2012

Gas Vapor Injection on Refrigerant Cycle Using Piston Technology

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ABSTRACT

Gas vapor injection on refrigerant cycle is always used with Scroll, Rotary or others compressors technology to improve efficiency of the system at low and high ambient temperatures. Probably this kind of compressor is more adapted than the piston technology owing to their mechanical system.

In this paper, we present the challenge of vapor injection realized on piston technology compressor range non for improving the cooling capacity of the system but to maintain the compressor temperature in conformity without damage the capacity. Indeed, the principal action of gas injection is to refresh the mechanical system according to the ambient temperature for improving the capacity of the system.

In this case of study, the compressor is enclosure on a room without opening at the ambient, thus the temperature of the compressor exceed 130°C, which is the limit temperature of compressor functioning. To reduce the compressor temperature on this refrigerant cycle a gas injection is done from output of condenser to the input of the compressor thanks to the capillary tubes. Therefore, the quantity of gas injection must be sufficient to reduce the temperature, and not damage the capacity of the system. In addition, the piston technology compressor is more sensitive than the others compressors technologies because the compressor valve behavior could be damaged by the liquid phase of the refrigerant. That why the capillary tubes and the density of gas are defined by simulation and the results have been comforted by test.

Thus, thanks to gas injection, we can reduce the temperature of the compressor on the refrigerant system with only a capillary tube.

1. INTRODUCTION

Today, the acoustic level of product is more important point for customer. A lots of solutions could be proposed for improve the acoustic level of the product and one of these solutions is to isolate the main noises sources.
On the refrigerant application the two main noises sources are: the compressor, which represents approximately 50% of global noise, and the ventilation noise. Thus, to reduce the noise level, we propose to isolate the compressors room into the condensing unit without ambient opening in order to reduce the acoustic leakage. This solution could reduce 4dBA (average) of global noise on the refrigerant application. Therefore, closing the compressor at the ambient reduce the convective exchange and increase the temperature of the compressor upper than 130°C, which is

the limit temperature of compressor damage. That why, we are focused on a refrigerant injection technique, not to increase the capacity but to maintain temperature.
The first part of the present paper is devoted to describe the simulation model done in order to estimate the compressor behavior with different mass flow injection. The simulation model is done thanks to a one dimension multi physics tool. The injection of the refrigerant is done from the outlet of the condenser to the input of the compressor like a capillary tube with 3% maximum reduction of the cooling capacity of condensing unit.

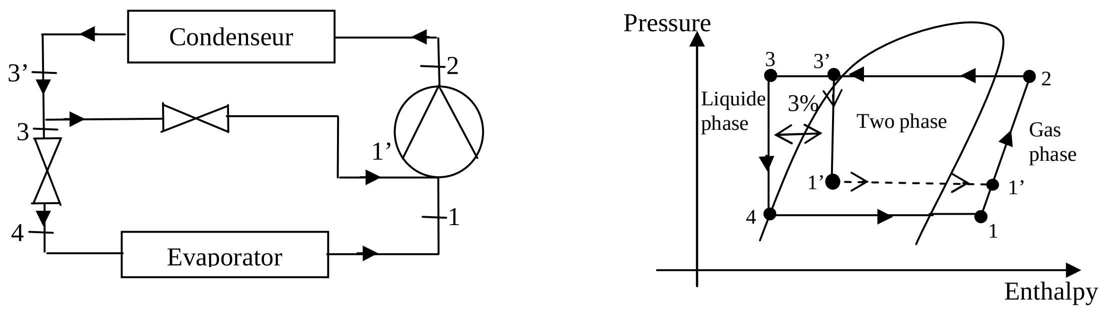


Figure 1: Schematic representation of injection system and P-h diagram representation

The injection simulation model can be able to define the compressor temperature evolution according to the mass flow injection with the thermal convection exchange on the compressor room temperature. The results obtain by the simulation model, will be confirm by laboratory test result on the second part of the paper. Through this paper we will try to present not a liquid or gas injection technique, but a two phase flow refrigerant injection by using a capillary tube.

2. Simulation model of refrigerant injection

The definition of the simulation model of the refrigerant injection requires the knowledge of thermal behavior of compressor on the condensing unit's room with or without opening at the ambient. Thus, the model is composed of two main parts which are: the thermal model of compressor and the condenser, only for extract the flow quantity to inject at the inlet of thermal model of compressor.

