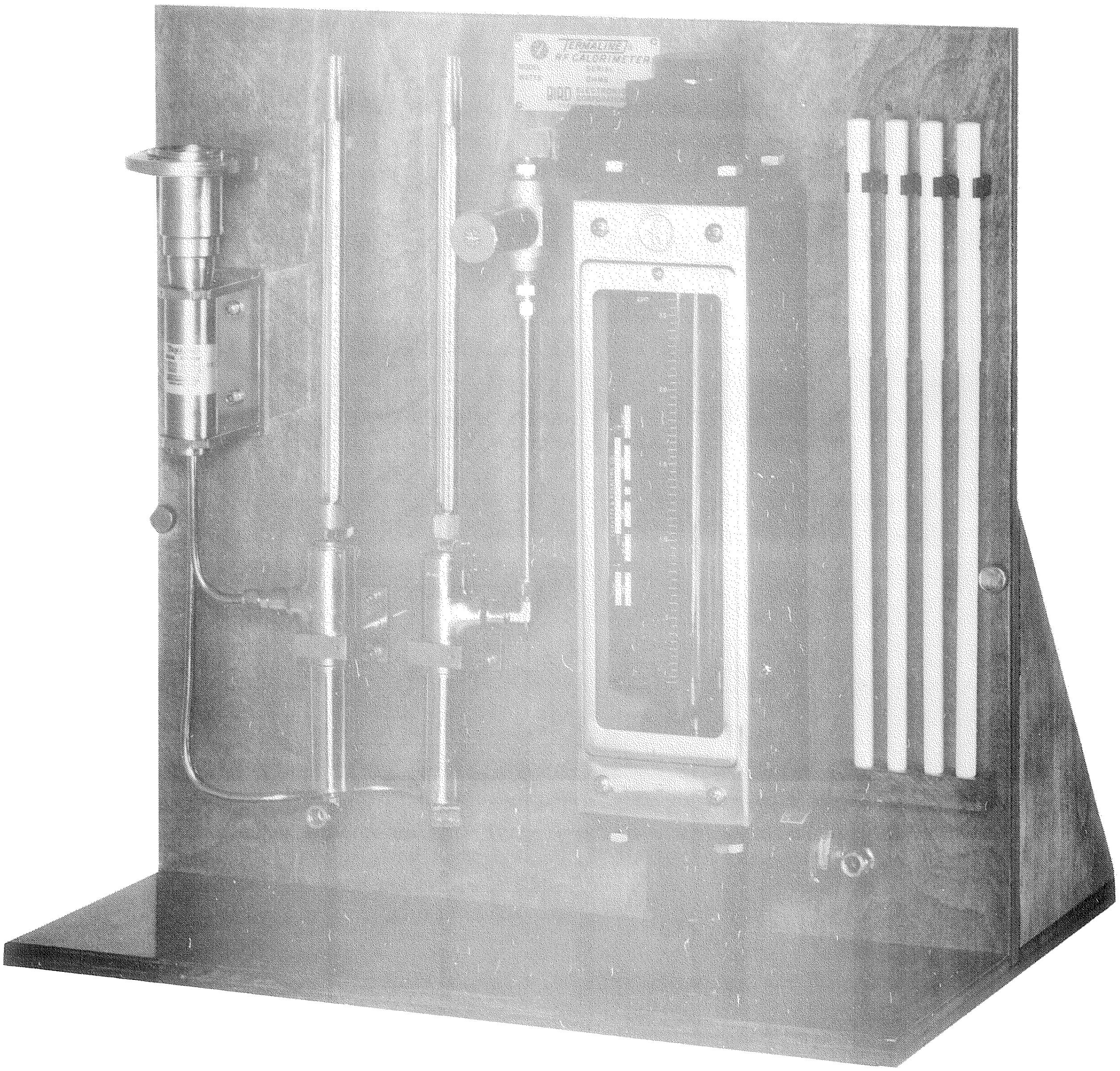
TERMALINE

Hi-Power RF Calorimeter

Series 6070



Series 6070

SPECIFICATIONS

Calorimeter Series 6070

Minimum measureable power	1000 Watts
Maximum measureable power (for standard package)	5000 Watts
Accuracy	±3.0%
Frequency	DC to 2000 MHz
VSWR	DC to 1000 MHz- Under 1.1 to 1.0
	1000 to 2000 MHz-Under 1.20 to 1.0
Minimum input-output water Δt	5^0C
Minimum input water temp.*	5^0C
Maximum input water temp.**	$+60^0C$
Minimum water flow	.76 GPM
Maximum water flow	2.65 GPM
Reading waiting period (stabilization time)	5 Minutes
Water purity	Any potable
Mounting	Table

