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A Performance Based Method to Determine Refrigerant Charge Level in Unitary Air Conditioning and Heat Pump Systems

Keith A. Temple
KAT Consulting

A PERFORMANCE BASED METHOD TO DETERMINE REFRIGERANT CHARGE LEVEL IN UNITARY AIR CONDITIONING AND HEAT PUMP SYSTEMS

KEITH A. TEMPLE

KAT Consulting
Pittsburgh, PA, USA
412-754-2184, KTemplePE@aol.com

ABSTRACT

A method is presented for determining the refrigerant charge level in a unitary air conditioning or heat pump system. The method is based on performance characteristics of the system and applies to systems with either an expansion valve or a fixed expansion device. Application of the method requires initial laboratory testing of a system to determine the performance characteristics as a function of refrigerant charge level. The test data are used to determine coefficients in a correlation for refrigerant charge level. Field evaluation of refrigerant charge level only requires measurements at the outdoor unit during near steady operation of the system. Data are presented for two systems to demonstrate the application of the method and agreement between the predicted and actual charge levels is ±10% over the range from 70% to 130% of the base charge level. Further investigation is recommended to verify the applicability of the method to other systems.

1. INTRODUCTION

The need for proper refrigerant charge in air conditioning (AC) and heat pump (HP) systems is documented in the literature, including publications by Farzad and O'Neal (1993, 1994), Robinson and O'Neal (1994), and Davis (2001). Undercharge or overcharge results in a reduction in both capacity and efficiency of a system. Methods are available to determine refrigerant charge level in systems; however, implementation can be problematic due to the required measurements. An improved method of refrigerant charge determination could contribute to improved system servicing and operation.

A new method is presented for determining the refrigerant charge level in a unitary air conditioning or heat pump system. The proposed method requires measurements only at the outdoor unit and can be applied to systems with either an expansion valve or a fixed expansion device. The method is illustrated using test data for two systems.

2. BACKGROUND

There are a number of methods that have been suggested for determining the charge level in AC and HP systems. The most common methods, charge weight, subcooling, and superheat, are reviewed by Wray et al. (2002) and the Consortium for Energy Efficiency (2000). Holder (2000) also discusses the subcooling and superheat methods. Charge determination based on refrigerant weight can be applied to any system, but the refrigerant must be removed from the system in order to be weighed. Additionally, the target charge value provided by the equipment manufacturer must be adjusted for refrigerant line length and possibly indoor coil volume. The subcooling method is recommended for systems with an expansion valve. The method is relatively straightforward to implement and requires only measurement of the liquid line pressure and temperature during steady system operation. Equipment manufacturers typically provide a single target subcooling value (independent of ambient conditions). In contrast to the single target value, Holder (2000) presents a table of target subcooling values for different outdoor temperatures and indoor wet bulb temperatures. The superheat method is recommended for systems with a fixed expansion device (orifice or capillary tube). The method requires measurement of the suction pressure and temperature during steady system operation. Additionally, the outdoor air temperature (dry bulb) entering the condenser and the indoor return air wet bulb temperature are required to determine the target superheat value. The equipment manufacturer typically provides a superheat table to determine the target superheat value based on the ambient temperature conditions. Siegel and Wray (2002) conducted an evaluation of refrigerant charge diagnostics that are based on superheat measurement and identified problems with the three methods that were evaluated. They also recommended the development of an improved charge determination method. Wurts (2003) also identified problems associated with the three temperature measurements required to apply the superheat method for evaluating refrigerant charge level.

3. REFRIGERANT CHARGE DETERMINATION METHOD

A new method for determining the refrigerant charge level in a unitary air AC or HP system is presented. The method was developed based on experimental observations of system performance variations with charge level and ambient conditions. The basic concept of the method will be discussed and then the method will be illustrated for two systems: a system with an expansion valve and a system with a fixed expansion device.