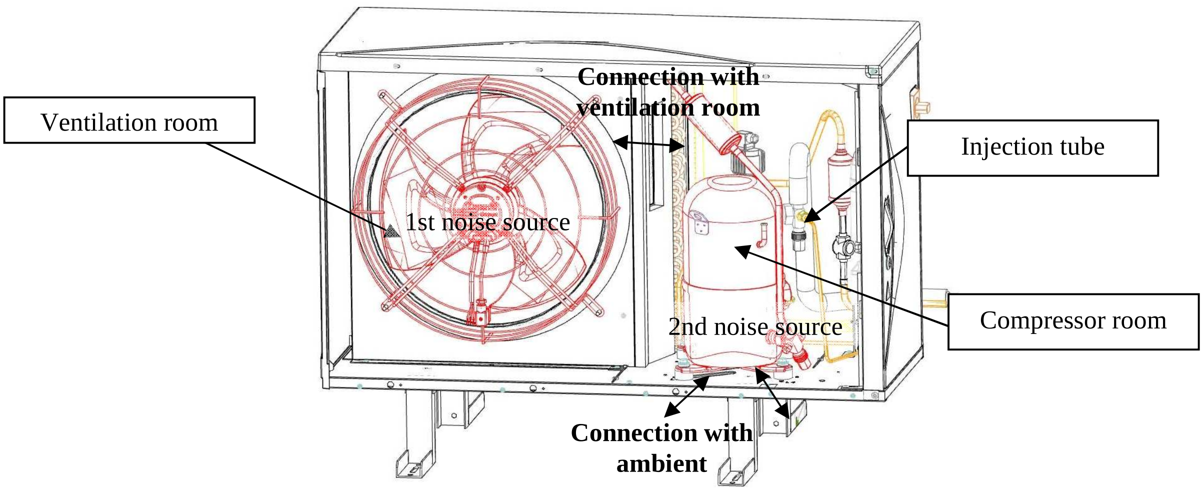


Figure 2: Condensing Unit used for refrigerant injection

On this system, the two openings are composed by the ventilation room and the ambient opening which can create thermal convection into the compressor room and refresh the temperature functioning of compressor. The closure one of this opening could not maintain good thermal exchange, consequently the temperature increase on the compressor room and exceed 130°C into the compressor.

Thus the idea is to refresh the hot part of the system by the cold part easily without use a flash tank, an internal heat exchange or other system, but only by a capillary tube defined by the useful flow quantity needed to refresh the compressor. That why, the simulation model is focused on the thermal flow model of the compressor.

2.1 The thermal model of compressor

The compressor model is composed of thermal exchange element and a flow part in order to evaluate the temperature of the flow through the compressor according to the ambient exchange condition thanks to the one dimension multi physic tool.