* For 1000 Watts. The input water temperature is lower for higher power

**Maximum input water temperature depends on range of thermometers.

The standard package includes:-

1 Thermometer 0 to 10^0C

2 Thermometers 10 to 20^0C

1 Thermometer 20 to 30^0C

For these thermometers, maximum input water temperature is 20^0C

For higher temperature, optional thermometers are available.

6070 CALORIMETER ACCURACY

The list below summarizes the sources of uncertainty involved in direct power measurements. In the least favorable case, when all errors add in the same direction (+ or -), they total 3%. Since such conditions are unlikely, a more realistic value is about one half of the maximum.

(a)	Temperature uncertainty at recommended minimum Δt due to thermometer legibility and calibration.		1.0%
(b)	Flow rate uncertainty		1.0%
(c)	Heat energy leakage(calibrated maximum)		1.0%
		TOTAL	3.0% of reading between 1kW & 5kW

Under comparison measurement conditions (e.g., 60Hz vs RF), the remaining uncertainties are half:

(a)	Temperature uncertainty at recommended minimum Δt due to thermometer legibility and calibration.		1.0%
(b)	Flow stability uncertainty		.5%
		TOTAL	± 1.5%

Series 6070 TERMALINE RF Calorimeter

SECTION I - GENERAL DESCRIPTION

The Series 6070 RF Calorimeters are designed to make calorimetric measurements of RF power under non-radiating conditions, with an accuracy of ± 3 percent. With this high degree of accuracy, it may be used as a comparison standard for laboratory wattmeters. Other uses include measurement of total RF power under AM conditions or transfer type measuring of direct power. The entire Calorimeter assembly consists of a Bird TERMALINE RF dummy load, a flowmeter, flow rate control valve, four mercury partial-immersion type stem thermometers and complete piping. The unit is mounted on a wooden panel.

Mercury in glass thermometers are used for measuring temperature differential. These thermometers are calibrated in degrees centigrade, with calibration markings of 0.05 of a degree, making it possible for the average observer to properly differentiate 0.025 degree centigrade.

A Rotameter is employed as the flowmeter, and calibrated in gallons per minute, with a range of approximately 0.76 to 2.65 gallons per minute. The calibration accuracy is $\pm$ one percent in region of 30 to 100 percent of the scale length at a temperature of 70^0F (21.1^0C).

A Bird 8700 Series Coaxial Load Resistor is used for the RF line termination. This load provides a very low-reflection non-radiating termination which assures exceptionally high absorption of the applied RF power, and virtually complete transfer of the energy to the flowing coolant water.

SECTION II - THEORY OF OPERATION

1. Basic Calorimeter

The term calorimetry refers to the measurement of quantities of heat. Heat is energy in transition resulting from a temperature differential. This energy in transition may be expressed in ft-lb/hr, BTU/min, or cal/sec.

The "First Law" of thermodynamics states that energy can neither be created nor destroyed, but only converted from one form to another. This then, is the basic concept behind the calorimetric method of measurement. A basic definition should be noted: If a quantity of heat is transferred into one gram of water until the temperature of the water is increased one Centigrade degree, it would be called one gram-calorie, or more commonly referred to as one calorie. In the English system, if one pound of water will increase its temperature one Fahrenheit degree, one BTU of heat has been transferred into it.

$$\text{Hence:}\quad \begin{aligned} 1\ \text{BTU} &= \text{lb} \times {}^{0}\text{F} \\ 1\ \text{calorie} &= \text{gram} \times {}^{0}\text{C} \end{aligned} \qquad (1)$$

The relationship of grams to pounds and ^{0}C to ^{0}F is such that it makes one BTU equal to 251.996 calories.

