Purdue University
Purdue e-Pubs

International Compressor Engineering Conference

School of Mechanical Engineering

2014

Efficiency Improvement of Rotary Compressor by Improving the Discharge path through Simulation

Siva Rama Krishna Bolloju
Tecumseh Products India Private Limited, India, b.sivaramakrishna@tecumseh.com

Vamsi Tiruveedhula
Tecumseh Products India Private Limited, India, t.vamsikrishna@tecumseh.com

Naveen Munnangi
Tecumseh Products India Private Limited, India, naveen.reddy@tecumseh.com

Koteswara Rao Vaddadi
Tecumseh Products India Private Limited, India, Koteswararao.Vaddadi@tecumseh.com

Pratap Reddy M
Tecumseh Products India Private Limited, India, Mpratap.Reddy@tecumseh.com

Efficiency Improvement of Rotary Compressor by Improving the Discharge Path through simulation

Siva Rama Krishna Bolloju[1]*, Vamsi Tiruveedhula[2], Naveen Munnangi[3], Koteswara Rao Vaddadi[4], Prathap Reddy M[5]

Tecumseh Products India Private Limited,
Balanagar Township, Andhra Pradesh, 500037
INDIA

+91-40-30116968, b.sivaramakrishna@tecumseh.com

ABSTRACT

To help raise consumer awareness on saving energy and create more energy efficient appliances, the government is upgrading the requirements of star rating of air conditioners. The enhanced star rating in air conditioners will significantly support the energy conservation and protect the environment by reducing greenhouse gas emissions in the fight against climate change. The increasing demand for star rated air-conditioners is compelling the compressor designers to develop & optimize more energy-efficient components. This paper deals with discharge port optimization in a rotary compressor, which is heart of an air-conditioner.

The existing discharge port is studied & analyzed for the performance in the aspect of its capacity, EER, mass flow rate, over pressure power, area of PV diagram, motor power, valve functioning & stability. The port is redesigned to obtain improved performance, by analyzing the compressor performance parameters. Analysis is performed to study the stresses on the discharge valve and valve lift. Computational fluid dynamics is used to observe the flow behavior & pressure phenomenon in the rotary compressor, since the compressor shell accumulates the discharge gas pressure. The results are validated with the test and improved EER is observed.

1. INTRODUCTION

1.1. Objective

To study the effect of change of port size variation and gas path change through the stator on various performance parameters of compressor. The performance parameters are compared against the calorimeter testing. The performance parameters include Capacity, EER, Motor Input power, Over Pressure, Area of PV Diagram, Valve Displacements & Velocities, and Stresses on Discharge Valve Leaf.

CFD analysis is performed to study the pressure loss across the discharge path, which will subsequently effect the performance parameters of compressor.

1.2. Theoretical approach

Discharge path for the current study is split among the mechanical kit and the path from kit to discharge tube, through the gaps of motor. Performance parameters are calculated using custom based programs by considering the major dimensions of the kit, while CFD is considered to study pressure drop from the outlet of pump to the discharge tube.

Theoretical calculations are performed to obtain the performance parameters, by varying the port size, number of ports and re-expansion volume, keeping all other dimensions of the pump constant. Performance parameters are calculated at AHSRAE/T conditions. Calculations are carried out using simulations and customized programs, which run on high performance computing machines to reduce the computing time of complex matrices.

The calculations are carried out for 1.5 ton capacity compressor. The major dimensions mentioned in this paper pertain to cylinder block bore diameter, rolling piston outside diameter and cylinder block height, which are key to displacement of the compressor.

1.2.1. Calculations on pump

Calculations on pump are based on the following assumptions:
For a similar capacity compressor, only the following parameters are altered and the variation is observed, keeping the operating conditions same.

- ✓ Port diameter
- ✓ Re-expansion volume
- ✓ Number of ports

The trends that will be plotted on performance parameters, would help to understand an optimum port configuration, which contributes to less motor power requirement, together with a required capacity.

The variation in port size would show if there is a blockage of mass flow due to port. The blockage of port increases load on motor in return.

The number of ports are also altered to see the effect on Efficiency of compressor.

Major dimensions of the pump, Pump assembly with single and dual port configuration are shown below.