Subcooling and superheat are the two main performance parameters that are frequently used for evaluating charge level in AC and HP systems. Subcooling is typically used for a system with an expansion valve and superheat is used for a system with a fixed expansion device. Subcooling, evaluated at the condenser outlet, is defined as

$$\Delta T_{sc} = T_{satl} - T_{liqv} \tag{1}$$

where T_{liqv} is the refrigerant temperature in the liquid line and T_{satl} is the saturated liquid temperature at the liquid pressure P_{liqv}. Superheat, evaluated at the compressor inlet (total superheat according to Holder, 2000), is defined as

$$\Delta T_{sh} = T_{suct} - T_{satv} \tag{2}$$

where T_{suct} is the refrigerant temperature in the suction line and T_{satv} is the saturated vapor temperature at the suction pressure P_{suct}. A system schematic is presented in Figure 1 and the measurement locations are identified. The parameters of subcooling and superheat are normally used independently of each other; however, they can be used together to provide an improved indicator of the system performance.

In the following paragraphs and figures, data are presented from laboratory tests conducted in accordance with ARI Standard 210/240 (ARI, 1994). An air conditioning system with an expansion valve and a system with an orifice were tested and the system characteristics are summarized in Table 1. Tests were conducted at eleven sets of ambient conditions and five charge levels. The ambient conditions are presented in Table 2 and the charge levels are 70%, 85%, 100%, 115%, and 130% of the base charge level. The data were all recorded with the system operating at steady conditions.

Application of both subcooling and superheat will first be considered for a system with an expansion valve. Experimental data for the test system are presented in Figure 2 as subcooling versus superheat. Data are presented for all the test conditions and trend-lines are included for 85%, 100%, and 115% charge levels. It can be observed that at a given charge level there is some variation of subcooling with ambient conditions. Additionally, as charge level decreases and subcooling approaches zero, there can be no further variation of this parameter with charge level. There is, however, a corresponding increase in superheat as can be observed by following the line for a fixed set of ambient conditions such as 80/67/95 (27/19/35°C). This provides an indication that superheat combined with subcooling may provide an improved indicator of charge level for a system with an expansion valve.

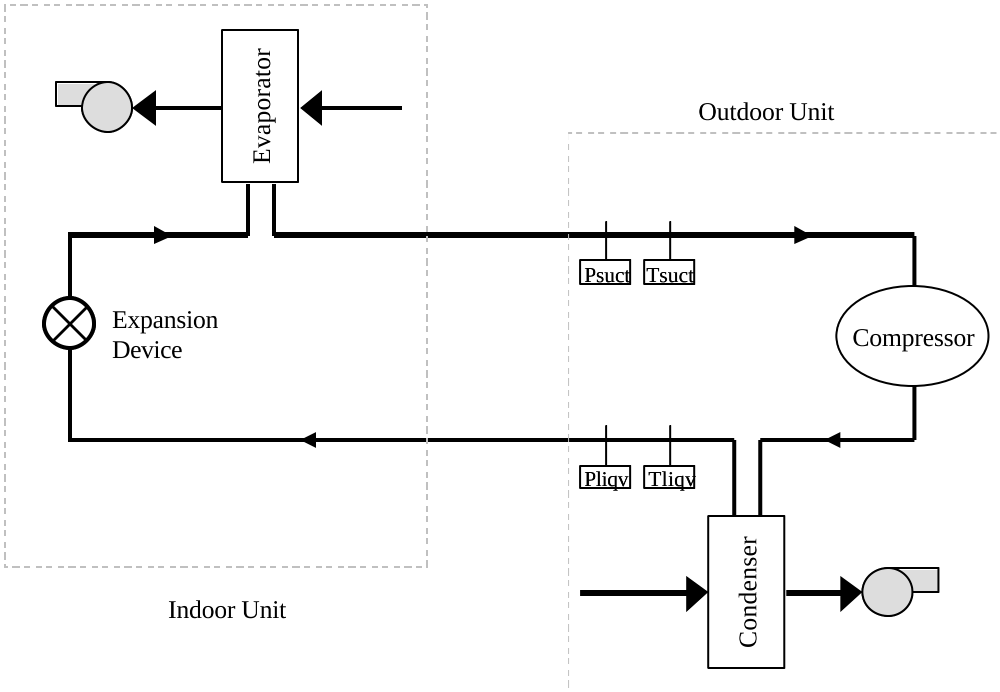

Figure 1: System Schematic with Measurement Locations

Table 1. Test Unit Data

Expansion Device	**Expansion Valve (TXV)**	**Orifice**
System Type	split system AC	split system AC
Nominal Total Cooling Capacity, Btu/h (kW)	48,000 (14.1)	48,000 (14.1)
Refrigerant	R-22	R-22
Base Refrigerant Charge, lb (kg)	6.7 (3.0)	6.7 (3.0)
Evaporator Airflow Rate, cfm (l/s)	1400 (660)	1600 (755)
Refrigerant line length, ft (m)	25 (7.6)	25 (7.6)
Total Cooling Capacity, Btu/h (kW), at base charge and 80/67/95 (27/19/35)	41,900 (12.3)	45,200 (13.2)
Energy Efficiency Ratio, Btu/Wh (W/W), at base charge and 80/67/95 (27/19/35)	8.9 (2.6)	9.3 (2.7)