Another factor in calorimetric measurement should also be taken into consideration; the specific heat of a substance. It has been proven that different substances having a weight of one pound would require less or more energy to increase their temperature one Fahrenheit degree. To compensate for this behavior of different materials, including water, a correction factor was assigned called specific heat. The units for specific heat are BTU/lb^{0}F. By employing this correction factor to equation (1), the calorimetric formula for heat thus becomes:

$$1 \text{ BTU} = 1 \text{ lb} \times 1 \text{ F}^0 \times 1 \text{ BTU/lbF}^0 \qquad (2)$$

or, $\text{heat} - \text{mass} \times \Delta t \times C_p$

Since 1 BTU of heat is equal to 778.16 ft-lb of work, and the time rate of doing work is power, ft-lb/hr or BTU/hr could be a description of electrical watts of mechanical ft-lb power.

Thus, when the time element is introduced into equation (2), it simply becomes:

$$\text{BTU/hr} = \text{mass(lb/hr)} \times \Delta t\ (\text{F}^0) \times C_p(\text{BTU/lbF}^0) \qquad (3)$$

This is the equation of calorimetry. Knowledge of Δt, rate of mass flow, and specific heat would produce BTU/hr equal to power.

2. 6070 Series Calorimetry

Calorimetry as applied to the Model 6070 Series Calorimeter is essentially the same as described in the preceeding paragraphs.

The availability of RF loads, such as the TERMALINE 8700 Series, with almost 100% transfer of RF power into a cooling liquid(in this case water), has made possible such an arrangment that the elementary calorimetric form could be utilized:

$$\text{RF Power} = \text{flow} \times \Delta t \times \text{constant} \times C_p$$

The constant is used to present the power relation in direct form, converting F^0 to C^0, and rendering easier and possible direct reading of the calorimeter.

The Δt is most accurately indicated by thermometers which utilize the thermal expansion of a liquid isolated from the environment. For this measurement, mercury stem thermometers are used. In order for the thermometers to have a high accuracy and not be affected by outside temperature, the ratio of the mercury chamber volume to the volume of the total indicating column must be as high as possible. The thermometers are calibrated in ^{0}C.

The water flow is measured by a Rotameter which is calibrated in gallons per minute. The scale calibration is ± one percent from 30 to 100 percent of the scale length. This calibration is made for a water temperature of 70^0F (21.1^0C). The flowmeter is not sensitive to changes in viscosity; it is a Viscosity Compensated Rotameter. However, the density error is still present, and the graph of Figure C should be used as a multiplier to correct power measurements.

3. Coaxial Load Termination

The termination resistor used to dissipate the RF energy in the 6070 Series Calorimeter is a Bird 8700 Series Coaxial Load Resistor. The load itself is a carbon film-on-ceramic resistor, with a protective plastic coating covering the outer surface. The RF energy is converted into heat and transferred directly to the cooling agent (water) without the use of an intermediate transfer fluid. Organic hydrocarbon coolants are not required as the dielectric media, because the generated heat is conducted to the inside of the resistor. Air will suffice as the coaxial dielectric. The resistor is enclosed in an exponentially tapered housing which provides a linear reduction in surge impedance directly proportional to the distance along the resistor.

With this configuration, the characteristic impedance is therefore 50 ohms at the RF input (connector end), 25 ohms at the mid-point to compensate for the resistance already passed over, and zero ohms where the resistor joins the housing, forming the return conductor of the coaxial circuit. This produces the uniform, practically reflectionless line termination over the stated frequencies of the load resistor.

When cool water enters the load, it is led by a center pipe down to the RF input end of the inside of the load resistor and released through peripheral holes in its wall. The water flows out of the unit by first passing over the inside surface of the ceramic resistor tube. This pipe, which is supported at both ends, is constructed of a dielectric material to prevent interaction with the electrical properties of the device.

The heat carried off by water as a result of the dissipation of energy in the load produces an increase in water temperature flowing out of the unit. This difference in water temperature from input to output is the basis for the 6070 Series calorimetric type of measurement.

SECTION III INSTALLATION

The Termaline Calorimeter is portable in this series. It is also designed for vertical fixed mounting. When mounted, the instrument should be located convenient to both a supply of running water (with drain facilities), and feasible connection to the RF transmission line. For best accuracy, calorimeter should be installed with shortest feasible transmission line length. The unit should be affixed for easy reading at eye level, otherwise misreadings of the rotameter and thermometers could occur.

Before mounting, fill the Calorimeter with water and insert the float into the rotameter by removing the drain cock at the top of the rotameter. The float must be inserted with the spoked wheel facing the bottom of the rotameter. DO NOT DROP THE FLOAT. DAMAGE TO THE FLOAT WILL CAUSE INACCURATE READINGS. Refer to Figure 4-1 for an illustration of the float.

