Al-Khwarizmi Engineering Journal,Vol. 11, No. 4, P.P. 89-106 (2015)

Al-Khwarizmi Engineering Journal

# Prediction of Performance Equations for Household Compressors Depending on Manufacturing Data for Refrigerators and Freezers

**Louay Abd Alazez Mahdi*** **Emad Esmaael Habib****
**Laith Abd Almunam*****

*,**,***Department of Mechanical Engineering/ University of Technology
Email: louayalkaesy@gmail.com
Email: emad_1955_emad@yahoo.com
Email: laith.ismael@ymail.com

(Received 20 November 2015 ; accepted 16 June 2015)

## Abstract

A surface fitting model is developed based on calorimeter data for two famous brands of household compressors. Correlation equations of ten coefficient polynomials were found as a function of refrigerant saturating and evaporating temperatures in range of (-35℃ to -10℃) using Matlab software for cooling capacity, power consumption, and refrigerant mass flow rate.

Additional correlations equations for these variables as a quick choice selection for a proper compressor use at ASHRAE standard that cover a range of swept volume range (2.24-11.15) $cm^3$.

The result indicated that these surface fitting models are accurate with in ± 15% for 72 compressors model of cooling capacity and 50 models for power consumption and 25 models for refrigerant mass flow rate.

***Keywords:*** *Performance, compressors, manufacturing, data, equations.*

## 1. Introduction

The household compressors are widely manufactured in the world due to the wide range of usage in refrigerators and freezers. A lot of brands and models are available which may cause troubles in selecting the proper compressor and type. The refrigerators and freezers may have no identifying data when the maintenance engineers work to replace the compressors. Also, engineers who asked about general model can be used to select the household compressors .

All these reasons stand behind the present research to find general correlations for cooling capacity, power consumption, and mass flow rate that cover the compressors performance and application.

## 2. Literature Review

It is found in literatures that few researchers pay attention to the subject of general performance equation among them

- Duggan.et.al. [1] Compared between two experimental methods of compressor test, calorimeter and flow rater test in order to know the more efficient method. The researcher recommended that the flow rater test is more accurate than calorimeter.
- Cavallini.et.al. [2] In their work presented a procedure for a steady state thermal analysis of a hermetic reciprocating compressor. The compressor machine was subdivided into six parts. The energy balance was established for each part and overall system to obtain the temperature distribution inside the compressor machine and the heat flow rates exchanged. The results were compared against the experimental measurements carried out on commercial units operating with R-

600a and R-134a, and a good agreement was found.

- Mackensen.et.al. [3] identified a physics based method to characterize the compressor performance in refrigeration systems with limited experimental data. The work focused on positive displacement compressors, semi-hermetic and open type. The compressors data were obtained from various manufacturers. The refrigerant mass flow rates were based on the polytropic compression process with clearance volume that leads to a volumetric efficiency expression. The overall performance of the model was acceptable with maximum average mean errors of 3.7% for reciprocating compressor, 2.3% for scroll compressor, and 0.6% for screw compressor.
- Kim and Bullard.[4] Developed a simple physical model for small hermetic reciprocating, rotary and scroll compressors based on thermodynamic principles and large data sets from the compressor calorimeter and in situ tests. Pressure losses along the refrigerant path were neglected, and the compression process was isentropic. A mass flow rate model reflected the clearance volume efficiency and simulated the suction of gas heating using an effectiveness method. Compressor work was calculated using the compressor efficiency represented by two empirical parameters. A linear relationship between the discharge and shell temperatures was extracted from large data sets and applied to the model for calculating the discharge temperature. The model that found can predict the mass flow rate and power consumption within $\mp$3.0% accuracy.
- Jähnig.et.al. [5] investigated a semi-empirical model to represent the compressor performance. The model was based on the volumetric efficiency and assumed a polytropic compression process. The single point condition currently used for rating refrigerator/freezer compressors is an evaporating temperature of –23.3°C (–10°F) and a condensing temperature of 54.4°C (130°F) in a 32.2°C (90°F) environment. The model was not extrapolated from static (zero air velocity) cooling to forced cooling or vice-versa.
- Cezar.et.al. [6] Proposed a semi-empirical mathematical model to simulate the unsteady behavior of mass flow rate and power of reciprocating compressors. The model based on thermodynamic equations is linearly fitted to calorimeter data sets of two compressors. Comparisons of computed and measured values of mass flow rate and power, in transient regime, were conducted for two fitted compressor curves. A good agreement of results was found for both compressors in start-up tests. They concluded that the proposed semi-empirical model can safely applied to dynamic simulations of the whole refrigeration system. The work proposed a semi-empirical model to predict the performance of reciprocating compressor in transient regime. The model based on thermodynamic equations fitted to manufacturer data by using linear correlations and compared with experimental data are which quite accurate with the prediction of compressor mass flow rate and power.

The previous literatures do not explore the performance of a wide range of compressors and help the designer and the engineers to select the proper compressor size from the wide production brands.

Therefore, the aim of this work is to find theoretical general equations for cooling capacity, power consumption, and refrigerant mass flow rate for ranges of compressors swept volume (2.42-11.15) cm3 depending on calorimeter data, these equations are easy to use and find the requirement of the compressors without depending on the brand.

## 3. Data Collection

The compressors brands are: Danfoss, Electrolux, Tecumseh, TEE, Embraco, ACC, KULTHORN KIRBY, and Donper.

Twenty-five sets of calorimeter test data for hermetic reciprocating compressors have been studied for Danfoss and Electrolux compressors which cover the swept volume from (2.42-11.15) cm3 working with refrigerant 134a.

The cooling capacity calorimeter set data that available are ninety sets and fifty-nine for power and thirty-four for refrigerant mass flow rate. These sets were used to compare and find the deviation from the correlations that obtained.

The compressor brands and models and the available data set for cooling capacity, power, and refrigerant mass flow rate which depend on the following common points for the compressors used in thesis research are presented in Table (4):

1. Hermetic reciprocating
2. Low back pressure
3. Static cooling method
4. RSIR motor type (Resistance Start—Induction Run)
5. R-134a is working fluid
6. Ester oil type
7. 220V, 1ph, 50Hz power.

## 4. Approximation Functions

The goal of the approximation functions, is to obtain the best dependable fitting curves to measure the dependability of the fitted curves corresponding values R2 were calculated, where $R^2$ is given by [7]:

$$R^2 = \frac{\sum(y^n - \bar{y})^2}{\sum(y - \bar{y})^2}$$

y is the measured data $y^n$ is the estimated(calculated) value and $\bar{y}$ is the mean of y.

Depending on Electrolux and Danfoss compressor brand using the available data for capacity, power, and refrigerant mass flow rate for 25 size that cover 2.42 - 11.15 cm3 swept volume represented are in Table (4). A surface fitting method was used with Matlab software to find the following correlations:

### 4.1. Cooling Capacity

The cooling capacity correlation was found based on ARI 540-90 standard [8]. The results are plotted in Figure (1); the correlation was as follow:

$$Q_e = a_0 + a_1 * S + a_2 * T_e + a_3 * S^2 + a_4 * S * T_e + a_5 * T_e^2 + a_6 * S^3 + a_7 * T_e * S^2 + a_8 * S * T_e^2 + a_9 * T_e^3 \quad \ldots(1)$$

**Table 1,**
**Coefficients of cooling capacity correlation.**

| Coefficient | Value | Range |
|---|---|---|
| $a_0$ | -18.24 | -53.16, 16.67 |
| $a_1$ | 78.54 | 68.45, 88.64 |
| $a_2$ | 0.7153 | -3.1, 4.531 |
| $a_3$ | 0.2132 | -1.123, 1.549 |
| $a_4$ | 2.877 | 2.505, 3.248 |
| $a_5$ | 0.04653 | -0.118, 0.2111 |
| $a_6$ | -0.04921 | -0.1119, 0.01344 |
| $a_7$ | -0.01148 | -0.03118, 0.008213 |
| $a_8$ | 0.02749 | 0.02149, 0.03349 |
| $a_9$ | 0.0006736 | -0.00169, 0.003037 |
| Goodness of fit: $R^2$: 0.9968 | | |

where S: swept volume cm3
Te: evaporator temperature.

The value of $R^2$ is 0.9968 which indicates the degree of correlation i.e. (99.68%) of total variation present.

### 4.2. Power Consumption

It depends on ARI 540-90 standard, the corresponding data is plotted in Figure (2) and the following correlation was found:

$$P = b_0 + b_1 * S + b_2 * T_e + b_3 * S^2 + b_4 * S * T_e + b_5 * T_e^2 + b_6 * S^3 + b_7 * T_e * S^2 + b_8 * S * T_e^2 + b_9 * T_e^3 \quad \ldots(2)$$

**Table 2,**
**Coefficients of power consumption correlation.**

| Coefficient | Value | Range |
|---|---|---|
| $b_0$ | 42.46 | 17.59, 67.33 |
| $b_1$ | 28.26 | 21.07, 35.45 |
| $b_2$ | -0.1031 | -2.821, 2.615 |
| $b_3$ | 1.266 | 0.3142, 2.218 |
| $b_4$ | 0.9115 | 0.6466, 1.176 |
| $b_5$ | -0.01531 | -0.1325, 0.1019 |
| $b_6$ | -0.06662 | -0.1112, -0.022 |
| $b_7$ | -0.00426 | -0.01829, 0.009771 |
| $b_8$ | 0.003956 | -0.0003186, 0.00823 |
| $b_9$ | -0.0004349 | -0.002119, 0.001249 |
| Goodness of fit: $R^2$: 0.9945 | | |

The value of $R^2$ is 0.9945 which indicates the degree of correlation, i.e., (99.45%) of total variation included.

### 4.3. Refrigeration Mass Flow Rate

The results of the fitting are shown in Figure [3] and given by;

$$\dot{m}_r = c_0 + c_1 * S + c_2 * T_e + c_3 * S^2 + c_4 * S * T_e + c_5 * T_e^2 + c_6 * S^3 + c_7 * T_e * S^2 + c_8 * S * T_e^2 + c_9 * T_e^3 \quad \ldots(3)$$

**Table 3,**
**Coefficients of refrigerant mass flow rate correlation.**

| Coefficient | Value | Range |
|---|---|---|
| $c_0$ | -0.4668 | -1.29 ,0.3564 |
| $c_1$ | 1.55 | 1.312,1.788 |
| $c_2$ | 0.0006981 | -0.08926,0.09066 |
| $c_3$ | 0.007452 | -0.02405,0.03896 |
| $c_4$ | 0.05961 | 0.05085,0.06838 |
| $c_5$ | 0.0005814 | -0.003298,0.004461 |
| $c_6$ | -0.0009898 | -0.002467,0.0004873 |
| $c_7$ | -0.000175 | -0.0006394,0.0002894 |
| $c_8$ | 0.0006249 | 0.0004834,0.0007663 |
| $c_9$ | 1.29e-005 | -4.282e-005,6.863e-005 |
| Goodness of fit: $R^2$: 0.9955 | | |

Where the value of R2 is 0.9955 which indicates high dependability of fitted.

Table (5) indicates the minimum and the maximum deviation for each compressor from the results of equations 1, 2, 3 and the indications are:

-For cooling capacity Qe: It was found that 89 compressors have 30% deviation and 72 compressors have 15% deviation.The deviated compressor brands are Donper, Tee, K.K.

