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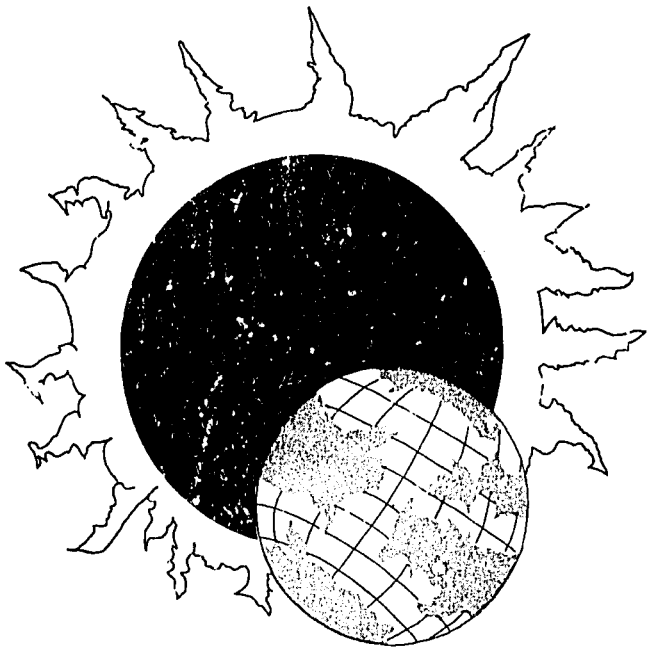

TRAINING IN ALTERNATIVE ENERGY TECHNOLOGIES

Solar Energy Laboratory

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A COMPARISON OF EFFICIENCIES FOR SIMILARLY BUILT CORRUGATED STEEL SOLAR COLLECTOR AND A COPPER FLAT PLATE SOLAR COLLECTOR

Project Group

1.	Jorge Doria-Medina (Project Leader)	Bolivia
2.	Ramadan Abdel-Rahman Basha	Egypt
3.	Kelland Barthelmy	St. Lucia
4.	Gamal Abdel-Rahman	Egypt
5.	Eltayeb Swar	Sudan
6.	Nour Idris	Sudan
7.	Kawther Ahmed	Sudan

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II INTRODUCTION

The renewed interest in solar collectors, as a response to rising energy costs, has produced a wide range of models and designs which are now available in the market place. The need to test the performance of these collectors established the necessity for standardized procedures. These now exist and are used in many testing facilities, both in the U.S. and abroad. Therefore, the theoretical considerations on which the tests are based will not be discussed here.

The authors will stress instead the special problems encountered while testing two similarly constructed solar collectors, one of which was built using a flat copper plate and copper tubing while the other (actually built for this project) was built using steel corrugated sheet and steel pipes.

The basic aim of this project was to test the idea that it should be much more practical, in most countries, to build solar flat plate collectors of corrugated steel plates and steel tubes than to build copper plate and copper tube collectors, not withstanding the obvious intrinsic properties of copper for use in solar energy systems.

It is widely known that corrugated steel and steel tubes (pipes) are widely available even in the more remote areas of most countries; while it is also known that copper materials are not only more expensive but more difficult to find, especially in areas far from the main cities.

Therefore this project, as previously stated, aimed to show that a corrugated steel flat plate collector could be built with a degree of efficiency; that, while not as good as one similarly built of copper, would be still good enough to make its use attractive in some countries.

III CONSTRUCTION

A flat plate collector was built from corrugated steel plate, following closely the dimensions of a previously built copper plate collector. The dimensions are: length, 29.5 in.; width, 29.5 in.; depth 6 in. The pipe's dimensions used are: 1/2 in. diameter for the tubes and 2 in. diameter for the headers.

While constructing the collector, bracing was first used to attach the tubes to the headers. However, during testing, leaks were detected and several attempts were made to solder the pipes until finally the problem was solved.

Common low iron content glass was used for the collector top. The glass was fixed to the collector frame by means of a sealing compound and by screwing aluminum sections to the wooden frame. Thermocouples were attached in strategic places on the collector plate and tubes by means of epoxy (see Table 1).

IV DATA ACQUISITION, CONVERSIONS AND RESULTS

A 36 lamp light array, 75 feet from the gound, was used to simulate solar insolation. Several insolation measurements were taken under the light array geometrically placed to give valid readings. The readings were taken at the same level of the collectors. The average of the readings obtained was 230 Btu/Hr/sq.ft. The collectors were filled during testing, at a 10° angle from the horizontal, to achieve a thermosyphon effect.

The collectors were fed tap water by two separated hoses whose flow rate was maintained as close as possible to .02 kg/sec/m^2. This task became extremely difficult as the bypass valves were not sensitive enough. So a needle valve was affixed to the galvanized collector replacing the existing gate valve which had failed to achieve good control of the flow rate.

The lack of a flow meter in the lab added greatly to the problem of obtaining exact flow rates. The flow rate was obtained by adjusting the needle valve mounted on the collector at the water exit. This process was carried out in two steps: by volumatric measurements and stop watch and by weighing the volume obtained in the first step. In order to have good control on the water temperature at the collector's inlet, an electric heater was used. The heat was maintained by means of a variable electric resistance device.

The data obtained during the test was by means of a Leeds Northrup 30 Channel Recorder. This instrument was set to measure and record 10 channels. Channel number 3, designed to measure ambient temperature, was not used. Instead, a normal bulb thermometer (mercury) was used for this purpose. A description of the channels used and the data

obtained can be found in Table 1, while other data will be found in Tables 2, 3 and 4.