After the Calorimeter has been placed in the vertical position, unscrew the thermometer guards from the thermometer wells and fill the wells with water. Remove the thermometers from their cylindrical containers (noting input and output) which are attached next to the rotameter. Carefully slide the thermometers into the guards. With care, slide the thermometer and guard into the well, making sure that the thermometer is resting on the bottom. Do not subject the thermometers to any binding. Screw the thermometer guard down snugly into the well, making sure the opening of the guard is facing outward.

Connect the water input and output using 1/4" O. D. copper tubing. Attach the RF generator to the load. The Calorimeter is now ready for operation. See Caution note Pg. 3-2.

CAUTION:

Apply RF power <u>only</u> when suffcient water flow is established. Burn out possibilities are greatly increased if this procedure is not followed.

SECTION IV - OPERATION

After the Calorimeter has been properly installed, follow the procedure below to operate. At the end of the operating procedure, an illustrative example is given to show clearly the steps described.

1. Turn on the water and adjust the flow rate for the maximum power of the load being used. These are minimum values. Flow rate must be regulated at the water flow valve with the source valve turned on full. See Fig. 4-1 below to determine the reading edge of the float.

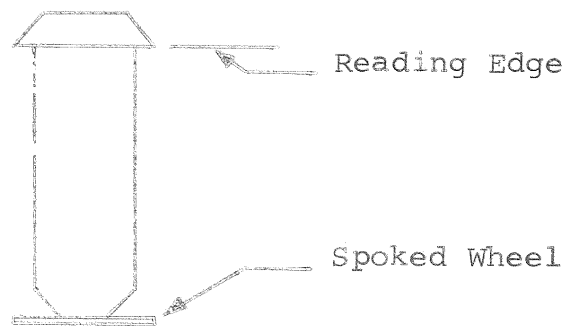


Figure 4-1. Rotameter Float

2. Adjust the input thermometer for easy reading. The thermometer should be resting on the bottom of the test well.

3. Read the input water temperature and obtain the correction factor from the graph of Figure B.

4. Apply RF power to the load. Make sure not to exceed the load rating.

5. Adjust the output thermometer for easy reading. Follow the same procedure as in Step 2.

6. Read the output water temperature after the mercury column has stabilized not less than 5 minutes. Make sure constant RF power and water flow is maintained when taking this reading.

7. Obtain Δt by subtracting the input temperature from the output.

8. Find the RF power, P_x, from the graph of Figure A, using flow rate us Δt.

This method, using Figure A, is primarily to provide a quick approximation of RF Power, P_x, but with some sacrifice in accuracy. To determine power accuracy, within the capabilities of the Calorimeter, use the following equation in Step 8:-

$$\text{Watts } (P_x) = 262.8 \times (\text{gal/min}) \times \Delta t\ (^\circ C)$$

9. Find the specific heat of water, C_p, using the graph of Figure C. This is the average C_p of the input and output water temperature.

10. To find the actual power, P_a, apply the information obtained in the above steps to the following equation:

$$P_a = P_x \times \text{Correction Factor} \times C_p$$

The unified equation for the calculation of actual power, P_a, utilizing all factors at once is:-

Watts (P_a) - 262.8 (Correction Factor) (gal/min) (Δt in $^\circ C$) (avg. spec. heat)

EXAMPLE

1. Flow rate set at 1.5 gallons per minute.

2. Input temperature read at $10^\circ C$. Correction Factor read from graph of Figure B - at $10^\circ C$ = .9985

3. Output water temperature read at $15^\circ C$.

4. Δt obtained; $+15^\circ C$ minus $+10^\circ C$ = $5^\circ C$

5. RF power P_x, found on graph of Figure A. With 1.5 gpm and Δt $5^\circ C$ P_x = 1971 Watts

6. Average Specific Heat found from Graph C by:
   a) C_p of input water temperature ($10^\circ C$) = 1.0013
   b) C_p of output water temperature ($15^\circ C$) = .9998
   c) Average C_p would be 1.0005

7. Find the actual power, P_a, by multiplying P_x x Correction Factor x C_p

$$P_x = 1.971 \times .9985 \times 1.0005$$
$$= 656.01$$

8. P_x = 1969 Watts

SECTION V - MAINTENANCE

1. General

The Series 6070 Calorimeters are generally maintenance free. Handle the instrument with care; this equipment contains delicate precision components. Store the unit in a clean location when not in use, and do not subject it to shock or vibration.