-For power consumption: the deviated compressors were found 59 within 30% deviation and 50 compressors within 15% deviation. The compressor brands that are deviated are Donper, K.K.

-For refrigerant mass flow rate: 29 compressors were found to be deviated with 30% and 25 compressors were found to be deviated ±15%.

The compressor brand that deviated is for TECUMSH, this brand is very dependable brand in the world and capacity, and the power data are within the 15% deviation.

Due to the high demand on the type of compressor that works at (54.4) ℃ condenser temperature and (-23.3) ℃ evaporator temperature for swept volume range [2.42-11.15] $cm^3$, the data of cooling capacity, power consumption, and refrigerant mass flow rate which are working according to ASHRAE standard 23-1993[9] are correlated where the refrigerant temperatures in the cycle as follows:

| Temperature location | ℃ |
|---|---|
| Condenser | 54.4 |
| evaporator | -23.3 |
| sub cooled | 32 |
| suction | 32 |
| Ambient | 32 |

The first number printed in the label plate of the compressors or refrigerators and freezers represents the power consumption (P). This number is used to calculate the swept volume via the following correlation to find the swept volume;

$$S = -3.46234361297 + (1.02257271308E - 001 * P) + (-3.29252164432E - 004 * P^2) + (7.45584362830E - 007 * P^3) \quad \ldots(4)$$

Standard Error is 0.0034096 with $R^2$= 0.9999991 ،

After that, the cooling capacity and the refrigerant mass flow rate can be found as follow according to the swept volume found:

$$Q_e = (-1.84013586272E + 001) + (2.65613665790E + 001 * S) + (4.59664932840E - 001 * S^2) + (-4.81895917828E - 002 * S^3) \quad \ldots(5)$$

Standard Error is 0.0249453 and $R^2$: 0.9999999.

$$\dot{m}_r = (-2.91401871854E - 001) + (4.95966412918E - 001 * S) + (1.23494398093E - 002 * S^2) + (-1.03344762424E - 003 * S^3) \quad \ldots(6)$$

Standard Error: 0.0030522 with $R^2$=0.9999974

Table (5) is included the deviation results for 76 compressors type according to swept volume. The table represents the cooling capacity, power consumption, and refrigerant mass flow rate for each one according to equations 1, 2, and 3 .

These correlations are very helpful for engineers and the designers in order to find the closed compressor type needed for replacement or for new refrigerators or freezers.

Figures 4, 5,and 6 show the results obtained by correlations 1, 2, 3 for each swept volume at -35 ℃ to -10℃ evaporator temperature and 54.4℃ fixed condensing temperature for cooling capacity, power consumption, and refrigerant mass flow rate. These figures are helpful to find the performance data of all compressors for a wide range of evaporator temperatures.

Figures 7, 8, and 9 depict the deviation of the correlated and standard data for cooling capacity, power consumption, and refrigerant mass flow rate, respectively. It can be seen that the deviation does not exceed the value of ∓15% for the three parameters, which is acceptable accuracy in practical engineering problems .

Figures (10-a to10-w), (11-a to 11-s), and (12-a to 12-w) represent the deviation between the calorimeter data and correlated data of cooling capacity, power consumption, and refrigerant mass flow rate for swept volume range (2.42 to 11.15) cm3 corresponding to various types compressors, as indicated at each figure. These detailed comparisons show a fairly good agreement with acceptable accuracy for services, maintenance and retrofit proposes.

**Table 4,**
**The available data of compressors brands.**

| Item | Swept | Compressor brand and legend | Data | | |
|---|---|---|---|---|---|
| | $cm^3$ | | Qe | P | mr |
| 1 | 2.24 | CUBIGEL (GD24AA) | Y | Y | Y |
| 2 | 2.5 | DANFOSS (PL50F) | Y | Y | Y |
| | 2.5 | CHINA(D25CZ) | Y | Y | Y |
| 3 | 2.61 | DANFOSS (TL2.5F) | Y | Y | Y |
| 4 | 2.7 | TECUMSEH(1324Y) | Y | N | N |
| 5 | 2.8 | TEE (AZ47YP) | Y | N | N |
| 6 | 3 | EMBRACO (EMT22HLP) | Y | N | N |
| | 3 | DONPER CHINA (D30CZ) | Y | N | N |
| 7 | 3.05 | CUBIGEL(GD30AA) | Y | Y | Y |
| 8 | 3.13 | DANFOSS (TL3F) | Y | Y | Y |
| 9 | 3.36 | ACC (OF605) | Y | Y | N |
| 10 | 3.38 | CUBIGEL(GL35AA) | Y | Y | Y |
| 11 | 3.58 | CUBIGEL (GD36AA) | Y | Y | Y |
| | 3.58 | TECUMSEH(THB1335Y) | Y | Y | Y |
| 12 | 3.59 | TEE (AZ68YD) | Y | N | N |
| 13 | 3.6 | DONPER CHINA (S36CS) | Y | N | N |
| 14 | 3.66 | ACC (GQY35AA) | Y | Y | N |
| 15 | 3.86 | DANFOSS (TL4F) | Y | Y | Y |
| 16 | 3.9 | KULTHORN KIRBY(AE1327Y) | Y | Y | N |
| 17 | 3.97 | EMBRACO (EMT36HLP) | Y | N | N |
| 18 | 4 | TEE (AZ82 YP) | Y | N | N |
| 19 | 4.01 | CUBIGEL (GL40AA) | Y | Y | Y |
| | 4.01 | ACC (GQY40AA) | Y | Y | N |
| 20 | 4.03 | CUBIGEL (GD40AA) | Y | Y | Y |
| 21 | 4.07 | ACC (GVM40AA) | Y | Y | N |
| 22 | 4.08 | KULTHORN KIRBY(AE1330Y) | Y | Y | N |
| 23 | 4.23 | TECUMSEH(THB 1340Y) | Y | Y | Y |
| 24 | 4.3 | CHINA(S43BZ) | Y | N | N |
| 25 | 4.38 | ACC(OF789.02) | Y | Y | N |
| 26 | 4.56 | CUBIGEL (GL45AA) | Y | Y | Y |
| 27 | 4.6 | KULTHORN KIRBY(AE1335Y) | Y | Y | N |
| 28 | 4.85 | EMBRACO (EMT43HLP) | Y | N | N |
| 29 | 5.0 | TEE(AZ90 YP) | Y | N | N |
| | 5.0 | DONPER CHINA(S50CZA) | Y | N | N |
| 30 | 5.08 | DANFOSS (TLS5F) | Y | Y | Y |
| 31 | 5.11 | KULTHORN KIRBY(AE1340Y) | Y | Y | N |
| 32 | 5.12 | CUBIGEL (GL50AA) | Y | Y | Y |
| 33 | 5.2 | TECUMSEH(THB1350Y) | Y | Y | Y |
| 34 | 5.3 | CHINA(S53BZ) | Y | N | N |
| 35 | 5.46 | ACC(GL50AA.02) | Y | Y | N |
| 36 | 5.5 | Donper CHINA(EK1112CZA) | Y | N | N |
| 37 | 5.56 | EMBRACO (EMT49HLP) | Y | N | N |
| 38 | 5.58 | TECUMSEH(THB1350YS) | Y | Y | Y |
| 39 | 5.7 | DANFOSS (TLS6F) | Y | Y | Y |
| | 5.7 | ACC (GVM57AA) | Y | Y | N |
| 40 | 5.75 | TEE(AE148 YP) | Y | N | N |
| 41 | 5.8 | DONPER CHINA(L58CZ) | Y | N | N |
| 42 | 5.99 | CUBIGEL (GL60AA) | Y | Y | Y |
| | 5.99 | KULTHORN KIRBY(AE1350Y) | Y | Y | N |
| | 5.99 | ACC(GQY60AA) | Y | Y | N |
| 43 | 6.1 | TECUMSEH(THB 1360 Y) | Y | Y | Y |
| 44 | 6.13 | DANFOSS (NL6F) | Y | Y | Y |
| 45 | 6.2 | EMBRACO(NBT1114Z) | Y | N | N |
| 46 | 6.3 | DONPER CHINA(EK1114CZA) | Y | N | N |
| 47 | 6.49 | DANFOSS (TLS7F) | Y | Y | Y |
| 48 | 6.5 | DONPER CHINA(L58CZ) | Y | N | N |
| 49 | 6.6 | ACC(GVM66AA) | Y | Y | N |
| 50 | 6.64 | CUBIGEL (GL70AA) | Y | Y | Y |
| | 6.64 | ACC(L70AN.02) | Y | Y | N |
| 51 | 6.76 | EMBRACO (EMT60HLP) | Y | N | N |
| 52 | 6.9 | DONPER CHINA(EK1116CZA) | Y | N | N |
| 53 | 6.91 | KULTHORN KIRBY (AE1360Y) | Y | Y | N |
| | 6.91 | TEE (AE148 YP) | Y | N | N |
| 54 | 6.93 | DANFOSS(FR7.5F) | Y | Y | Y |
| 55 | 7.0 | ACC(GVY66AA.01) | Y | Y | N |
| 56 | 7.2 | DONPER CHINA(EK1118CZA) | Y | N | N |
| | 7.2 | DONPER CHINA(L72CZ) | Y | N | N |
| 57 | 7.27 | DANFOSS (NL7F) | Y | Y | Y |
| 58 | 7.39 | CUBIGEL (GL75AA) | Y | Y | Y |
| | 7.39 | ACC (GL80AA.02) | Y | Y | N |
| 59 | 7.4 | EMBRACO (NBT1116Z) | Y | N | N |
| 60 | 7.52 | ACC (GVY75AA) | Y | Y | N |
| 61 | 7.94 | TEE (AE176 YP) | Y | N | N |
| 62 | 7.95 | DANFOSS (NL8F) | Y | Y | N |
| 63 | 8.07 | EMBRACO(NB1118Z) | Y | N | N |
| 64 | 8.09 | ACC (GL80AN) | Y | Y | N |
| 65 | 8.1 | CUBIGEL (GL80AA) | Y | Y | Y |
| | 8.1 | EMBRACO (NB1116Z) | Y | N | N |
| 66 | 8.12 | KULTHORN KIRBY (AE1370Y) | Y | Y | N |
| 67 | 8.35 | DANFOSS (NL9F) | Y | Y | Y |
| 68 | 8.8 | TECUMSEH (AEZ 1365Y) | Y | Y | N |
| 69 | 8.99 | TEE (AE196YP) | Y | N | N |
| 70 | 9.05 | DANFOSS (FR10F) | Y | Y | Y |
| | 9.05 | ACC (GQY90AA) | Y | Y | N |
| 71 | 9.08 | CUBIGEL (GL90AA) | Y | Y | Y |
| 72 | 9.27 | EMBRACO (NE1121Z) | Y | N | N |
| 73 | 9.407 | TECUMSEH (AEA 1410 YXC) | Y | Y | Y |
| 74 | 9.42 | KULTHORN KIRBY(AE2390Y) | Y | Y | N |
| 75 | 9.93 | CUBIGEL (GL99AA) | Y | Y | Y |
| 76 | 11.15 | DANFOSS (NL11F) | Y | Y | Y |

| | |
|---|---|
| Number of compressors to find the general equations(yellow) | 25 |
| Total number of compressors with swept volume | 90 |
| Total number of cooling capacity data compressors | 90 |
| Total number of power data compressors | 59 |
| Total number of refrigerant mass flow rate data compressors | 34 |

