

Digital Scroll With Enhanced Vapor Injection Technology

Part 5 (concluding)

by **Arup Majumdar**

*Global Program Director – A/C Modulation
Emerson Climate Technologies Asia Pacific,
Hong Kong*

This is the 5th article in the series explaining the VRF technologies and their increasingly diverse applications. In the first article, I explained how the Copeland Scroll works and the principle behind the operation of the Digital Scroll technology. I concluded the article by explaining some of the key advantages of the Digital Scroll technology. In the second article, I provided a more detailed analysis and comparison between the DC inverter and Digital Scroll. I discussed the challenges of measuring the energy efficiency of VRF systems and talked about the advances that are happening on the Digital Scroll platform – namely, equipping the Digital Scroll compressor with enhanced vapor injection technology.

In the 3rd article, I explained how

the electronic controller works in a VRF system. System design engineers have always been confronted with a very complicated logic to drive the VRF systems due to the various parameters that need to be managed and so in the 3rd article, I explained the control logic in a very simple way. In the 4th article, I talked more about the diverse applications of VRF systems and specially focused on tall buildings and large commercial

spaces. Traditionally, large commercial buildings have been air-conditioned by chillers of various types, but now we have an increasing phenomenon of VRF being applied in such applications. In this concluding article, I am going to discuss the Vapor Injection technology – which has been applied on the Copeland Digital Scroll platform, and explain the technology and the technical advantages versus other technologies.

About the Author

Arup Majumdar has a B. Tech in mechanical engineering from the Indian Institute of Technology, Kanpur and an MBA from the Indian Institute of Management, Ahmedabad. Arup has been instrumental in introducing the Digital Scroll technology to multiple OEMs spread across Asia, Middle East, Europe and North America and establishing this technology as a strong alternate to the incumbent Japanese inverter. He has been awarded the Emerson Technology Award for his contribution to establishing this technology globally. Arup is a regular speaker on modulated technologies in various industrial forums globally and has written several technical articles on this topic. He can be reached at Arup.Majumdar@emerson.com

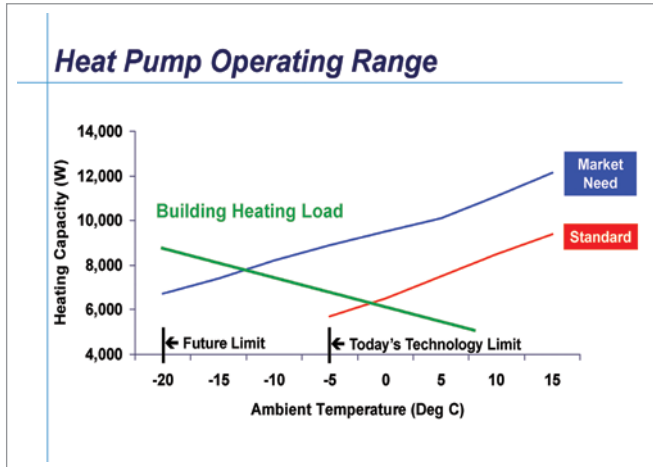


Chart #1: Building heating load and supply versus ambient

Market Needs from HVAC Systems

There are two challenges that have always faced the HVAC engineer:

1. How to improve the EER/COP of the a/c system at the rating point
2. How to provide adequate heating capacity with the best possible efficiency at low ambient conditions

While the first need is pretty much self explanatory, let us explain the second one more.

A standard heat pump is able to provide heating during the winter season and the reason they are popular is due to the fact that they provide reasonable amount of heating capacity at ambient above 0°C. However, the operating efficiency of the heat pump decreases with decreasing ambient and so when the ambient starts dropping, the COP also starts dropping. The other limitation of heat pumps relates to the operating range – most of the heat pumps are unable to deliver adequate heating capacity when the ambient becomes less than 0°C. Chart #1 shows the building heating load – as the ambient becomes lower, the heating need increases. The red line shows the output from a standard heat pump – when the ambient drops, the heating capacity drops and it can also be seen that around 0°C and below, the heat pump output is not adequate. However, if there was a technology that could shift the red line entirely to the blue line above it, then we have an enhanced heat pump that can cover a wide ambient range.

