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RHIC PROJECT

Brookhaven National Laboratory

Performance of RHIC Refrigerator II: Turbines

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PERFORMANCE OF RHIC REFRIGERATOR II: TURBINES

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ABSTRACT

In February 1996, the RHIC Refrigerator was successfully cooled to liquid helium temperature with 10 kilowatts of heat input at 4.5 K, 53 kilowatts of heat input at 60 K and 44 grams per second of liquid extraction. A comprehensive analysis was performed to evaluate the performance of the refrigerator including the turbines, the cold vacuum compressor and the heat exchangers. Because of the amount of data and the number of charts involved, the report is divided into five technical notes on, respectively: 1). Flowmeters, 2). Turbines, 3). Cold Vacuum Compressor, 4). Heat Exchangers and 5). Refrigerator Overall Performance. This technical note describes the performance of the Turbines.

I. Introduction

There are thirteen turbines installed in the RHIC Refrigerator. For normal operation, the RHIC refrigerator requires seven turbines and the six others are redundant. The capacity and the reliability of the refrigeration plant depend on these turbines. While the operation of turbines and their oil skids is not easy, the performance evaluation of the turbines is rather straight forward. These turbines reach "quasi " steady state quickly. The pressure and temperature at the inlet and exit of each turbine, and the flow rate and the speed are readily available.

In this technical note, the adiabatic efficiency is given in terms of the parameter U/C, where U is the impeller tip speed and C, the speed evaluated from ideal expansion. The work of energy extraction and flow rate are plotted against the speed. Except for Turbine 5, the performance of these turbines agrees with the information provided by the manufacturer. The performance of Turbine 5 can not be determined accurately because of insufficient resolution on the temperature display and because the unit is operating in a region of rapidly changing thermodynamic properties. However, the overall performance for Turbine 5 looks "reasonable".

II. Turbine Efficiency

The adiabatic efficiency of the turbine is defined as the ratio of the change of enthalpy through a turbine to that of an adiabatic expansion. The efficiency depends on the operating conditions and are conventionally given as a function of U/C. For cryogenic application, the turbine efficiency also depends on the seal gas and heat leak. During the test, the amount of seal gas in these turbines basically followed the manufacturer's recommendation and the effect of seal gas is neglected in this report. The heat leak is included in the following results.

The efficiency is low at low U/C. It increases with U/C and typically peaks at a value of U/C around 0.65. Because of the dependence on U/C, the turbine efficiency should be interpreted carefully. For example when a turbine is operating at a U/C of 0.4, the efficiency will only be 0.6 as compared to a peak efficiency of 0.8. The low efficiency is simply a result of the low operating speed.

The adiabatic efficiency for Turbines 1B1, 1B2, 2B1, 2B2, 3B, 4B and 5 are given in Figures 1 through 7 below. In Figures 1 through 6, the efficiencies for Turbines 1B1 through 4B are fairly close to the values provided by Rotoflow, the turbine manufacturer. In Figure 7, there are great fluctuations in the efficiency of Turbine 5 because Turbine 5 was operating in a region of rapid changing properties and there was not enough resolution in the temperature readings during this test. A two digit readout on the temperature sensors will be implemented for the next run and the efficiency of Turbine 5 will be re-evaluated.