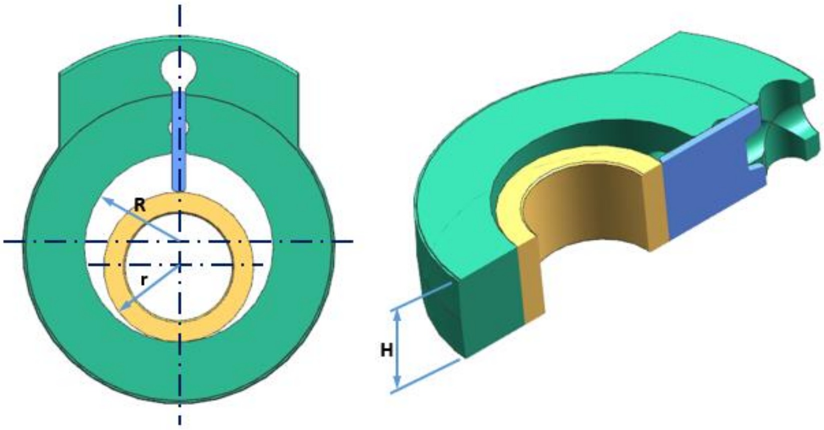

Figure **1:** Major dimensions of the Pump

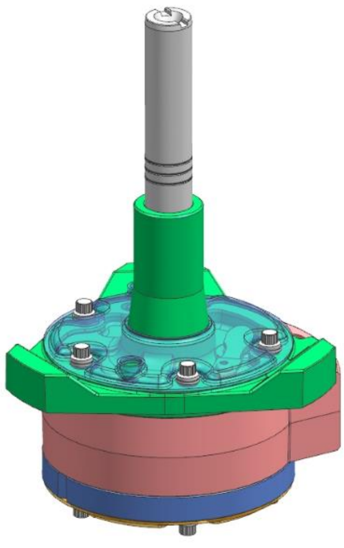

Figure **2:** Pump Assembly

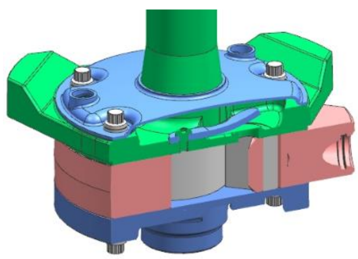

Figure **3:** Pump with single port

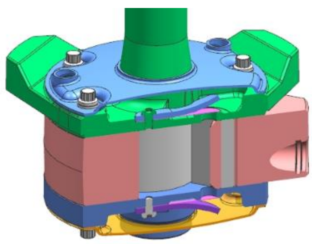

Figure **4:** Pump with dual port

1.2.2. Calculations on discharge path from pump to discharge tube outlet

Discharge path from Outlet of pump to the outlet of discharge tube is considered for CFD analysis to study the effect of pressure drop. Pressure drop across this section of compressor causes the system pressure to drop, subsequently drop in cooling capacity and COP.

The gas path is represented by a fluid model, as shown below. The holes through the stator are varied in size and the flow through them are studied to see the effect of pressure drop, from a base line analysis.

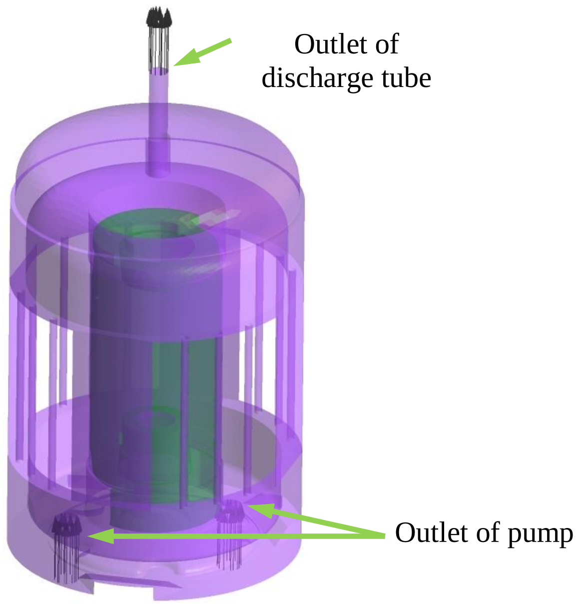

Figure **5:** Fluid model of gas path

The stator holes configuration used for study are as below:

- ✓ Discharge gas path with base line stator holes, Figure 6 (a)
- ✓ Discharge gas path with stator holes increased in diameter, Figure 6 (b)
- ✓ Discharge gas path with stator holes geometry varied in, size and shape, Figure 6 (c)

The stator 3D geometry is shown below for reference.

