the TXV bulb. The conventional valves used for many years for liquid injection oil cooling used either the 764 or 830 charge. With a nominal 75 psig pressure set at the equalizer line the control temperature of these valves is in the 110° to 120° degree F range. Because the

Sporlan pressure regulator normally used to establish the equalizer pressure has a maximum adjustment pressure of 80 psig, it is normally impossible to adjust the control temperature on these valves much above 130°F. If a different, (non-Sporlan), regulator is used it is possible to adjust these valves somewhat higher in pressure. However, even at 100 psig the control temperature is only about 140°F and still too low to be optimum on the HFC gases or some NH3 applications.

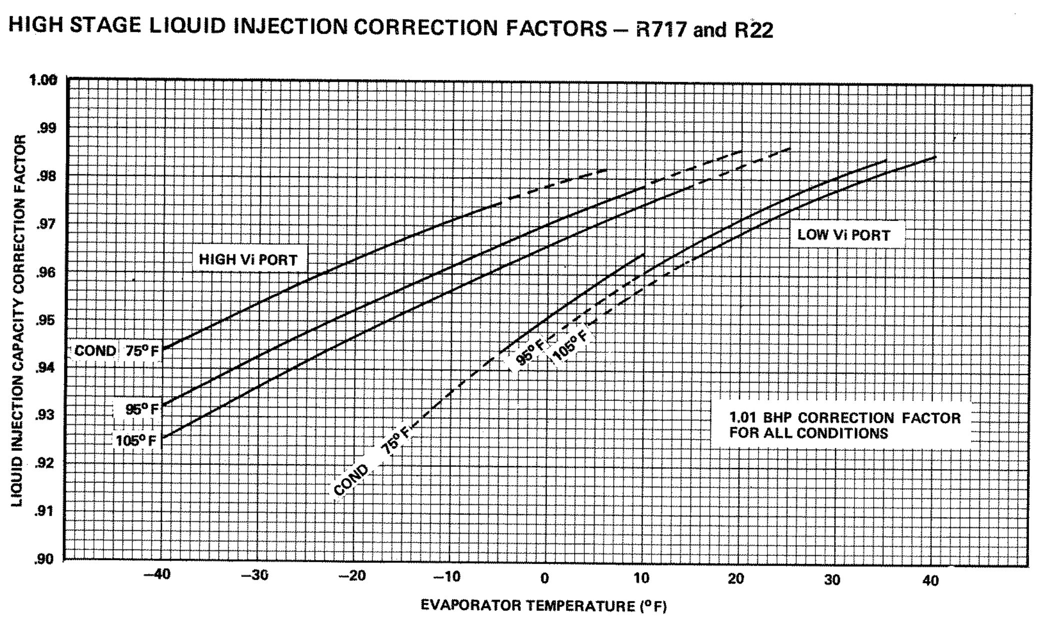
Switching the charge in the bulb to the other family, (1199-1202 charge), makes it possible to adjust the control temperature much higher. For example, looking at the 1200 charge curve, we see that at 75 psig equalizer pressure the control temperature is about 200° F. This unfortunately is too high to be optimum for most screw compressor applications. To establish a control temperature of approximately 165° F, which we consider optimum for HFC applications, the control pressure needs to be set at approximately 30 psig. For reference NH_3 Liquid Injection Systems are normally run from 140° F to 165° F discharge temperature. This lower control pressure is ideal for booster screw packages where now the hot gas source can be taken directly off of the booster discharge pressure without the necessity to run high stage discharge pressure to the TXV just to get 75 psig, for the equalizer line. Most boosters will operate below 75 psig discharge. With the lower pressure requirements of these valves a regulator pressure down to 10 psig is still suitable to adjust the control temperature to about 140° F. Elimination of a small hot gas line in the engine room just to the TXV equalizer line allows elimination of a potential leak source, sometimes running hundreds of feet from wherever the closest high-pressure source is found.

These higher temperature valves cannot be used in all cases. In systems where the suction pressure is higher than 30 psig, (15° F on NH_3), the control temperature cannot be adjusted down below about 170° F because there is no lower pressure in the system to allow adjustment of the equalizer pressure. For higher evaporating temperatures the low temperature charges must be used in the TX valves.