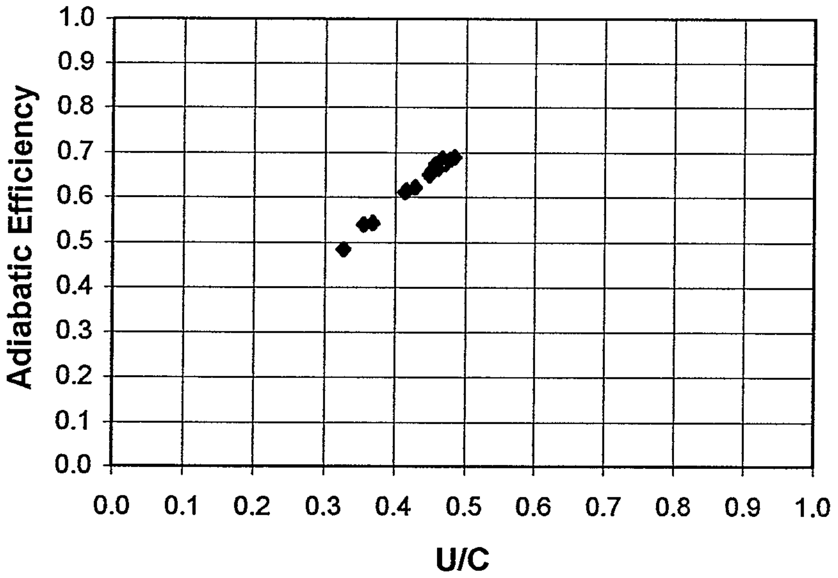

Figure 1 Efficiency of Turbine 1B1 as a function of U/C

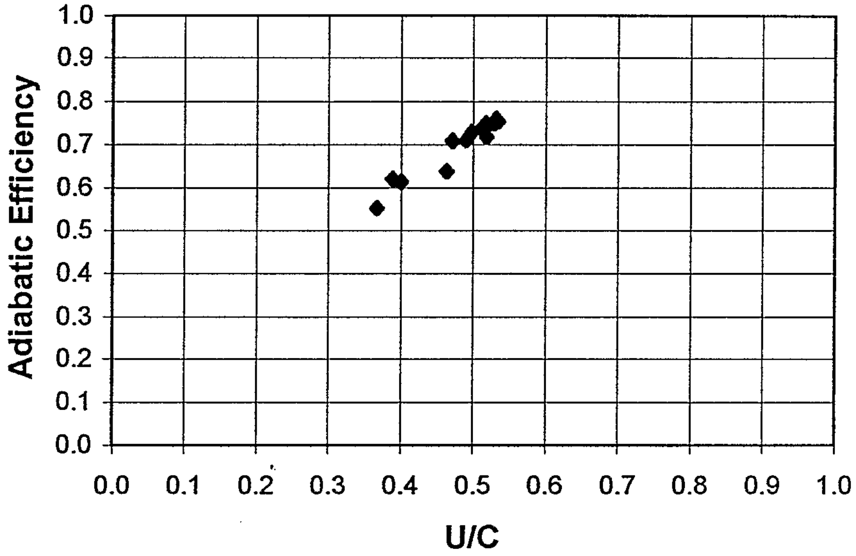

Figure 2 Efficiency of Turbine 1B2 as a function of U/C

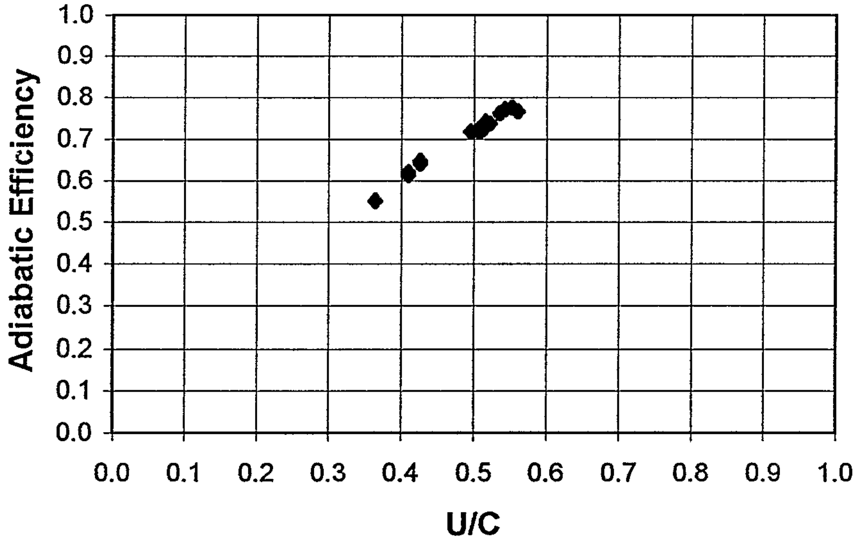

Figure 3 Efficiency for Turbine 2B1 as a function of U/C

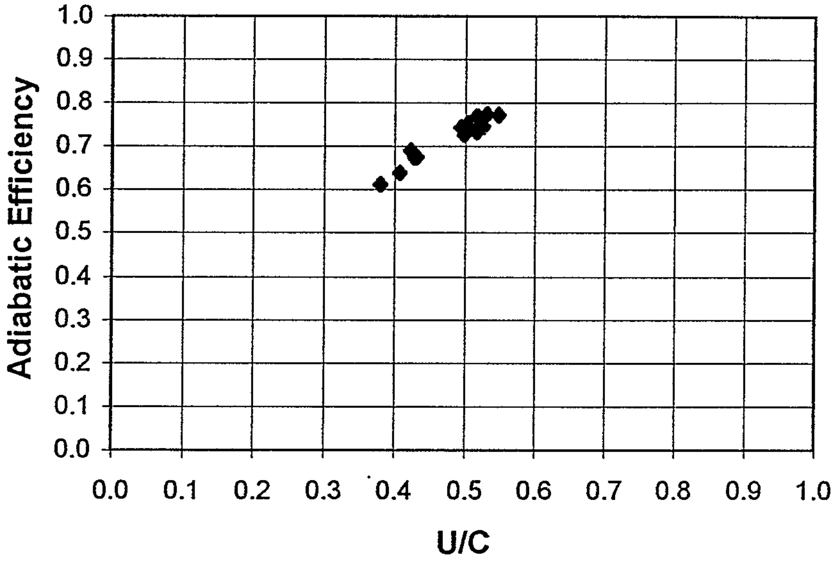

Figure 4 Efficiency of Turbine 2B2 as a function of U/C

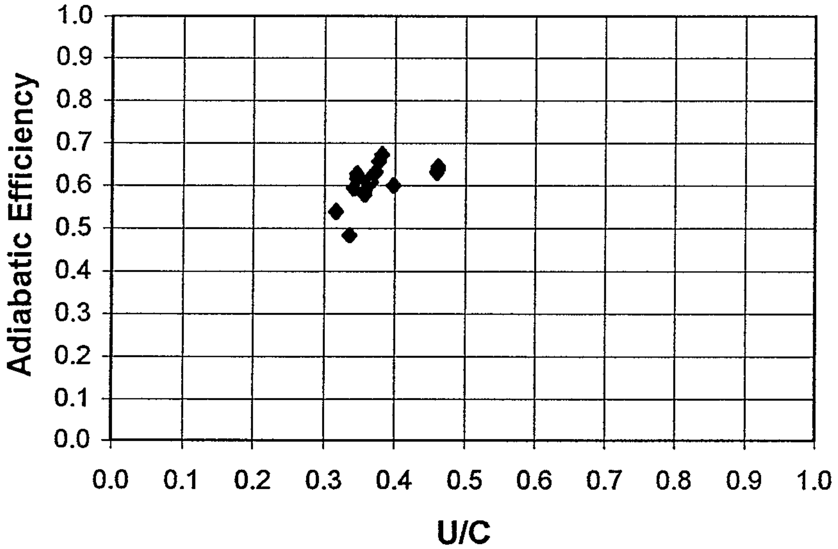

Figure 5 Efficiency of Turbine 3B as a function of U/C

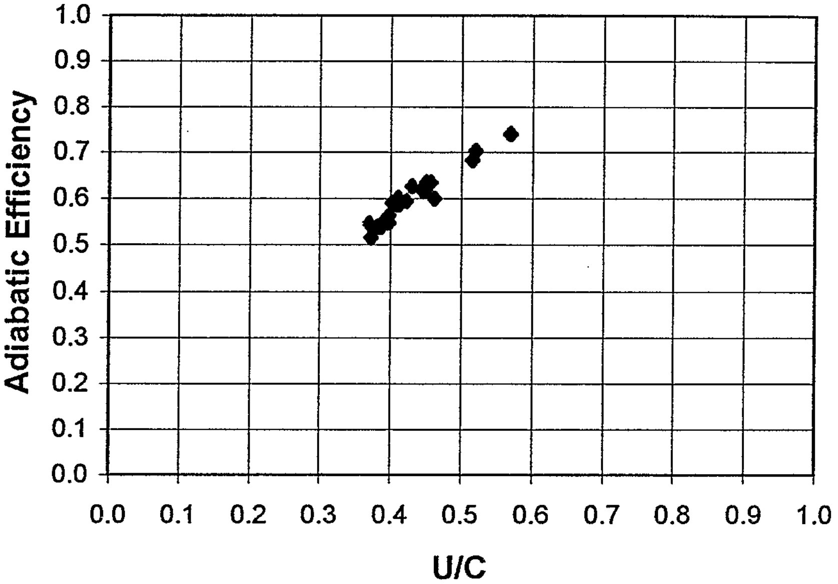

Figure 6 Efficiency of Turbine 4B as a function of U/C

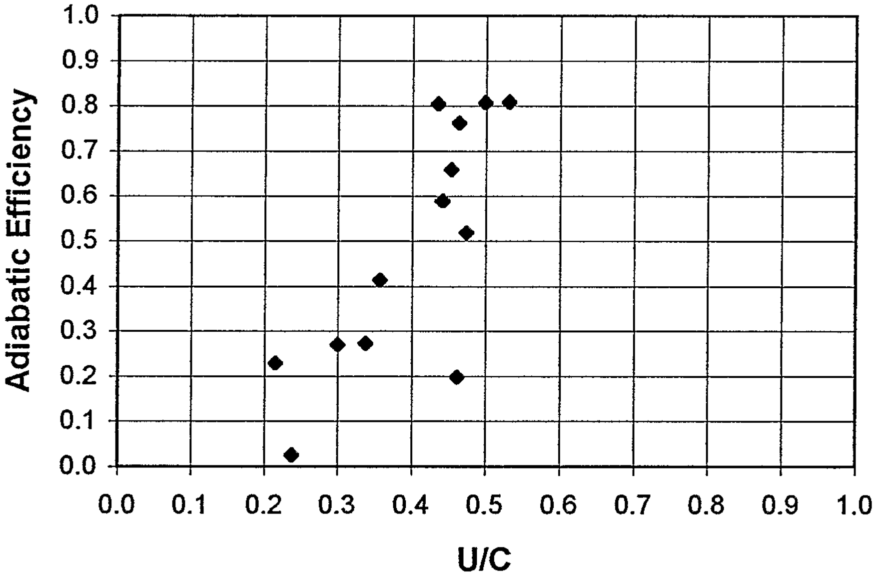

Figure 7 Efficiency of Turbine 5 as a function of U/C

III. Work Extraction

The cooling in the refrigerator is generated by the work extraction of the turbines. To perform the energy balance analysis of the refrigerator, the work extraction must be evaluated for each turbine. The work extraction for each turbine is calculated from the flow rates and enthalpies of the process helium at the inlet and exit of the turbine. The work extraction is absorbed by the dynamometer and the oil bearing. Neglecting the effect of the oil bearing, the work extraction will vary approximately as the third power of the speed since the dynamometer is a centrifugal compressor.

The work extraction for the above mentioned seven turbines are presented in Figures 8 through 14. The original conditions designed for ISABELLE, for these turbines are also shown on these figures for comparison. Except for Turbine 5, the work extraction for these turbines has been shown to increase with the speed at a power between 2 and 3 as expected. These results demonstrate the validity of the measurements. For Turbine 1B1, 1B2, 3B and 4B, the operating speeds are lower than the design speeds and therefore produce a smaller work extraction. For Turbine 2B1 and 2B2, the maximum operating speed and work extraction are very close to the design conditions.

