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Methods of fluid properties for compressible refrigerant CFD analysis

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ABSTRACT

There are numerous ways of defining fluid properties for computational fluid dynamic (CFD) simulations. This paper examines three methods of defining fluid properties that are available in a commercial CFD code. Simulations were carried out for an R410a scroll compressor used in air conditioning applications and the effects are illustrated through the compression process.

The first method used is the real gas property data from the National Institute of Standards and Technology (NIST). While considered the most accurate, it is not available in all CFD codes. A second method is the Peng Robinson equation of state, which approximates the real gas properties. The most widely available method, the ideal gas equation of state model, is also examined.

Using the three different methods for defining fluid properties, CFD simulations of two different discharge porting schemes were analyzed. Modeling results are evaluated, used in overall compressor performance estimates, and then compared to laboratory tests results.

The results of these analyses are reviewed to illustrate the impact of the choice of property-definition methods on important design decisions. This information can also have an impact on the choice of CFD software, since not all CFD software has the fluid property options described in this paper.

1. INTRODUCTION

CFD analysis has become more popular for analyzing compressors. Back in 2004, (Shiva,2004) wrote about how CFD analysis is now being used to help analyze compressors. Today there are many different computational fluid dynamic (CFD) codes capable of simulating a scroll compressor compression process. Not all of these CFD codes have the same methods of defining the fluid properties. This paper analyzes the results of using three different methods of defining fluid properties for a CFD simulation (NIST Lemon,2013),(Peng Robinston,1976) and ideal gas. The NIST fluid property method is a standardized method maintained by the National Institute of Standards and Technology. The Peng Robiniston method is an equation of state method. For this comparison ANSYS CFX version 14.5.7 was selected as the CFD simulation tool, because it was capable of simulating the scroll compressor using all three of these methods. The results of these simulations are compared to each other as well as to actual lab data to determine the accuracy of these different methods.

Two different discharge porting schemes are used on a 13 ton scroll compressor. Discharge porting scheme one is the baseline which is used today. Discharge porting scheme two has a slightly larger discharge port than the baseline compressor. Investigating the two different discharge porting schemes will determine how well the three different fluid property methods do at predicting the compression power and the overall efficiency differences of the compressors. The 13 ton scroll compressors are evaluated at the air-conditioning refrigeration institute (ARI) rating condition 45/130/20/15 °F (7.2/54.4/-6.7/-9.4 °C). Comparisons of compression power, energy efficiency ratio (EER) as well as mass flow rate and volumetric flow rates are used to draw conclusions of the different methods.

2. REVIEW OF THE MODELING APPROACH

The scroll compressor CFD simulations used the same geometry, mesh, and setup assumptions.

- Compressor speed = 3500 RPM
- Movement per time step = 2 degrees
- No Oldham coupling was modeled
- No oil was modeled in this simulation
- Turbulence modeling = Shear stress transport (SST)
- Heat transfer model = Total energy equation
    - Which includes the viscous work term
- Transient Scheme = Second Order Backwards Euler
- All of the walls are adiabatic
- Buoyancy is turned off

The only differences between the CFD models is the two different discharge porting schemes and the different fluid property methods.

The geometry was setup similar to (Cui, 2003) & (Cui, 2006) in four pieces. Figure 1 illustrates the setup of the simulations. The bottom section is referred to as the suction domain and is where the simulation begins. There is a transitional mesh/volume is named the outside. The outside domain connects the suction domain to the involute volumes. The involute domain mesh is the third mesh, shown in Figure 2. Mesh motion is created for the outside and the involute meshes to simulate the positive displacement compression process. Finally, there is the discharge domain where the simulation ends. The discharge domain includes a check valve to more realistically model pressure drop in the simulation.

The NIST property method was created in a table format and is also called RGP for real gas property. The Peng Robinson method was also put in a table. Both of these methods were created to capture the range of fluid properties needed for this simulation. For the ideal gas technique, the fluid properties were selected near the middle of the range between the suction and discharge pressures and temperatures.