In the following pages the authors present several examples of flow rate conversions of actual temperature measured by means of lab prepared thermocouples, and of efficiency calculations. Whenever a particular problem arose, an example of how it was solved is presented. A nomenclature defining the terminology used can be found in the appendix.

SET I DATA TAKEN NOV. 23, 1982

Channel No.	I-A Inlet temp. same as temp. of mains (°F)	I-B Inlet temp. raised by heater (°F)	I-C Inlet temp. raised (°F)	$\dot{m}$ Flow rate (Kg/s)	
1	77	79	83	Copper	Galvanized
2	67	69	74		
3	*	*	*		
4	77	80	97		
5	121.5	123	132.5		
6	108	109	119		
7	117	118	127	.0103 Kg/s	.0110 Kg/s
8	81	84	97		
9	67	70	82		
10	97	98	102.5		

Average ambient temperature = 79.5° F.

Readings IB for both copper and galvanized and IC for galvanized were rejected due to fluctuations in flow rate. Reading A was accepted because of stable conditions.

ΔV between Channels 4 and 9

Set	ΔV (mV)
IA	0.217
IB	0.233
IC	0.375

* The ambient temperature is measured by a mercury-bulb thermometer, the coupling with Channel No. 3 is disconnected.

SET II DATA TAKEN NOV. 29, 1982

Channel No.	IIA Inlet temp. same as mains (°F)	IIB Inlet temp. raised by heater (°F)	ṁ Flow rate Kg/s	
			Copper	Galvanized
1	78	83		
2	68.5	73		
3	*	*		
4	78.5	83	0.01026	0.01072
5	120	123	0.01018	0.01062
6	108	111	0.01022	0.01037
7	116	120		
8	82	87	ṁ average	
9	69	73	0.01022	0.01057
10	97	102		

Average ambient temperature = 78° F., during testing period.

Readings IIA were rejected because of fluctuations and disruption of flow rates. Readings IIB were accepted because of stable conditions.

ΔV between Channel 4 and Channel 9 = 0.221 mV for Set IIB.

SET III DATA TAKEN NOV. 30, 1982

Note: Due to the problem of obtaining equal flow rates for both collectors, only the galvanized steel collector was tested to obtain its efficiency curve.

Channel No.	IIIA Inlet temp. same as mains	IIIB Inlet temp. raised by heater	ṁ Flow rate Kg/s
1	Copper Collector not tested		0.01126
2			0.01130
3	-	-	0.01128
4	80	91	0.01106
5	121	128	0.01141
6	109	117	0.01102
7	117	125	0.01137
8	84	94	0.01107
9	72	82	ṁ average
10	Copper Collector not tested		0.01122

Average ambinet temperature = 78.5°F

ΔV between Channel 4 and Channel 9

Set	ΔV (mV)
IIIA	0.205
IIIB	0.200

CONVERSIONS

Notes

I Since we are using engineering (British) units in our calculations, we have converted the flow rate from kilograms per second to pounds per hour as shown below.

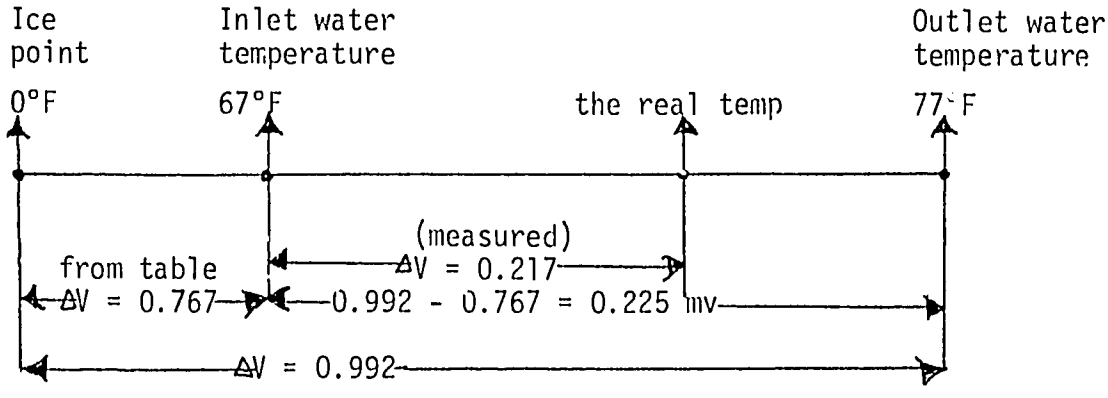
II We constructed the thermocouples which measured the inlet and outlet temperatures of the galvanized steel collector out of copper-constantan. Due to the method of consturction, a correction had to be made to the temperature difference (ΔT) between inlet and outlet temperatures by considering the corresponding voltage difference (ΔV) recorded on the digital voltmeter. This correction was unnecessary for the copper collector because the thermocouples were designed to read accurate temperatures.

Example of flowrate conversion. Other conversions are similar.