For Turbine 5, Figure 14, the results vary widely because the unit is operating in a "sensitive" thermodynamic region and there is insufficient resolution on the temperature readouts. The flowmeter reading has also been found to read off scale when operating above 29,000 rpm. More measurements will be made for Turbine 5 during the next refrigerator run.

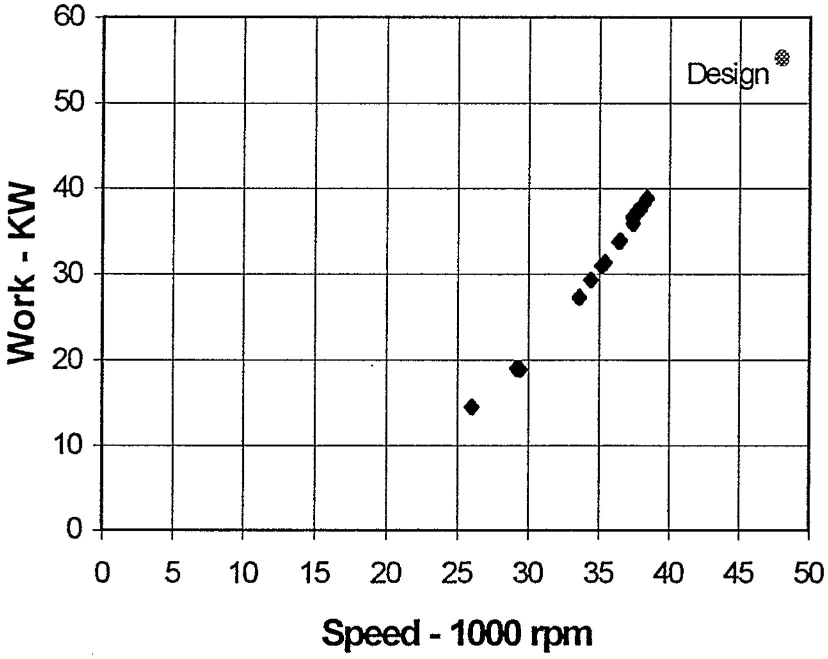

Figure 8 Work extraction as a function of Speed for Turbine 1B1

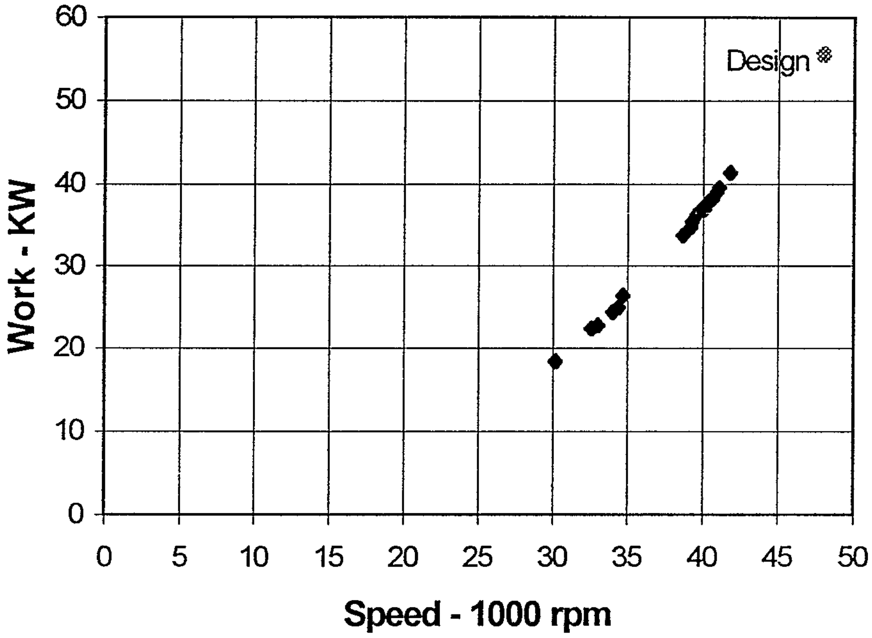

Figure 9 Work Extraction for Turbine 1B2 as a function of Speed

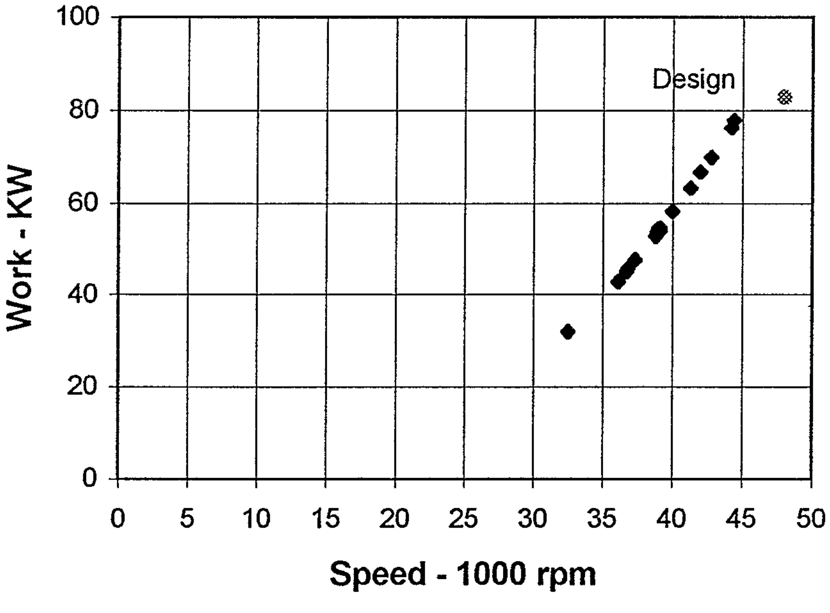

Figure 10 Work extraction for Turbine 2B1 as a function of Speed

