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A Simple Method of Approximating The Efficiency of a Rotary Freon Compressor

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ABSTRACT

A reference exhaust temperature is defined. The difference between exhaust temperature and this temperature shows a good correlation to efficiency data. This difference is then non-dimensional with respect to difference of exhaust and inlet temperatures. A theoretical study was performed to approximate the efficiency in terms of this non-dimensional ratio.

SYMBOLS

BHP shaft horse power
C1 constant
C2 constant
 C_p specific heat at constant pressure
 C_t specific heat at constant temperature
 $d()$ derivative of (\quad)
 DT_{ab} temperature at a - temperature at b
Eff efficiency
h enthalpy (Btu/lb)
H enthalpy (Btu)
P pressure
Q heat
R gas constant for freon 22
T temperature
v specific volume
W work
subscripts:
1 inlet
2 exhaust
i isentropic

INTRODUCTION

Efficiency calculation of a freon compressor is a time consuming process. Various methods can provide different results with minor differences. For on-line performance testing a programmable data logger is needed for performing efficiency

calculations. It is desirable to use some alternate method to indicate efficiency changes for performance and maintenance purposes and approximate the efficiencies by a simple means. The method introduced in this paper uses temperature measurements to indicate performance changes. A simple expression is then introduced to approximate the efficiency in terms of a non-dimensional form of this temperature

TEST SPECIFICATIONS

A non-hermetic single-stage trochoidal-type (1-3) rotary compressor is tested for heat pump applications using freon 22 as the working fluid. The evaporator temperature was varied from -17.5 to 50°F in four steps. For each evaporator temperature, the condenser temperature was varied from 80 to 150°F in five steps. For each temperature setting, the compressor speeds varied from 1000 to 2500 rpm in 500 rpm steps. A 20°F superheat was maintained for all the tests.

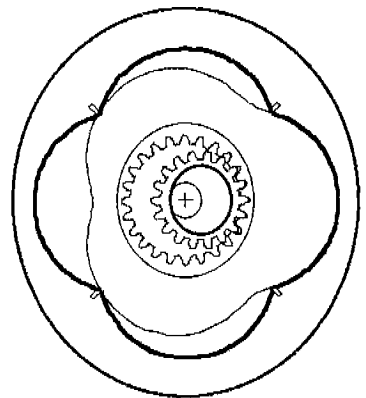


Fig 1

REFERENCE TEMPERATURE

The compressor part of test assembly can be considered as an open system which receives work from a motor and transfers heat to or from environments by conduction and convection. If two similar compressors are compared, the less efficient compressor would have a higher exhaust enthalpy. For the same inlet conditions and pressure ratios, a less efficient compressor would have a higher exhaust temperature. The exhaust temperature of a compressor running at different speeds and exhaust conditions will depend on the work input, the heat transfer and the compressor efficiency. If the inlet conditions and speed are fixed, then the exhaust temperature will depend on working pressure ratio and inefficiencies. For these conditions, if a reference temperature is defined which corresponds to exhaust temperature of the most efficient compressor, then any deviation of exhaust temperature from this reference temperature should be a measure of inefficiencies. Isentropic exhaust temperature is used as the reference temperature. This temperature is calculated using exhaust pressure and inlet entropy (1). The difference between exhaust temperature and isentropic exhaust temperature heretofore is referred to as excess superheat. Figures 2-5 shows the comparison of excess superheat and efficiency vs pressure ratios for different inlet conditions and rpms. Higher excess superheats correspond to lower efficiencies and minimum excess superheat corresponds to maximum efficiency. The excess superheats is non-dimensional with respect to the difference of exhaust and the inlet temperatures. Figures 6-9 shows that the non-dimensional form of excess superheat has the same maximum to minimum relation to efficiency data. The next section investigates the correlation between efficiency and the excess superheat. It uses the non-dimensional excess superheat to approximate the efficiency.

THEORETICAL CALCULATION

For compressor as an open system

$$H_2 - H_1 = W - Q$$

If the heat transfer from or to the compressor is small compared to other terms then

$$H_2 - H_1 = W$$

$$\text{Eff} = (H_1 - H_2) / \text{BHP}$$

$\text{BHP} = \text{Linkage Eff} * W = W$; for direct connect

$$\text{Eff} = (H_1 - H_2) / (H_2 - H_1)$$

$$\text{Eff} = (h_1 - h_2) / (h_2 - h_1)$$

For fixed inlet and speed, efficiency can be expressed in terms of two independent variables, P_2 and T_2 . At the best performance

$$d(\text{eff}) / d(P_2) = 0$$

$$d(\text{eff}) / d(T_2) = 0$$

Also h_2 can be approximated by

$$h_2 = h_1 + C_p * (T_2 - T_1)$$

$$d(\text{eff}) / d(T_2) = d[(h_1 - h_2) / (h_1 - h_1 + C_p * (T_2 - T_1))] / d(T_2)$$

$$d(\text{eff}) / d(T_2) = -d(T_2 - T_1) / d(T_2) * C_p * (h_1 - h_1) / (h_2 - h_1)^2$$