Y: available data N: not available

**Table 5,**
**The deviations from the surface fitting model.**

| Item | Swept | Compressor brand and legend | Deviations | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Qe % | | P % | | mr % | |
| | $cm^3$ | | min | max | min | max | min | max |
| 1 | 2.24 | CUBIGEL (GD24AA) | 0 | 2.3 | 1.1 | 7.5 | 0 | 13 |
| 2 | 2.5 | DANFOSS (PL50F) | -10 | -4.5 | 13 | 15 | -8 | 5 |
| | 2.5 | CHINA(D25CZ) | -9 | -1 | 18 | 23 | 4 | 14 |
| 3 | 2.61 | DANFOSS (TL2.5F) | 9 | 15 | 12 | 14 | 9 | 15 |
| 4 | 2.7 | TECUMSEH(1324Y) | 2 | 36 | X | X | X | X |
| 5 | 2.8 | TEE (AZ47YP) | 3 | 22 | X | X | X | X |
| 6 | 3 | EMBRACO (EMT22HLP) | -17 | -12 | X | X | X | X |
| | 3 | DONPER CHINA (D30CZ) | -6 | 11 | X | X | X | X |
| 7 | 3.05 | CUBIGEL(GD30AA) | -6 | 2 | -4 | -1 | -3 | 3 |
| 8 | 3.13 | DANFOSS (TL3F) | 7 | 14 | 14 | 15 | 8 | 15 |
| 9 | 3.36 | ACC (OF605) | -10 | 2 | 5 | 14 | X | X |
| 10 | 3.38 | CUBIGEL(GL35AA) | -6 | 4 | -4 | 0 | -4 | 4 |
| 11 | 3.58 | CUBIGEL (GD36AA) | 1 | 6 | -2 | 2 | 0 | 10 |
| | 3.58 | TECUMSEH(THB1335Y) | -12 | -3 | 4 | 7 | 30 | 33 |
| 12 | 3.59 | TEE (AZ68YD) | 9 | 16 | X | X | X | X |
| 13 | 3.6 | DONPER CHINA (S36CS) | -10 | -4 | X | X | X | X |
| 14 | 3.66 | ACC (GQY35AA) | -12 | -7 | 13 | 18 | X | X |
| 15 | 3.86 | DANFOSS (TL4F) | 0 | 7 | 8 | 11 | 0 | 8 |
| 16 | 3.9 | KULTHORN | 3 | 25 | 17 | 21 | X | X |
| 17 | 3.97 | EMBRACO (EMT36HLP) | -23 | -12 | X | X | X | X |
| 18 | 4 | TEE (AZ82 YP) | 6 | 12 | X | X | X | X |
| 19 | 4.01 | CUBIGEL (GL40AA) | 0 | 10 | 4 | 9 | 0 | 15 |
| | 4.01 | ACC (GQY40AA) | -11 | -8 | 13 | 17 | X | X |
| 20 | 4.03 | CUBIGEL (GD40AA) | -1 | 2 | -7 | -3 | 2 | 7 |
| 21 | 4.07 | ACC (GVM40AA) | -24 | -10 | 4 | 6 | X | X |
| 22 | 4.08 | KULTHORN | 6 | 17 | 20 | 26 | X | X |
| 23 | 4.23 | TECUMSEH(THB 1340Y) | -7 | 0 | 7.13 | 7.36 | 30 | 35 |
| 24 | 4.3 | CHINA(S43BZ) | -5 | 7 | X | X | X | X |
| 25 | 4.38 | ACC(OF789.02) | -13 | -11 | -5 | 0 | X | X |
| 26 | 4.56 | CUBIGEL (GL45AA) | 0 | 8 | 3 | 5 | 0 | 6 |
| 27 | 4.6 | KULTHORN | -3 | 15 | 8 | 11.5 | X | X |
| 28 | 4.85 | EMBRACO (EMT43HLP) | -19 | -10 | X | X | X | X |
| 29 | 5.0 | TEE(AZ90 YP) | 24 | 25 | X | X | X | X |
| | 5.0 | DONPER CHINA(S50CZA) | -5 | 7 | X | X | X | X |
| 30 | 5.08 | DANFOSS (TLS5F) | -11 | -8 | -3.5 | 3.5 | -4 | 0 |
| 31 | 5.11 | KULTHORN | -15 | 16 | 3 | 9 | X | X |
| 32 | 5.12 | CUBIGEL (GL50AA) | -2 | 4 | 0 | 3 | 0 | 6 |
| 33 | 5.2 | TECUMSEH(THB1350Y) | 2 | 6 | 4 | 6 | 35 | 38 |
| 34 | 5.3 | CHINA(S53BZ) | -10 | 10 | X | X | X | X |
| 35 | 5.46 | ACC(GL50AA.02) | 2 | 4 | 3 | 5 | X | X |
| 36 | 5.5 | Donper CHINA(EK1112CZA) | -8 | -6 | X | X | X | X |
| 37 | 5.56 | EMBRACO (EMT49HLP) | -7 | -15 | X | X | X | X |
| 38 | 5.58 | TECUMSEH(THB1350YS) | 9 | 14 | 10 | 10.5 | 40 | 43 |
| 39 | 5.7 | DANFOSS (TLS6F) | -6 | -2 | 0 | 3 | -7 | 0 |
| | 5.7 | ACC (GVM57AA) | -14 | -8 | -4 | 2 | X | X |
| 40 | 5.75 | TEE(AE148 YP) | 11 | 12 | X | X | X | X |
| 41 | 5.8 | DONPER CHINA(L58CZ) | -19 | -5 | X | X | X | X |
| 42 | 5.99 | CUBIGEL (GL60AA) | 0 | 5 | -3 | 0 | 0 | 6 |
| | 5.99 | KULTHORN | -5 | 9 | -5 | 5 | X | X |
| | 5.99 | ACC(GQY60AA) | -10 | -6 | 8 | 11 | X | X |
| 43 | 6.1 | TECUMSEH(THB 1360 Y) | -2 | 4 | -2 | 7 | 34 | 39 |
| 44 | 6.13 | DANFOSS (NL6F) | -5 | 5 | 5 | 9 | -5 | 6 |
| 45 | 6.2 | EMBRACO(NBT1114Z) | -6 | -4 | X | X | X | X |
| 46 | 6.3 | DONPER | -10 | -8 | X | X | X | X |
| 47 | 6.49 | DANFOSS (TLS7F) | -5 | -1 | -2 | 0 | -5 | 0 |
| 48 | 6.5 | DONPER CHINA(L58CZ) | 0 | 6 | X | X | X | X |
| 49 | 6.6 | ACC(GVM66AA) | -11 | -7 | -4 | -1 | X | X |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 50 | 6.64 | CUBIGEL (GL70AA) | 0 | 5 | -3 | 0 | 0 | 9.5 |
| | 6.64 | ACC(L70AN.02) | -8 | -4 | -12 | -3 | X | X |
| 51 | 6.76 | EMBRACO (EMT60HLP) | -9 | -3 | X | X | X | X |
| 52 | 6.9 | DONPER | -12 | -3 | X | X | X | X |
| 53 | 6.91 | KULTHORN KIRBY | -3 | 9 | 2 | 6 | X | X |
| | 6.91 | TEE (AE148 YP) | 12 | 14 | X | X | X | X |
| 54 | 6.93 | DANFOSS(FR7.5F) | 5 | 14 | 8 | 11 | 8 | 20 |
| 55 | 7.0 | ACC(GVY66AA.01) | -8 | -4 | 4 | 9 | X | X |
| 56 | 7.2 | DONPER | -28 | 6 | X | X | X | X |
| | 7.2 | DONPER CHINA(L72CZ) | -6 | 9 | X | X | X | X |
| 57 | 7.27 | DANFOSS (NL7F) | -6 | -3 | -2 | 6 | -4 | 2 |
| 58 | 7.39 | CUBIGEL (GL75AA) | 0 | 3 | 0 | 4 | 2 | 8 |
| | 7.39 | ACC (GL80AA.02) | -8 | -5 | 0 | 2 | X | X |
| 59 | 7.4 | EMBRACO (NBT1116Z) | -5.3 | -4.3 | X | X | X | X |
| 60 | 7.52 | ACC (GVY75AA) | -9 | -7 | 3 | 7 | X | X |
| 61 | 7.94 | TEE (AE176 YP) | 10 | 12 | X | X | X | X |
| 62 | 7.95 | DANFOSS (NL8F) | -7 | -4 | -4 | 6 | X | X |
| 63 | 8.07 | EMBRACO(NB1118Z) | -1.5 | 1.5 | X | X | X | X |
| 64 | 8.09 | ACC (GL80AN) | -2 | 5 | -8 | -2 | X | X |
| 65 | 8.1 | CUBIGEL (GL80AA) | 0 | 9 | -3 | 3 | 0 | 10 |
| | 8.1 | EMBRACO (NB1116Z) | -6 | 10 | X | X | X | X |
| 66 | 8.12 | KULTHORN KIRBY | -16 | 16 | -6 | 13 | X | X |
| 67 | 8.35 | DANFOSS (NL9F) | -3 | 3 | 0 | 5 | -2 | 3 |
| 68 | 8.8 | TECUMSEH (AEZ 1365Y) | 10 | 26 | 0 | 8 | X | X |
| 69 | 8.99 | TEE (AE196YP) | 10 | 12.5 | X | X | X | X |
| 70 | 9.05 | DANFOSS (FR10F) | 2 | 16 | 6 | 9 | 10 | 12.5 |
| | 9.05 | ACC (GQY90AA) | -15 | -6 | 0 | 7 | X | X |
| 71 | 9.08 | CUBIGEL (GL90AA) | 0 | 3 | -6 | -3 | 3 | 6 |
| 72 | 9.27 | EMBRACO (NE1121Z) | -10 | -8 | X | X | X | X |
| 73 | 9.407 | TECUMSEH (AEA 1410 | -8 | 0 | -30 | -12 | -3 | 12 |
| 74 | 9.42 | KULTHORN | 2 | 20 | -3 | 12 | X | X |
| 75 | 9.93 | CUBIGEL (GL99AA) | 2 | 9 | 1 | 2.5 | -5 | 7 |
| 76 | 11.15 | DANFOSS (NL11F) | -4 | -1 | -2 | 4 | -4 | 2 |
| Total number of compressors with 15% ***cooling capacity*** deviation | | | | | | | 72 | 18 |
| Total number of compressors with 15% ***power*** deviation | | | | | | | 50 | 9 |
| Total number of compressors with 15% ***refrigerant mass flow rate*** deviation | | | | | | | 25 | 9 |
| Compressors Brand: Electrolux CUBIGEL, Danfoss, Tecumseh, TEE, Embraco, ACC, KULTHORN KIRBY(TURKY) , DONPER(CHINA) | | | | | | | 8 | |

