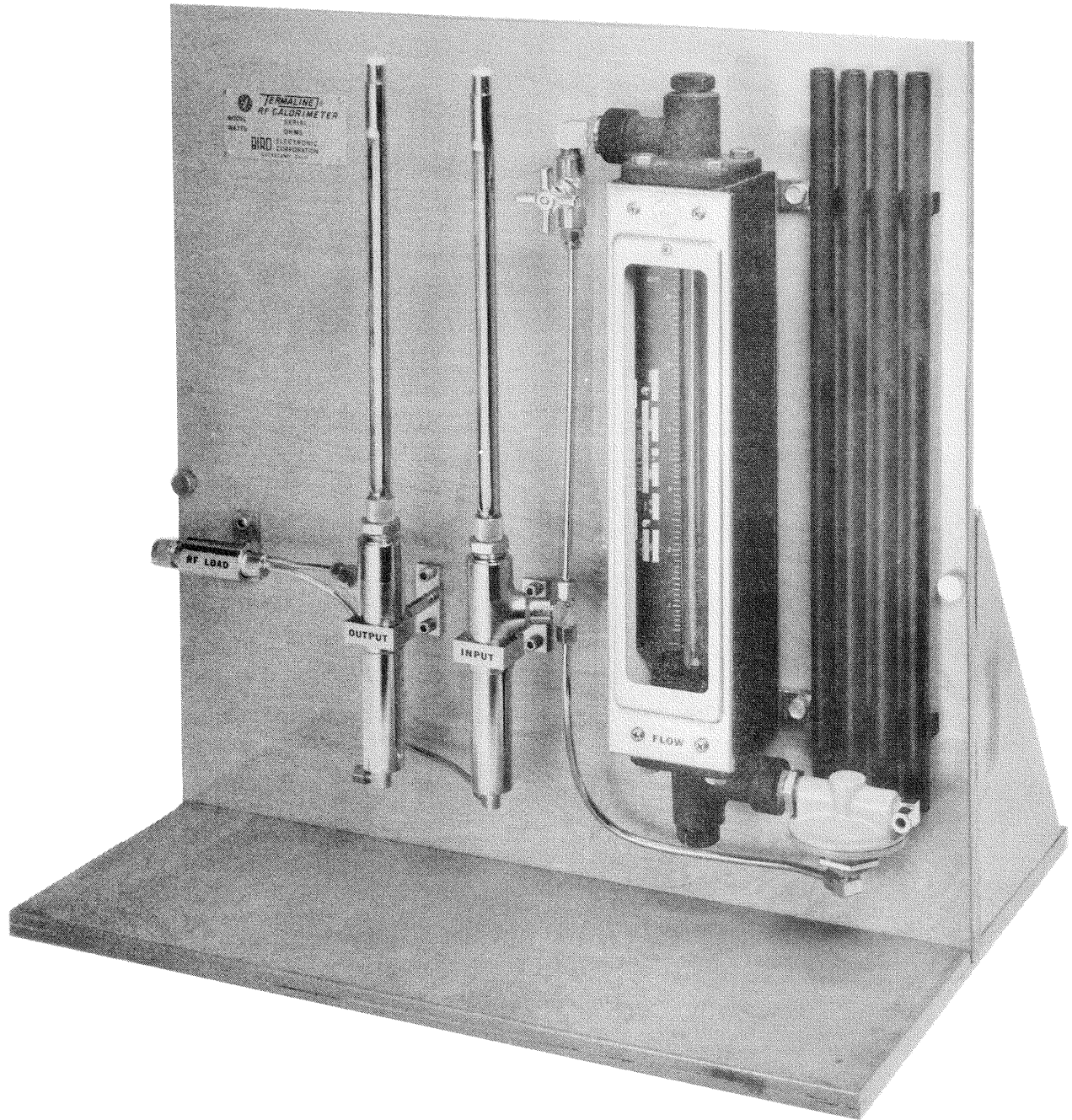TERMALINE

Hi-Power RF Calorimeter

Model 6020

Model 6020

Specifications

Calorimeter Model 6020

(Using R. F. Coaxial Load Model 8710)