This shows for fixed exhaust temperature, the best performance is achieved where $d(T_2 - T_1) / d(T_2) = 0$.

$$d(\text{eff}) / d(P_2) = d[(h_1 - h_2) / (h_1 - h_1 + C_p * (T_2 - T_1))] / d(P_2)$$

$$d(\text{eff}) / d(P_2) = -(h_1 - h_2) * d(C_p * \Delta T_{21} / (h_1 - h_2)) / d(P_2) * 1 / (h_2 - h_1)^2$$

Since $(h_1 - h_2) / C_p$ is monotonic increasing function of pressure ratio, the best efficiency therefore will correspond to the minimum reference temperature.

In order to approximate efficiency in terms of excess superheat ΔT_{21}

$$\text{Eff} = 1 - C_p * \Delta T_{21} / (C_p * \Delta T_{21} + h_1 - h_2); C_p = C_p(P_2)$$

$$\text{Eff} = 1 - \Delta T_{21} / \Delta T_{21} * 1 / [1 + C_1 / C_p * R / v]$$

Where C_1 and v are functions of inlet and exhaust conditions

$$\text{Eff} = 1 - \Delta T_{21} / \Delta T_{21} - C_2 * \text{function}(\text{inlet \& exhaust}) * \Delta T_{21} / \Delta T_{21}, C_2 = \text{constant}$$

To account for inefficiencies such as heat transfer losses, a two-parameter form was considered.

$$\text{Eff} = C_1 - \Delta T_{21} / \Delta T_{21} - C_2 * \text{function}(\text{inlet \& exhaust}) * \Delta T_{21} / \Delta T_{21}, C_1 = \text{constant}$$

Different practical functional relationships were considered and the following form was chosen

$$\text{Eff} = C_1 - DT_{21}/DT_{21} - C_2 * (DT_{21}/DT_{21})^2$$

Figures 10-13 show the comparison of efficiency with approximate efficiency.

CONCLUSION

The isentropic exhaust temperature was used as a reference level. A deviation of exhaust temperature from this reference temperature was shown to be directly related to the efficiency loss. A non-dimensional form of this difference showed the same properties. Further it was shown that the efficiency can be expressed in terms of this non-dimensional variable. A two-parameter quadratic expression showed a very close match to the efficiency data. The first parameter (zero power coefficient) was used to show the effect of heat interaction with environment. The second parameter (second power coefficient) can be eliminated for ideal gases. The contribution of the second order term in the expression for the efficiency is small compared to the other terms.

This method can be extended to other gases, especially for the cases where heat loss to environment is a small portion of the shaft power.

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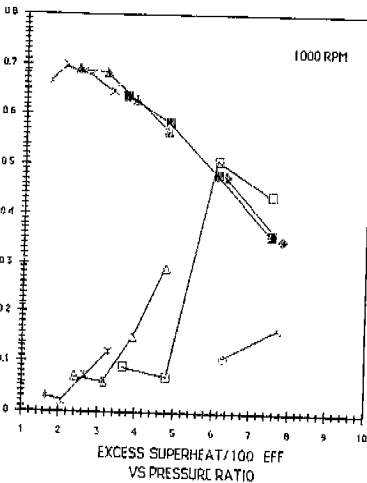
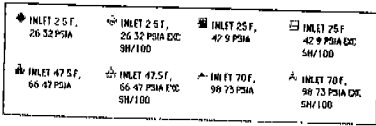


Fig. 2

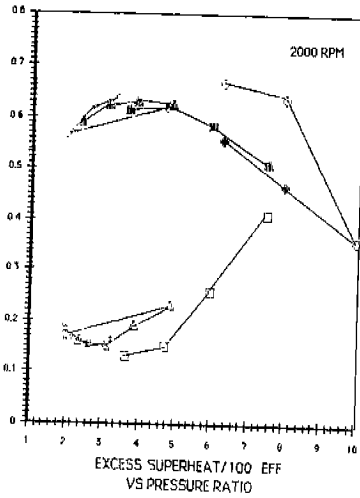
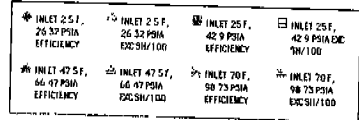