1 hour = 60 x 60 seconds 1 lb. = 0.4539 kg

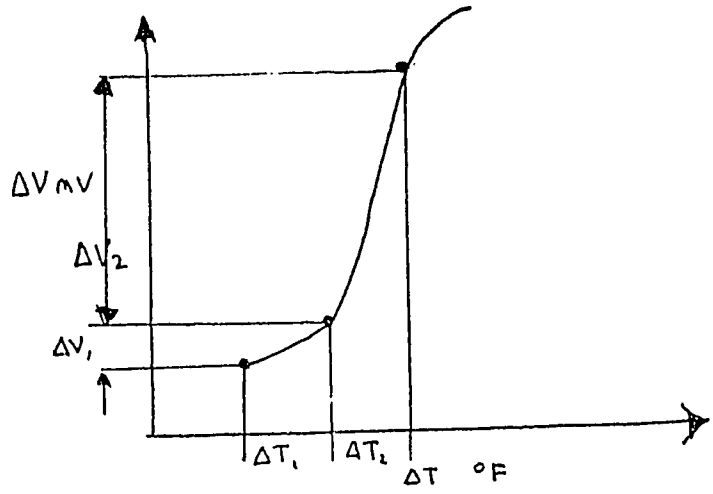
$$0.0103 \text{ kg/s} = [0.0103 \frac{\cancel{kg}}{\cancel{s}}] \times [60 \times 60 \frac{\cancel{s}}{hr}] \times [\frac{1 \text{ lb}}{0.4539 \cancel{kg}}] = 81.7 \text{ lb/hr}$$

Example of correction for outlet and inlet temperature difference (ΔT) from voltage difference (ΔV).



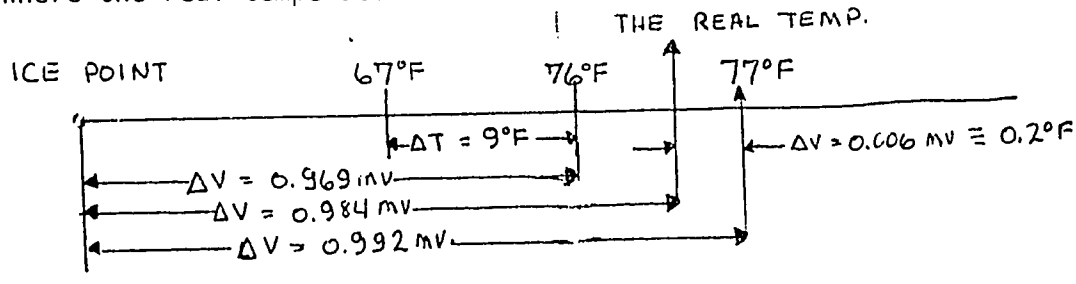
ΔV in mv

It is clear from the diagram above that the ΔV corresponding to 77°F - 67°F is 0.225 mv (from tables), while the actual ΔV measured is 0.217 mv which means that the actual outlet water temperature is less than 77°F. Bearing in mind the relationship between temperature and potential difference between the thermocouple terminals is as shown in the following diagram.



Any small difference in the region of ΔT_2 corresponds to a value of ΔV which is much more than the ΔV which may correspond to the same ΔT in the region of ΔT_1.

To avoid such errors, we may take small temperature difference of 1°F (one degree F), less than the outlet water temperature 77°F, we find the value of ΔV corresponding to 76°F in tables, that is to check where the real temperature is located.



ΔV corresponding to 1°F from tables = 0.992 - 0.969 = 0.023 mv -----(1)

ΔV for the real temperature = 0.767 + 0.217 = 0.984 mv

Note: The locally made thermocouples measure ΔT between inlet water temperature and outlet water temperature. The ΔV between 77°F and the real temperature is 0.992 - 0.984 = 0.008 mv ----------(2)

But we have from (1) above ΔV = 1°F = 0.023 mv

From (1) and (2) above

$$0.006 \text{ mv corresponds to } \frac{0.008}{0.023} = 0.347°F$$

∴Actual temp. = 77°F - 0.347 = 76.653

Actual ΔT = 76.653 - 67 = 9.653°F

Data for calculating efficiency for copper collector

Set	Average flow rate ($\dot{m}$) Kg/s	lb/hr	Inlet temp. TIN (°F)	Outlet temp. TO (°F)	ΔT = TO - TIN
IA	.01035	82.1	67	77	10
IB	.01035	82.1	74	83	9
IIB	0.01022	81.1	73	83	10

Data for calculating efficiency for galvanized steel collector

Set	Average flow rate ($\dot{m}$) Kg/s	lb/hr	Inlet temp.	Outlet temp.	ΔV (mV)	ΔT (°F)
IA	.01085	86.1	67	77	0.217	9.7
IIB	.01057	83.8	73	83	0.221	9.8
IIIA	.01122	89.0	72	80	0.205	9.1
IIIB			82	91	0.200	8.7

Calculation of Efficiencies

Calculating efficiency (η) for galvanized steel collector from IA above

$$\eta = \frac{\dot{m}_{ave} C_p \Delta T}{IA}$$

where I = 230 Btu/ft^{2}hr, A = 6.04 ft^2

$$\eta_{gal} = \frac{86.1 \times 1 \times 9.7}{230 \times 6.04} = 0.601 \simeq 60\%$$

Since the calculation for all other efficiences are identical, they are simply tabulated below.