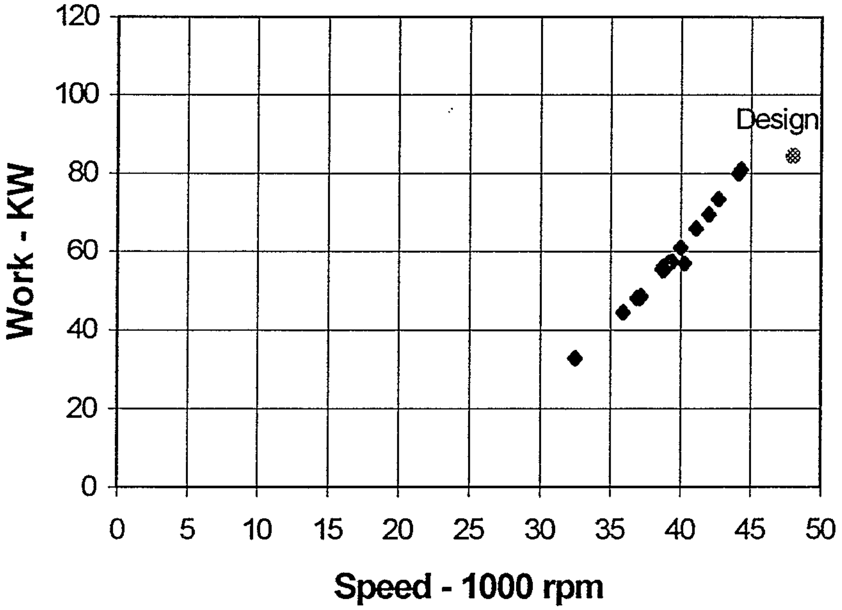

Figure 11 Work Extraction for Turbine 2B2 as a function of Speed

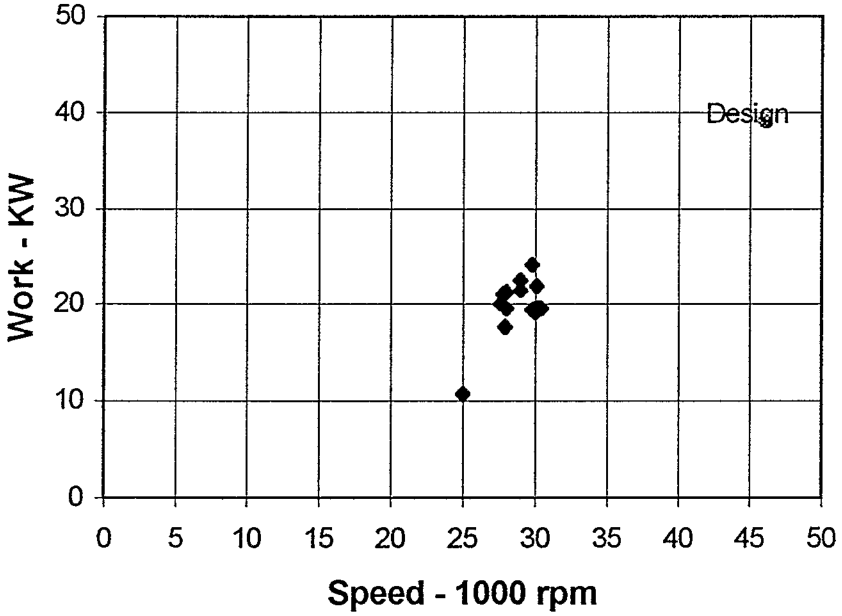

Figure 12 Work Extraction for Turbine 3B as a function of Speed

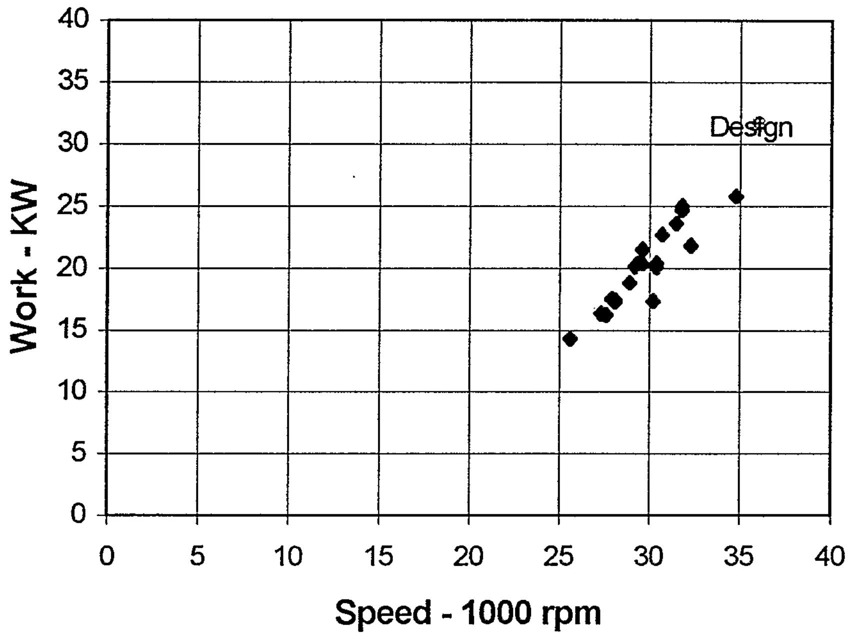

Figure 13 Work Extraction for Turbine 4B as a function of Speed

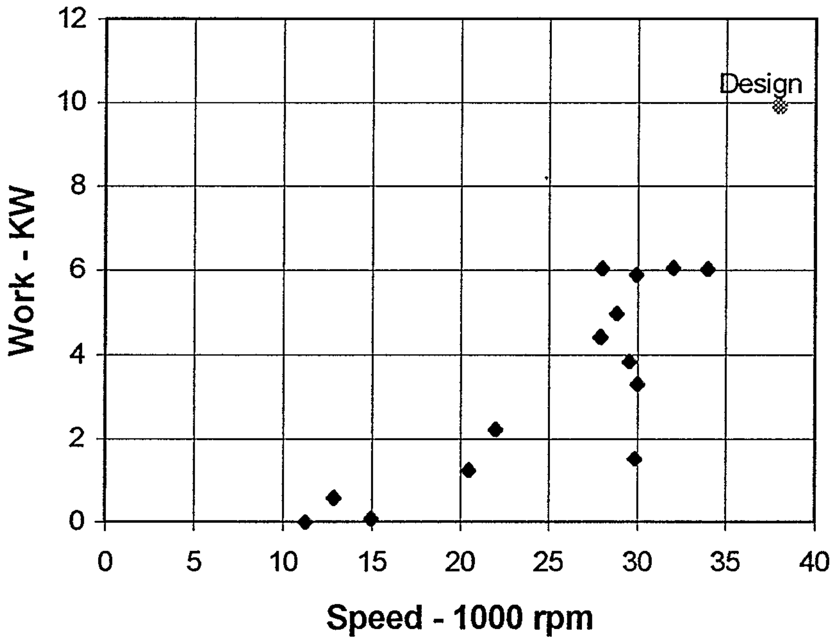

Figure 14 Work Extraction for Turbine 5 as a function of Speed

IV. Flow Rates

In Figures 15 through 21, the flow rates are given as a function of speed for the seven turbines under investigation. The purposes of this investigation is to see if the data correlates and, in particular, to observe the flow rates for Turbine 5 at speeds above 29,000 rpm. As shown in Figures 15 through 18, the flow rates increase with the speed as expected for Turbines 1B1, 1B2, 2B1 and 2B2. In Figures 19 and 20, the results for Turbines 3B and 4B show more fluctuations. As shown in Figure 21 for Turbine 5, the flow rates are low for speeds above 29,000 rpm which is consistent with the observation that the differential pressure transmitter exceeds full scale. In the energy balance for the refrigerator, the flow rates for Turbine 1B1 through 4B will be used without correction. For Turbine 5, an extrapolated flow rate based on Figure 21 will be used whenever the differential pressure transmitter exceeds the full scale.