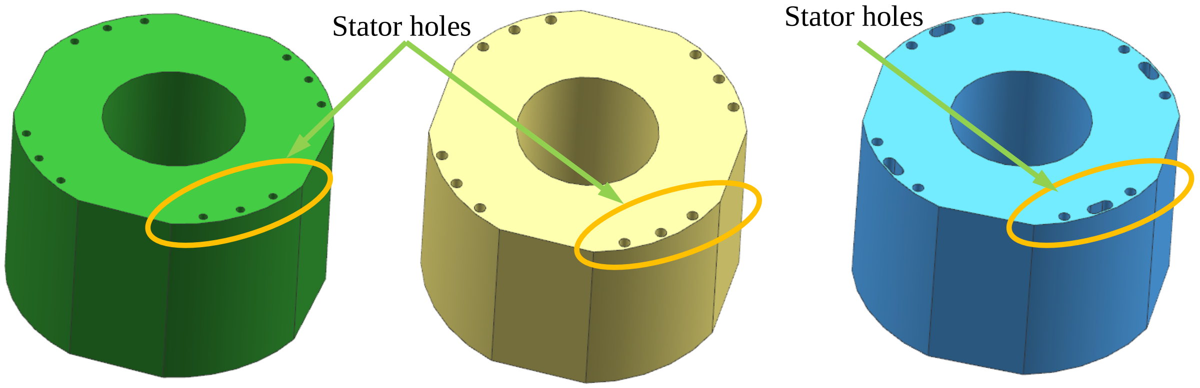

Figure **6:** Stator configurations
(**a**) Baseline, (**b**) case **1, (c)** case **2**

1.3. Simulation results

The results are plotted and the trends are as below:

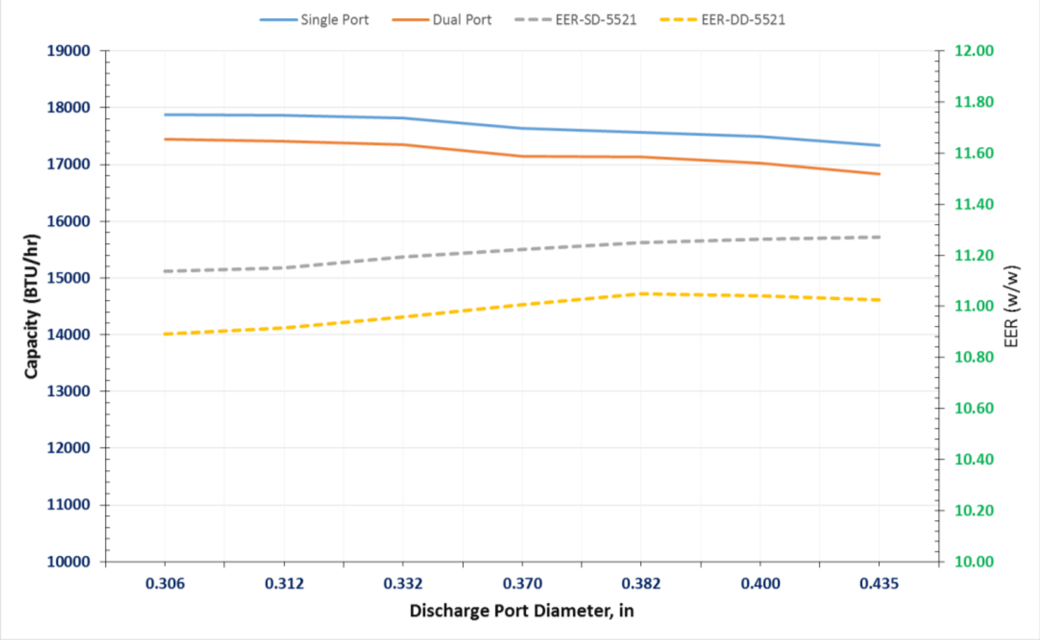

Figure **7:** Capacity & EER Vs Discharge Port Size

It is observed that there is an increase in EER, as diameter / re-expansion volume increases; also there is a decrease in capacity as re-expansion volume increases.

The selection of port, involves a combined effect of compromise between capacity and EER.