Care and cleanliness are the main factors. Keep the equipment free of visible accumulation. Clean the thermometers and wells with water. Use a dry solvent such as trichlorethylene on a cotton swab stick to clen the RF line input connector. This also applies to the RF input connector used to make the line connection. Carefully clean all metallic contact areas and also the exposed faces of the teflon insulators.

If the unit has not been used for a long time, flush it out thoroughly before placing it into operation. This equipment should only be used with clean fresh water. Do not use hard or salt water.

2. Inlet Valve and Plumbing

No special maintenance is required for the Inlet Valve or Plumbing. A defective component should be returned to the factory for repair.

3. Rotameter

If leakage should occur at either end of the glass tube, tighten the gland cap screws with a flat end wrench. There are four cap screws at both the top and bottom ends of the Rotameter. Care should be taken to pull down these glands evenly on both ends.

To clean the inside surface of the metering tube, unscrew the inlet plug and remove the float and float stop. Carefully insert a brush or soft swab on a wooden dowel and wipe the tube free of accumulation. When replacing the float, make certain it is inserted with the spoke wheel facing the bottom of the Rotameter.

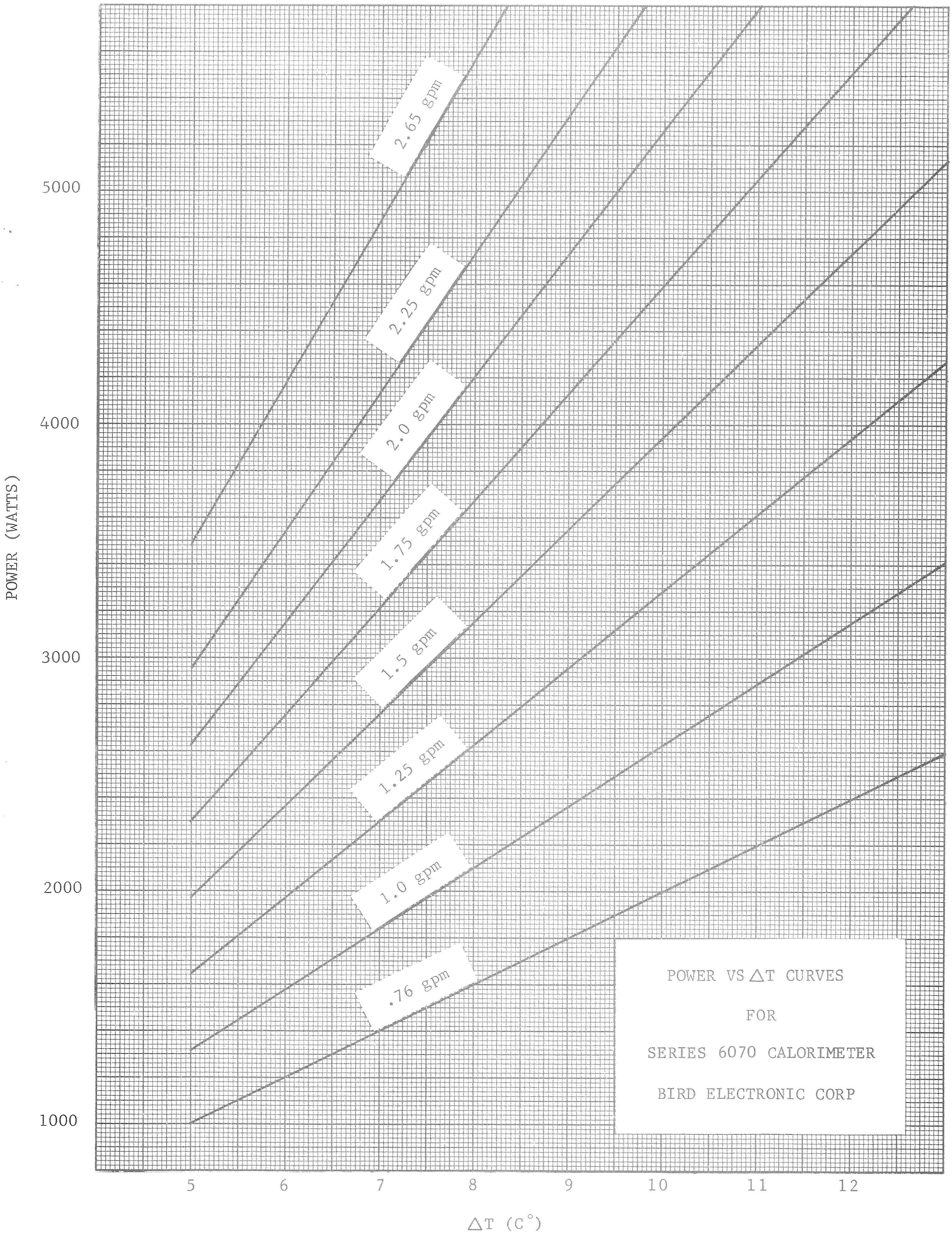
A defective Rotameter must be returned in its entirety to Bird Electronic Corporation for recalibration or repair.