Some people have questioned why compressors were run at nominally 120° F liquid injection temperatures for so many years but now they can be run higher. In fact the main consideration in setting the discharge temperature, (and the oil temperature) is the oil viscosity coming back to the compressor bearings. Because Frick screw compressors use all anti-friction bearings, the oil viscosity requirements are generally lower than sleeve bearing compressors that our industry grew up with. Operating on NH3, or any of the common HFC's and R22, we can achieve more than adequate operating viscosity at a 165° F control temperature using 68 ISO oils, even with the effects of dilution. It is possible to operate Frick screws up to 240° F oil temperature, as long as an oil is chosen with adequate operating viscosity at the higher temperature. Consult the factory for additional information on this issue.

Performance penalties

One of the greatest drawbacks to the use of liquid injection oil cooling is the fact that it can severely impact the overall efficiency of the compressor. Injection of liquid refrigerant into a screw compressor impacts performance in several ways. First, as the liquid comes through the expansion valve, a percentage of the liquid will be changed immediately into vapor. Injection of more vapor into the screw compressor takes more power to compress from the injection point to discharge. In addition, the liquid that is injected will mix with the oil injected into the screw threads. A portion of this liquid will leak from higher-pressure threads to lower pressure threads as it is carried through the compression process. This leakage occurs around the rotor tips, over the end faces of the threads, and through the blowhole between the rotors back into the open suction cavity. Any time liquid leaks from high pressure to low, a portion of the liquid will flash to vapor. If the flash vapor is into a lower pressure trapped thread, power will again be required to compress the vapor from the early threads back to the discharge from the machine. If the flash vapor is generated in the suction cavity, it will take up space that could have been filled by suction charge from the evaporators. This decreases the suction capacity of the compressor, but not the power, as the screw threads are still being filled with the same amount of vapor, just not from the evaporator.



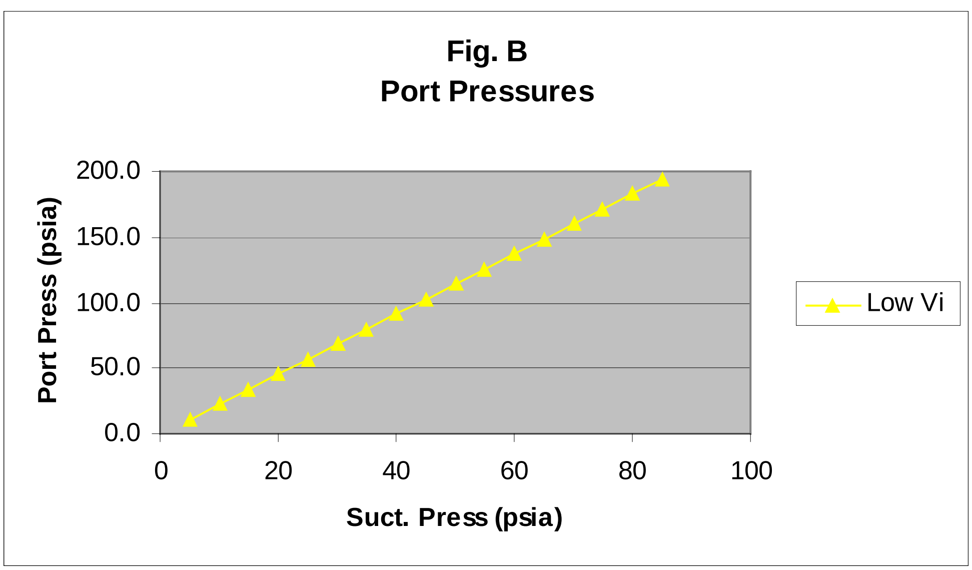
Performance Penalty Factors

Recognizing the source of the power and capacity penalty gives some possibilities to reduce the penalties. The first principal to reduce the performance penalties is to put the liquid into the compression as late as possible. If it comes in late, it has further to leak to suction, and the vapor is generated in later threads, where it does not have to be compressed as far to get to discharge.

The second principal to save power is to inject less liquid. Raising the liquid injection temperature can significantly reduce the quantity of injected liquid. When compressing dense gases with low heat of compression, a 170° F liquid injection temperature can totally avoid a liquid injection penalty at full load. In the case of R-507, R-404a or R-134a at higher suction temperatures, a 170° F injection temperature can avoid a liquid injection penalty down to very low slide valve percentage, as no injection is needed to maintain the desired discharge temperature. On ammonia applications a higher injection temperature will in some cases reduce the performance penalty by 0.5 to 1.0%.