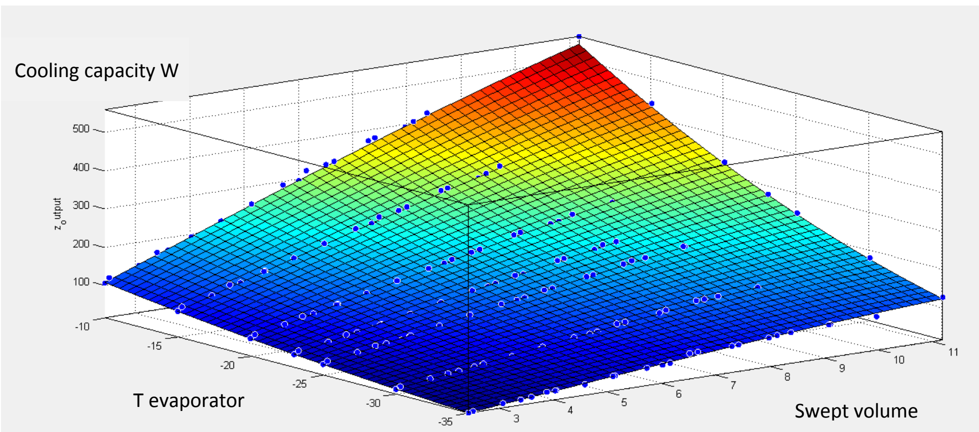



**Fig. 1. Show the surface fitting for compressors cooling capacity via Te & swept volume.**

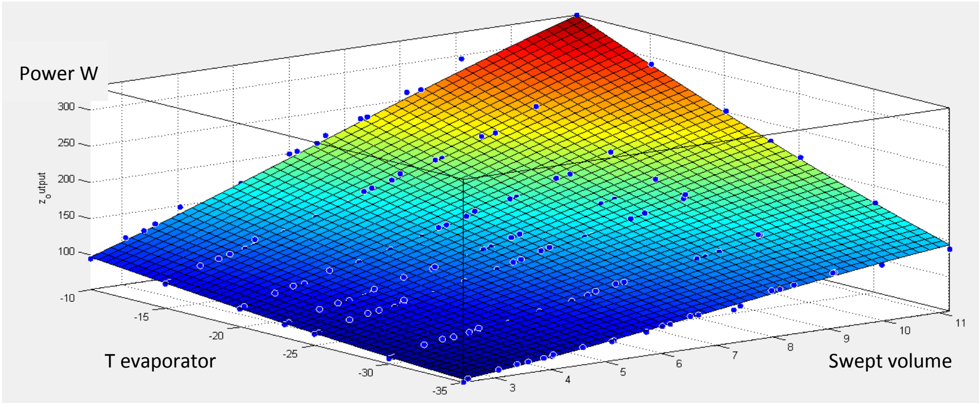



**Fig. 2. Show the surface fitting for compressors power via Te & swept volume.**

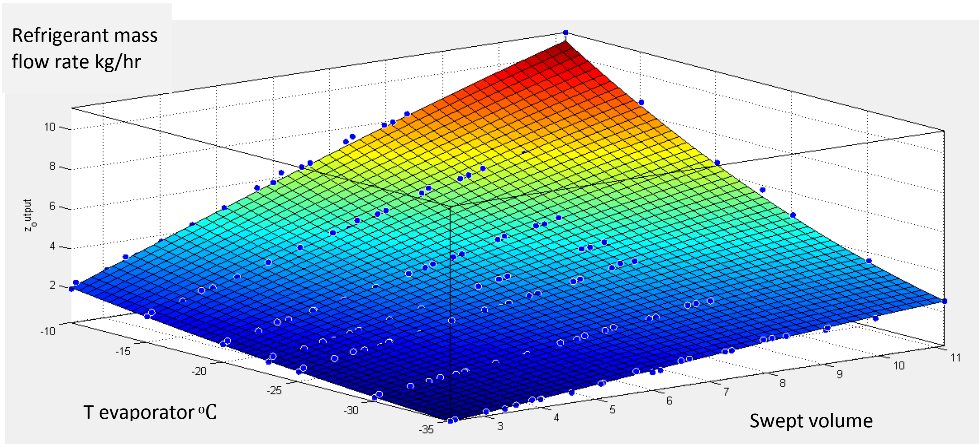



**Fig. 3. Show the surface fitting for compressors refrigerant mass flow rate via Te & swept volume.**

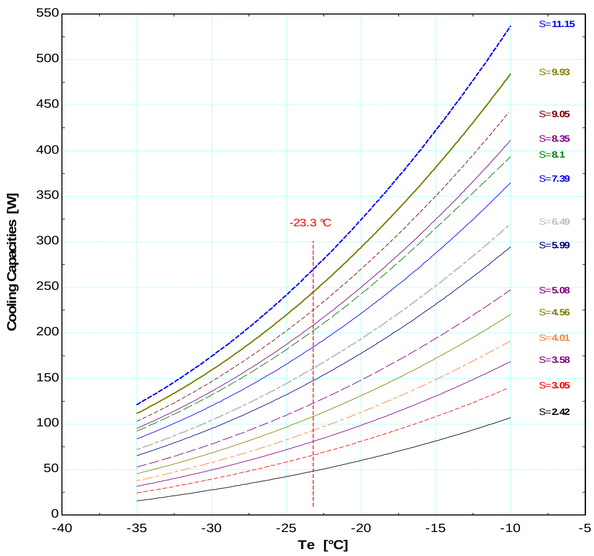



**Fig. 4. The cooling capacity curves for the compressors via the evaporator temperatures for range of swept volume [S=2.42 to 11.15] cm$^3$.**

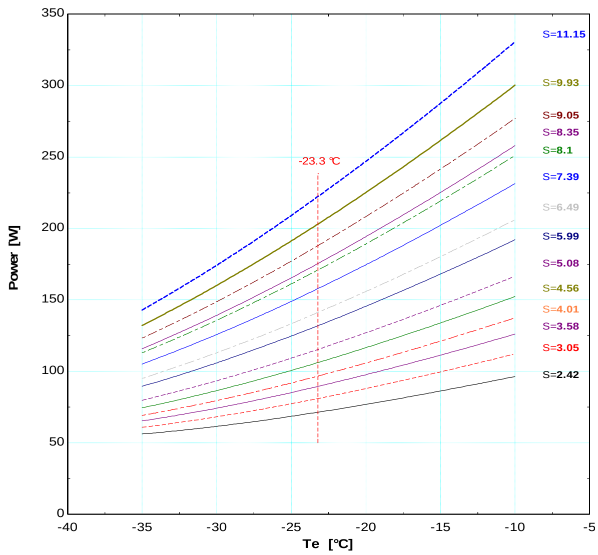



**Fig. 5. Power consumption curves for the compressors via the evaporator temperatures for range of swept volume [S=2.42 to 11.15] cm$^3$.**

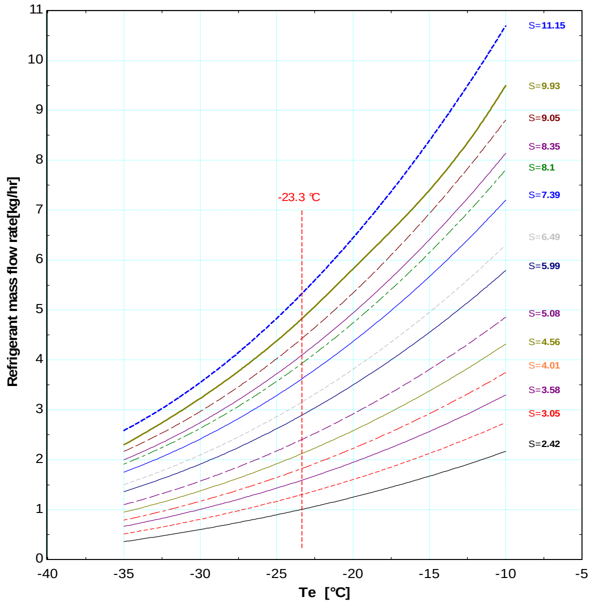



**Fig. 6. Refrigerant mass flow rate curves for the compressors via the evaporator temperatures for range of swept volume [S=2.42-11.15] cc.**