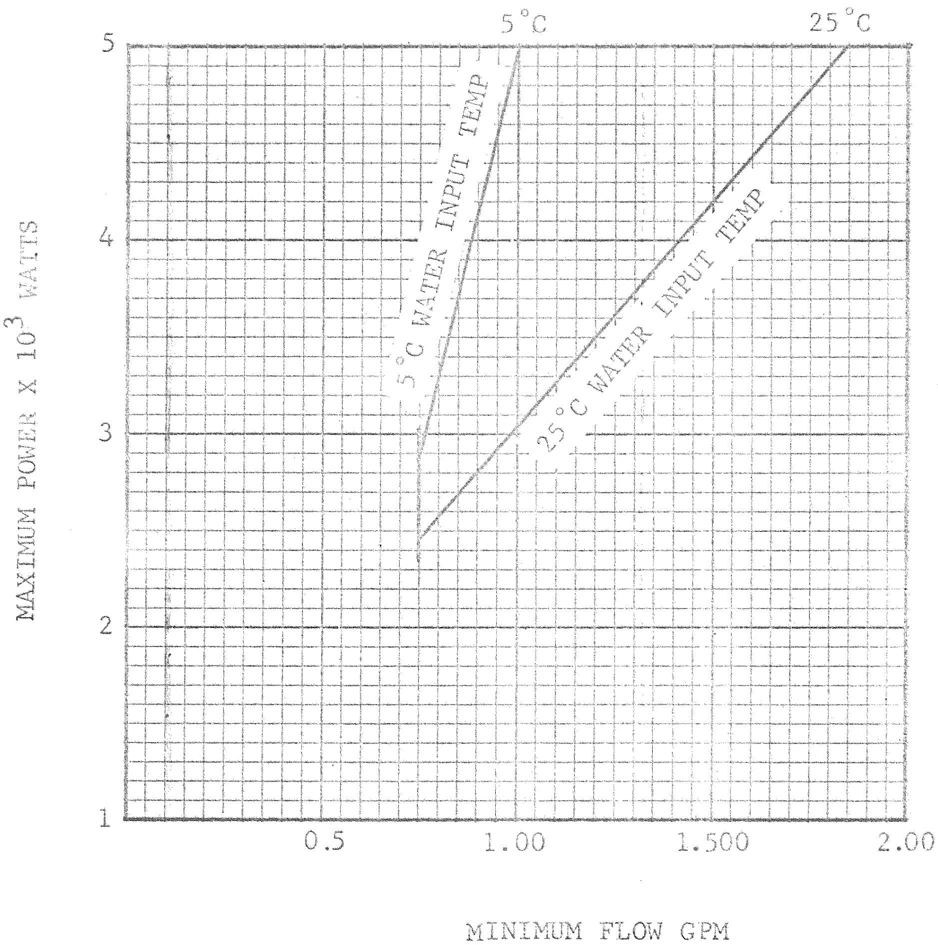
4. Thermometers

No special maintenance is required. Wipe clean with a soft cloth and water. Handle the thermometers with care, and do not expose them to temperatures above scale markings.

5. RF Load Resistor

As different Coaxial Resistors of the 8700 Series are supplied with the various Calorimeter Models, refer to the individual Load Resistor instruction manual for information covering them.