Several countries in Asia (China, Japan and Korea) face ambient temperatures that are sub zero and many regions, specially in the North, face temperatures lower than -5°C. As it is well known, the heating capacity delivered from an air source heat pump dramatically decreases at low ambients and, consequently, the heating output is insufficient to maintain room comfort. Several heating options are available and are in use today but all of these options are not energy efficient and have limitations that are explained as follows:

Central Boiler System: This has been a traditional option for Northern China. A large boiler (coal, oil or natural gas fired)

generates hot water that is piped to individual homes and offices. Radiators are located in the comfort areas and transfer the heat into the rooms. This option has several limitations: low efficiency as heat losses occur in the piping network, expansion of city limits puts pressure on the local authorities to expand the piping network, adding to the environmental pollution due to fuel burning, a fixed heating season that limits flexibility of usage and difficulty in collecting the energy bills by the administration. The room temperature control also is a challenge as the hot water is supplied at a constant temperature irrespective of the ambient.

Community Boiler System: This is very similar in concept to the central boiler – with the boiler being located in the community it is designed to serve. While this arrangement is more flexible as it does not depend on the city administration to provide the heating network, it has the added disadvantage of occupying property in the premises where located. With real estate being at a premium in all places, this is a significant cost burden on the developer/property manager.

Individual Home Heater: These are wall hung unitary systems that are used in each home and are gas fired. These systems have operation flexibility and can be turned on and off as per the users requirement. The disadvantages are that they have to be always fired for stand by and could potentially pose some hazard of CO emission.

Electric Resistance Heat : Many systems in China have resistance strip heaters that are located downstream of the indoor coil. Depending on the ambient temperature, the strip heat turns on or off. While this is the easiest way to provide heat, it is also the most inefficient as the COP of electric heat is 1. Additionally, the outlet air is very dry and is not comfortable to the human occupants.

Inverter overspeed : For inverter driven systems, the variable speed compressors can increase the RPM and deliver added capacity. The maximum added capacity is in the range of 20-30% but it comes at the expense of efficiency. The heating COP is poor at high frequency – a higher compressor frequency is in effect a larger compressor in the system and that pulls down the system COP. In addition, the compressor cannot operate at high frequency for an extended period of time and so providing continuous heat is a challenge.

As can be seen from the above analysis, each heating option has certain merits and demerits but all of them have an overriding problem of delivering heat at low efficiency. The Digital Scroll Heating technology – that uses the enhanced vapor injection principle, addresses the long overdue need of efficient heating solution. This technology is able to deliver the additional heat at low ambient conditions in the most efficient manner and also allows the heat pump to operate at very low ambients (up to -20°C). This has been made possible by the extension of the scroll compressor safe operating envelope and this article will explain the technology in more details.

continued on page 84

continued from page 82

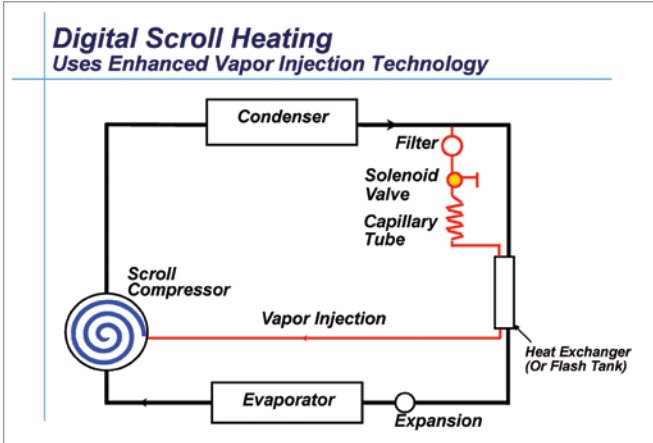


Chart #2: Vapor injection cycle diagram

Enhanced Vapor Injection Technology

The concept of Vapor Injection Technology can be explained with the aid of the Chart #2.