The data is tabulated for different port configurations:

Table **1**

Compressor Model	Port configuration	Port Diameters						
		0.306	**0.312**	**0.332**	**0.370**	**0.382**	**0.400**	**0.435**
1.5 ton	Single Port							
	Capacity	17879	17867	17814	17640	17569	17492	17342
	EER	11.14	11.15	11.19	11.22	11.25	11.26	11.27
	Motor Input power,w	1605.41	1602.15	1591.39	1571.74	1561.70	1552.98	1538.51
	Over Pressure, % of PV	9.32	9.16	8.62	7.66	7.19	6.77	6.10
	Area of PV Diagram, in-lbf/rev	226.37	225.91	224.39	221.62	220.20	218.97	216.93
	Stress on Discharge Valve Leaf, psi	139060	138780	137540	138530	145200	147570	150210
	Dual Port							
	Capacity	17441	17410	17351	17150	17130	17023	16838
	EER	10.89	10.92	10.96	11.01	11.05	11.04	11.02
	Motor Input power,w	1601.47	1595.00	1583.18	1558.32	1550.36	1541.74	1527.35
	Over Pressure, % of PV	7.29	6.96	5.84	4.71	4.41	4.11	3.63
	Area of PV Diagram, in-lbf/rev	219.56	218.67	215.69	212.31	211.22	210.05	208.09
	Stress on Discharge Valve Leaf, psi	134290	133890	134410	137410	143570	144430	147290

The motor input power is observed to be decreased as the re-expansion volume increases. This is due to the less work needed to compress the remaining volume sucked through the suction port. But the capacity decreases proportionately with respect to re-expansion volume.

Dual port also seems require less power when compared to the single port, but by a margin which has to be discussed as there is a considerable machining and part count increase due to additional port.

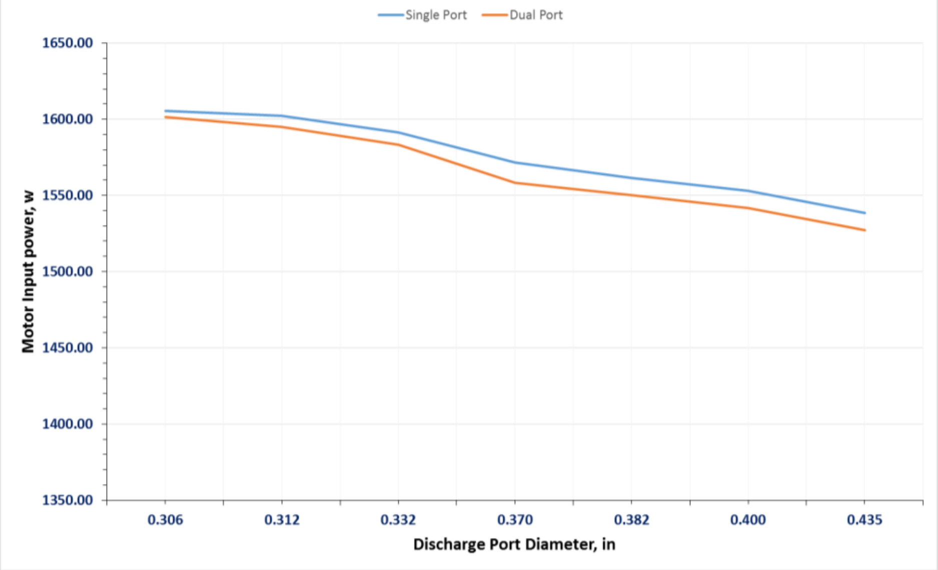

Figure **8:** Motor Input Power Vs Discharge Port Size

The cylinder pressure Vs crank angle is plotted for 2 different port sizes, with a single and dual port option. It can be observed that there is vast difference in pressure drop during the discharge cycle in smaller size port diameter. As the port size increases the pressure drop is almost flat or the pressure drop is less.

Dual port also shows an improvement from single port, in this aspect. The pressure drop is more in single port than a dual port.