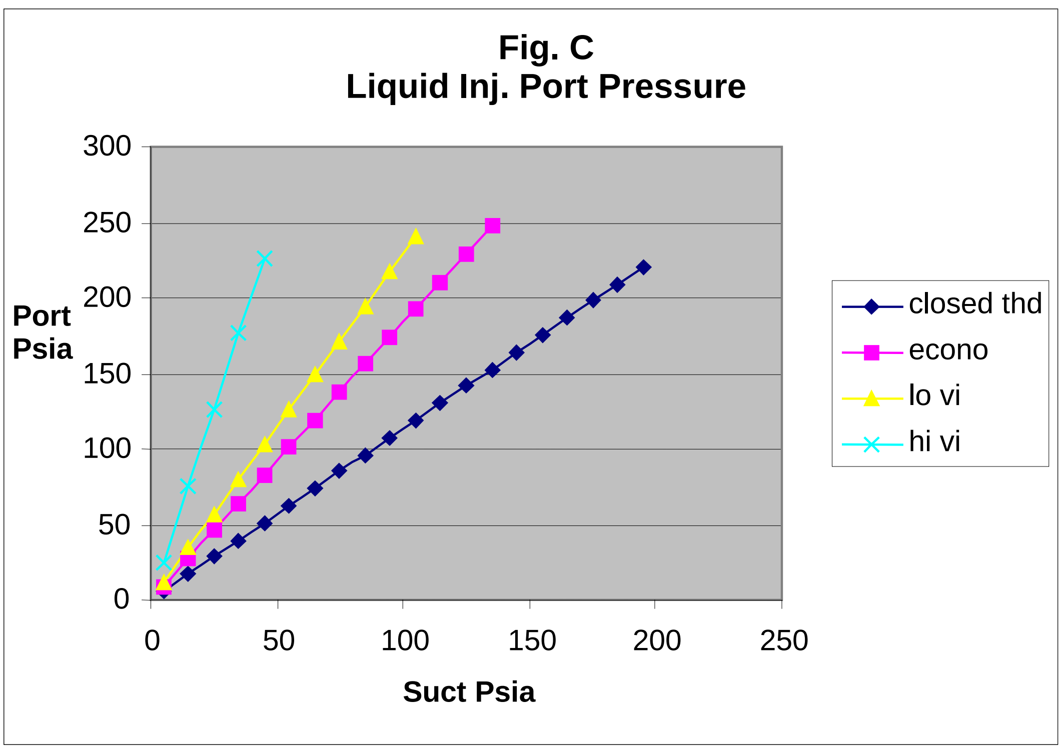
Port pressure

The liquid used for injection generally comes from the high-pressure receiver. A pressure difference is needed to drive liquid into the compressor. In order to minimize power, the liquid should be injected as late as possible, but in order for a Sporlan TXV to work it needs a minimum of about 55 psi pressure difference across it. The liquid injection ports are located in the compressor at fixed positions, which means the pressure measured at any port is a fixed function of suction pressure, see Figure "B" for the standard low vi port, (SL-1 Port).



In order for Frick to apply liquid injection in any application, we consider the highest suction and lowest liquid source pressure to be sure there is 55 psi of pressure difference available across the TXV. For example; at a suction pressure of 40 psia, the SL-1 port pressure is 90 psia, plus the 55 psi needed for the TXV gives a minimum liquid pressure needed of 145 psia; approximately 77° F minimum condensing temperature. If the head pressure on the job falls below 77° F condensing the liquid injection will stop feeding, and the compressor will get too hot. If this job is specified to have a 65° F minimum condensing temperature, (103 psig), the low vi injection port will not work all the time.

For the above reason all Frick compressors are equipped with four different ports, at varying pressures, that can be used for liquid injection. In the above case with a 103 psig minimum condensing temperature, we need 103 minus 55 psig, or 48 psig port pressure maximum to allow liquid to feed. Looking at figure "C" it is evident that even piping the liquid to the economizer port will not give a low enough port pressure to allow successful operation. Piping the liquid to the closed thread port however will allow successful operation even at the 65° F condensing temperature.