The basic components of the a/c system are shown in this chart – compressor, condenser, expansion valve and evaporator. The vapor injection circuit is shown through the red line. A part of the warm liquid coming out of the condenser is diverted to another heat exchange circuit. When the solenoid valve (as shown in Chart #2) is opened, a part of the liquid is extracted and it passes through an expansion device. This throttling process reduces the pressure and temperature of the refrigerant. This cold liquid is then passed through a heat exchanger – either a plate heat exchanger or a flash tank – and it exchanges heat with the main warm refrigerant flow that is going to the evaporator from the condenser. This exchange of heat cools the main liquid refrigerant and consequently increases the liquid sub-cooling significantly. During this heat exchange process, the scavenged cold liquid turns into vapor. This vapor is injected in the scroll set to cool the scrolls. The main liquid refrigerant (now significantly sub cooled) then passes through the second throttling process and enters the evaporator as the chilled liquid refrigerant.

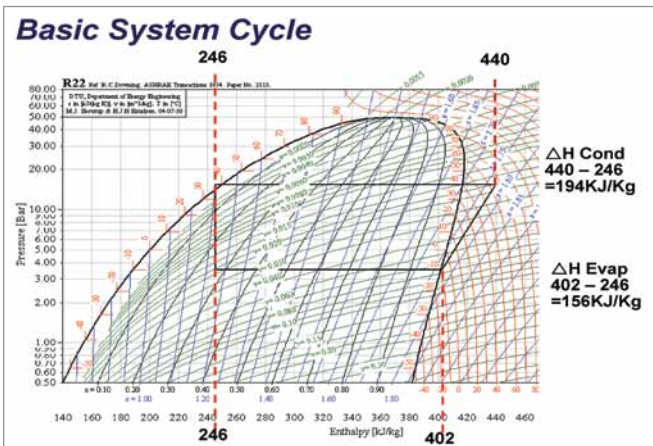


Chart # 4: Basic system cycle

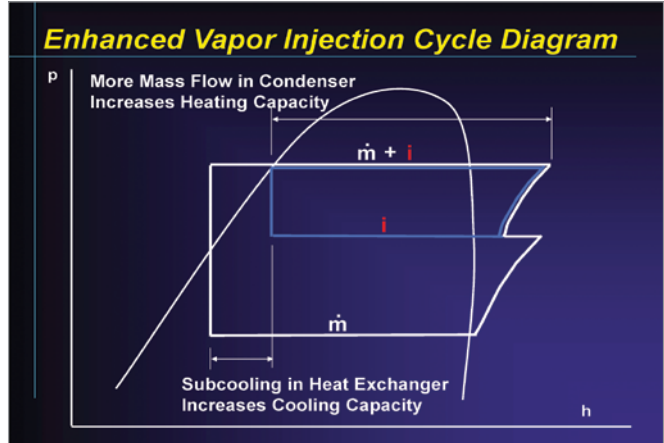


Chart #3: P-H diagram for vapor injection cycle

As can be understood, two major benefits are obtained with the above cycle. First, the cold vapor injected in the scroll set allows the scroll set to get cooled down and enhances the reliability of the compression mechanism. During low ambient operation, the pressure ratios are quite high and discharge line temperature is a challenge. Cooling the scroll set through this vapor injection allows for extended ambient operation. Secondly, the significant sub-cooling gain helps to increase the cooling/heating capacity significantly. As can be seen from the cycle diagram, the mass flow through the evaporator is M while the mass flow through this condenser is $M + I$. The added mass flow through the condenser contributes to the heat capacity gain.

The heat exchanger in the above cycle can be of several types depending on system design – plate heat exchanger, tube in tube exchanger or flash tank. For this discussion, we will focus on the plate heat exchanger now. The vapor injection cycle on a P-H diagram is shown in Chart #3.

The gain derived from vapor injection cycle can be explained with the help of the following P-H diagrams. Chart #4 shows the basic P-H cycle.