Set	Copper		Galvanized Steel	
	Flow rate	Efficiency	Flow rate	Efficiency
IA	82.1 lb/hr	59.1%	86.1 lb/hr	60.1%
IB	82.1 lb/hr	53.2%	no data	no data
IIB	81.1 lb/hr	53.4%	83.8 lb/hr	59.1%
IIIA	no data	---	89.0 lb/hr	58.3%
IIIB	no data	---	89.0 lb/hr	55.7%

To plot the efficiency curve for the collectors $\frac{T_{inlet} - T_{ambient}}{\text{insolation}}$ must be calculated for each inlet temperature.

For galvanized steel

IIIA (1) $$\frac{T_{in} - T_a}{I} = \frac{(72 - 78.5)°F}{230\ Btu/ft^2hr} = -0.0283°F\ \frac{ft^2hr}{Btu}$$

IIIB (2) $$\frac{T_{in} - T_a}{I} = \frac{(82 - 78.5)°F}{230\ Btu/ft^2hr} = 0.0152°F\ \frac{ft^2hr}{Btu}$$

For copper

IA (1) $$\frac{T_{in} - T_a}{I} = \frac{(67 - 79.5)°F}{230\ Btu/ft^2hr} = -0.054°F\ \frac{ft^2hr}{Btu}$$

IB (2) $$\frac{T_{in} - T_a}{I} = \frac{(74 - 79.5)°F}{230\ Btu/ft^2hr} = -0.024°F\ \frac{ft^2hr}{Btu}$$

CONCLUSIONS

On the basis of the data obtained, its analysis and an appraisal of the laborabory work, it is concluded that:

A. The data obtained for the copper collector is not reliable. It is felt that the thermocouples installed on this collector were rounded due to degradation of the contacts between the thermocouples and the collector plate and tubes. This precluded the accurate use of ΔT when using the inlet water as reference and the outlet as high junction. As a result, the data contains significant errors in the efficience data points. It is felt that the data obtained could be as $\pm$ 10% in error.

B. On the basis of theoretical considerations it was expected from the very beginning of the project that the copper collector would have a greater efficiency; however, it was also felt that the thicker components that make up the corrugated steel collector, in addition to its superior design, would compensate, to some degree, the thermoconductivity difference between copper and steel. An analysis of the data seems to confirm this. First, the overall heat loss coefficient (U_L) for copper is over 3 1/2 times that of the galvanized collector. The heat removal factor (F_R) for the galvanized steel collector is higher than that for copper.

	Copper	Galvanized Steel
U_L	3.306	0.885
F_R	0.605	0.706

On an apriori basis the authors interpret the data stated above to mean that due to the corrugations of the absorbing plate on the galvanized collector there exist air pockets under such corrugations. Some of the heat gained by the corrugated plate was spent in heating up the pockets previously mentioned. The latter acted as heat storage units. It is believed that the heat transferred by convection from the air pockets to the absorber plate finally heated the water and added to increase the efficiency of the corrugated steel collector. In addition to this, the flow rate through the galvanized steel collector was 89.1 lbs/hr., whereas the flow rate through the copper collector was 7 lbs/hr less.

C. A study of the efficiency curve drawn for the corrugated steel collector shows that to have a shallow slope, which means that the collector's efficiency does not drop too rapidly at higher inlet temperatures.

D. Even though the relative error for the copper collector is at least ten times greater than the error for the steel collector, the authors feel that a relative comparison can still be made between both collectors on the basis of the intercept points of the curves drawn for both collectors, which are practically the same (.56 and .48). A corollary of this would be that the steel collector compares favorably with the copper collector as far as their efficiency is concerned.

E. It is felt that the principal benefit gained by working on this project was to stabilize the testing procedures and to take notice of the problems that arose during construction and testing. Furthermore, it seems clear that a steel galvanized collector is feasible and may be the only way to have solar collectors operational in some areas of the world due to the greater availability and lower price of corrugated steel.

If the problem of a lower efficiency would become too great it could be easily solved by increasing the size of the collector. Even under this circumstance it is believed the steel collectors would be economically competitive.

In closing, the authors would like to stress as a corollary of their work that good conducting materials with a poor collector design is less efficient than poor conducting materials with a good design.

RECOMMENDATIONS

A. We would like to suggest to future participants in the TAET program to investigate further the theoretical aspects related to air pockets created beneath the corrugated plate and their significance in the solar cell efficiency.

B. Additionally, it is suggested that the idea of using corrugated steel plates for solar collectors be translated into using this principle in a much larger scale. The authors suggest the use of the actual roof of houses and buildings made of corrugated steel in many parts of the world to act not only as roofing but as very large corrugated collectors where the pipe would sit directly on the corrugated steel without soldering. We believe the large area of the collector would compensate for the lack of soldering between pipes and plate and would compensate also for direct heat losses to the atmosphere.

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APPENDIX!