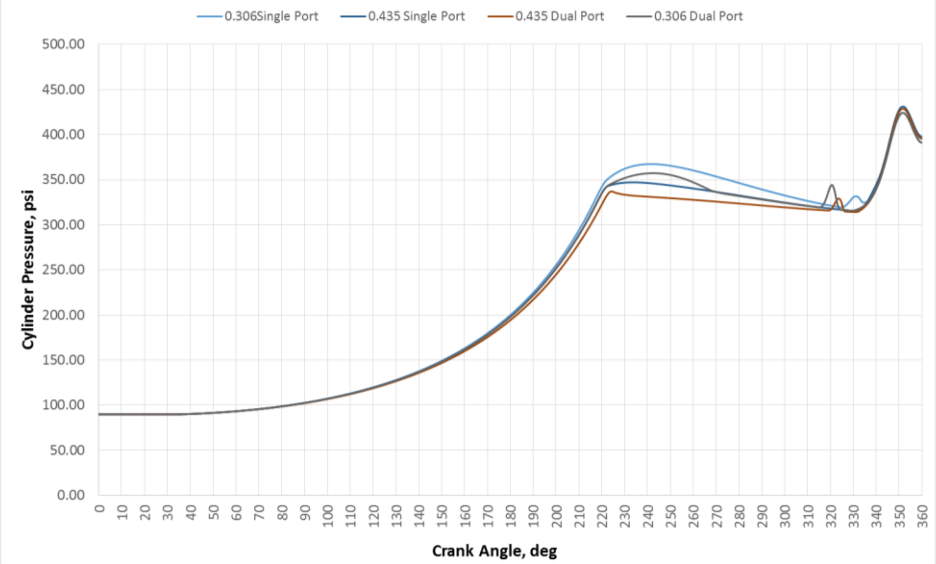

Figure **9:** Cylinder Pressure Vs Crank Angle

Discharge valve velocities are plotted for 2 different sizes of port, with a single and dual port option. The valve velocity over the port is smoother on a bigger port, when compared to a smaller port. This is due to the fact that the pressure drop is less in bigger size port than a smaller port.

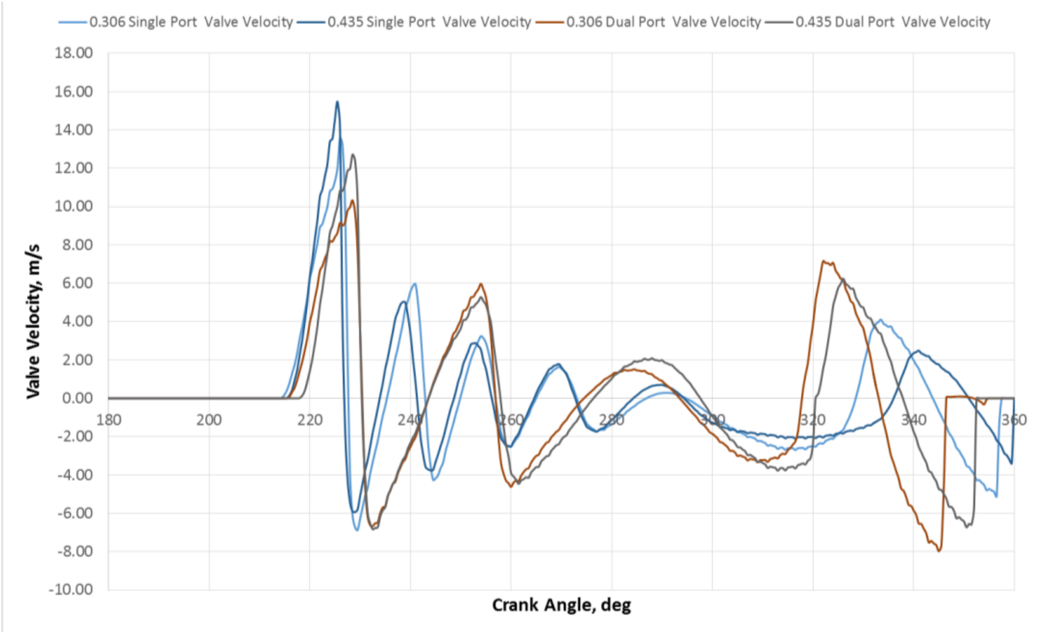

Figure **10:** Discharge Valve Velocity Vs Crank Angle

CFD results are as below

Holes provide more gas flow area through the stator and so may reduce the gas flow velocities in the upper part of shell. To understand the pressure drop and gas velocity variation in the shell along the gas flow path, 17 parallel planes were created (Figure **11**) at various locations of interests along the Vertical direction. The gas velocities at these planes were measured and compared in the two cases, apart from baseline model.

It can be seen that, as predicted, the gas velocities are decreased not only in the stator but also in the top shell region. In Figure **16** gas velocities, Figure **15** gas pressures across the various pipes formed by the holes in stator stack are compared. It can be seen that, due to the locations of pipes, the gas velocities vary at the entries of these pipes. However, at the exit, the velocities are more uniform in nature. This shows that gas flowing out of stator is now uniformly distributed along the stator periphery.

It was found that the pressure drop in the base line is observed to be 0.0414%, from outlet of pump to the outlet of discharge tube, while the pressure drop in case1 is about 0.0391% and the pressure drop is 0.0362% in case 2.