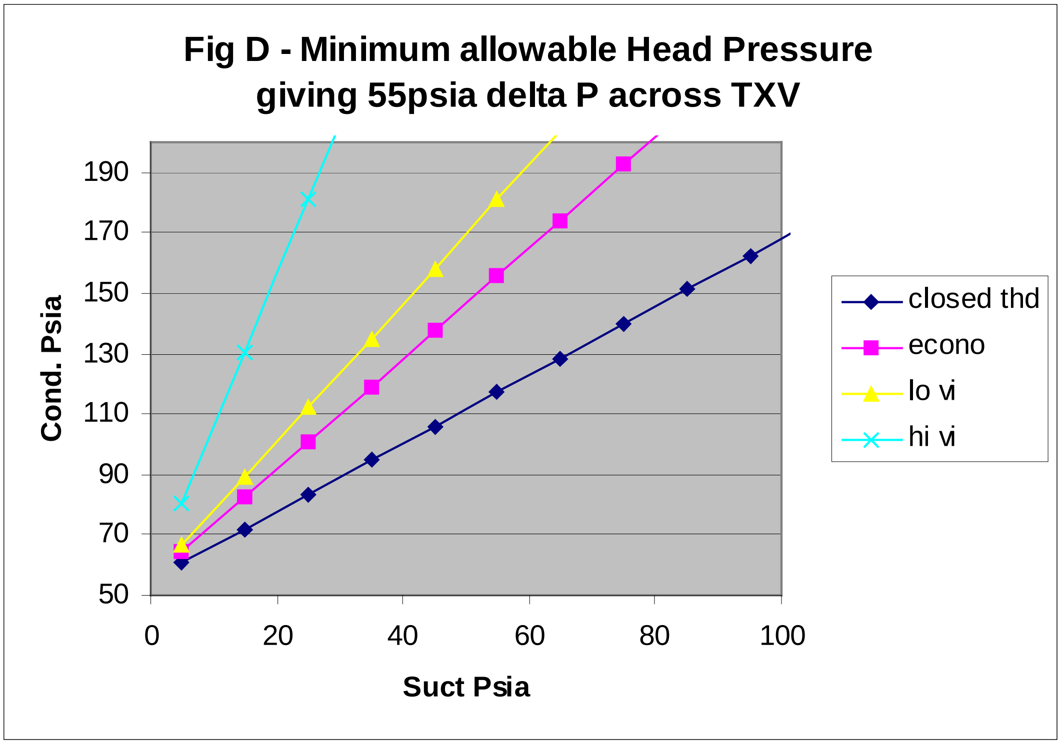
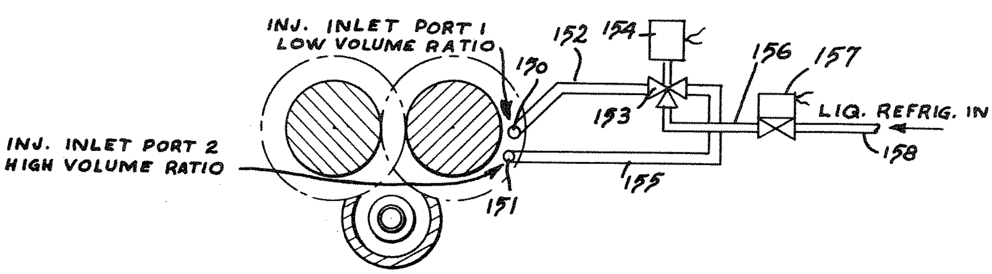


Figure “D” shows minimum allowable head pressure when injecting to any of the available ports using a Sporlan Valve.

Dual Automatic Liquid Injection



The earlier that liquid is injected into the compressor the more performance penalty will be recognized. Using the closed thread port will allow the system to operate at the high suction and low condensing condition; however, if the head pressure returns to normal levels most of the time, say 95° F condensing (181 psig), the higher pressure low Vi injection port will work and minimize the power penalty.

It would waste excessive power to permanently pipe the liquid to the closed thread port just so the system would work at the low head condition, which might only occur a few days of the year. Eliminating the excessive power penalty, while still allowing the low head operation is the purpose of Frick's patented dual port liquid injection system.