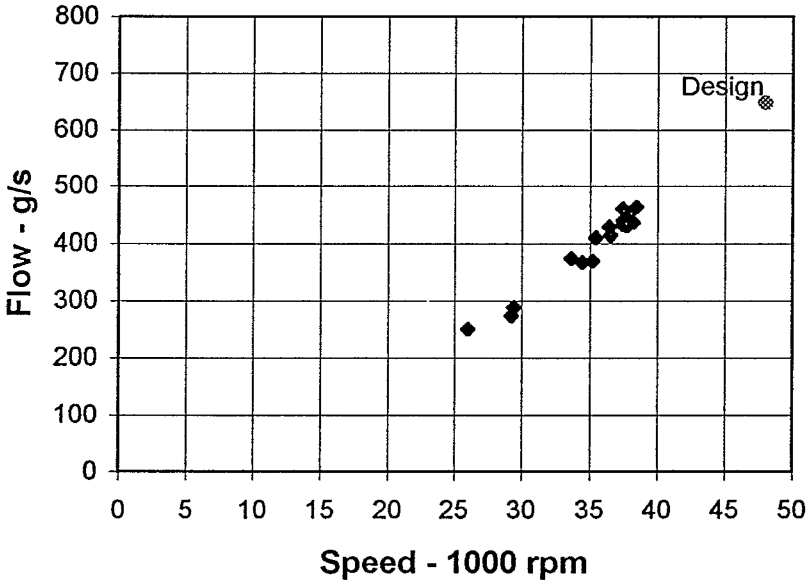

Figure 15 Flow rate as a function of Speed for Turbine 1B1

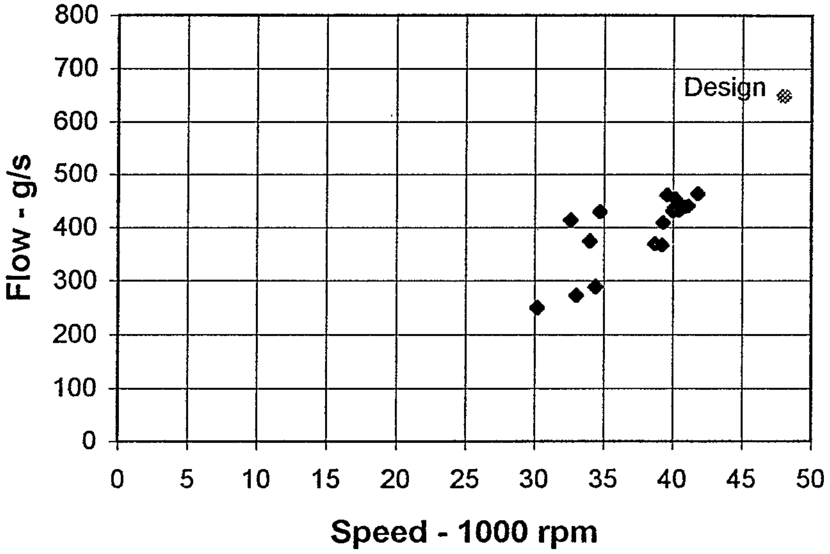

Figure 16 Flow Rate as a function of Speed for Turbine 1B2

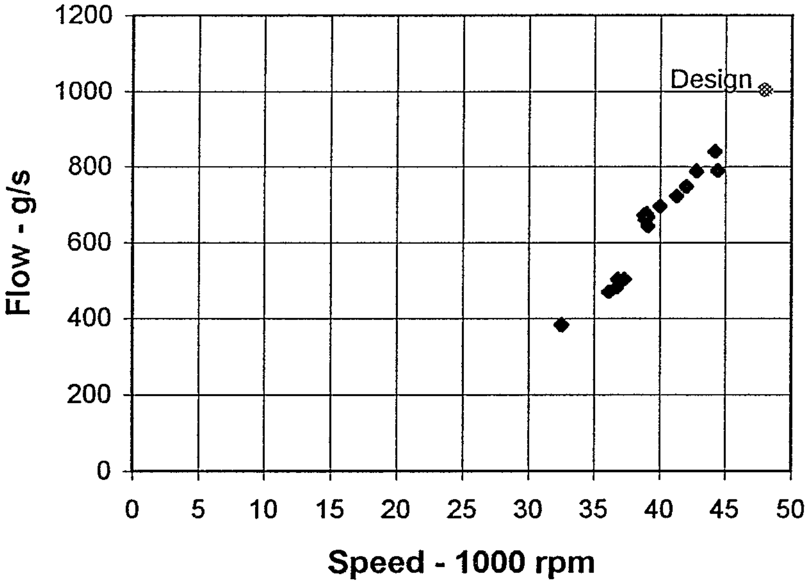

Figure 17 Flow Rate as a function of Speed for Turbine 2B1

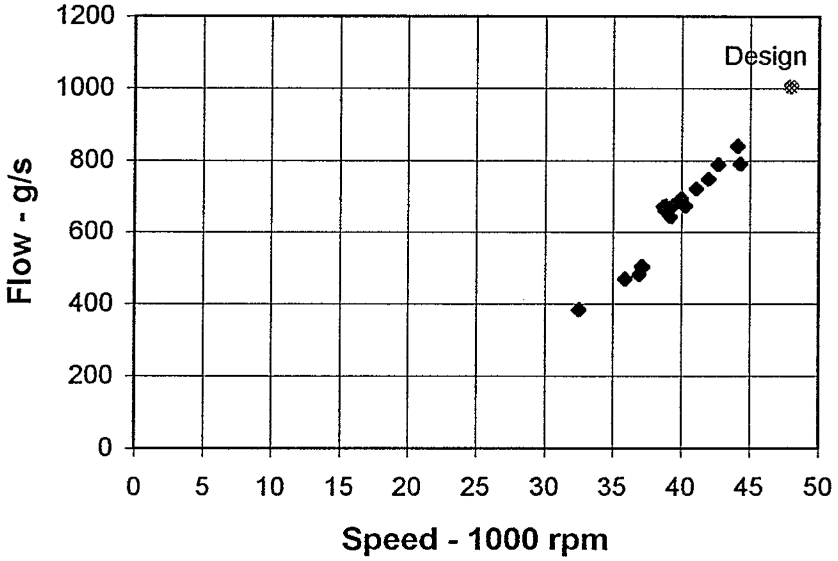

Figure 18 Flow Rate as a function of Speed for Turbine 2B2

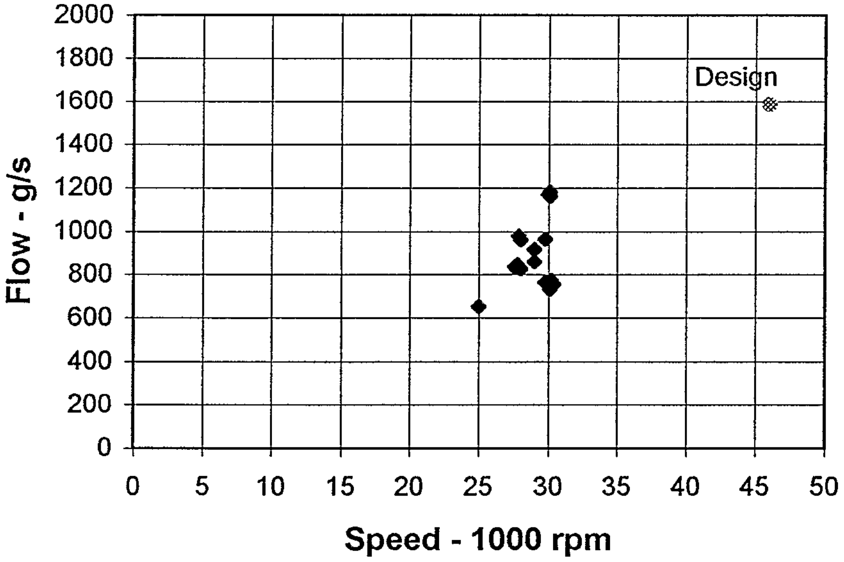

Figure 19 Flow Rate as a function of Speed for Turbine 3B

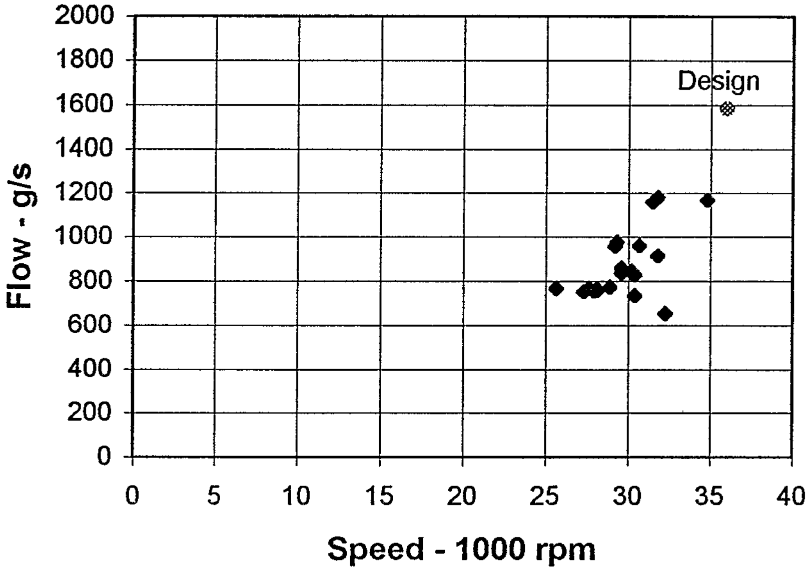

Figure 20 Flow Rate as a function of Speed for Turbine 4B