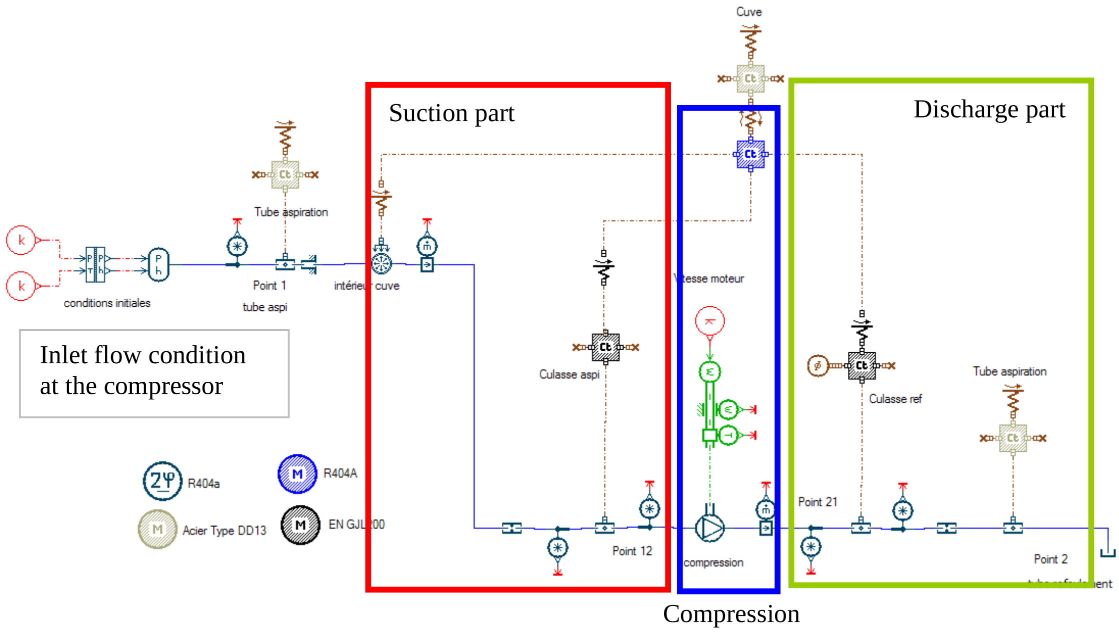


Figure 3: Thermal simulation model of compressor

Thanks to the simulation tools, it is easily to define rapidly the temperature at the different internal point on the compressor according to the ambient condition and the several operating point of compressor. All parameters, like contact surface, mass, pressure of flow, the convective and conduction coefficient are defined for each part of the compressor. The thermal parts of the compressor are principally composed by convective and conduction thermal equation (Fourier laws') like following equations:

Convection :

$$\Phi_{convection} = K.S.\Delta T \qquad (1)$$

Conduction :

$$\Phi_{conduction} = \frac{(K.S)}{e}.\Delta T \qquad (2)$$

Thus, with only the pressure and temperature values of the flow at the inlet of the compressor model, and the characteristics of the compressor like:

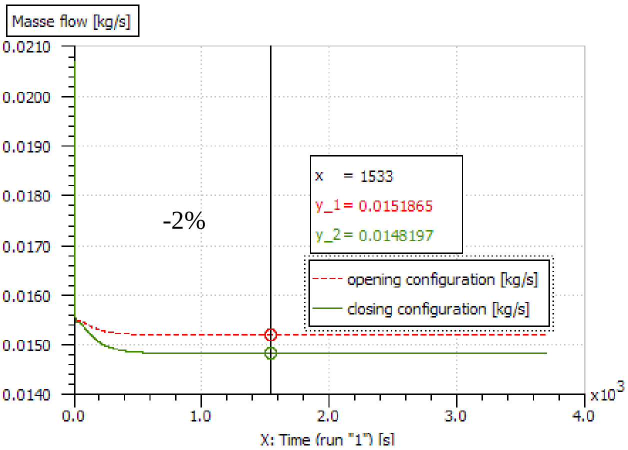
Capacity
Volumetric efficiency
Isentropic efficiency
Mechanical efficiency

It is possible to know the thermal behavior of compressor according to the ambient temperature and the operating point of the compressor. The quantity of mass flow injection can be defined after to know the difference of temperature increasing between the system with or without opening at the ambient.

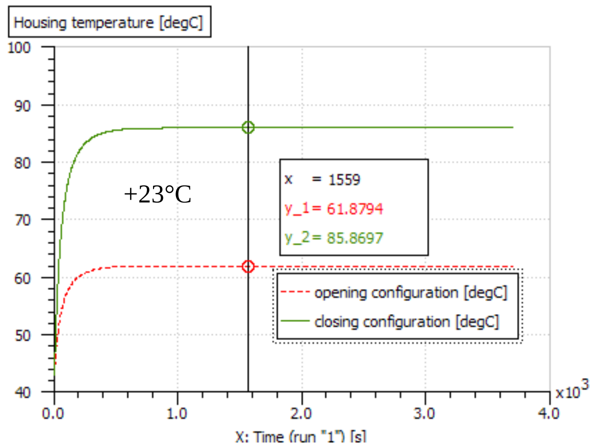
The simulation of the thermal behavior of compressor is done on the following test condition:

- *Flow boundaries conditions at inlet of the compressor*
  - Suction pressure: 2.5Bar
  - Discharge pressure: 23 Bar
  - Operating condition : -25°C/ 50°C
- *Compressor characteristics*
  - Capacity: 74 cc
  - Volumetric efficiency: 0.7
  - Isentropic efficiency : 0.9
  - Mechanical efficiency: 0.75
- *Ambient condition*
  - Temperature of standard compressor room: 60°C
  - Temperature with compressor room closing: 90°C