Minimum measurable power	250 Watts
Maximum measurable power (for standard package)	1,000 Watts
Maximum measurable power (with optional thermometers)	1,200 Watts
The accuracy	$\pm$ 3.0%
Frequency	DC to 3,500 MHz
VSWR	DC to 1,000 MHz – Under 1.1 to 1.0
	1,000 to 3,500 MHz – Under 1.25 to 1.0
Minimum input-output water t	5°C
Minimum input water temp.*	5°C
Maximum input water temp.**	+60°C
Minimum water flow	0.19 GPM
Maximum water flow	0.630 GPM
Reading waiting period (stabilization time)	5 Minutes
Water purity	Any potable
Mounting	Table or wall mounted

* For 250 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°C
2	Thermometers	10 to 20°C
1	Thermometer	20 to 30°C

For these thermometers, maximum input water temperature is 20°C

For higher temperature, optional thermometers are available.

-A-

6020 CALORIMETER ACCURACY

		250 Watt .19 gpm	500 Watt .32 gpm	750 Watt .48 gpm	1000 Watt .63 gpm
(a)	Temperature uncertainty at recommended flow rate	1.0%	.84%	.84%	.84%
(b)	Flow rate uncertainty	1.0%	1.0%	1.0%	1.0%
(c)	Heat energy leakage	1.0%	1.16%	1.16%	1.16%
	Total (max. if all additive) Direct reading	±3.0%	±3.0%	±3.0%	±3.0%

(60 Hz Substitution method)

		250 Watt .19 gpm	500 Watt .32 gpm	750 Watt .48 gpm	1000 Watt .63 gpm
(a)	Temperature uncertainty at recommended flow rate	1.0%	.84%	.84%	.84%
(b)	Flow stability uncertainty	–	.16%	.50%	.50%
	Total	±1.0%	±1.0%	±1.34%	±1.34%

-B-

6020:1167

Model 6020 TERMALINE RF Calorimeter

SECTION I - GENERAL DESCRIPTION

The Model 6020 RF Calorimeter is designed to make calorimetric measure-
ments 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, pressure
flow regulating device and complete piping. The unit is mounted on a wooden panel.

ASTM approved thermometers are used for measuring temperature differen-
tial. 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 0.19 to 0.63 gallons per minute. The cali-
bration accuracy is $\pm$ one percent in region of 30 to 100 percent of the scale length
at a temperature of 70ºF (21.1ºC).

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 trans-
fer of the energy to the flowing coolant water.

SECTION II - THEORY OF OPERATION

1.   Basic Calorimetry

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.

$$\text{Hence:}\quad 1 \text{ BTU} = \text{lb} \times {}^{o}F$$
$$1 \text{ calorie} = \text{gram} \times {}^{o}C \qquad (1)$$

The relationship of grams to pounds and ${}^{o}C$ to ${}^{o}F$ is such that it makes one

BTU equal to 251,996 calories.

Another factor in calorimetric measurement should also be taken into consi-

deration; the specific heat of a substance. It has been proven that different sub-

stances 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 dif-

ferent materials, including water, a correction factor was assigned called specific

heat. The units for specific heat are BTU/lb^{o}F. By employing this correction

factor to equation (1), the calorimetric formula for heat thus becomes:

$$1 \text{ BTU} = 1 \text{ lb} \times 1 \text{ F}^O \times 1 \text{ BTU}/\text{lbF}^O$$

or, $\text{heat} = \text{mass} \times \Delta T \times C_p$ (2)

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 mechani-

cal ft-lb power.

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

$$\text{BTU}/\text{hr} = \text{mass}(\text{lb}/\text{hr}) \times \Delta T(\text{F}^O) \times C_p(\text{BTU}/\text{lbF}^O) \quad (3)$$

This is the equation of calorimetry. Knowledge of ΔT, rate of mass flow, and

specific heat would produce BTU/hr equal to power.