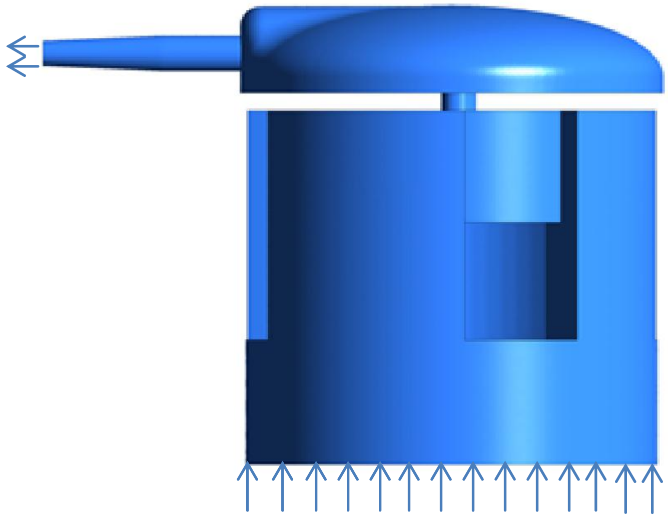

Figure 1: Scroll compressor CFD analysis setup.

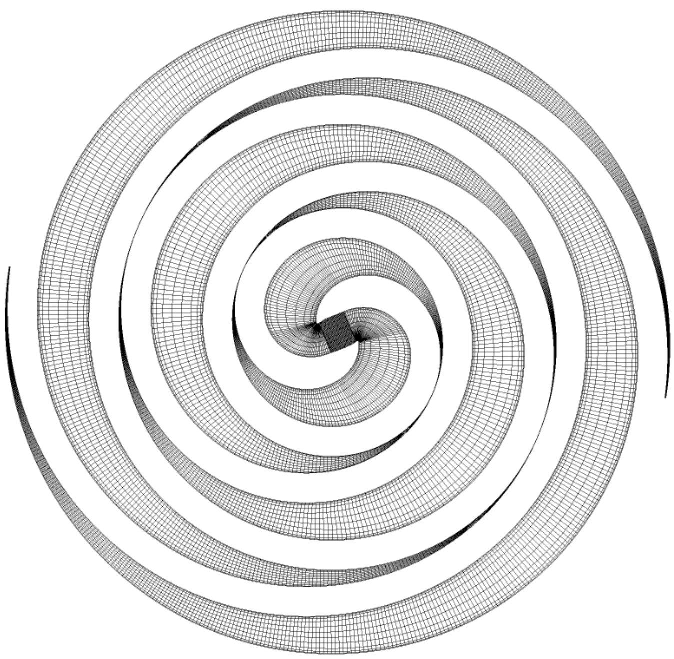

Figure 2: Scroll compressor involute mesh.

3. TEST AND ANALYSIS FOR A REFRIGERATION SCROLL COMPRESSOR

To compare the methods, a pressure volume diagram was created that shows the results of all three methods. The lab compressor was not instrumented to measure the pressures in the pockets and therefore was not used in this part of the comparison. A pressure volume diagram describes the compression process of a positive displacement compressor. The compression pocket starts with zero volume and suction pressure. After the pocket fills, the compression starts. At the end of compression the pocket discharges its gas into the discharge port. The scroll compressor has two compression pockets. The direct pocket, refers to the compression pocket that has a direct flow path to the discharge port. The indirect pocket does not have a direct path to the discharge port. The fluid path for the indirect pocket is to the center of the involute pocket and then to the discharge port. Figure 3 illustrates the pockets. Figures 4 and 5 show the results of the scroll compressor simulations with the discharge porting scheme one. The results showed that the Peng Robinson and NIST properties (RGP) had similar results.