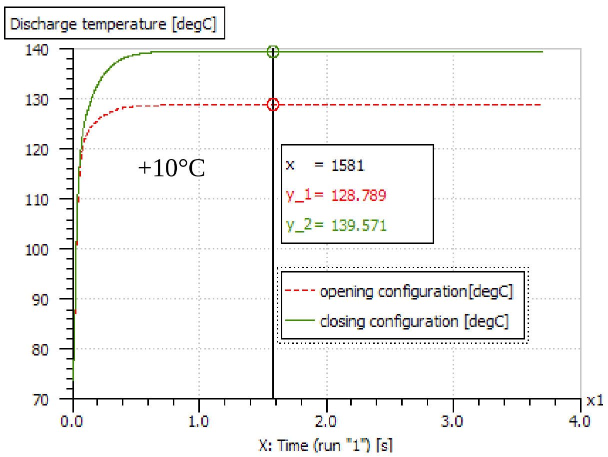
The simulation result is given by the following plots between the opening and closing configuration of the compressors room into the condensing unit platform for operating condition at -25°C/ 50°C



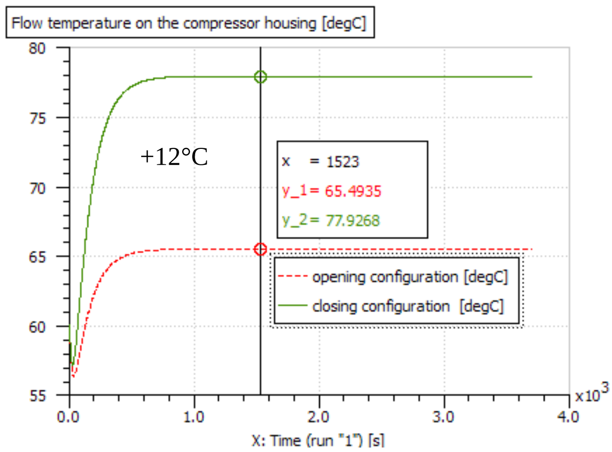
Plot 1: Mass flow through the compressor



Plot 2: Housing temperature of the compressor



Plot 3: Discharge temperature on the compressor



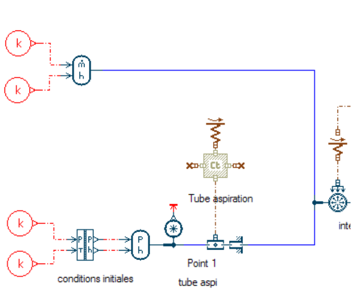
Plot 4: Flow temperature on compressor housing

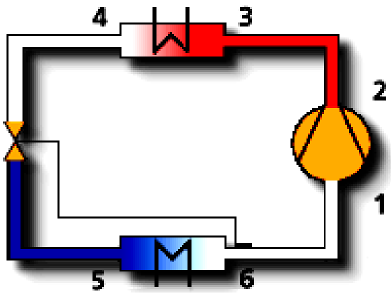
At this operating condition, the closing configurations damage the compressor capacity by decreasing 2% of the mass flow in comparison with the opening configuration. The discharge temperature is upper than 130°C. Therefore the efficiency of the refrigerant cycle decreases according to the compressor mass flow. Thus, it is necessary to

inject cold refrigerant for this Low Back Pressure* (LBP) application in order to reduce the temperature at the compressor and increases the mass flow.
This reduction, of the mass flow through the compressor could be explain by the superheat of the compressor rooms into the condensing unit, and induce the diminution of the density flow which impact the mass flow. According to this first simulation on the thermal behavior of the compressor, it seems to be necessary to inject lower than 2% of the mass flow from the outlet of condenser to the input at the compressor.

2.2 The refrigerant injection on the thermal model of compressor

The injection technique of refrigerant can be classified into two types: liquid refrigerant and vapor refrigerant. In these two types of injection techniques it is necessary to have a flash tank or an internal heat exchange for compressor injection.
In our case of study, it is not possible to use these kinds of materials owing to the surface restriction into the compressor room of the condensing unit. In addition, the more benefit type of refrigerant injection to refresh is the liquid injection. However, the piston compressor technology is more sensitive of the slugging phenomenon on the valve. Thus, the idea is to do an injection not by only gas but in two phase flow thanks to a capillary tube. Indeed, if the refrigerant extraction for injection is done at the saturation point on outlet of the condenser thanks a capillary tube it is possible to obtain a two phase flow refrigerant. In addition, a capillary tube does not need more surfaces and could install easily through on the condensing unit system.
After, to define the technicality of the injection system adopted, it is possible to modify the thermal model simulation of the compressor in adding only the enthalpy and the ratio of mass flow injection at compressor inlet.