Table 2. Test Conditions

Test Number	Indoor Dry Bulb Temperature, °F (°C)	Indoor Wet Bulb Temperature, °F (°C)	Outdoor Dry Bulb Temperature, °F (°C)	Indoor Relative Humidity (%)
1	65 (18.3)	51 (10.6)	70 (21.1)	35
2	65 (18.3)	51 (10.6)	95 (35)	35
3	65 (18.3)	51 (10.6)	115 (46.1)	35
4	80 (26.7)	62 (16.7)	95 (35.0)	35
5	80 (26.7)	67 (19.4)	70 (21.1)	50
6	80 (26.7)	67 (19.4)	95 (35.0)	50
7	80 (26.7)	67 (19.4)	115 (46.1)	50
8	80 (26.7)	71 (21.7)	95 (35.0)	65
9	95 (35.0)	84 (28.9)	70 (21.1)	60
10	95 (35.0)	84 (28.9)	95 (35.0)	60
11	95 (35.0)	84 (28.9)	115 (21.1)	60

short notation for ambient test conditions: xx/yy/zz

where xx is the indoor dry bulb, yy is the indoor wet bulb, and zz is the outdoor dry bulb

Application of both subcooling and superheat will know be considered for a system with an orifice expansion device. Experimental data for the test system are presented in Figure 3 as subcooling versus superheat. Data are presented for all the test conditions and trend-lines are included for 85%, 100%, and 115% charge levels. From this figure it can be observed that superheat increases and subcooling decreases as charge is reduced. The relatively parallel and separated trend-lines at the three different charge levels indicate that subcooling can potentially be used as an additional parameter to account for performance variations with ambient temperature. This would eliminate the need to measure ambient conditions to determine a target superheat value, indicating that superheat combined with subcooling may provide an improved indicator of charge level for a system with a fixed expansion device.

Based on the experimental observations, a simple correlation was developed to predict charge level based on the experimental measurements. The proposed method can then be evaluated by comparing the predicted charge level to the actual charge level. The correlation for predicted charge level, CL, is defined using dimensionless parameters as

$$CL = a\left(\frac{\Delta T_{sc}}{\Delta T_{ref}}\right) + b\left(\frac{\Delta T_{sh}}{\Delta T_{ref}}\right) + c + d\left(\frac{P_{liqv}}{P_{ref}}\right) + e\left(\frac{P_{suct}}{P_{ref}}\right) \tag{3}$$

where a, b, c, d and e are correlation coefficients. The reference temperature difference, ΔT_{ref}, was set at 15°F (8.3°C). The subcooling and superheat values would have the same units. The reference pressure, P_{ref}, was set at 14.7 psi (101.3 kPa). The pressure terms are absolute pressures with the same units. The key variables of the correlation are the subcooling and superheat terms; however, the correlation is further improved by including terms for the pressures. Because the method is based on the performance parameters of subcooling and superheat, the target performance characteristics are primarily a function of the outdoor components (outdoor coil and compressor) and expansion device; therefore, an adjustment should not be required for refrigerant line length variation.