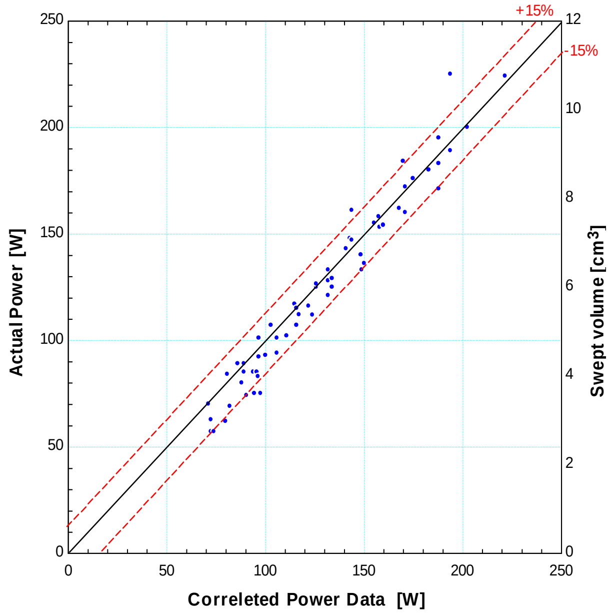



**Fig. 8. The deviation for the power consumption between correlated results and available Data.**

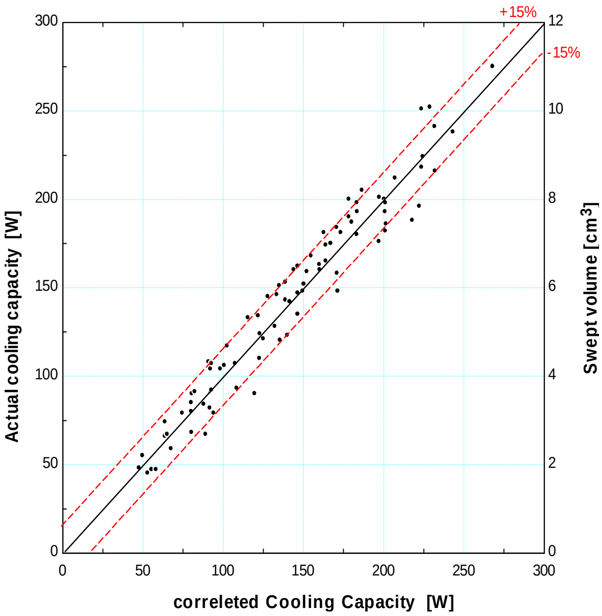



**Fig. 7. The deviation for the cooling capacity between correlated results and available Data**.

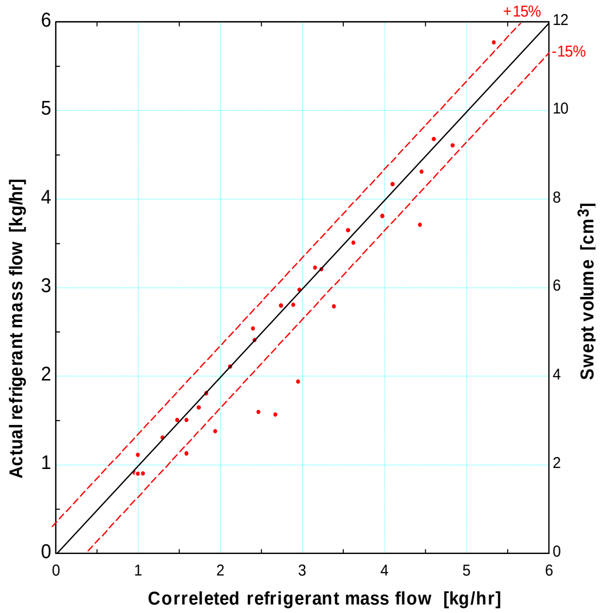
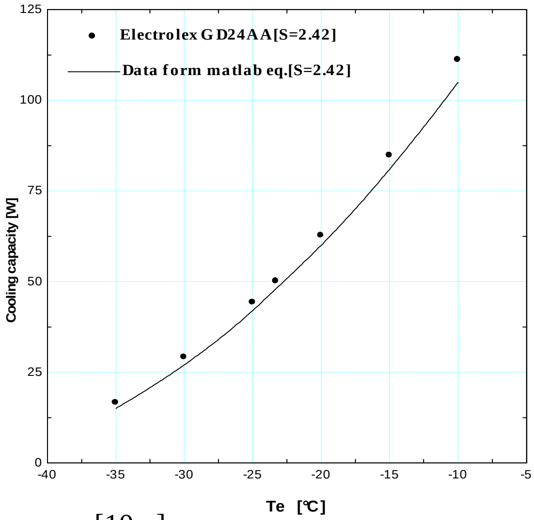
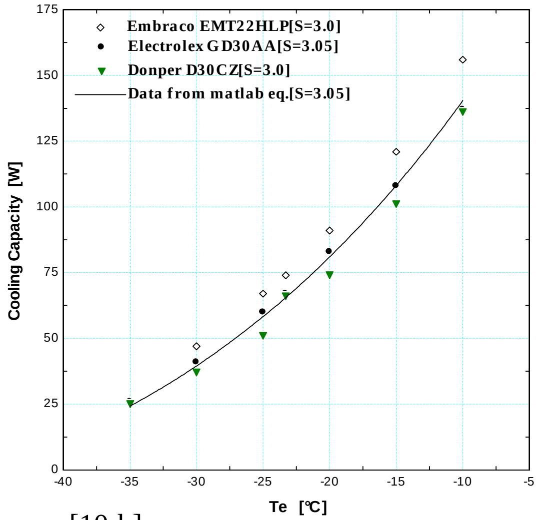


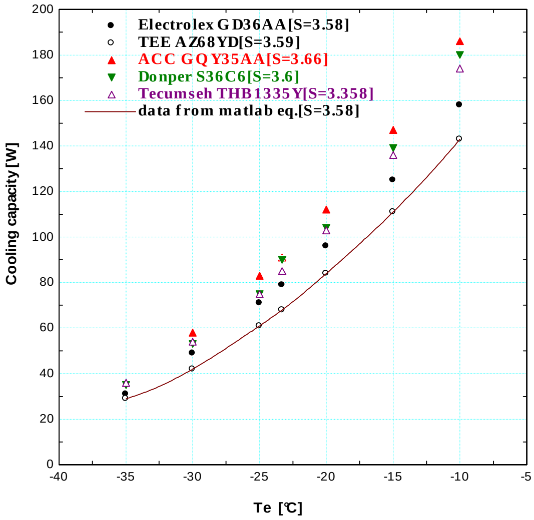

**Fig. 9. The deviation for the Refrigerant mass flow rate between correlated results and available Data.**



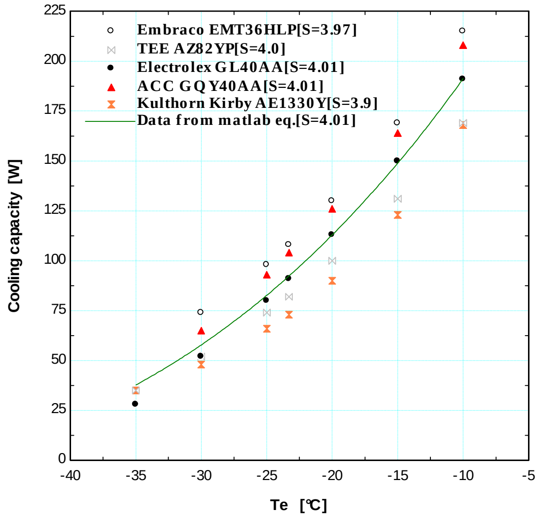

[10-a]



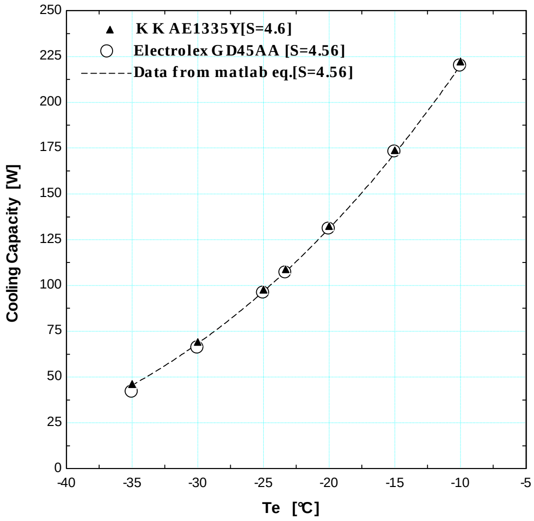

[10-b]



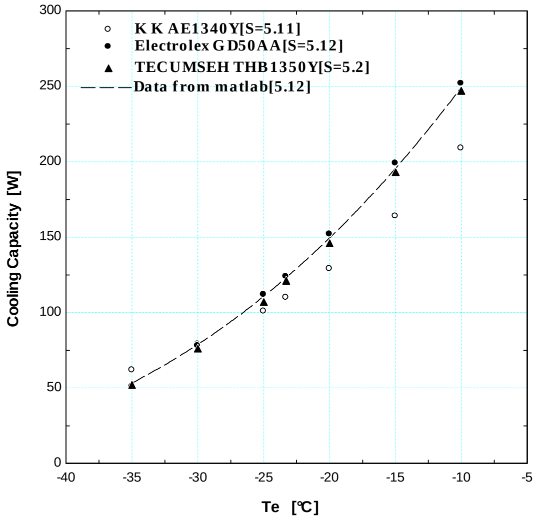

[10-c]



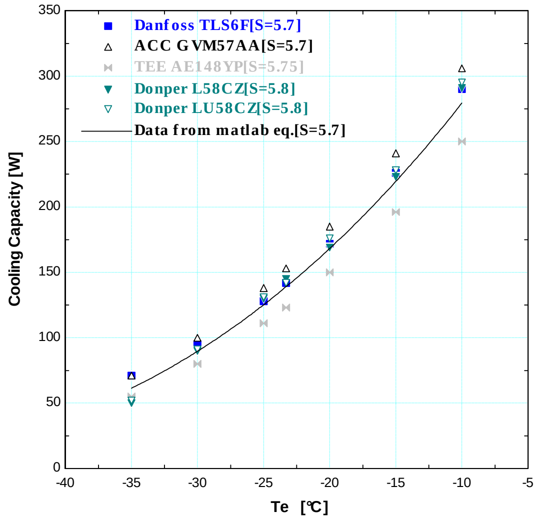

[10-d]



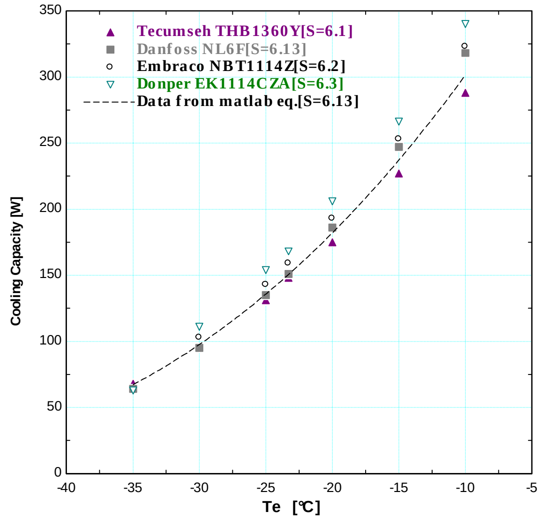

[10-e]



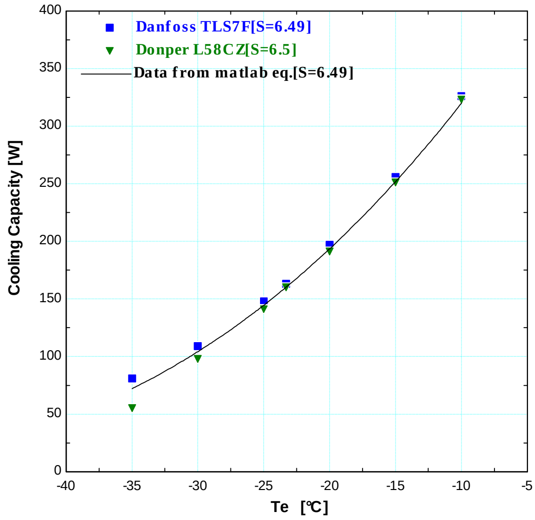

[10-f]



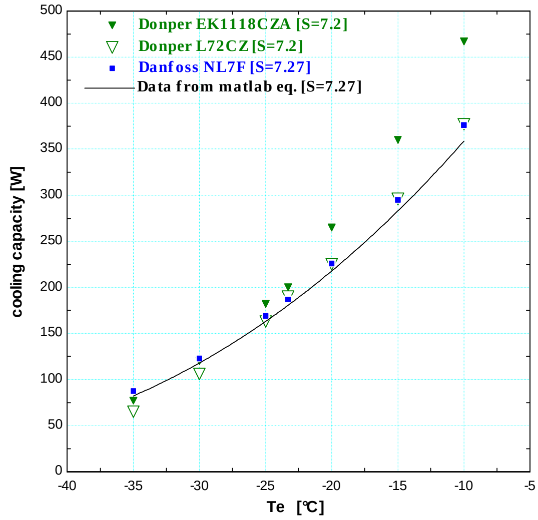

[10-g]



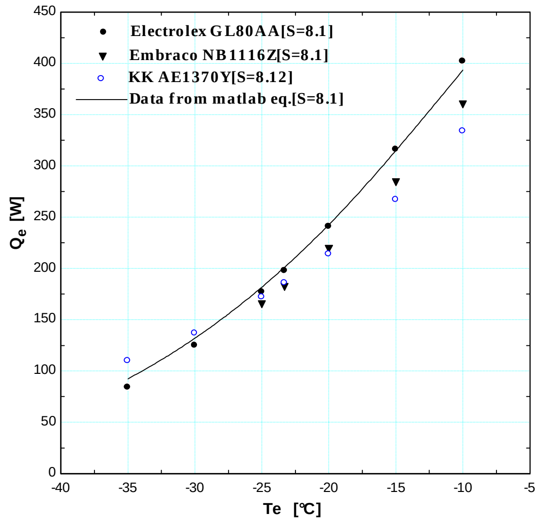

[10-h]



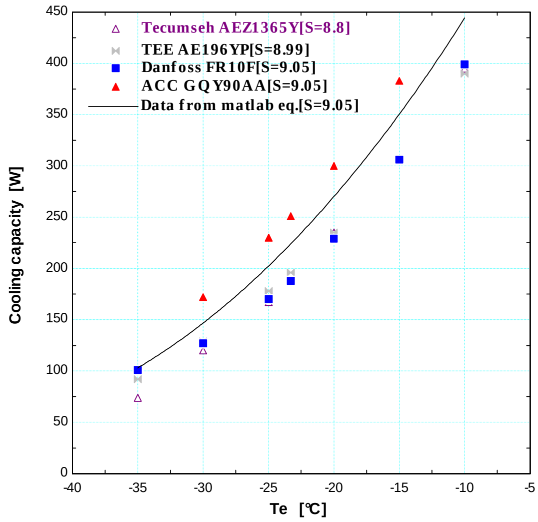

[10-i]