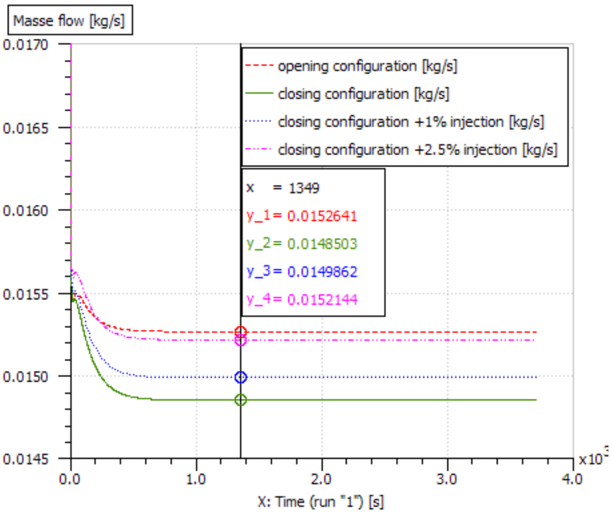
	p	t	v	h	s	x
Point	bar	°C	dm³/kg	kJ/kg	kJ/kgK	--
1	2.47	-18.00	81.17	358.46	1.6468	
2s	22.96	66.14	8.89	404.94	1.6468	
2	22.96	79.88	9.94	422.70	1.6981	
3	22.96	79.88	9.94	422.69	1.6981	
3'	22.96	50.00	7.26	380.62	1.5733	
3"4'm	22.92	49.78	4.18	328.58	1.4131	
4'	22.88	49.56	1.11	276.54	1.2530	
4	22.88	49.56	1.11	276.54	1.2530	
5	2.55	-24.45	45.10	276.54	1.3157	0.590
56"m	2.51	-24.72	61.64	314.50	1.4694	
6"	2.47	-25.00	78.18	352.47	1.6230	
6	2.47	-18.00	81.17	358.46	1.6468	

Figure 4: Injection model and thermodynamics properties

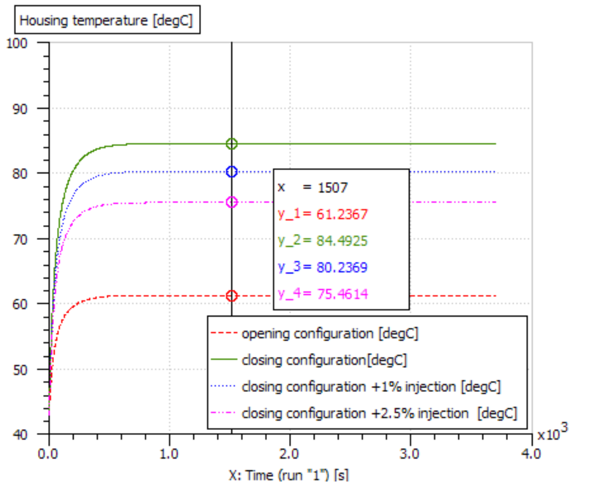
According to the first simulation, on the thermal behavior characterization of the compressor, we notice that the closing room, damage the mass flow through the compressor at 2% in comparison with the opening configuration. Thus, the simulation of the injection model is done on the following tests conditions:

- *Flow boundaries condition at inlet of the compressor (see thermal model of compressor)*
- *Compressor characteristics (see thermal model of compressor)*
- *Ambient condition(see thermal model of compressor)*
- *Mass flow injection*
  - Enthalpy: 276 kJ/kg
  - Mass flow injection n°1: 0.00015 kg/s (1% according to the standard), with ambient temperature at 90°C
  - Mass flow injection n°2: 0.0004 kg/s (2% according to the standard), with ambient temperature at 90°C