POWER (WATTS)
5000
4000
3000
2000
1000
2.65 gpm
2.25 gpm
2.0 gpm
1.75 gpm
1.5 gpm
1.25 gpm
1.0 gpm
.76 gpm
5
6
7
8
9
10
11
12
ΔT (C°)
POWER VS ΔT CURVES
FOR
SERIES 6070 CALORIMETER
BIRD ELECTRONIC CORP

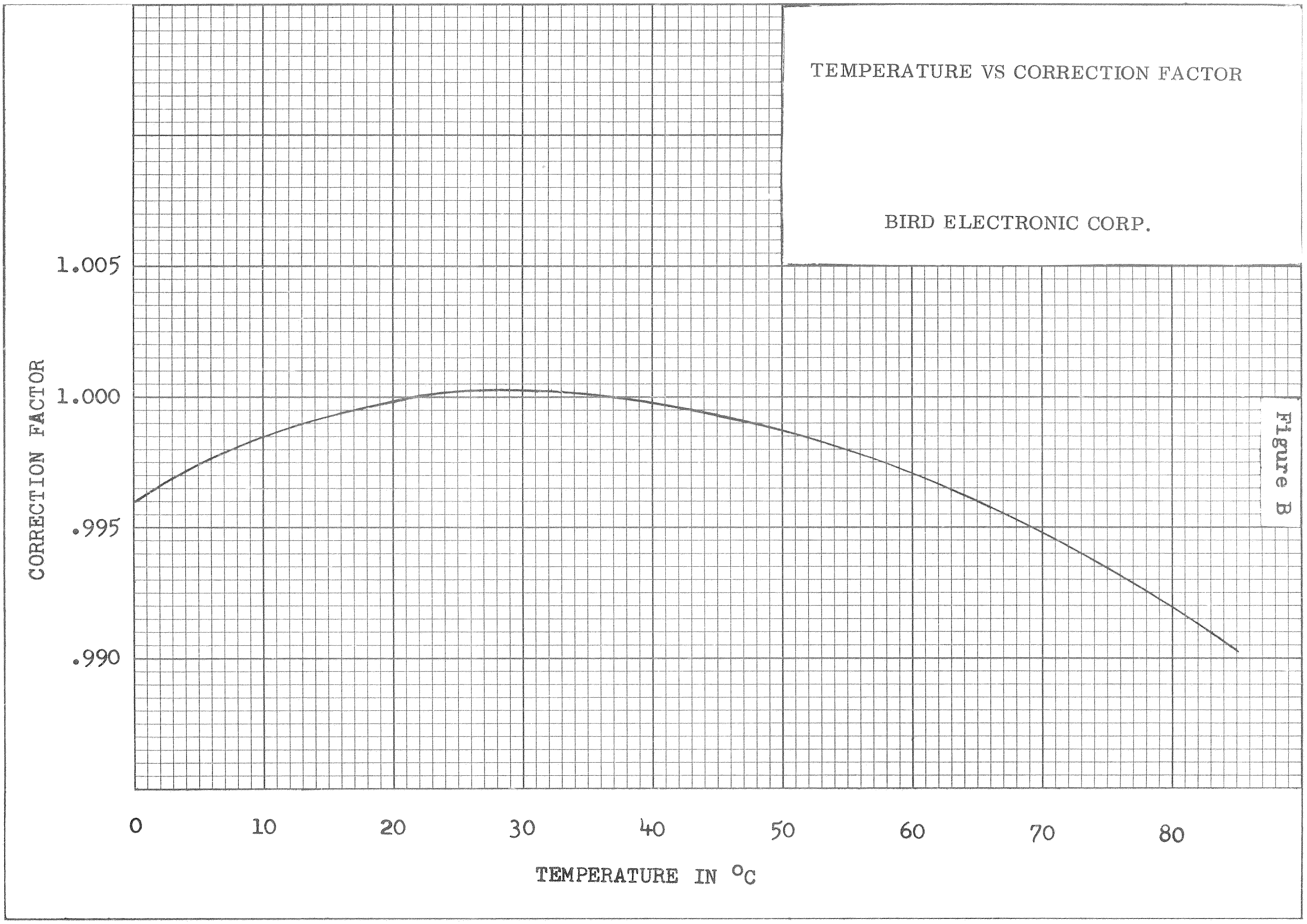


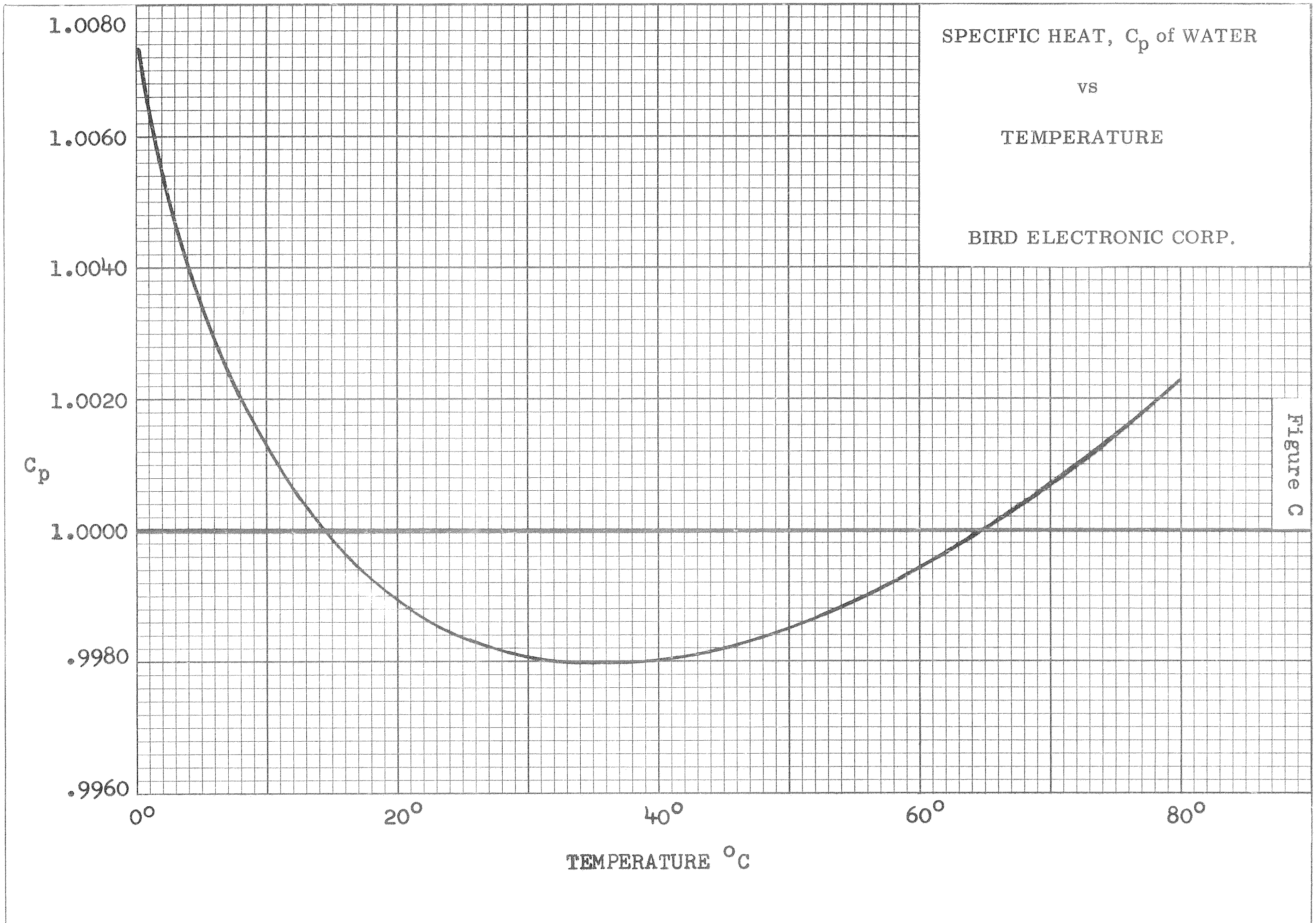
MINIMUM FLOW VS MAXIMUM POWER

FOR

SERIES 6070 CALORIMETER

BIRD ELECTRONIC CORP


TEMPERATURE VS CORRECTION FACTOR
BIRD ELECTRONIC CORP.
Figure B
CORRECTION FACTOR
1.005
1.000
.995
.990
0
10
20
30
40
50
60
70
80
TEMPERATURE IN °C


SPECIFIC HEAT, C_p of WATER
vs
TEMPERATURE
BIRD ELECTRONIC CORP.
Figure C
C_p
1.0080
1.0060
1.0040
1.0020
1.0000
.9980
.9960
0°
20°
40°
60°
80°
TEMPERATURE °C