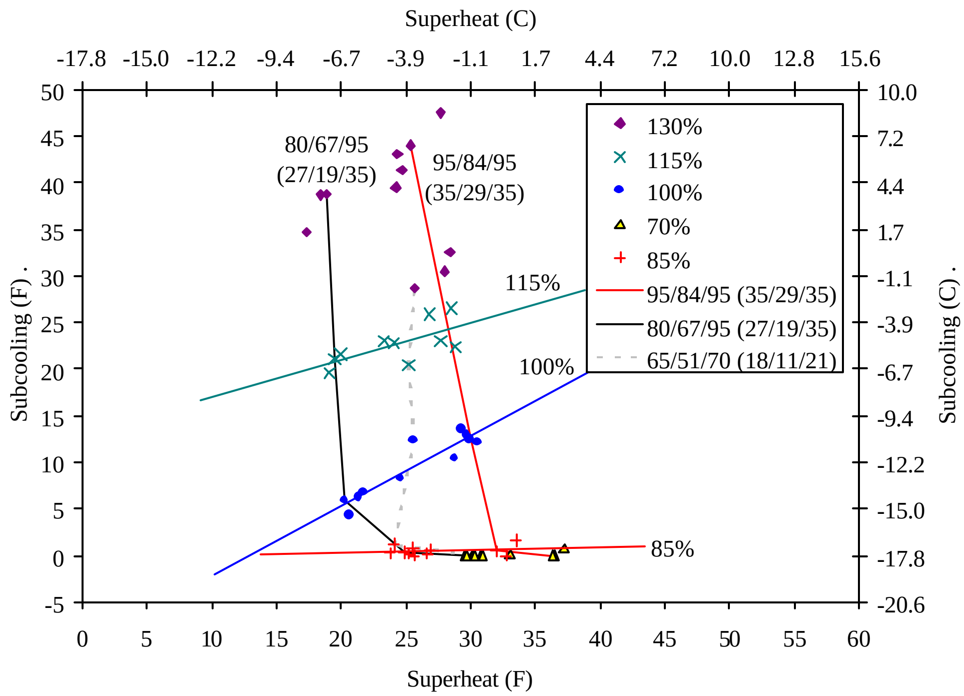

Figure 2: Subcooling versus Superheat for Expansion Valve Unit

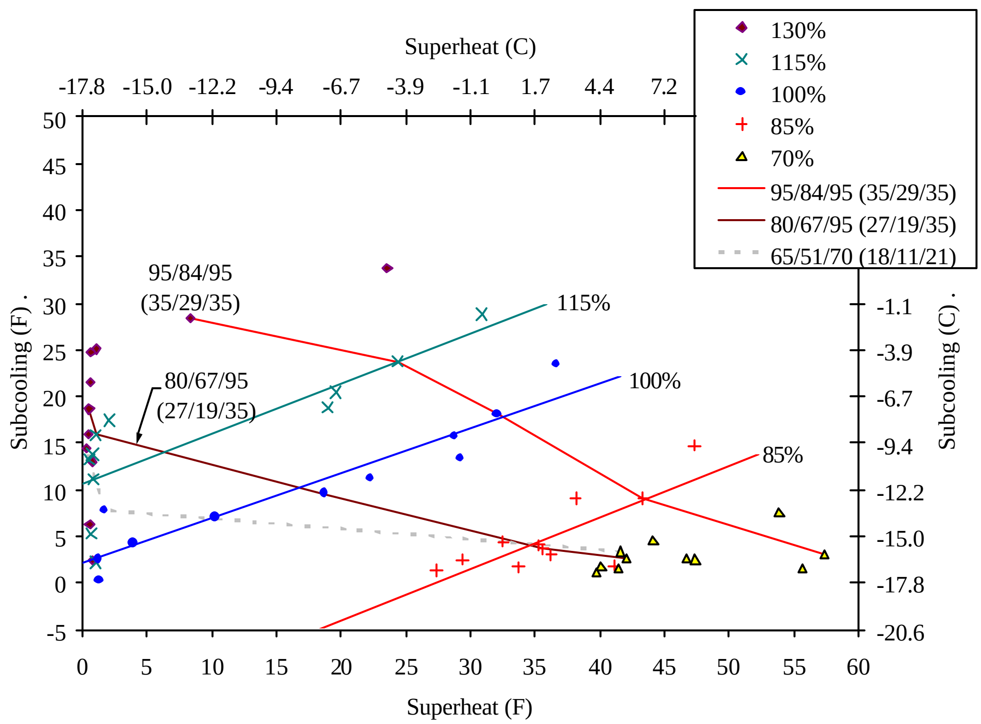

Figure 3: Subcooling versus Superheat for Orifice Unit

4. RESULTS

As previously noted, measurements were made for the two systems described in Table 1. Subcooling and superheat data were presented in Figure 2 and Figure 3. Selected pressure data are presented in Figure 4. The data were used to evaluate the proposed correlation of Equation 3.