2.   <u>6020 Series Calorimetry</u>

Calorimetry as applied to the Model 6020 Series Calorimeter is essentially the

same as described in the preceeding paragraphs.

The availability of RF loads, such as the TERMALINE 8700 Series, with al-

most 100% transfer of RF power into a cooling liquid (in this case water), has made

possible such an arrangement 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^O to

C^O, 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, ASTM

approved 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 pos-

sible. The thermometers are calibrated in ^{O}C.

6020:1167

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°F (21.1°C). 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 6020 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.

2-3

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 6020 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 float has been installed, place the Calorimeter on a solid surface vertically with fasteners of a suitable style. The pedestal must be removed for mounting on a vertical surface. The type of fastener will depend on the surface which the unit is mounted on.

After the Calorimeter has been mounted, 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, allowing about 4-1/2 inches to protrude from the base of the guard. Carefully slide the thermometer and guard into the well. 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.

3-1

Connect the water input and output using 1/4" O.D. copper tubing. Burnout possibilities are just as much a hazard with this instrument as in any 8700 Series installation.

Attach the RF generator to the load. The Calorimeter is now ready for operation.

3-2

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.
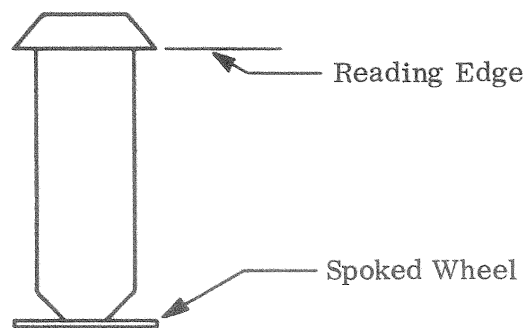

Figure 4-1. Rotameter Float

2. Adjust the input thermometer for easy reading. The thermometer should be immersed as low as possible and still allow reading.

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 vs ΔT.

This method, using Figure A, is primarily to provide a quick approximation of RF Power, Px, but with some sacrifice in accuracy. To determine power accuracy, within the capabilities of the Model 6020 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, Pa, utilizing all factors at once is:-

$$\text{Watts } (P_a) = 262.8 \ (\text{Correction Factor}) \ (\text{gal./min.})$$
$$(\Delta T \text{ in } ^\circ C) \ (\text{avg. spec. heat})$$

EXAMPLE

1. Flow rate set at 0.5 gallons per minute.

2. Input temperature read at 10°C. Correction Factor read from graph of Figure B - at 10°C = .9985

3. Output water temperature read at 15°C.

4. T obtained; +15°C minus +10°C = 5°C.

5. RF power P_x, found on graph of Figure A. With 0.5 gpm and ΔT 5°C P_x = 657W.

6. Average Specific Heat found from Graph C by:
   a) C_p of input water temperature (10°C) = 1.0012
   b) C_p of output water temperature (15°C) = .999
   c)   Average C_p would be .9997