As seen from the graph, the condenser heat rejection is

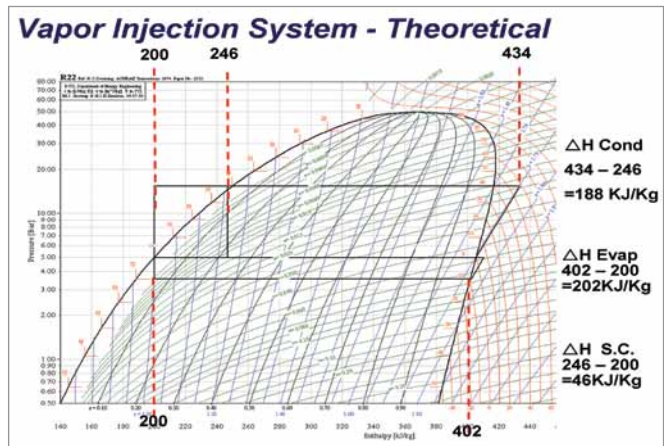


Chart #5: Basic cycle with vapor injection turned ON

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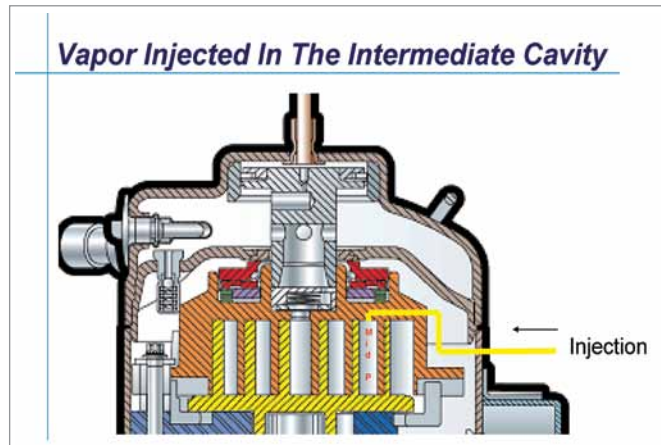


Chart #6: Vapor injection path in the scrolls

194 KJ/Kg while the evaporator heat exchange is 156 KJ/Kg. When the vapor injection cycle is turned ON, the heat exchange happens as shown in Chart #5. The heat exchange in the evaporator has now gone up from 156 KJ/Kg to 202 KJ/kg and the net sub-cooling has increased from 200 KJ/Kg to 246 KJ/kg – a gain of 46 KJ/kg.

Digital Scroll with Vapor Injection Technology

The Digital Scroll technology has been explained in the previous articles and so we will not go into the details here, but the top portion of the compressor is shown in Chart #6 to explain the vapor injection path. As can be seen in the chart, the vapor is injected in the intermediate cavity of the scrolls. Since the intermediate cavity is at a higher pressure, the injection pressure has to be higher – the optimization of the injection pressure is important to ensure adequate heating capacity gain.

The physical hardware that is used inside the compressor to inject the vapor is shown in Chart #7. A flexible pipe is connected from the compressor shell to the fixed top scroll. There is a fitting on the compressor shell and another fitting on the fixed scroll. The flexible pipe is looped inside the compressor so that there is enough flexibility in the tube to

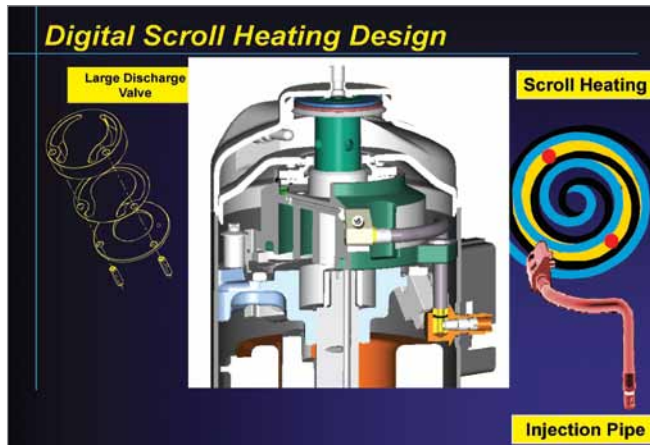


Chart #7: Vapor injection hardware inside Digital Scroll

accommodate the 1.0mm vertical movement of the scroll sets during loading and unloading.