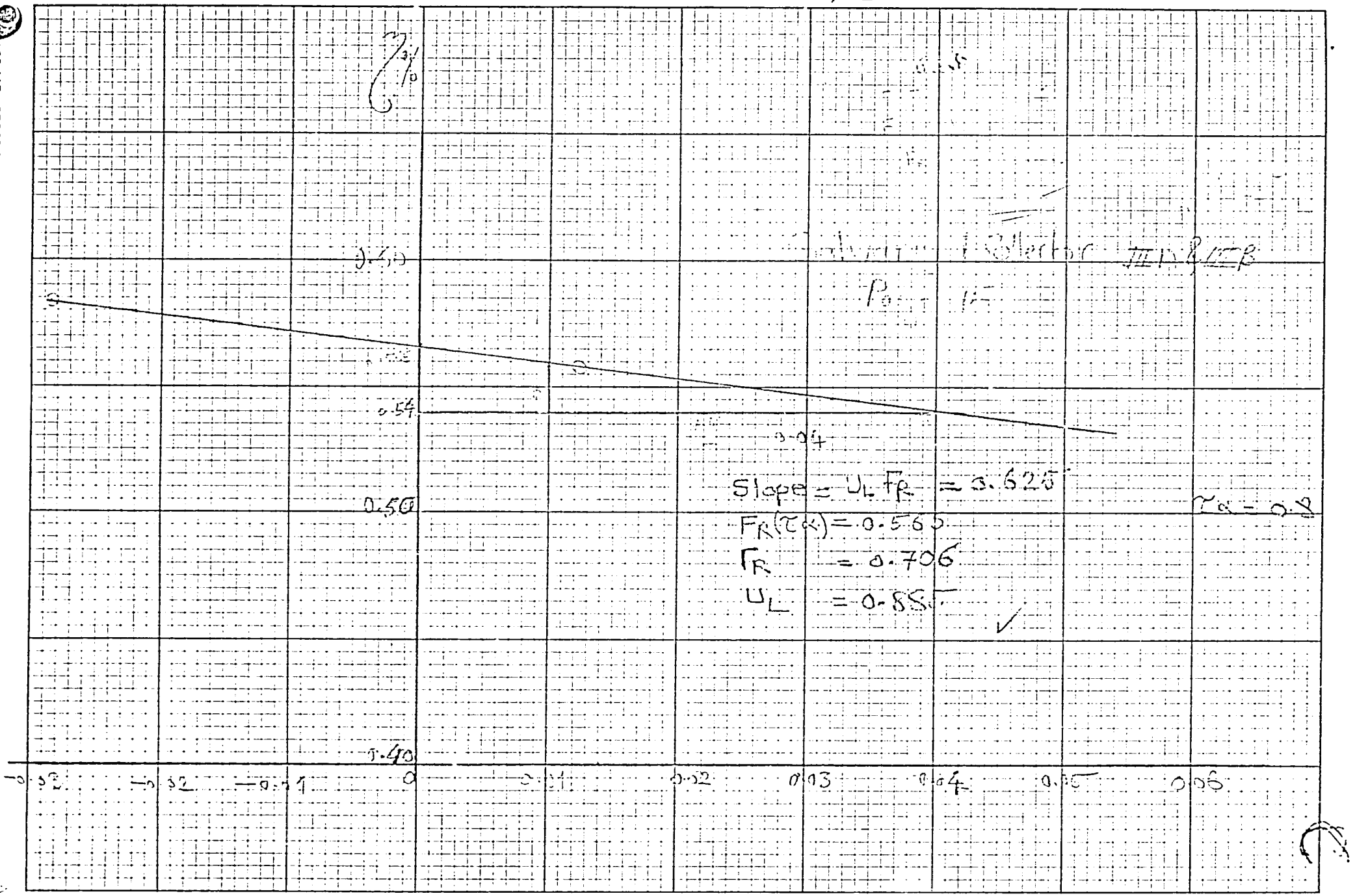
Channel Identification

Channel Number	Identification
1	The outlet temperature from the copper collector.
2	The inlet temperature to the copper collector.
3	The ambient temperature.
4	The outlet temperature from the galvanized collector.
5	The temperature of the valley . (thermocouple is coated with epoxy)
6	The temperature of the top of the galvanized sheet.
7	The temperature of the valley of the galvanized sheet. (thermocouple is soldered)
8	The temperature of the pipe of galvanized collector.
9	The inlet temperature of the galvanized collector.
10	The temperature of the absorber plate of the copper collector.

Nomenclature

A	:	transparent frontal area of the collector. ft^2
C_p	:	specific heat of the transfer fluid (Btu/16m.F)
F_R	:	solar collector heat removal factor, dimensionless
I	:	solar irradiation in (Btu/hr ft^2)
$\dot{m}$	:	mass flow rate of the transfer fluid
ΔT	:	temperature difference in °F
T_{in}	:	temperature of the transfer fluid entering the collector in °F
T_o	:	temperature of the transfer fluid leaving the collector
U_L	:	solar collector heat transfer loss coefficient (Btu/hr ft^2 °F)
$\tau\alpha$	:	effective transmittance - absorptance product - dimensionless
α	:	absorptance of the collector absorber surface for solar radiation
τ	:	transmittance of the solar collector cover plate, dimensionless
η	:	collector efficiency %
ΔV	:	voltage difference in (mv) between the two junctions of the thermocouples corresponding to temperature difference between inlet and outlet water