Table **2**

Configuration of stator	Pressure drop
Base Line	0.0414%
Case 1	0.0391%
Case 2	0.0362%

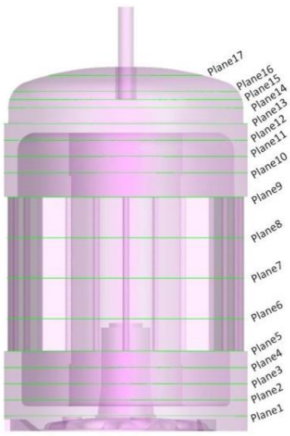

Figure **11**: Section Planes along the discharge path

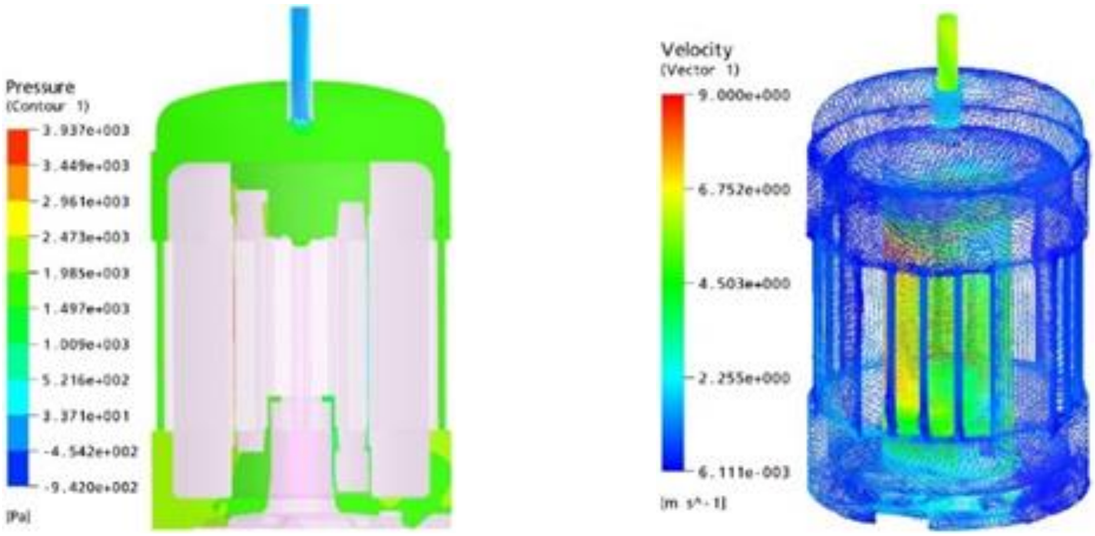

Figure **12:** Base Line Stator configuration, (**a)** Pressure contours, **(b)** Velocity Contours

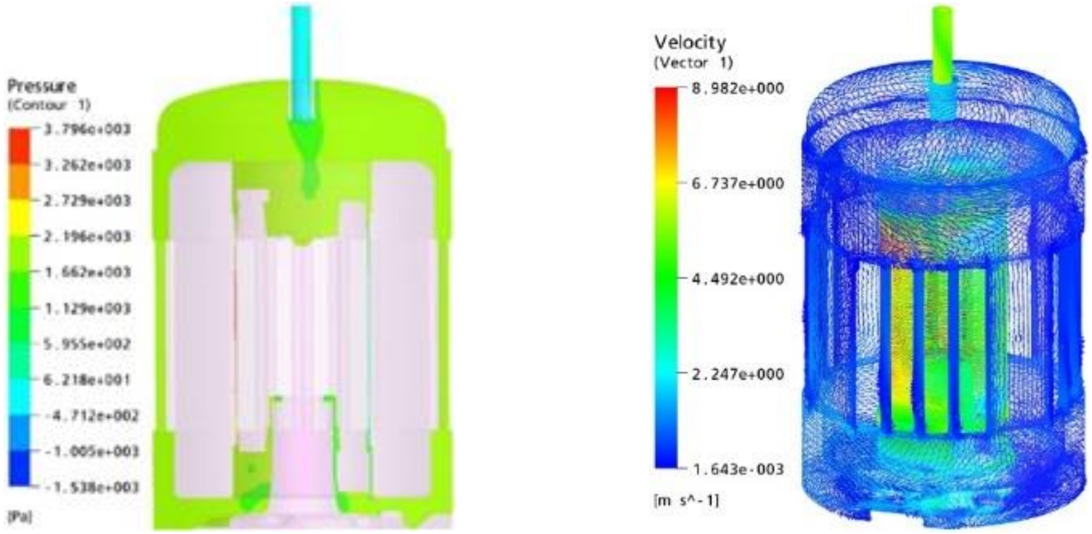

Figure **13:** Base Line Stator configuration, (**a)** Pressure contours, **(b)** Velocity Contours