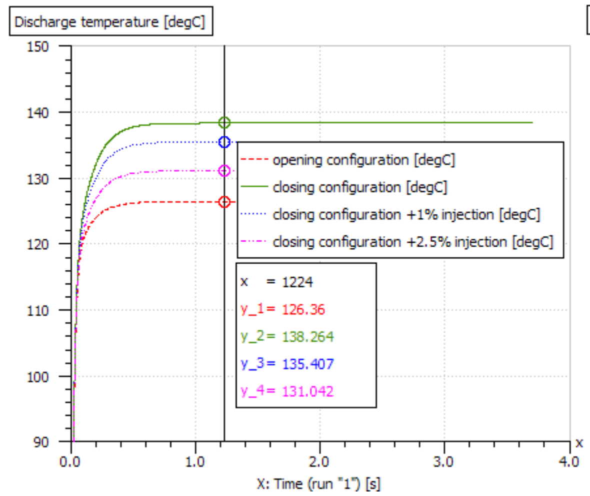
The simulation result of refrigerant injection is given by the following plots between the different quantities of mass flow injections according to the closing configuration and -25°C/ 50°C operating condition



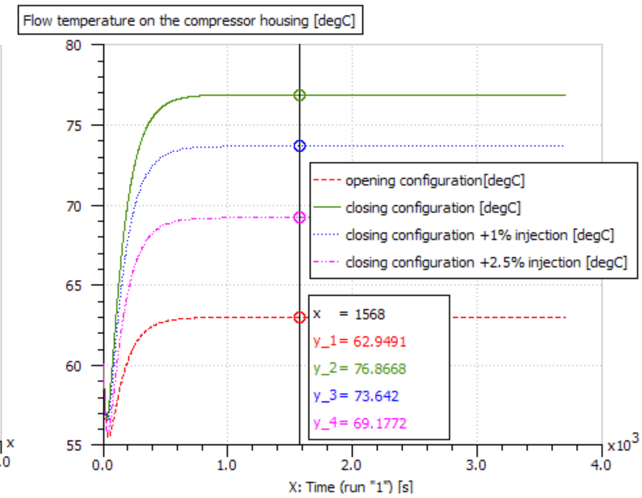
Plot 5: Mass flow through the compressor



Plot 6: Housing temperature of the compressor



Plot 7: discharge temperature on the compressor



Plot 8: Flow temperature on compressor housing

The simulation of two phase flow refrigerant injection has been done according to 1% and 2% of mass flow in order to estimate the thermal behavior of compressor according to the injection quantity define by the thermal simulation of compressor. The result of the simulation bring out that for each percentages of injection, it is possible to reduce the discharge temperature of 3°C. In this case of study, and according to the simulation results, the useful mass flow injection for this LBP application seems to be 2%. Indeed, with 2% of injection, the mass flows through the compressor seem to be alike to the opening configuration, and the temperature of compressor decrease approximately of 10°C.

In spite of the sufficient injection of mass flow, the temperature of housing and the flow temperature on the compressor, is not alike to the opening configuration, these differences could be explained by the static temperature condition put at the ambience on the simulation model. Thus, this static ambient temperature leads to reheat the housing temperature and compressor inlet flow. Therefore, the simulation model can not give the reality of the thermal behavior but can estimate keys parameter before the test. Indeed, the thermal model of compressor is based on hypothesis like the ambient temperature of the compressor room, which can change according to thermal mass on the ambience room. That why, the housing temperature of compressor simulation model present 6°C of different with the opening configuration in spite of 2% of injection.

After the simulation result, laboratory test will be presented at the following part of the paper.

3. VALIDATION BY LABORATORY TEST

The validation of thermal behavior on compressor according to the quantity mass flow injection defined from simulation model is done by the laboratory tests on the condensing unit application. The test is useful to validate the injection with capillary tube. Indeed, knowing that the liquid phase of refrigerant is bad for piston technology, but more benefit than gas injection, we decided to test the injection of two phase of the refrigerant. The goal of refrigerant injection is to increase the density in order to improve the thermal behavior. Therefore, in this case of study, the injection can be applied only for LBP application owing to lower density and higher temperature.

3.1 Tests results and platform definition

The injection is done thanks to the mass flow on the refrigerant circuit, in other word there is no adding flow on the circuit. That why, it is not possible to extract more than 3 or 4% of the mass flow in order to not damage the cooling capacity on the refrigerant circuit.

In order to not damage the compressor, the tests start not by a capillary tube but by a valve system linking the outlet of condenser to the inlet of compressor. Thus, the valve opening can be use to define the characteristic of capillary tube. Indeed, it is necessary to validate the 2% of mass flow injection extract by the simulation before using capillary tube defines by simulation results.