Optimal Injection

Pressure: Various parameters affect the optimal injection pressure – suction pressure, discharge pressure, condenser sub-cooling, vapor injection superheat, and the difference between liquid outlet temperature and saturated injection temperature. The average port pressure is empirically calculated at P_s (suction pressure) x 1.26. The most optimal pressure has to be determined after doing some system testing.

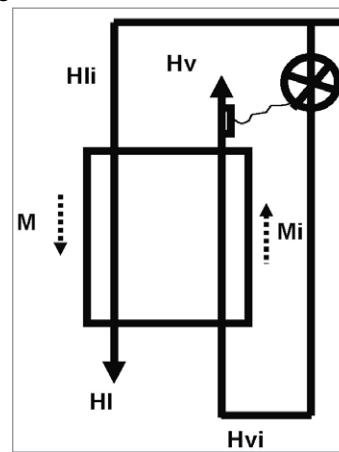


Figure 1: Flow of refrigerant inside secondary HX

Figure 1 shows the theoretical calculation of the Saturated Injection Temperature (SIT).

The energy balance equation is as follows:

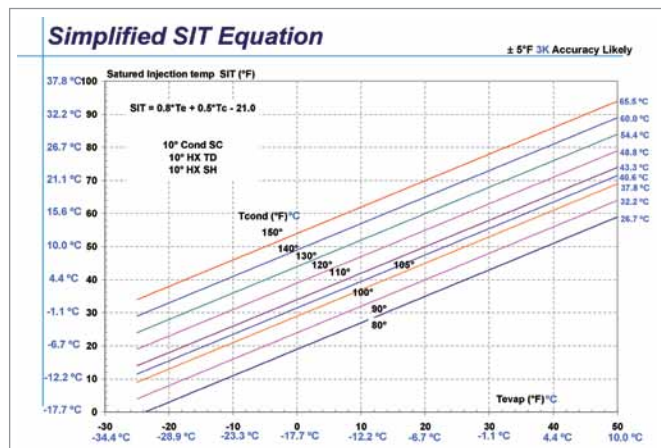


Chart #8: SIT values plotted empirically

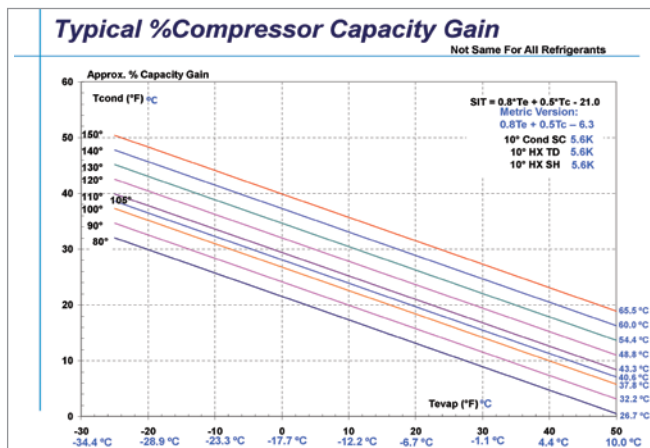


Chart #9: Capacity gain through vapor injection

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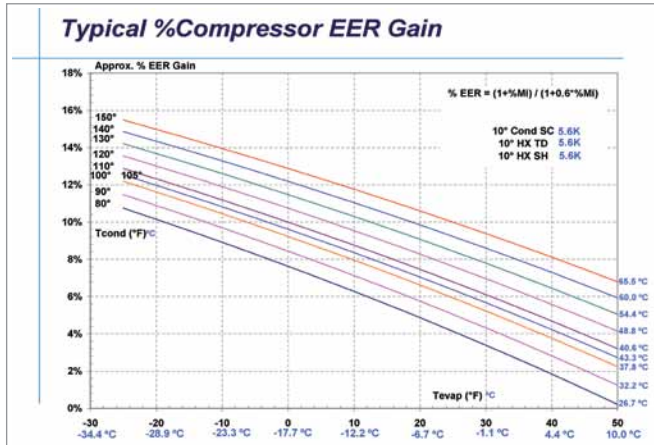


Chart #10: EER gain through vapor injection

$$Me * (Hli - Hlo) = Mi * (Hvo - Hvi)$$

$$Hvi = Hli$$

Above equation is an indicator of the value of the optimal injection temperature that will ensure the energy balance.