Correlation coefficients were determined for the expansion valve system and the predicted charge level is presented as a function of actual charge level in Figure 5. Data are included for 5 sets of ambient conditions that adequately represent the complete set of data. In the charge level range from 85% to 115% the agreement between predicted and actual charge level is approximately ±6%. Over the charge level range from 70% to 130% the agreement is approximately ±10% as indicated by the straight lines at +10% charge and –10% charge.

In Figure 6 predicted charge level is presented as a function of actual charge level for the orifice based system. Data are included for 5 sets of ambient conditions. In the charge level range from 85% to 115% the agreement between predicted and actual charge level is approximately ±9%. Over the charge level range from 70% to 130% the agreement is approximately ±10%.

The analysis presented considers the impact of a range of ambient conditions (Table 2) on the predicted charge level, but has not addressed a number of other factors. The ambient conditions tested cover a fairly wide range of operating conditions, but it may be desirable to expand or reduce the set on conditions. The analysis has not explicitly included the impact of measurement uncertainty on the predicted charge level. The analysis also does not include the impact of simultaneous faults; however, limited testing indicates that the method is relatively insensitive to low evaporator airflow and low condenser airflow.

The results of the investigation indicate that the proposed method has potential as a diagnostic method for refrigerant charge level. Further investigation of the method is recommended to determine its applicability to other systems and also to explore possible improvements and address the issues indicated above.