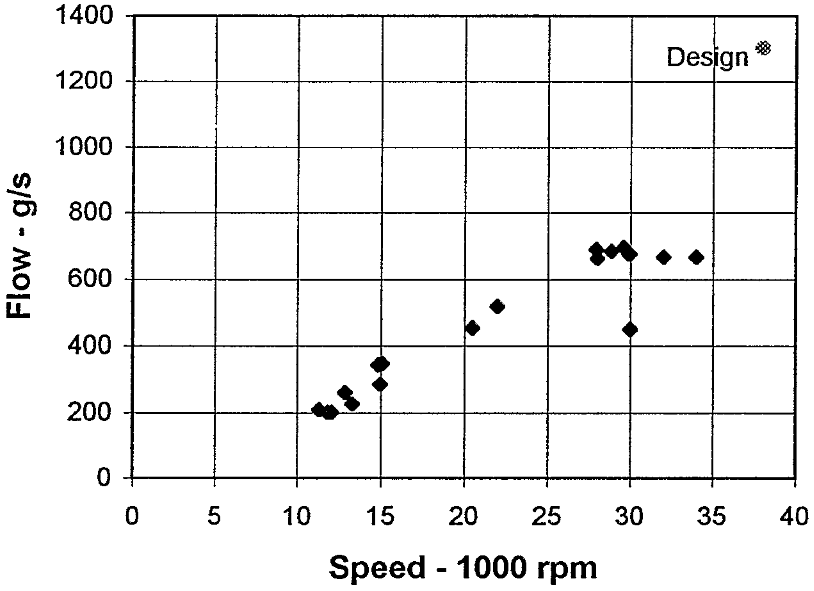

Figure 21 Flow Rate as a function of Speed for Turbine 5

V. Summary

The adiabatic efficiencies, work extraction and flow rates have been investigated for the turbines installed on the RHIC refrigerator. Other than Turbine 5, the performance of these turbines agrees quantitatively with the information provided by the manufacturer. The performance of Turbine 5 seems “reasonable”, however a quantitative analysis of the performance needs to be performed during the next refrigerator run.

ACKNOWLEDGMENT

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