It is difficult to model the SIT accurately due to variations in pressure drop and heat transfer losses with practical hardware. Some of the parameters that affect the SIT are: vapor injection line/solenoid, internal compressor passage length and openings, inter stage cooling, connecting pipes between condenser, heat exchanger and evaporator and the heat transfer efficiency.

Tests have been conducted to plot an empirical curve of SIT. This is an empirical line and should only be used as a guide. This curve, however, shows the pattern of this SIT line (See Chart #8).

Compressor Performance Improvement

The vapor injection functions increases the capacity gain and COP of the compressor and also of the system. At the compressor calorimeter, the improvement has been plotted and Chart #9 and Chart #10 show the capacity and COP improvement at various evaporating and condensing temperatures.

A/C System Performance Improvement

Improvement in Cooling COP: In order to get the benefits

Digital Heating Provides +20% Capacity				
Ambient	Injection OFF	Injection ON	Capacity Gain	% Gain
7°C	18,166 W	19,561 W	1,395 W	7.7%
-3°C	13,176 W	14,936 W	1,760 W	13.4%
-7°C	11,808 W	13,817 W	2,009 W	17.0%
-10°C	10,574 W	12,794 W	2,220 W	21.0%
-15°C	8,671 W	11,076 W	2,405 W	27.7%
-20°C	7,388 W	9,906 W	2,518 W	34.1%

Heating Capacity Of 6HP System

Chart #12: Gain in heating capacity & COP through vapor injection

Vapour Injection On Cooling

Baseline System With ZR125

	EVI OFF	EVI ON	EVI Capacity Gain W	Capacity % Gain	COP % Gain
Cooling Capacity W	25495	27287	1792	7.0%	
COP	2.76	2.74			-0.7%

Same System With ZR108

	EVI OFF	EVI ON	EVI Capacity Gain W	Capacity % Gain	COP % Gain
Cooling Capacity W	23497	25435	1938	8.2%	
COP	3.00	2.96			-1.3%

Capacity Maintained And 7% COP Gain With Smaller EVI Compressor

Chart #11: Smaller compressor selection leading to COP gains

of vapor injection on the COP of the system, the compressor has to be sized smaller. The reason is that activating the vapor injection in effect increases the size of the base compressor. Since the heat exchangers are sized for the cooling capacity, a smaller compressor has to be used that delivers a larger capacity (with vapor injection turned ON) and provides the COP benefits. To verify this, a Copeland ZR125K compressor (ARI capacity of 125,000 Btu/Hr at 60 Hz) was used for the base line test. Heating capacity and COP was measured. Subsequently, in the same system, a Copeland ZR108K compressor (ARI capacity of 108,000 Btu/Hr at 60 Hz), which is about 15% smaller sized, was dropped in. Tests were done with vapor injection turned On and Off. Results are shown in Chart #11. As can be seen from the data, the cooling capacity was nearly the same as with the larger compressor and there was a 7% improvement in the system COP.

Improvement in Heating Capacity & COP: A test was done with a 6HP system and the system capacity and COP was measured with both Vapor Injection ON and OFF. The result is shown in the Chart #12. As can be seen, at -10°C ambient, there is 21% improvement in capacity. The system is also able to operate at ambients as low as -20°C.

Summary

Vapor Injection technology is a powerful tool to improve the capacity and COP in a system. It can be used to improve the cooling COP – by using a smaller compressor in the system and get the same cooling capacity and better cooling COP with vapor injection turned ON. It can also be used in heating – to get 20-30% more heating capacity at low ambient operation. The reliability of this technology builds on the base Digital Scroll compressor that has a 99.996% field performance spread over 9 years. The applied cost of vapor injection technology is minimal – it needs a set of solenoid valves, flash tank/heat exchanger and an expansion device. This technology addresses the two needs of the HVAC industry – better cooling COP and increased heating capacity/COP at low ambient operation.