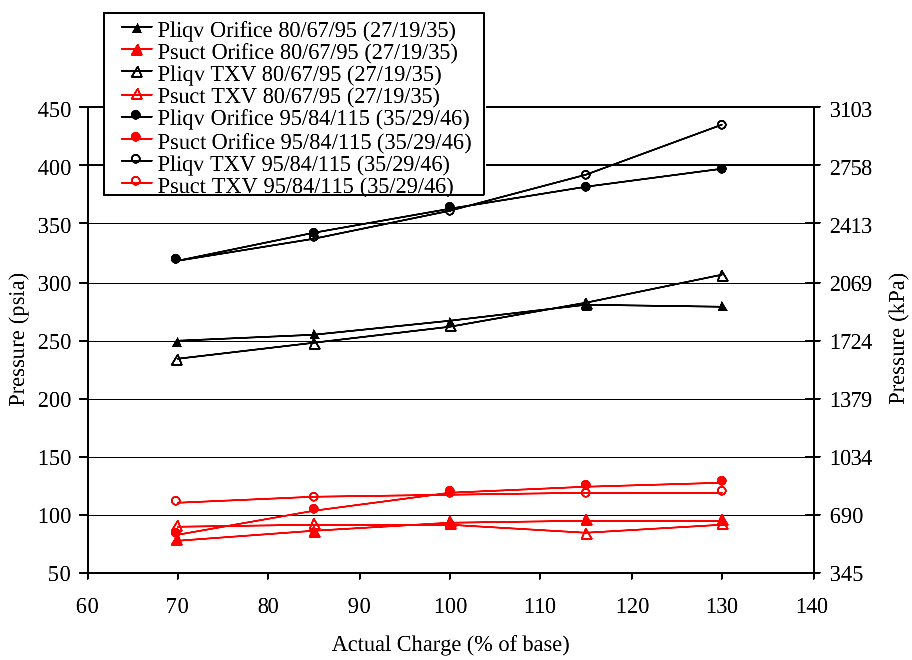

Figure 4: Operating Pressures versus Charge Level

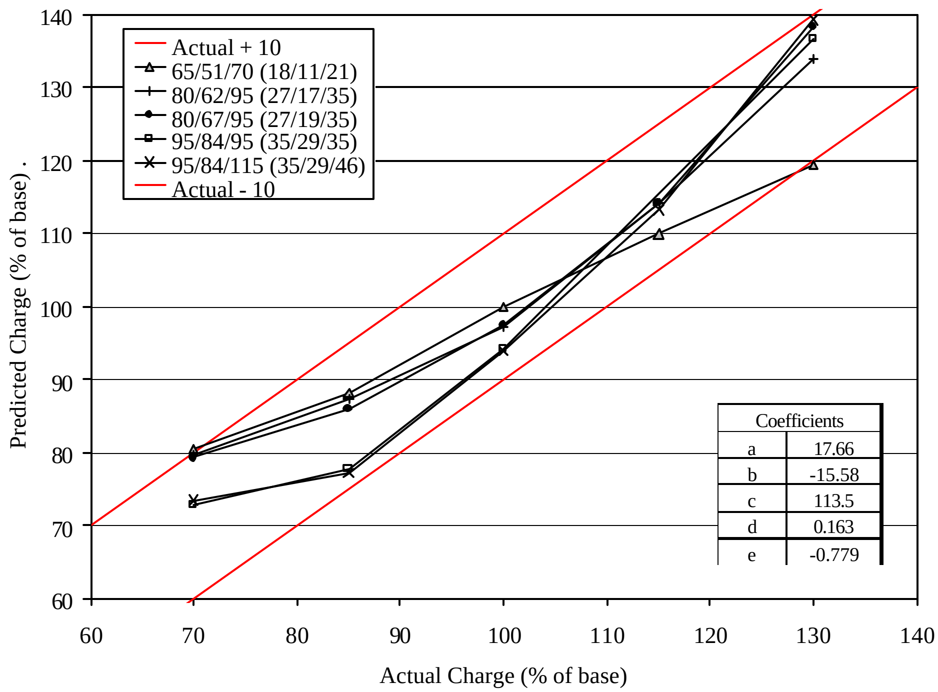

Figure 5: Predict ed Charge versus Actual Charge for Expansion Valve Unit

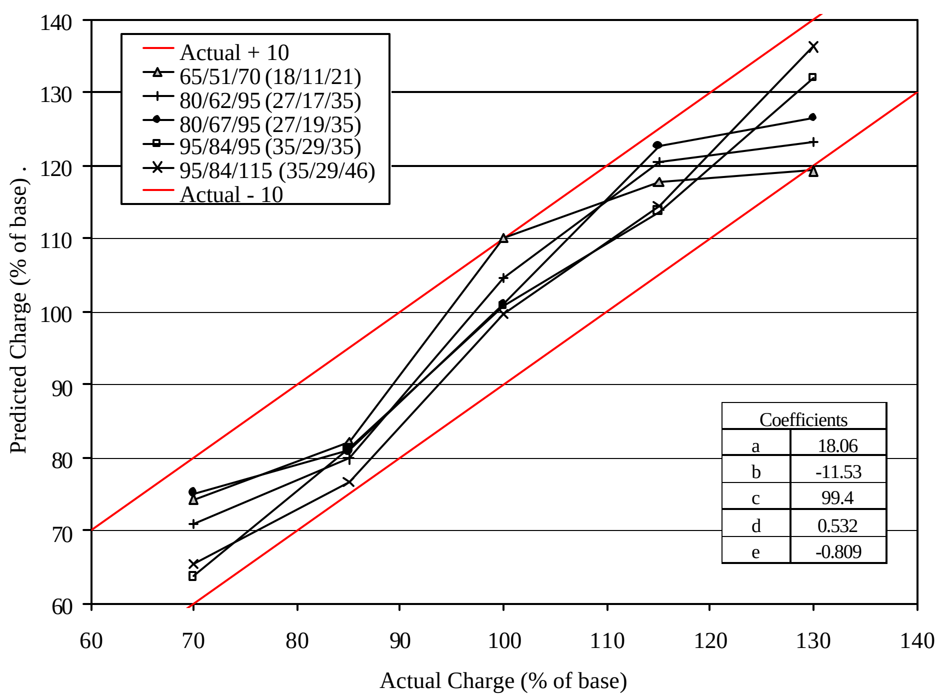

Figure 6: Predicted Charge versus Actual Charge for Orifice Unit

5. CONCLUSIONS

A new method is presented for determining the refrigerant charge level in a unitary AC or HP system. The method is based on performance characteristics of superheat and subcooling and requires only four measurements made at the outdoor unit. The method can be applied to systems with either an expansion valve or a fixed expansion device (orifice or capillary tube). Application of the method requires initial laboratory testing of a system to determine the performance characteristics as a function of refrigerant charge level. The target performance characteristics are primarily a function of the outdoor components (outdoor coil and compressor) and expansion device. The results for the two systems tested indicate that the proposed method can be used to predict refrigerant charge to within ±10% over the range from 70% to 130% charge level. The analysis does not explicitly include the uncertainty associated with field measurement of the temperatures and pressures. Because the method is based on the performance parameters of subcooling and superheat, an adjustment should not be required for refrigerant line length variation. Further testing is recommended to verify the general applicability of the method.

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