$\dot{m}^{o} = 89.0$ lb/hr



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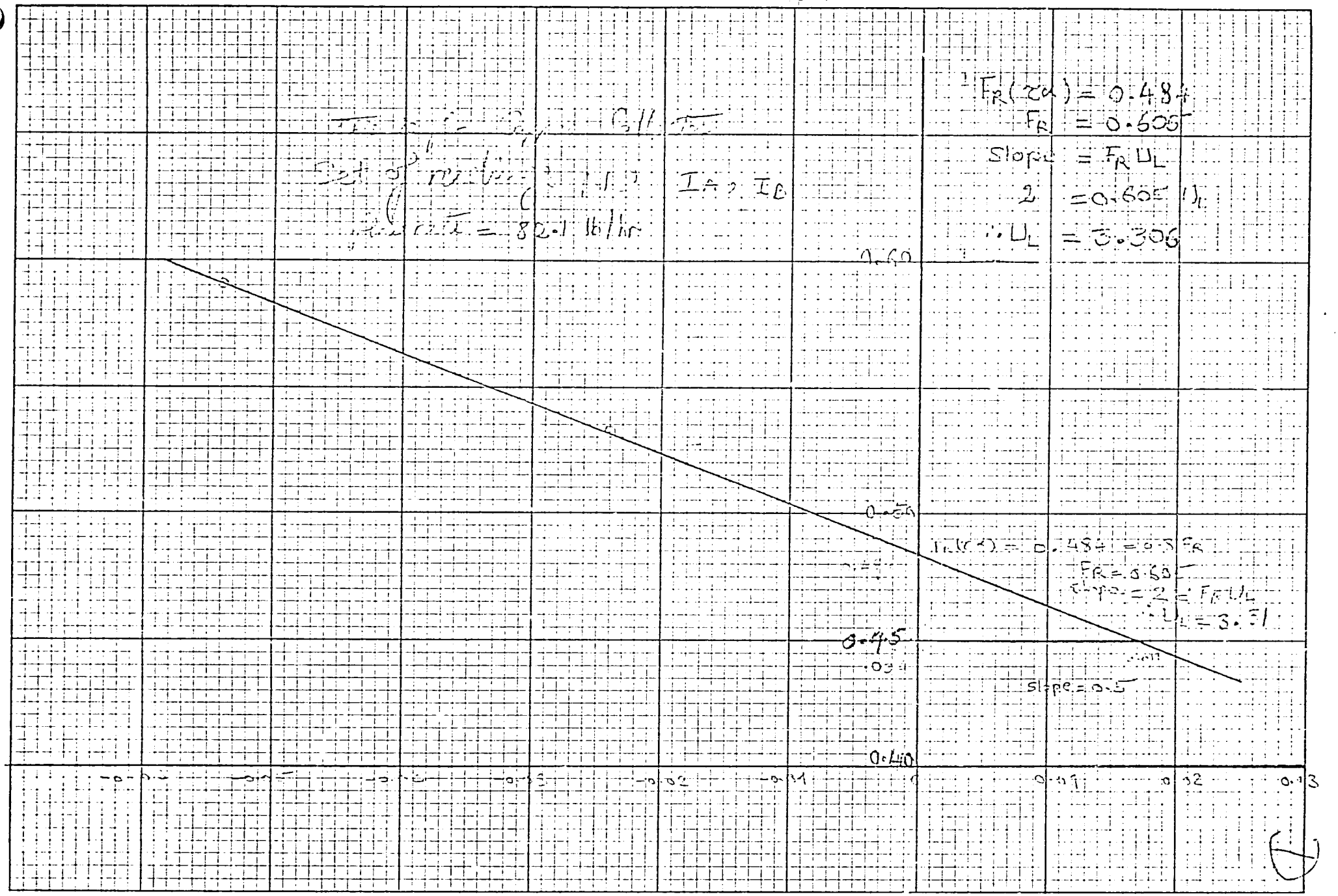

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TABLE XI —Continued

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TYPE T

New Reference Tables
Supersedes N.B.S.
Circular #561

Copper Vs. Copper-Nickel

(Copper-Constantan)