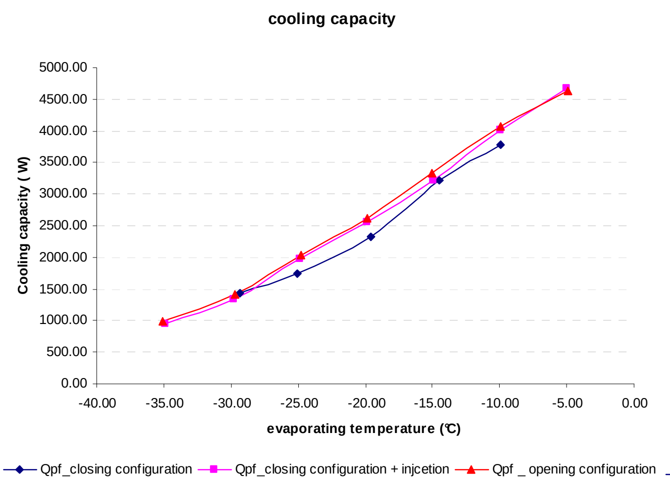
The definition of capillary is done according to the singularity pressure losses by the valve system and the linear pressure losses according to the following equation:

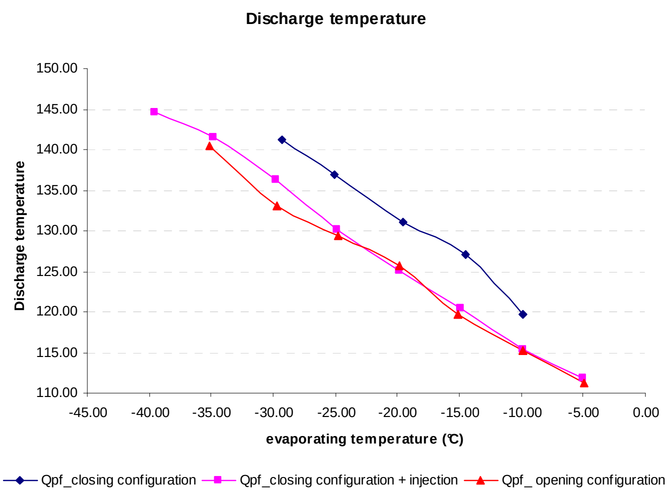
$$\Delta P_{\sin gularity} = \zeta \frac{1}{2} \cdot \rho \cdot v^2 \qquad (3)$$

$$\Delta P_{linearity} = \lambda \frac{1}{2} \cdot \frac{l \cdot v^2}{d} \qquad (4)$$

$$if\ \ consider\ \ same\ velocity:$$

$$l_{capilarity} = \frac{\zeta}{\lambda} \cdot \rho \cdot d \qquad (5)$$





Plot 9: Cooling capacity and discharge temperature evolution

The test is done for all LBP evaporating temperature range from -35°C to -5°C. The opening valve has been adjusted one time, then it was replacing by the capillary tube corresponding of the equivalent of the singularity pressure losses. The ratio of cooling capacity between the opening and closing configuration is 1.2% by test.

The comparison between test and simulation results is done on the ratio of mass flow injected on the compressor. The test result can conclude the thermal model of compressor which defined 2% of mass flow while the test brings out 1.2%. The others temperatures, like discharge and housing were compared with the simulation results, and as predicted on the simulation results, there is only the housing temperature present differences.

4. CONCLUSIONS

Operating compressors at high compression ratios or high ambient temperature can result in excessively high discharge temperature, which can chemically degrade refrigerant oil and lead to mechanical and motor failure. Therefore, employing refrigerant injection is a good option for high pressure ratio compressor, or a high ambient temperature. The goal of the refrigerant injection is to improve the density of refrigerant on the compressor in order to reduce the compressor thermal behavior.

Two phase flow injection by capillary tube can be possible but only on the LBP application owing to the low mass flow. Indeed for higher mass flow, it will be necessary to have a controller to inject the just necessity to refresh in order to not damage the capacity.

NOMENCLATURE

K	heat coefficient	($W.m^{-2}.K$)	ΔP	Pressure losses	(MPa)
S	total surface of exchange	(m^2)	d	diameter	(m)
e	distance	(m)	ς	coefficient of pressure losses	(-)
θ	heat flux	(W)	λ	coefficient of pressure losses	(-)
ρ	density	(kg/m3)			
v	velocity	(m/s)			
l	length	(m)			

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