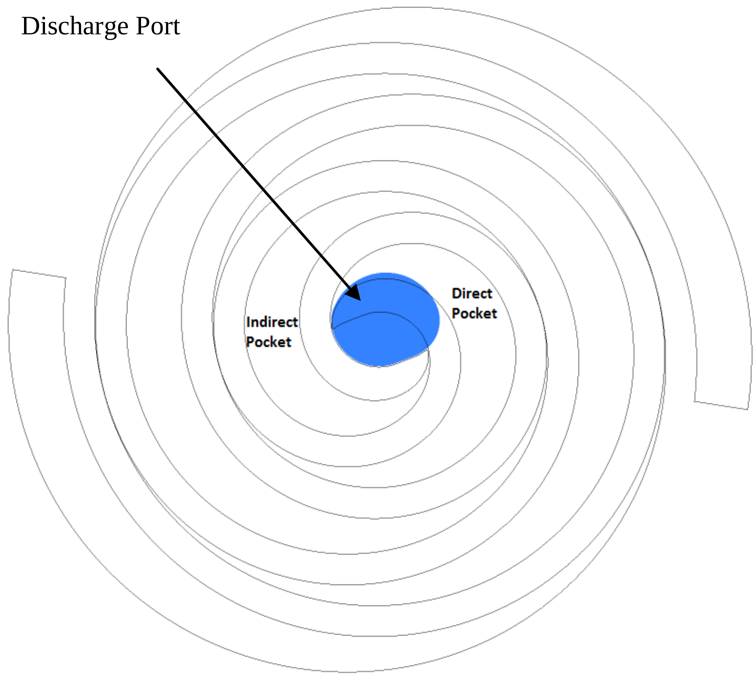

Figure 3: Direct and indirect pocket

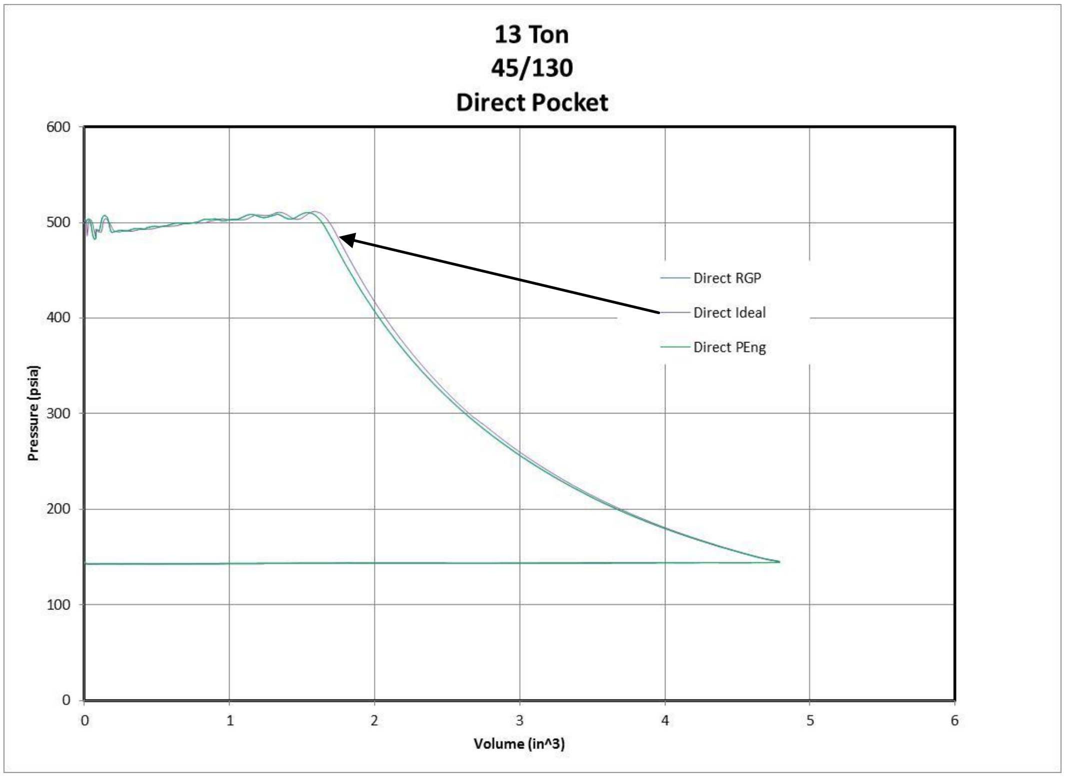

Figure 4: Direct pocket.

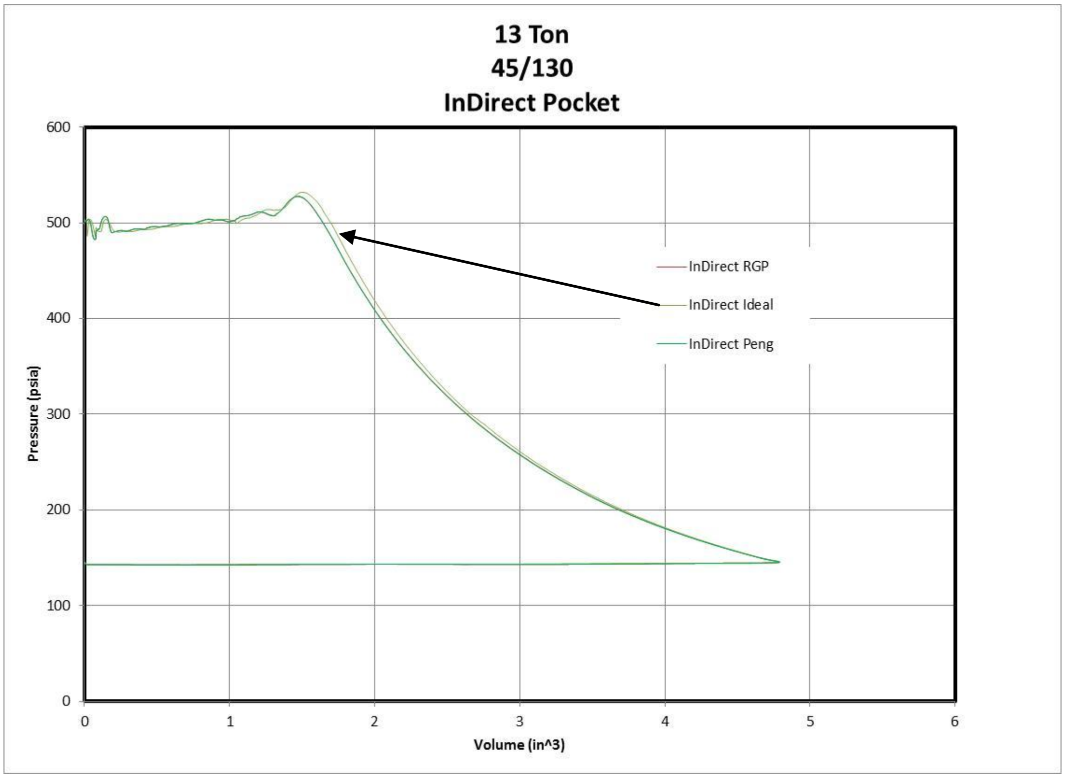

Figure 5: Indirect pocket.

Figures 6, 7 and 8 looked more closely at the results of the direct pocket in Figure 4 to better illustrate the differences of all three cases. Figure 6 focused at the beginning of the compression process. From this figure it is observed that the direct RGP (NIST) method and the Peng Robinson methods are identical, where the ideal method deviates. Figure 7 illustrates the variations in the middle of the compression process. Figure 8 highlighted the effects of the different methods during the discharge process.