Temperature in Degrees F
Reference Junction at 32°F

THERMOELECTRIC VOLTAGE IN ABSOLUTE MILLIVOLTS

DEG F	0	1	2	3	4	5	6	7	8	9	10	DEG F
-190	-4.089	-4.023	-4.037	-4.051	-4.065	-4.079	-4.093	-4.107	-4.121	-4.135	-4.149	-190
-180	-3.946	-3.979	-3.994	-3.905	-3.923	-3.937	-3.951	-3.966	-3.980	-3.994	-4.009	-180
-170	-3.717	-3.732	-3.746	-3.761	-3.776	-3.791	-3.806	-3.820	-3.835	-3.850	-3.866	-170
-160	-3.565	-3.580	-3.596	-3.611	-3.626	-3.641	-3.656	-3.671	-3.687	-3.702	-3.717	-160
-150	-3.410	-3.425	-3.441	-3.457	-3.472	-3.488	-3.503	-3.519	-3.534	-3.550	-3.565	-150
-140	-3.251	-3.267	-3.283	-3.299	-3.315	-3.331	-3.347	-3.362	-3.378	-3.394	-3.410	-140
-130	-3.089	-3.105	-3.121	-3.138	-3.154	-3.170	-3.186	-3.203	-3.217	-3.235	-3.251	-130
-120	-2.923	-2.939	-2.956	-2.973	-2.989	-3.006	-3.023	-3.039	-3.056	-3.072	-3.089	-120
-110	-2.755	-2.771	-2.788	-2.805	-2.822	-2.838	-2.855	-2.872	-2.889	-2.906	-2.923	-110
-100	-2.583	-2.598	-2.616	-2.633	-2.650	-2.667	-2.685	-2.702	-2.719	-2.736	-2.753	-100
-90	-2.405	-2.422	-2.440	-2.458	-2.475	-2.493	-2.511	-2.528	-2.546	-2.563	-2.581	-90
-80	-2.225	-2.243	-2.261	-2.279	-2.297	-2.315	-2.333	-2.351	-2.369	-2.387	-2.405	-80
-70	-2.042	-2.061	-2.079	-2.098	-2.116	-2.134	-2.152	-2.171	-2.189	-2.207	-2.225	-70
-60	-1.856	-1.875	-1.894	-1.912	-1.931	-1.950	-1.968	-1.987	-2.005	-2.024	-2.042	-60
-50	-1.667	-1.686	-1.705	-1.724	-1.743	-1.762	-1.781	-1.800	-1.819	-1.838	-1.856	-50
-40	-1.475	-1.494	-1.513	-1.533	-1.552	-1.571	-1.591	-1.610	-1.629	-1.648	-1.667	-40
-30	-1.279	-1.299	-1.319	-1.338	-1.358	-1.377	-1.397	-1.416	-1.436	-1.455	-1.475	-30
-20	-1.081	-1.101	-1.121	-1.141	-1.160	-1.180	-1.200	-1.220	-1.240	-1.260	-1.279	-20
-10	-0.879	-0.899	-0.920	-0.940	-0.960	-0.980	-1.000	-1.021	-1.041	-1.061	-1.081	-10
0	-0.676	-0.695	-0.716	-0.736	-0.757	-0.777	-0.798	-0.818	-0.838	-0.859	-0.879	0
DEG F	0	1	2	3	4	5	6	7	8	9	10	DEG F
0	-0.676	-0.654	-0.633	-0.613	-0.592	-0.571	-0.550	-0.529	-0.509	-0.488	-0.467	0
10	-0.467	-0.446	-0.425	-0.404	-0.383	-0.362	-0.341	-0.320	-0.299	-0.277	-0.256	10
20	-0.256	-0.235	-0.214	-0.193	-0.171	-0.150	-0.129	-0.107	-0.086	-0.064	-0.043	20
30	-0.043	-0.022	0.000	0.022	0.043	0.065	0.086	0.108	0.130	0.151	0.173	30
40	0.173	0.195	0.216	0.238	0.260	0.282	0.303	0.325	0.347	0.369	0.391	40
50	0.391	0.413	0.435	0.457	0.479	0.501	0.523	0.545	0.567	0.589	0.611	50
60	0.611	0.634	0.656	0.678	0.700	0.722	0.745	0.767	0.789	0.812	0.834	60
70	0.834	0.857	0.879	0.902	0.924	0.947	0.969	0.992	1.014	1.037	1.060	70
80	1.060	1.082	1.105	1.128	1.151	1.173	1.196	1.219	1.242	1.265	1.288	80
90	1.288	1.311	1.334	1.357	1.380	1.403	1.426	1.449	1.472	1.495	1.518	90
100	1.518	1.542	1.565	1.588	1.611	1.635	1.658	1.681	1.705	1.728	1.752	100
110	1.752	1.775	1.799	1.822	1.846	1.869	1.893	1.917	1.940	1.964	1.988	110
120	1.988	2.011	2.035	2.059	2.083	2.107	2.131	2.154	2.178	2.202	2.226	120
130	2.226	2.250	2.274	2.298	2.322	2.347	2.371	2.395	2.419	2.443	2.467	130
140	2.467	2.492	2.516	2.540	2.565	2.589	2.613	2.638	2.662	2.687	2.711	140
150	2.711	2.736	2.760	2.785	2.809	2.834	2.859	2.883	2.908	2.933	2.958	150
160	2.958	2.982	3.007	3.032	3.057	3.082	3.107	3.131	3.156	3.181	3.206	160
170	3.206	3.231	3.256	3.281	3.307	3.332	3.357	3.382	3.407	3.432	3.458	170
180	3.458	3.483	3.508	3.533	3.559	3.584	3.609	3.635	3.660	3.686	3.711	180
190	3.711	3.737	3.762	3.788	3.813	3.839	3.864	3.890	3.916	3.941	3.967	190
200	3.967	3.993	4.019	4.044	4.070	4.096	4.122	4.148	4.174	4.199	4.225	200
210	4.225	4.251	4.277	4.303	4.329	4.355	4.381	4.408	4.434	4.460	4.486	210
220	4.486	4.512	4.538	4.565	4.591	4.617	4.643	4.670	4.696	4.722	4.749	220
230	4.749	4.775	4.821	4.828	4.854	4.881	4.907	4.934	4.960	4.987	5.014	230
240	5.014	5.040	5.067	5.093	5.120	5.147	5.174	5.200	5.227	5.254	5.281	240
250	5.281	5.307	5.334	5.361	5.388	5.415	5.442	5.469	5.496	5.523	5.550	250
260	5.550	5.577	5.604	5.631	5.658	5.685	5.712	5.739	5.767	5.794	5.821	260
270	5.821	5.848	5.875	5.903	5.930	5.957	5.985	6.012	6.039	6.067	6.094	270