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

$$P_a = 657 \times .9985 \times .9997$$
$$= 655.8 \text{ watts}$$

4-2

SECTION V - MAINTENANCE

1.   General

The 6020 Calorimeter is generally maintenance free. Handle the instrument with care; this equipment contains delicate precision components. Store the 6020 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 clean 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.
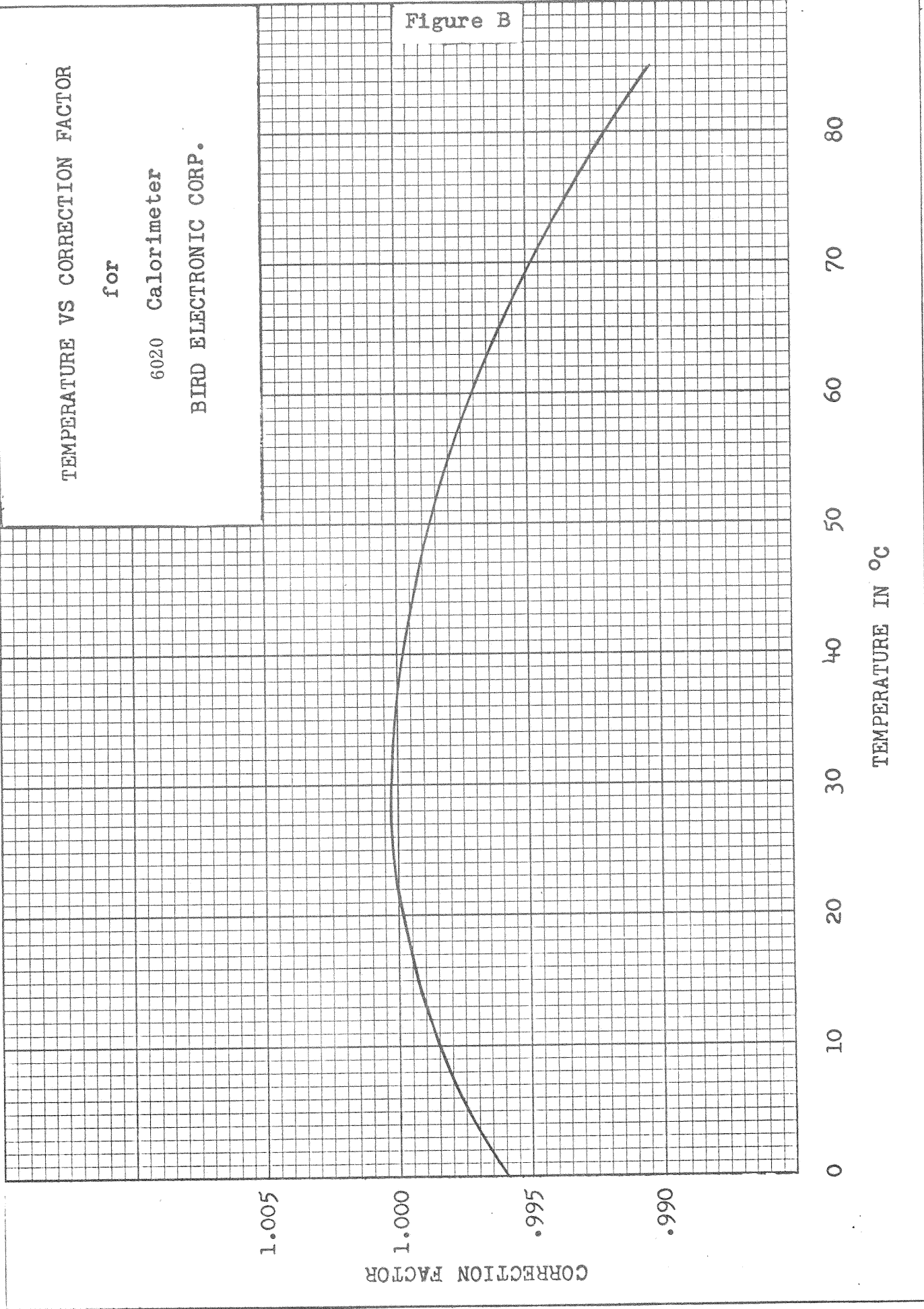
6020-1167