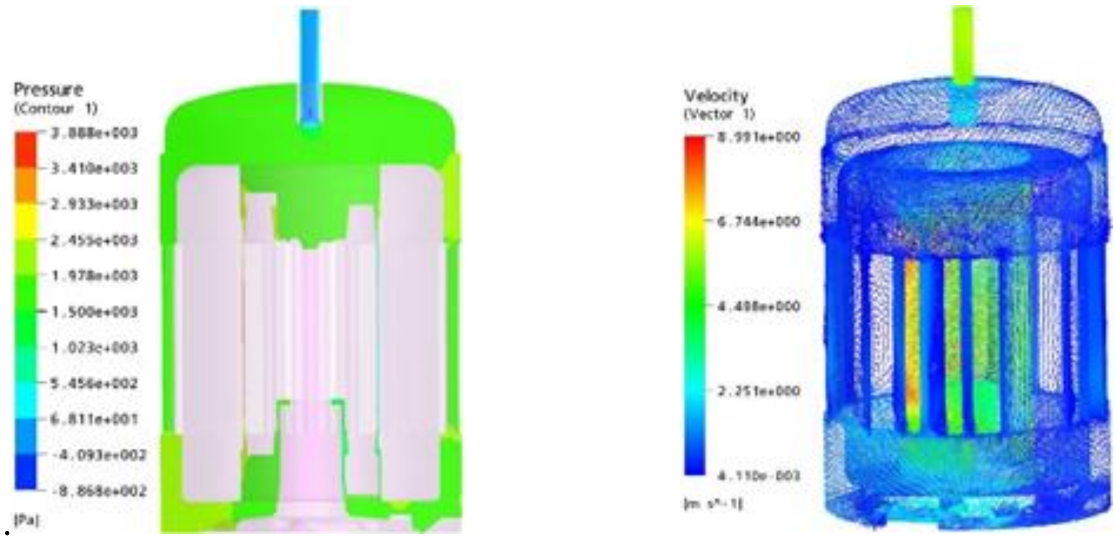

Figure **14:** Base Line Stator configuration, (**a)** Pressure contours, **(b)** Velocity Contours