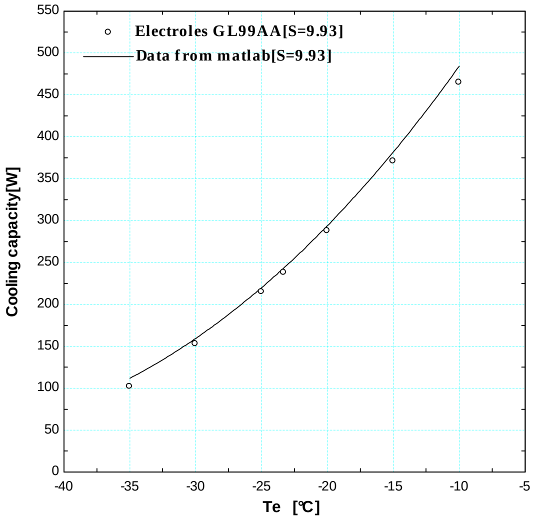

[10-j]



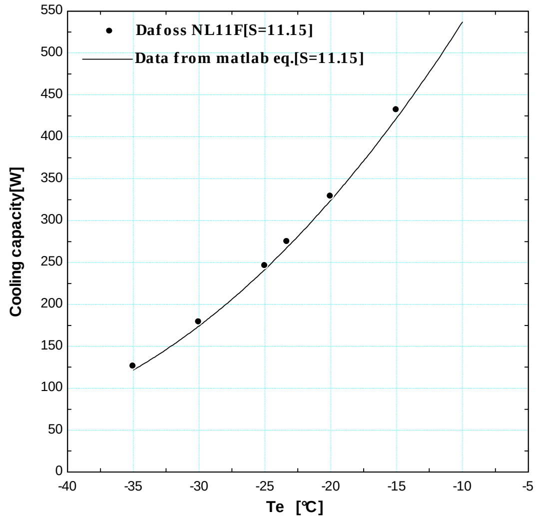

[10-k]




[10-l]

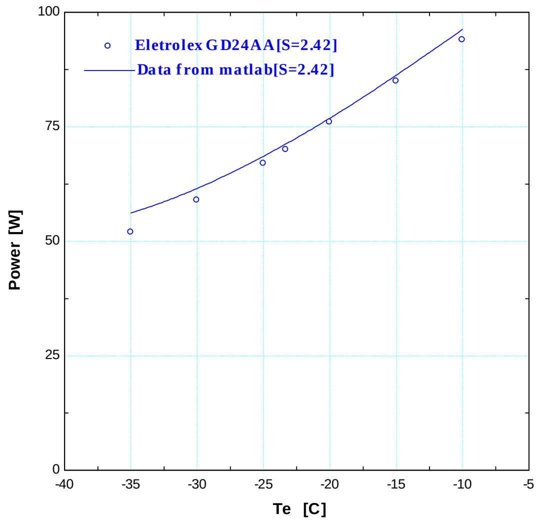



[10-m]

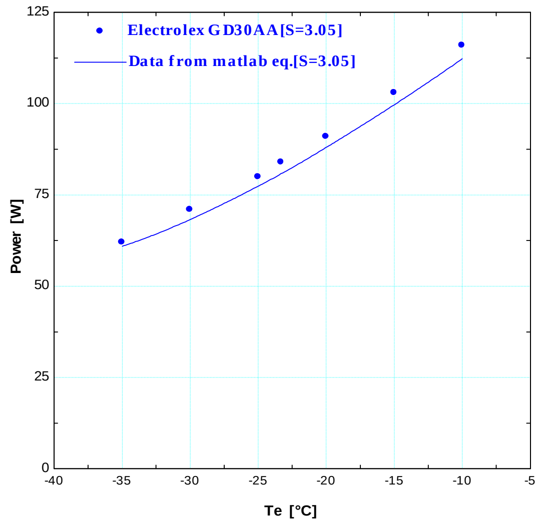



[10-n]

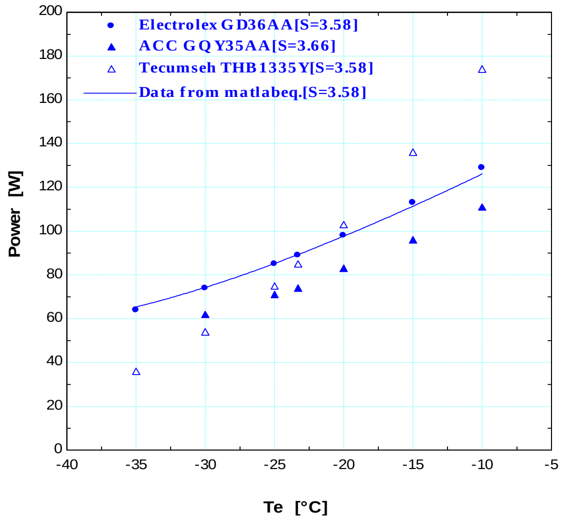
**Fig. 10-a to 10-n. Show the deviation of the calorimeter data from correlated data for cooling capacity for the range of swept volume [2.42 to 11.15] cm$^3$.**



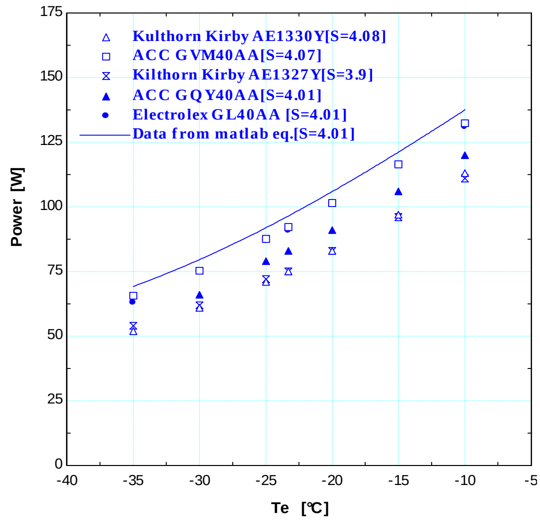

[11-a]



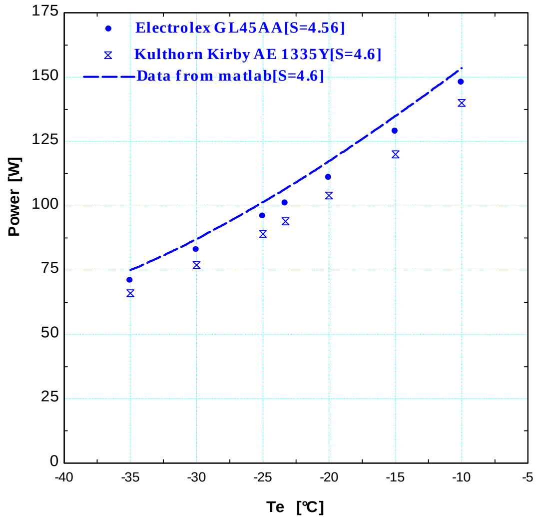

[11-b]



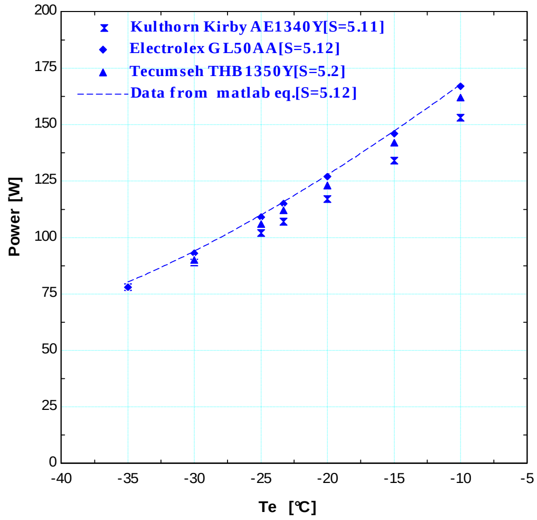

[11-c]



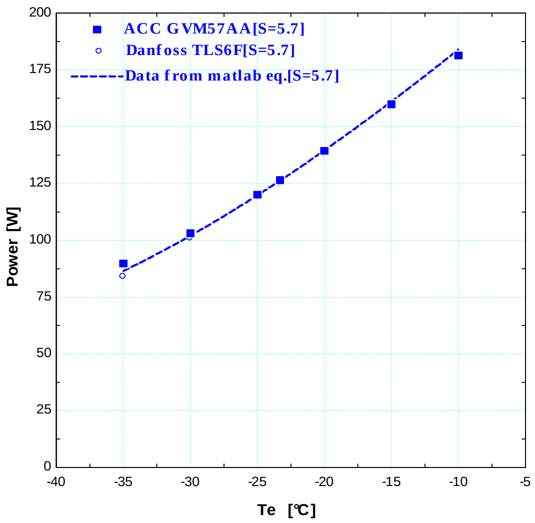

[11-d]



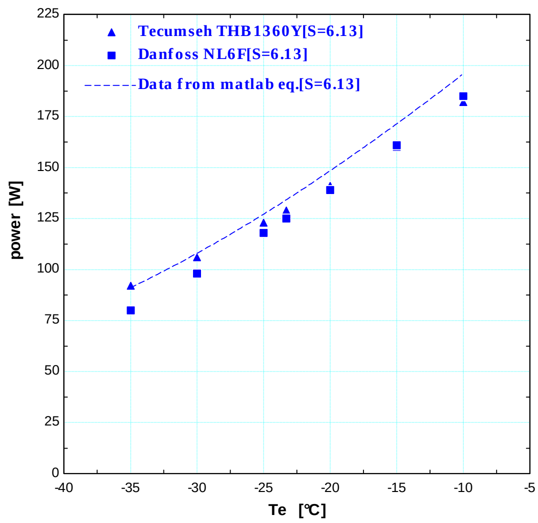

[11-e]



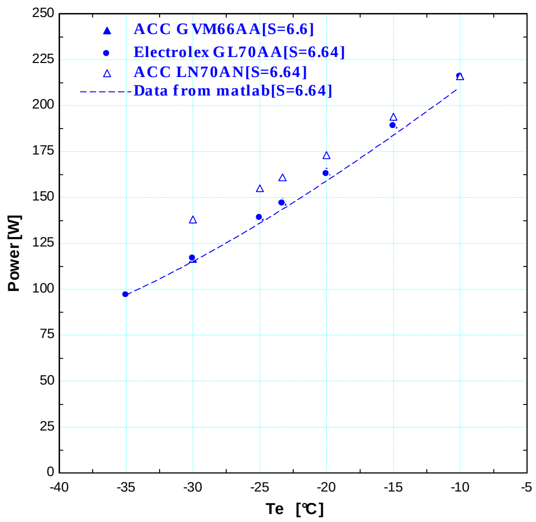

[11-f]



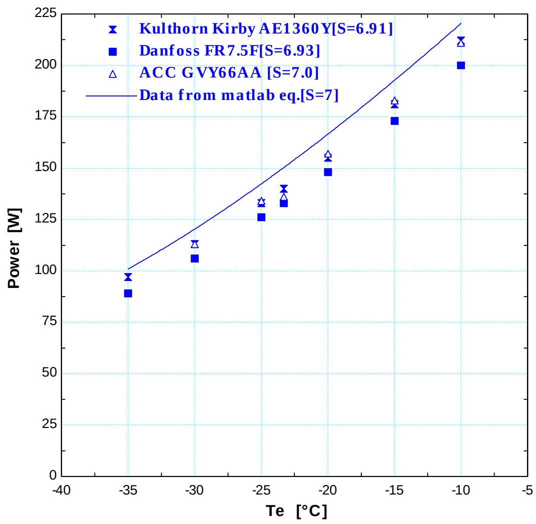

[11-g]