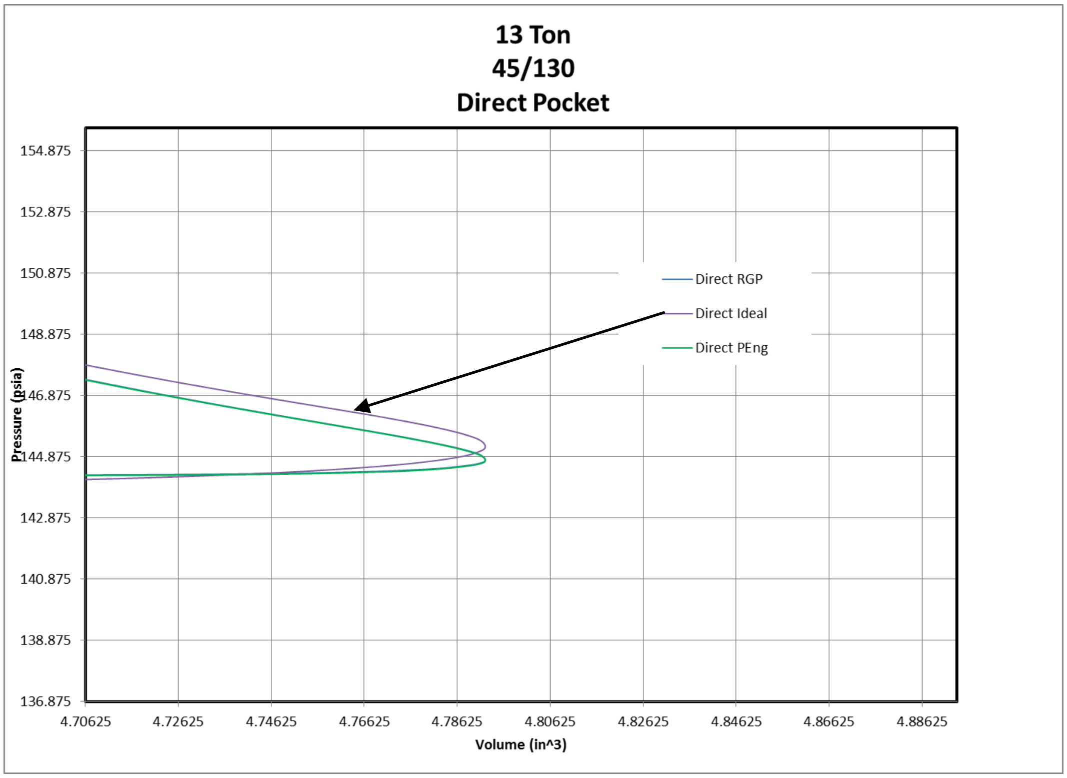

Figure 6: Beginning of compression.