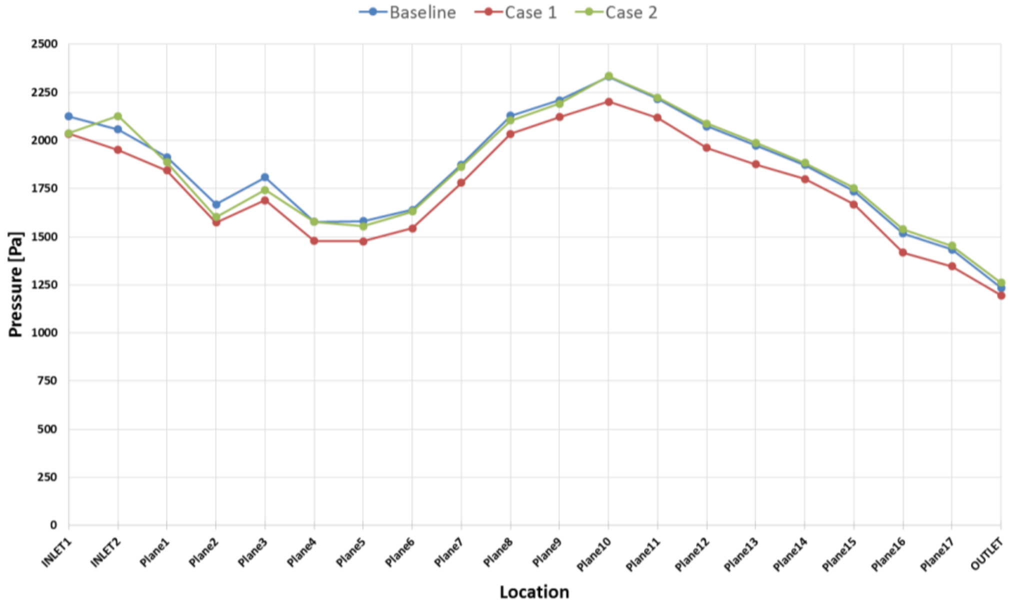

Figure **15:** Pressure drop across the domain

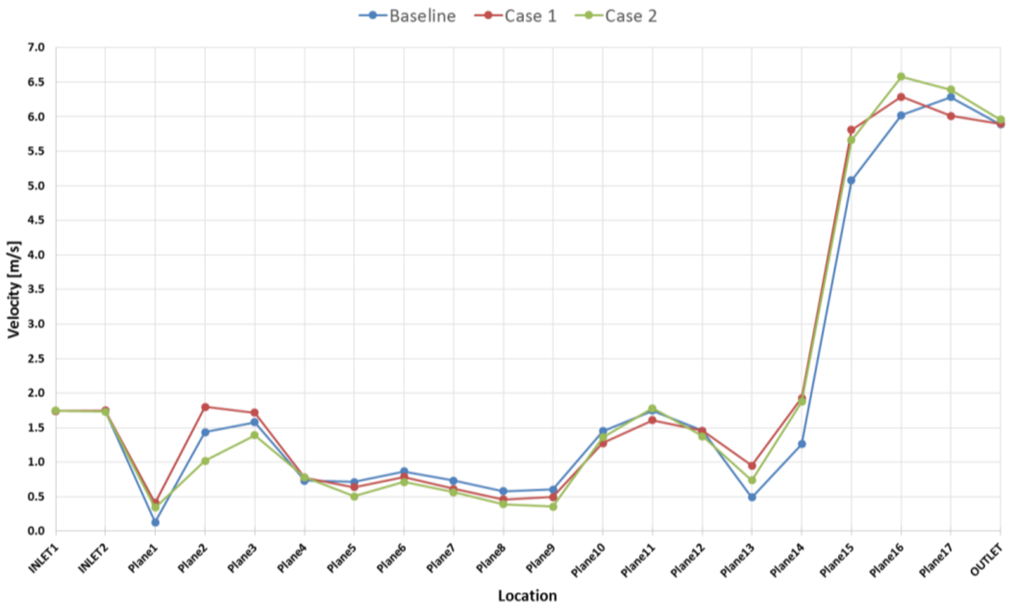

Figure **16:** Velocity across the domain

1.4. Test Results

Testing is planned with 3 of various port configurations mentioned above, to support the theoretical calculations. The configurations tested are presented below. Compressors are tested for performance under ASHRAE/T conditions. The performance parameters considered from testing are capacity, EER and motor power.

The port configurations selected for testing are as below
- ✓ 0.382 & 0.435 discharge port in single port configuration
- ✓ one compressor with 0.382 discharge port in dual port configuration

Results are tabulated below. The results are agreeing well with the theoretical calculations.

Table **3**

Compressor Model	**Port configuration**	**Port Diameters**	
		0.382	**0.435**
1.5 ton	Single Port		
	Capacity	17496	17417
	EER	11.13	11.23
	Motor Input power,w	1572.00	1551.00
	Dual Port		
	Capacity	17192	-
	EER	11.02	-
	Motor Input power,w	1560.00	-

6. CONCLUSIONS

Following are the conclusions from the theoretical calculation's and testing
- There is 0.8% increase in EER observed in testing, while there is a pressure drop of 0.45%.
- It is observed that there is an increase in EER, as diameter / re-expansion volume increases; also there is a decrease in capacity as re-expansion volume increases.
- The selection of port, involves a combined effect of compromise between capacity and EER.As the discharge port diameter increases, EER increases with a drop in capacity.
- By opening the discharge path, it is observed that there is less reduction in pressure drop; which is subsequently helpful in improving the compressor capacity.

NOMENCLATURE

R	Cylinder block Bore diameter	(inch)
r	Outside diameter of Rolling Piston	(inch)
H	Cylinder block height	(inch)

REFERENCES

Lenz, J, 2010, A Study of Flapper Valve Motion in a Variable Speed Compressor, Proceedings of the 2010 International Compressor Engineering Conference at Purdue, paper 1343

Ishii, N. et al., A Fundamental Optimum Design for High Mechanical and Volumetric Efficiency of Compact Rotary Compressors, Proceedings of 1998 International Compressor Engineering Conference. Paper 1314.

Kamal Sharma, et al, CFD Analysis of Discharge Gas flow in Rotary Compressor for OCR Reduction, Proceedings of 2010 International Compressor Engineering Conference. Paper 1224.

ACKNOWLEDGEMENT

The authors would like to acknowledge Nagarjuna E for contributions towards CFD analysis.