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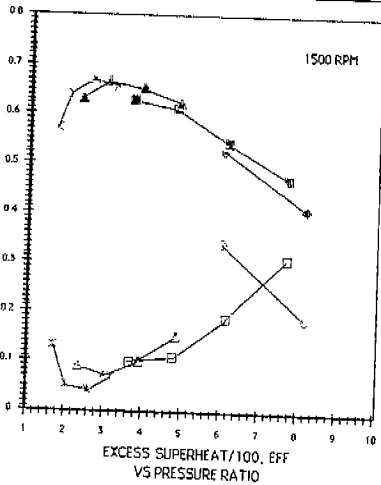
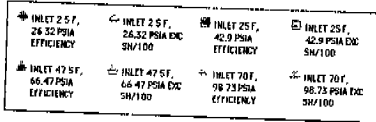


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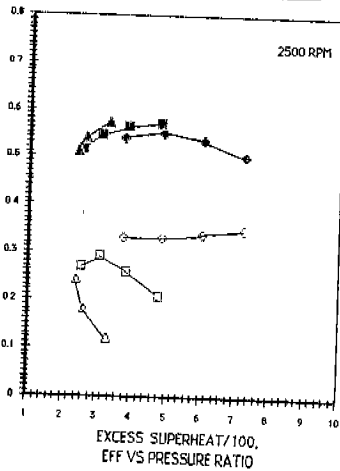
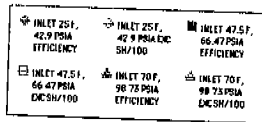


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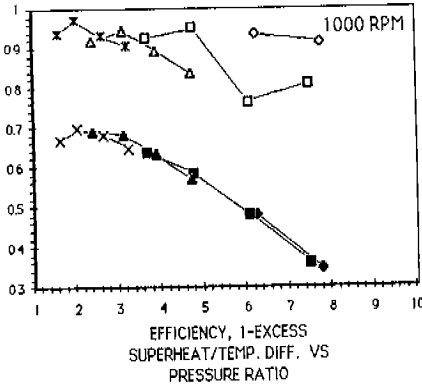
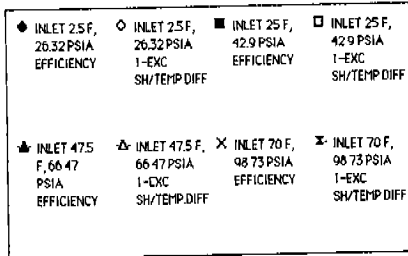


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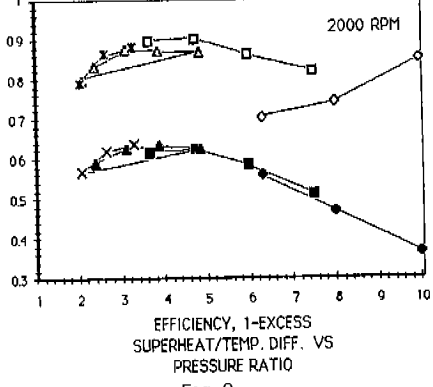
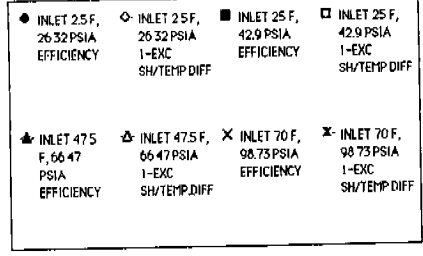


Fig. 8

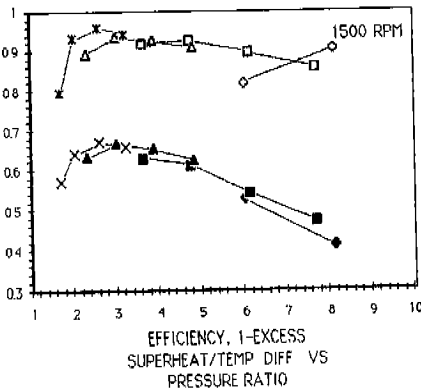
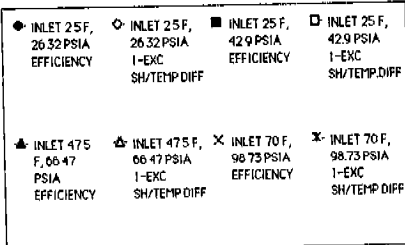