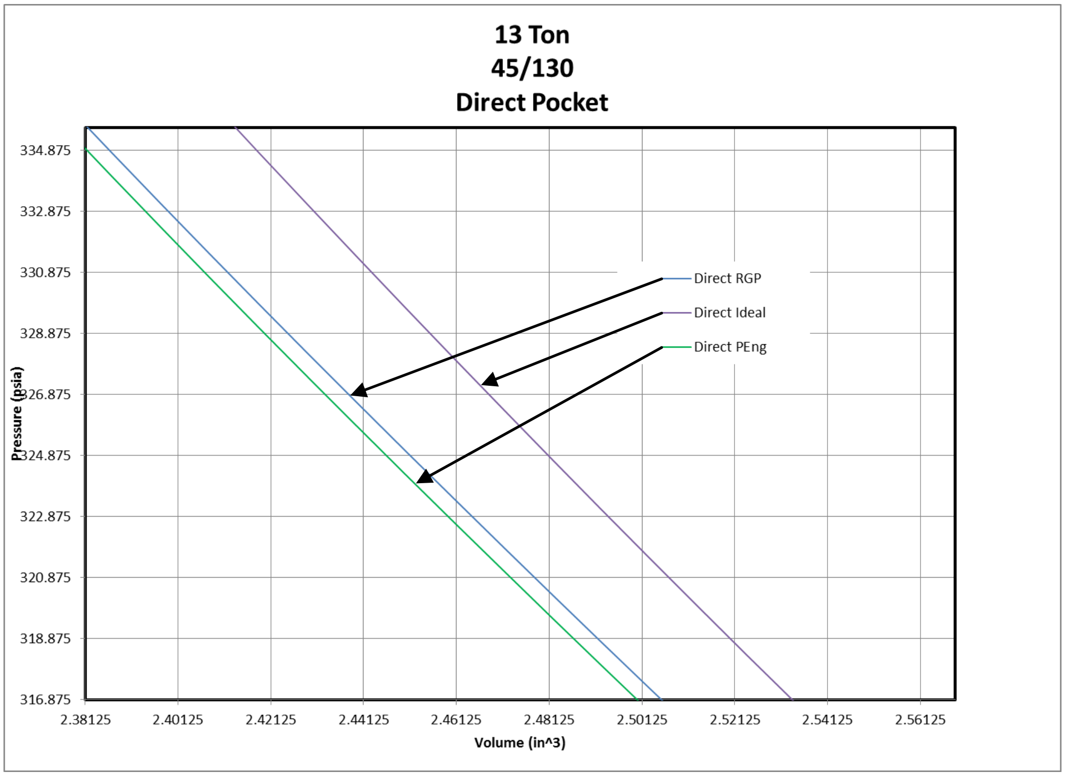

Figure 7: Middle of the compression process.