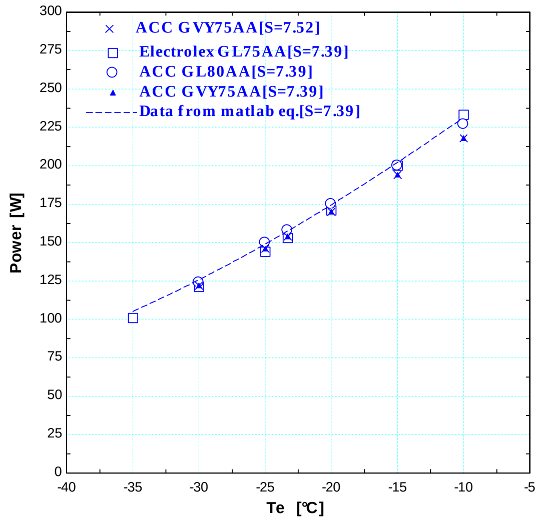

[11-h]



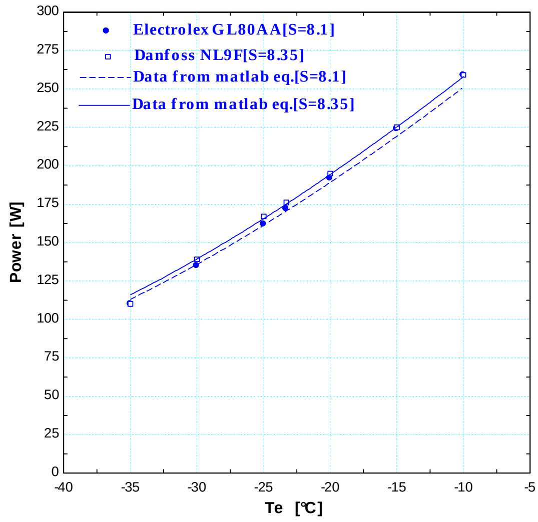

[11-i]



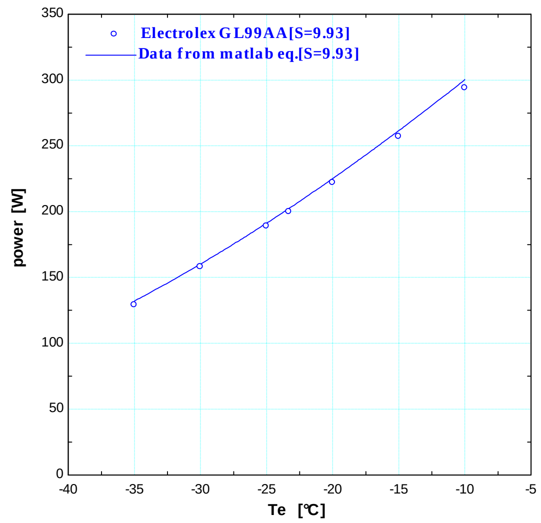

[11-j]



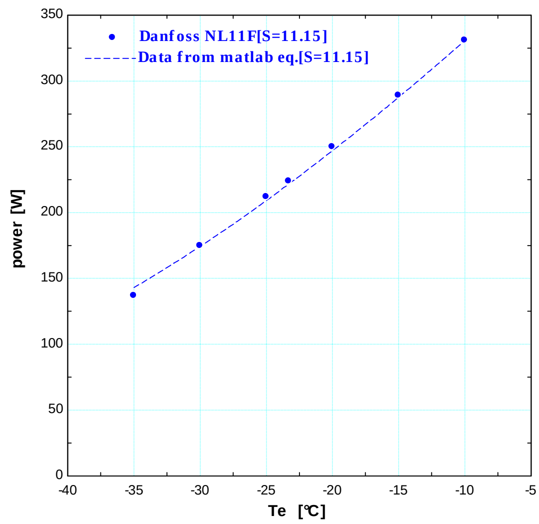

[11-k]




[11-l]

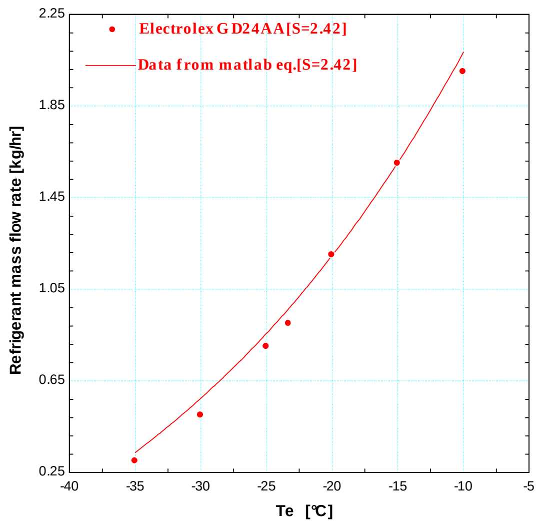



[11-m]

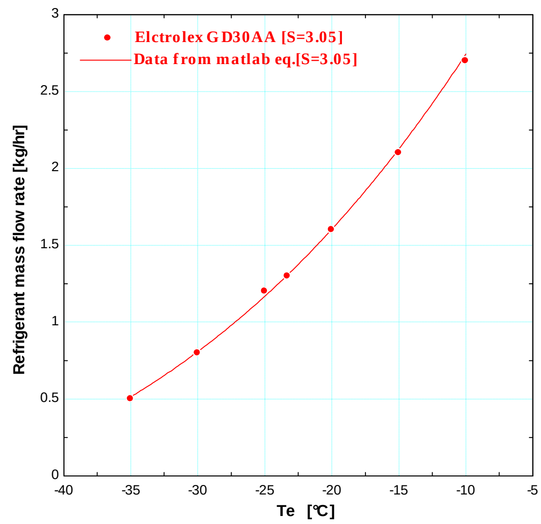



[11-n]

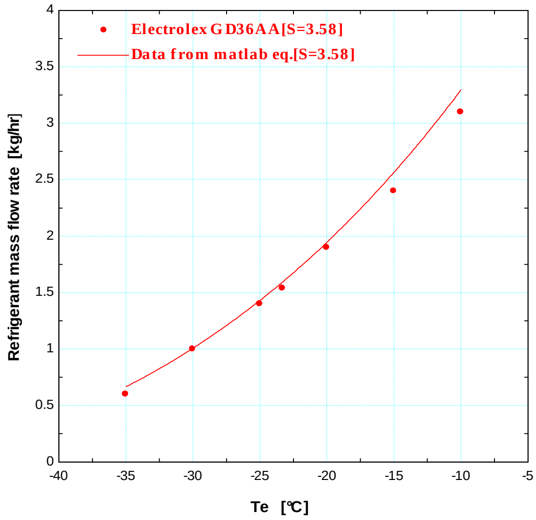
**Fig. [11-a to 11-n]. Show the deviation of the calorimeter data from correlated data for power consumption for the range of swept volume [2.42-11.15] cm$^3$.**



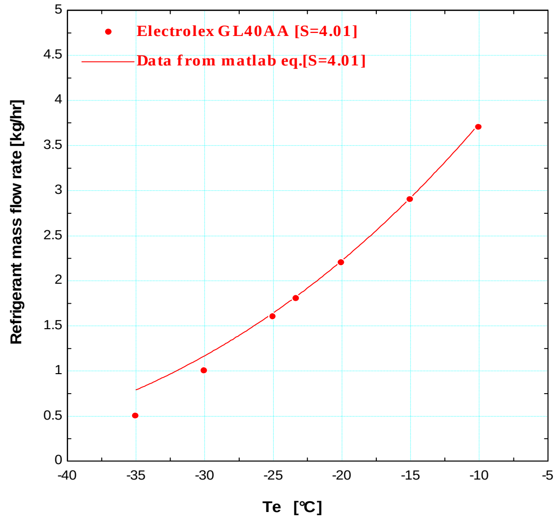

[12-a]



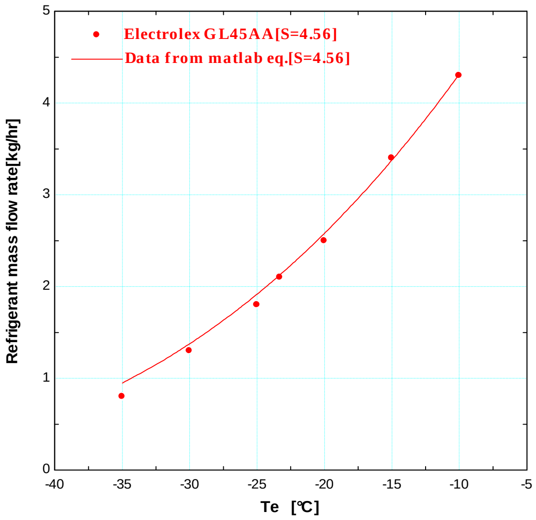

[12-b]



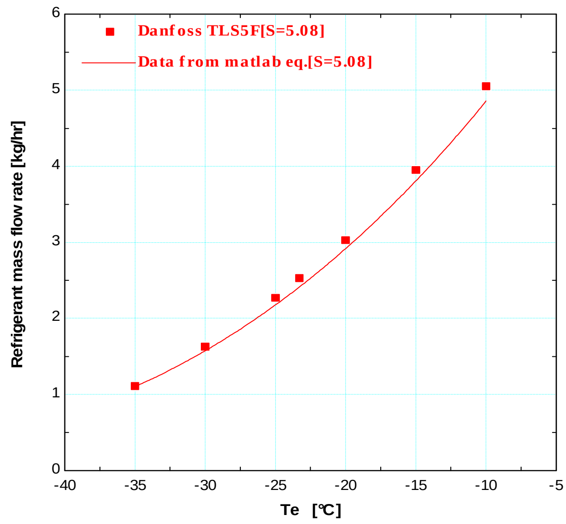

[12-c]



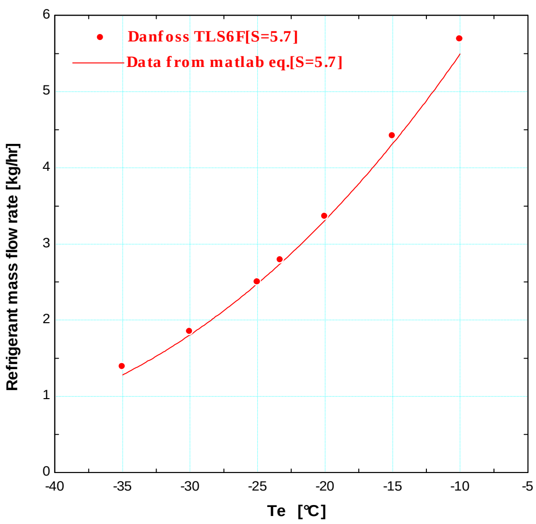

[12-d]