Figure A

POWER VS ΔT CURVES

for
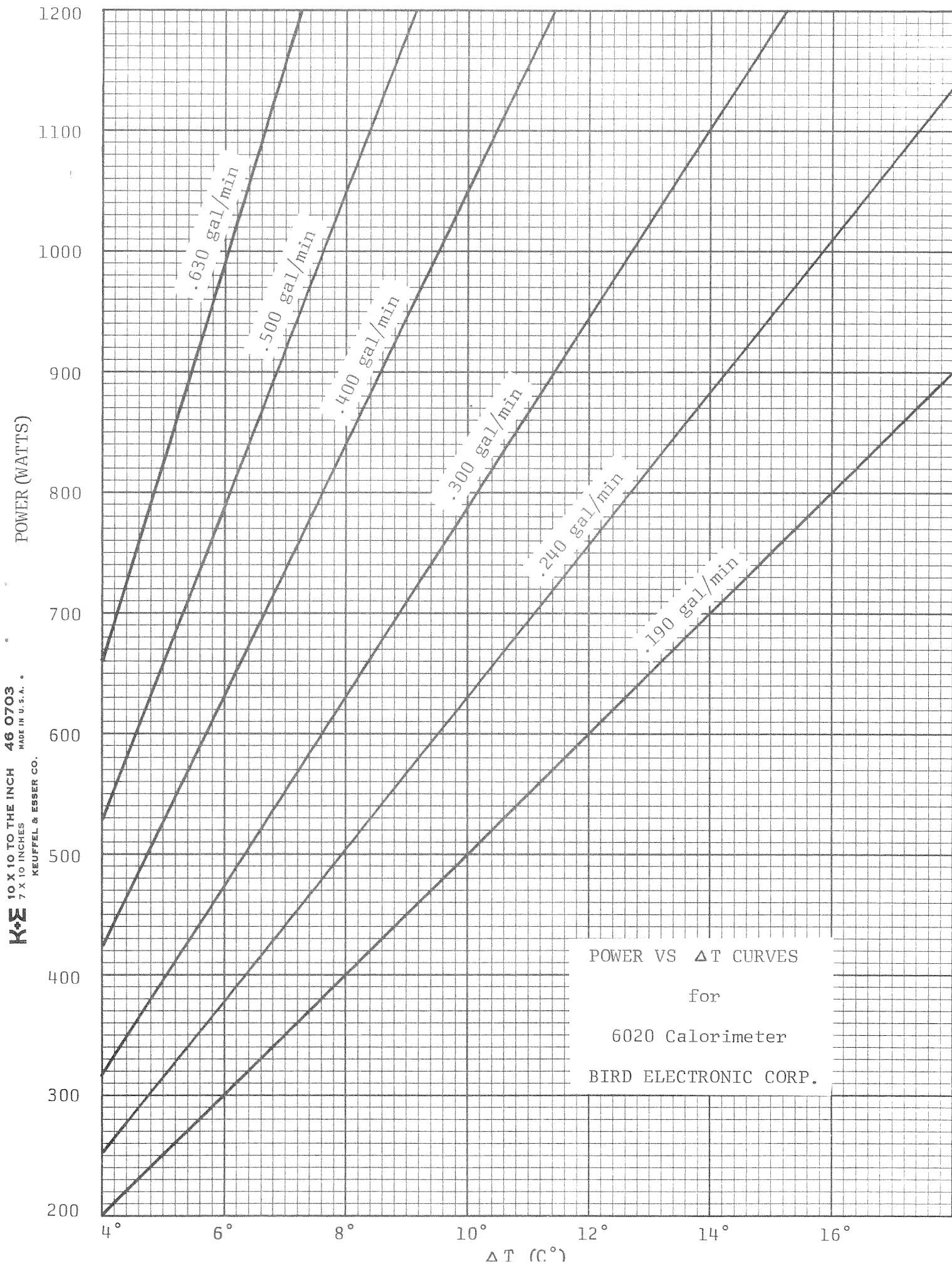
6020 Calorimeter

BIRD ELECTRONIC CORP.

Figure B

TEMPERATURE VS CORRECTION FACTOR

for

6020 Calorimeter

BIRD ELECTRONIC CORP.

TEMPERATURE IN °C

CORRECTION FACTOR

Figure C

SPECIFIC HEAT, C_p of WATER
vs
TEMPERATURE

Model 6020