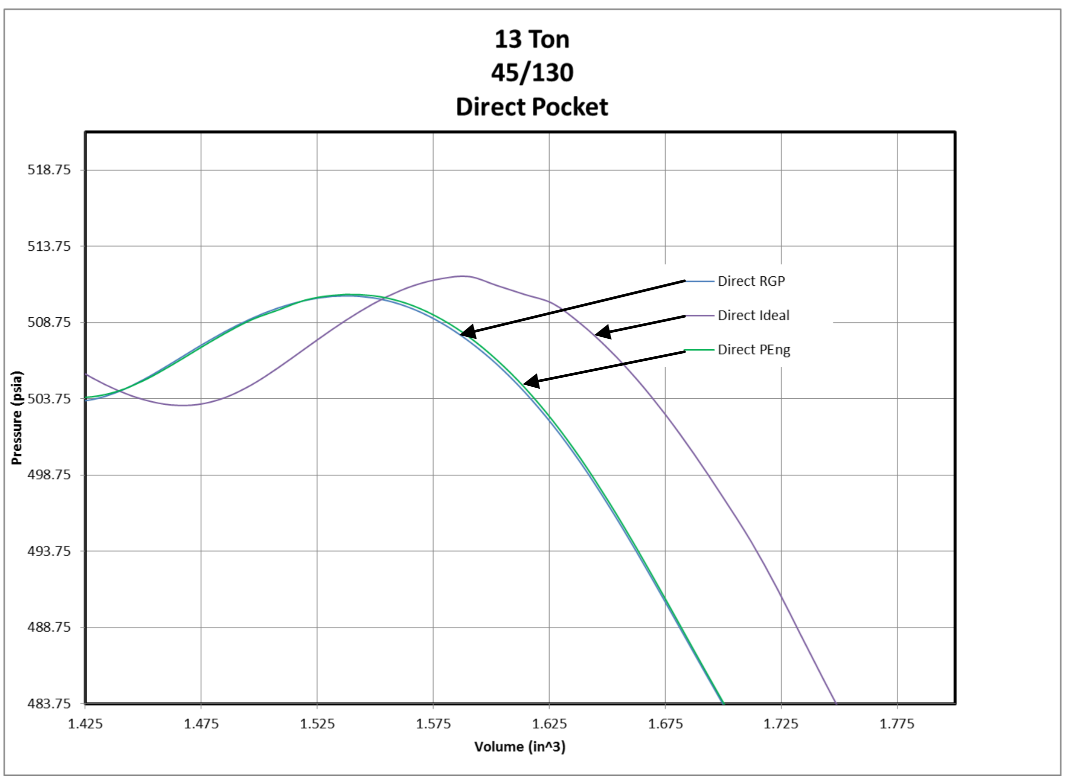

Figure 8: Discharging process

Next, the CFD analysis results were compared to actual laboratory test data. In Table 1 the three different refrigerant methods are compared to actual laboratory test data. The NIST method predicted the mass flow rates (MFR) and the energy efficiency ratios (EER) the closest. The power differences between the Peng Robinson and the NIST methods were basically the same. In Table 2 these values are converted into percent differences from the laboratory data to help highlight the differences among the three methods.

Table 1: Mass flow rate, EER, and compression power normalized.

		MFR (normalized)	EER (normalized)	Power (normalized)
Discharge Port Scheme One	Lab Compressor	1.000	1.000	1.000
	NIST	0.999	0.991	1.012
	Peng	0.985	0.980	1.010
	Ideal	0.857	0.859	1.022
Dicharage Port Scheme Two				
	Lab Compressor	1.000	1.002	0.999
	NIST	0.999	0.994	1.008
	Peng	0.985	0.981	1.009
	Ideal	0.859	0.861	1.022

Table 2: Mass flow rate, EER, and compression power differences from test results.

		MFR diff. (%)	EER diff. (%)	Power diff. (%)
Discharge Port Scheme One				
	NIST	0.11	0.90	1.15
	Peng	1.49	1.96	1.01
	Ideal	9.49	14.06	2.25
Dicharage Port Scheme Two				
	NIST	0.13	0.79	0.89
	Peng	1.48	2.04	1.01
	Ideal	9.51	14.02	2.28

Table 1 showed that all three methods predicted that discharge porting method two had a higher EER than discharge porting method one. The major differences among the methods were the mass flow rates and EER differences from the actual laboratory results. The mass flow rate differences were due in large part to the differences in calculated densities. A sample of the density differences was taken at the entrance to one of the involutes. These results are shown in Table 3. The CFD mass flow rates from discharge porting scheme one were converted to volumetric flow rates and are presented in Table 4.

Table 3: Density differences.

	Density (kg/m^3)	% difference from NIST
NIST	33.83	
Peng	33.37	1.36
Ideal	28.97	14.36

Table 4: CFD Volumetric flow rates from Discharge Porting Scheme One

	Normalized from NIST
NIST	1.0000
Peng	0.9998
Ideal	1.0017

4. SUMMARY AND CONCLUSIONS

A simplified CFD analysis was used to predict the compression process of a scroll compressor. The analysis was analyzed at the ARI operating condition. The following differences among the cases were observed.

- The NIST property method predicted the actual mass flow rates at 0.1% different from the actual lab data. The NIST property method also predicted the EER to less than 1% of the actual laboratory test data. The Peng Robinson method was close behind, and the ideal gas method was more than 10% off.
- When comparing compression power, the NIST and Peng Robinson methods both predicted the power to around 1% different from the actual laboratory test data. The ideal gas method was a little over 2% different from the other two.
- The volumetric flow rates were all basically the same, with the ideal gas method the worst at 0.17%.
- All of the fluid property methods agreed with the laboratory test data that discharge porting scheme two was more efficient than one. The differences in these predictions were similar and only varied by 0.3%.
- Because the ideal gas method deviates so much from the other two methods, additional operating conditions need to be simulated to validated that the ideal gas method can consistently predict the optimal discharge port.
- Creating a set of ideal gas properties closer to the discharge conditions will increase the density and improve the mass flow rates of the ideal gas method.

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