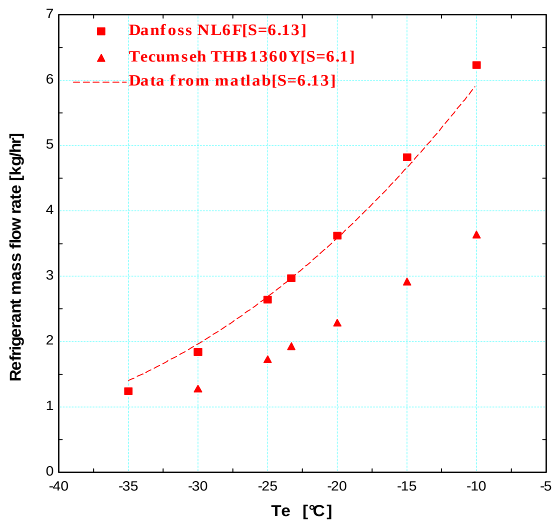

[12-e]



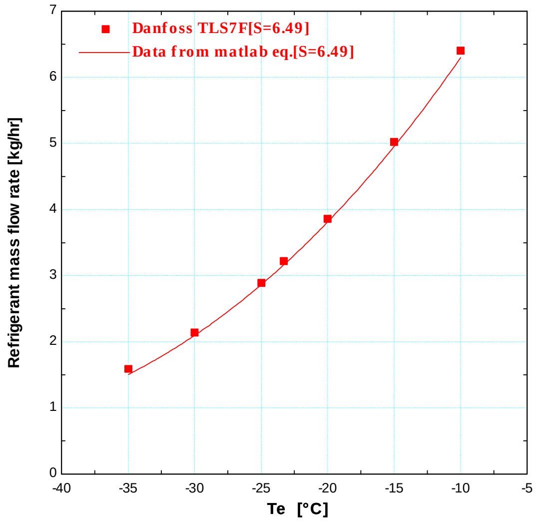

[12-f]



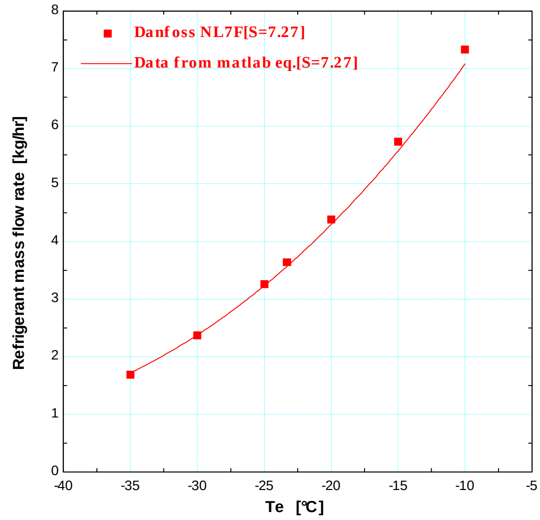

[12-g]



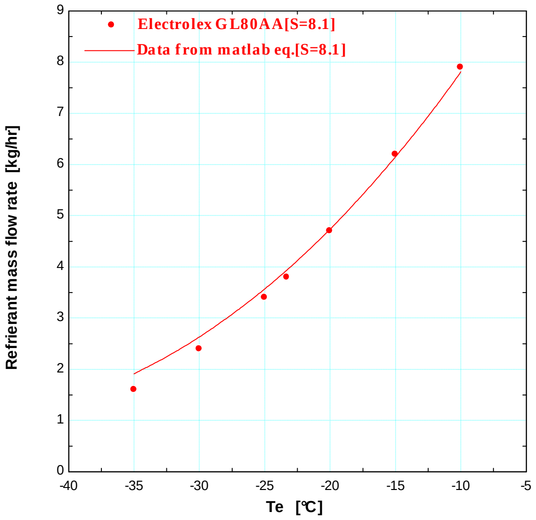

[12-h]



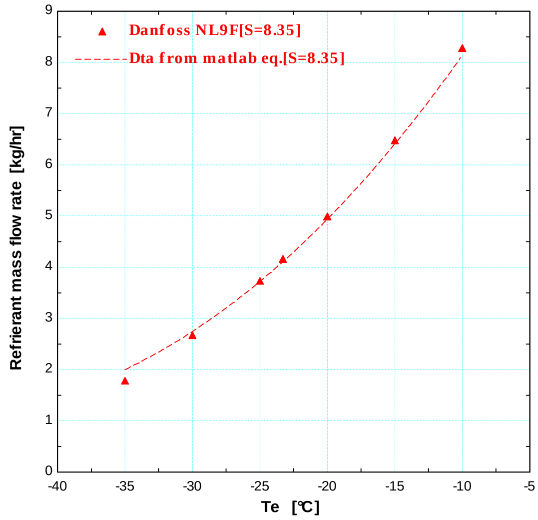

[12-i]



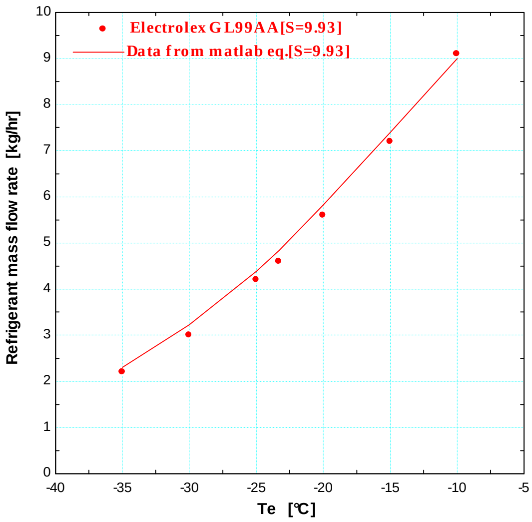

[12-j]



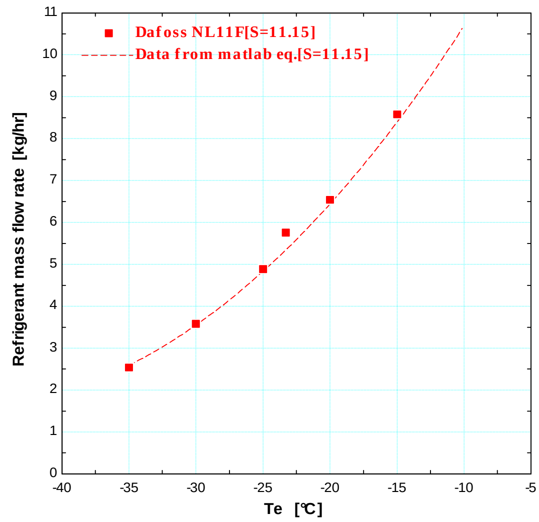

[12-k]




[12-l]




[12-m]




[12-n]

**Fig. [12-a to 12-n]. Show the deviation of the calorimeter data from correlated data for refrigerant mass flow rate for the range of swept volume [2.42-11.15] cm$^3$.**

## 5. Conclusion

Semi-empirical models were found to represent household compressors. First: The calorimeter data which are correlated (according to ARI standard 540-90) which must involve to coefficients to cover the swept volume range (2.24-11.15) $cm^3$ at constant condensing temperature 54.4 ℃ and evaporating temperature range (-35 to -10)℃, by using Matlab software-surface fitting method as in equations (1),(2), and (3). The models represent the cooling capacity, power consumption, and refrigerant mass flow rate with ∓15% deviation.

Second: Another correlations as quick selection was found depending on the label power consumption and according to SHRAE standard 23-1993, in order to find the household compressor specifications, like swept volume and cooling capacity as in equations (4), (5), and (6).

## List of symbols

| | | |
|---|---|---|
| $a_1,a_2,\ldots,a_9$ | Constant | |
| ARI | Air conditioning and Refrigeration Institute | |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers | |
| $b_1,b_2,\ldots,b_9$ | constant | |
| $c_1,c_2,\ldots,c_9$ | constant | |
| mr | Refrigerant mass flow rate | Kg/hr |
| P | Power consumption | Watt |
| Qe | Cooling capacity | Watt |
| $R^2$ | Goodness of fit | |
| S | Swept volume | $cm^3$ |
| Te | Evaporator Temperature | ℃ |

## 6. References


[1] Duggan.M.G., Hundy.C.F.,and Lawson.S. "Refrigeration compressor performance using calorimeter and flow rater techniques", Purdue University, Int. Compressor Engineering Conference,1988 .

[2] Cavallini, Doretti, Longo, and Rossetto."Thermal analysis of hermetic reciprocating compressor" , Purdue University, Int. Compressor Engineering Conference,1996.

[3] Mackensen, Klein, and eindl,"Characterization of refrigeration system compressor performance", Purdue University, Int. Compressor Engineering Conference, 2002.

[4] Kim,and Bullard. "Thermal performance analysis of small hermetic refrigeration and air conditioning compressors" International Journal of JSME, series B, Vol.45, No.4, 2002.

[5] Jähnig, Reindl, and Klein, “A semi-empirical method for representing domestic refrigerator/freezer compressor calorimeter test data”, ASHRAE Transactions, 106 (2000),PP 122-130.

[6] Cezar O. R. Negrao, Raul H. Erthal, Diogo E. V. Andrade, and Luciana W. Silva”Embraco An Algebraic Model for Transient Simulation of Reciprocating Compressors.“

[7] Holmn. J.P." Experimental Methods for Engineers", eight editions. Mc GrawHill Company.2010.

[8] A.R.I. Standard 540-99, “Positive Displacement Refrigerant Compressors and Compressor Units”. Air-Conditioning and Refrigeration Institute, 1999.

[9] ASHRAE/ANSI Standard 23-1993, “Methods of Testing for Rating Positive Displacement Refrigerant Compressors and Condensing Units”, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1993.

# ايجاد معادلات الاداء للضواغط المنزلية اعتمادا على البيانات التصنيعية للثلاجات والمجمدات

**لؤي عبد العزيزمهدي*   عماد اسماعيل حبيب**   ليث عبد المنعم*****

**،**،***قسم الهندسة الميكانيكية/ الجامعة التكنولوجية*

البريد الالكتروني:louayalkaesy@gmail.com

البريد الالكتروني: emad_1955_emad@yahoo.com

البريد الالكتروني: laith.ismael@ymail.com

**الخلاصة**

تم ايجاد معادلات أداء عامة للضواغط المنزلية استنادا إلى بيانات المسعرللشركات المصنعة لاثنين من العلامات التجارية الشهيرة ، هذه المعادلات ذات عشر ثوابت بالاستناد الى توثيقات مؤسسة التبريد الامريكية بدرجة حرارة مكثف ثابتة قدرها ٥٤.٤ مئوية ودرجة حرارة مبخر من (٣٥- الى ١٠-) مئوية باستخدام برنامج ماتلاب، هذه المعادلات تمثل القدرة التبريدية، واستهلاك الطاقة، ومعدل تدفق كتلة مائع التبريد الذي هو R-134a . وكان معدل الحيود ± ١٥٪ ويمثل مقارنة ٧٢ بيان مسعرضاغط للقدرة التبريدية و ٥٠ بيان مسعر لاستهلاك الطاقة و٢٥ بيان مسعر لتدفق كتلة مائع التبريد.

كما تم إيجاد معادلات أداء للضواغط بالاعتماد على القيمة المثبتة على لوحة الضاغط لايجاد الحجم المكافيء و باستخدام هذا الحجم المكافيء لسعة الضاغط يتم معرفة الطاقة التبريدية ومعدل جريان كتلة مائع التبريد ، وهذا يعد اختيارا سريعا للضاغط بالاستناد الى توثيقات ASHRAE القياسية التي تغطي مجموعة واسعة من احجام الضواغط لمدى (٢.٤٢ الى ١١.٥١) $cm^3$.