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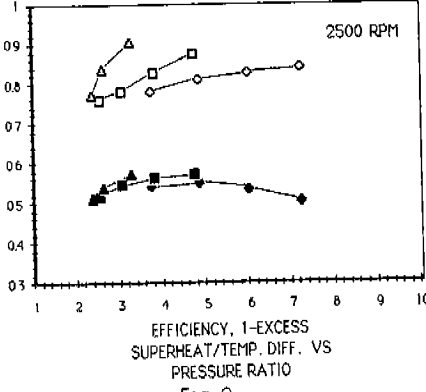
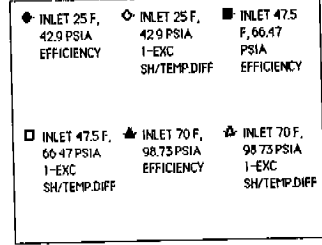


Fig. 9

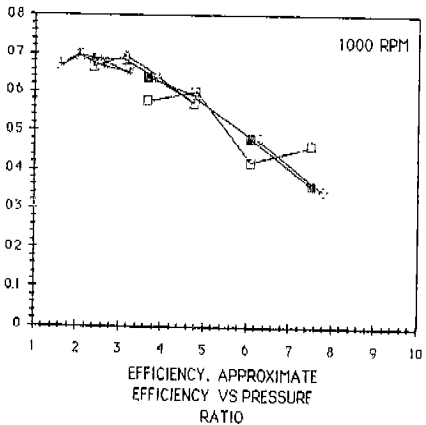
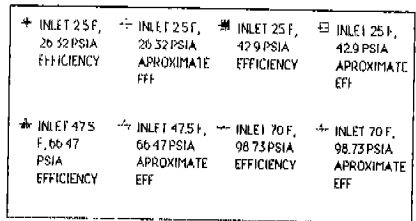
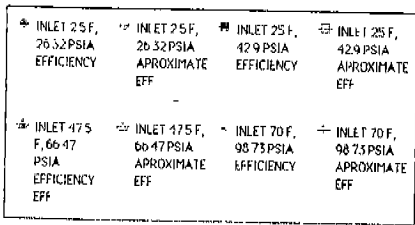


Fig 10

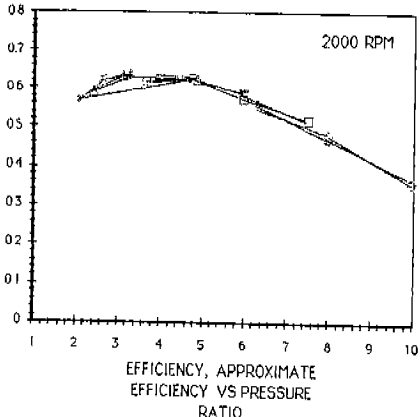


Fig. 12

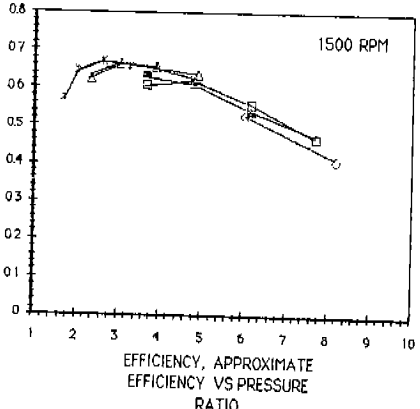
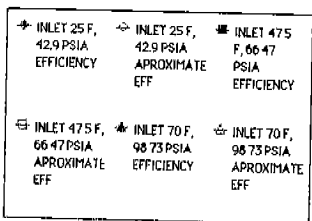
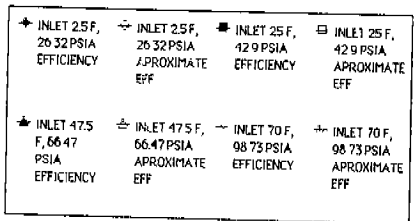


Fig. 11

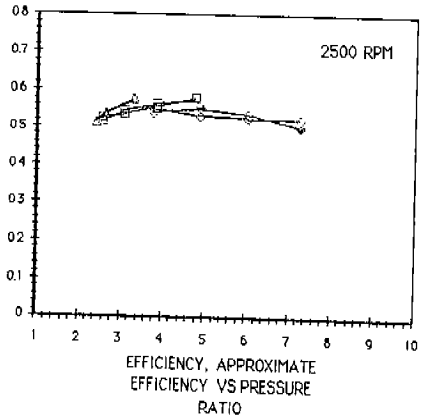


Fig. 13