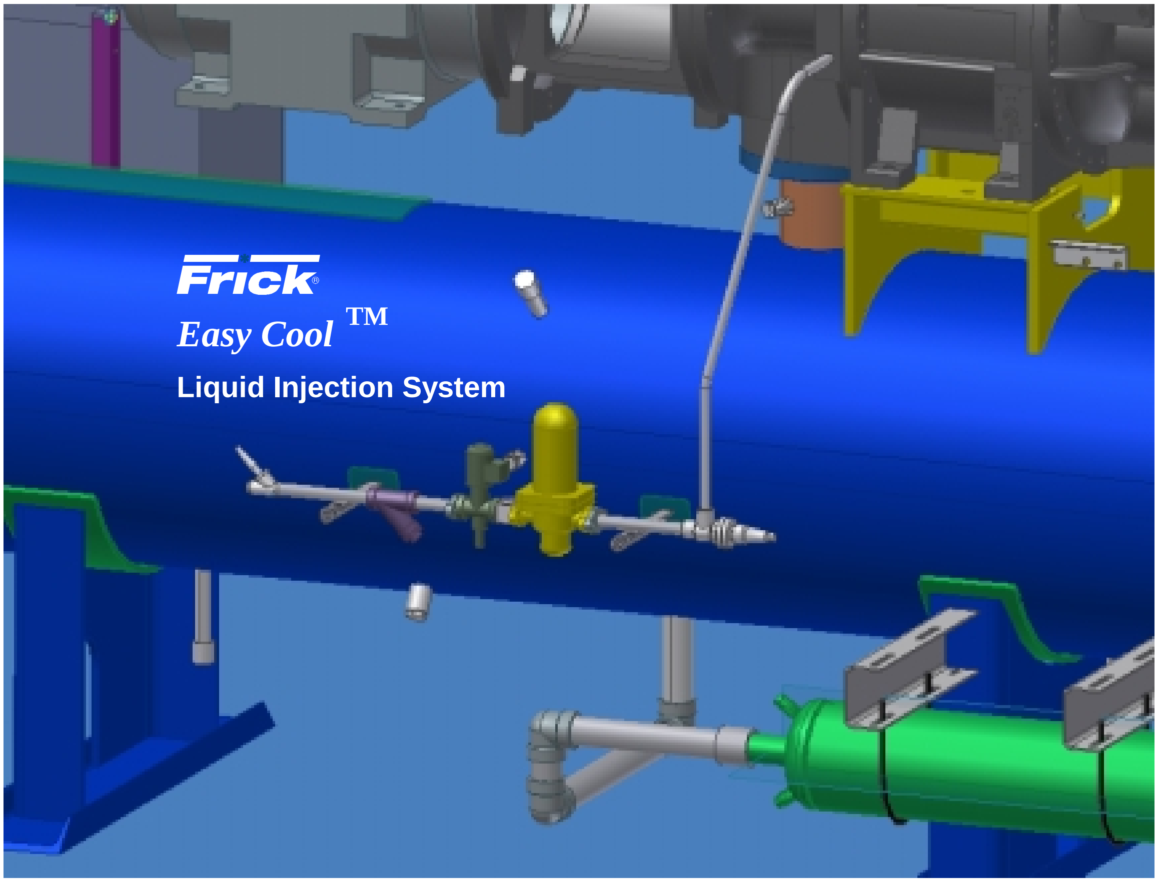
Frick installs dual liquid injection on applications with varying conditions, where energy can be saved by using a lower port pressure when needed, but switching back to a higher port pressure when it will start to feed again. Frick is the only manufacturer to offer a system like this. At the time of the order entry the conditions are reviewed and if energy can be saved with dual port liquid injection we use it as our standard system. Our competitors only pipe to a low port pressure, and the customer pays the excessive power penalty every day of the year that the head pressure is at the higher level.

With dual liquid injection operating, the liquid will be expanded normally through the TXV, but after the TXV enters a full ported spool valve that will divert the liquid to the most efficient liquid injection port that has adequate differential pressure to allow proper feed. The changeover signal is generated in the micro panel based on the volume ratio the compressor is running at any time. This system is saving thousands of horsepower today in plants around the world.

Jordan liquid injection valves are sometimes applied instead of Sporlan TX valves. These are primarily used on very large systems where the valve capacity exceeds the normal Sporlan sizing. They are also sometimes applied in systems where the 55psi differential requirement cannot be met, even with the lowest available compressor port location. The Jordan valve only requires about 20 psi differential pressure instead of 55 psi, and will sometimes allow liquid injection to be successfully applied on applications with very low operating differential pressures.

Easy Cool ™

Frick's latest innovation in liquid injection systems is the new *Easy Cool* ™ liquid injection system. This system replaces the Sporlan TXV and the Jordan valves with a motorized expansion valve, controlled directly out of the Quantum panel. *Easy Cool* ™ eliminates the need for different bulb changes in the TX valves, setting of regulators for temperature setting, and changing of the valve size and discharge tubes in the TX valves for relatively small changes in design load. With *Easy Cool*™ liquid injection, adjustment is completely controlled in the Quantum panel. You can set the control temperature as easily as setting suction temperature. Because the valves have much better regulation than the Sporlan valves, they are usable down to 20 psi differential pressure instead of the 55 psi limit. More information on this new innovation will be forthcoming in the near future, but it is available for delivery now. After reading this paper and understanding some of the complexity of applying liquid injection systems it is clear that it is time for *Easy Cool* ™.



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