280	6.094	6.122	6.149	6.177	6.204	6.232	6.259	6.287	6.314	6.342	6.369	280
290	6.369	6.397	6.425	6.452	6.480	6.508	6.536	6.563	6.591	6.619	6.647	290
300	6.647	6.675	6.702	6.730	6.758	6.786	6.814	6.842	6.870	6.898	6.926	300
310	6.926	6.954	6.982	7.010	7.038	7.066	7.094	7.122	7.151	7.179	7.207	310
320	7.207	7.235	7.263	7.292	7.320	7.348	7.377	7.405	7.433	7.462	7.490	320
330	7.490	7.518	7.547	7.575	7.604	7.632	7.661	7.689	7.718	7.746	7.775	330
340	7.775	7.804	7.832	7.861	7.889	7.918	7.947	7.975	8.004	8.033	8.062	340
350	8.062	8.090	8.119	8.148	8.177	8.206	8.235	8.264	8.292	8.321	8.350	350
360	8.350	8.379	8.408	8.437	8.466	8.495	8.524	8.553	8.583	8.612	8.641	360
370	8.641	8.670	8.699	8.728	8.757	8.787	8.816	8.845	8.874	8.904	8.933	370
380	8.933	8.962	8.992	9.021	9.050	9.080	9.109	9.139	9.168	9.198	9.227	380
390	9.227	9.257	9.286	9.316	9.345	9.375	9.404	9.434	9.464	9.493	9.523	390
400	9.523	9.553	9.582	9.612	9.642	9.671	9.701	9.731	9.761	9.791	9.820	400
410	9.820	9.850	9.880	9.910	9.940	9.970	10.000	10.030	10.060	10.090	10.120	410
420	10.120	10.150	10.180	10.210	10.240	10.270	10.300	10.330	10.360	10.390	10.420	420
430	10.420	10.451	10.481	10.511	10.541	10.572	10.602	10.632	10.662	10.693	10.723	430
440	10.723	10.753	10.784	10.814	10.845	10.875	10.905	10.936	10.966	10.997	11.027	440
450	11.027	11.058	11.088	11.119	11.149	11.180	11.211	11.241	11.272	11.302	11.333	450
460	11.333	11.364	11.394	11.425	11.456	11.487	11.517	11.548	11.579	11.610	11.640	460
470	11.640	11.671	11.702	11.733	11.764	11.795	11.826	11.856	11.887	11.918	11.949	470
480	11.949	11.980	12.011	12.042	12.073	12.104	12.135	12.166	12.198	12.229	12.260	480
490	12.260	12.291	12.322	12.353	12.384	12.416	12.447	12.478	12.509	12.540	12.572	490
500	12.572	12.603	12.634	12.666	12.697	12.728	12.760	12.791	12.822	12.854	12.885	500
510	12.885	12.917	12.948	12.979	13.011	13.042	13.074	13.105	13.137	13.168	13.200	510
520	13.200	13.232	13.263	13.295	13.326	13.358	13.390	13.421	13.453	13.485	13.516	520
530	13.516	13.548	13.580	13.611	13.643	13.675	13.707	13.739	13.770	13.802	13.834	530
540	13.834	13.866	13.898	13.930	13.961	13.993	14.025	14.057	14.089	14.121	14.153	540
550	14.153	14.185	14.217	14.249	14.281	14.313	14.345	14.377	14.409	14.441	14.474	550
560	14.474	14.506	14.538	14.570	14.602	14.634	14.666	14.699	14.731	14.763	14.795	560
570	14.795	14.828	14.860	14.892	14.924	14.957	14.989	15.021	15.054	15.086	15.118	570
580	15.118	15.151	15.183	15.215	15.248	15.280	15.313	15.345	15.378	15.410	15.443	580
590	15.443	15.475	15.508	15.540	15.573	15.605	15.638	15.671	15.703	15.736	15.769	590
600	15.769	15.801	15.834	15.866	15.899	15.932	15.965	15.997	16.030	16.063	16.096	600
610	16.096	16.128	16.161	16.194	16.227	16.259	16.292	16.325	16.358	16.391	16.424	610
620	16.424	16.457	16.490	16.523	16.555	16.588	16.621	16.654	16.687	16.720	16.753	620
630	16.753	16.786	16.819	16.852	16.886	16.919	16.952	16.985	17.018	17.051	17.084	630
640	17.084	17.117	17.150	17.184	17.217	17.250	17.283	17.316	17.350	17.383	17.416	640
650	17.416	17.450	17.483	17.516	17.549	17.583	17.616	17.649	17.683	17.716	17.750	650
660	17.750	17.783	17.816	17.850	17.883	17.917	17.950	17.984	18.017	18.051	18.084	660
670	18.084	18.118	18.151	18.185	18.218	18.252	18.285	18.319	18.353	18.386	18.420	670
680	18.420	18.454	18.487	18.521	18.555	18.588	18.622	18.656	18.689	18.723	18.757	680
690	18.757	18.791	18.824	18.858	18.892	18.926	18.960	18.993	19.027	19.061	19.095	690
700	19.095	19.129	19.163	19.197	19.230	19.264	19.298	19.332	19.366	19.400	19.434	700
710	19.434	19.468	19.502	19.536	19.570	19.604	19.638	19.672	19.706	19.740	19.774	710
720	19.774	19.808	19.843	19.877	19.911	19.945	19.979	20.013	20.047	20.081	20.116	720
730	20.116	20.150	20.184	20.218	20.252	20.287	20.321	20.355	20.389	20.423	20.458	730
740	20.458	20.492	20.526	20.560	20.595	20.629	20.663	20.698	20.732	20.766	20.801	740
750	20.801	20.835	20.869									750
DEG F	0	1	2	3	4	5	6	7	8	9	10	DEG F

* CONVERTED FROM DEGREES CELSIUS 1968.

OMEGA ENGINEERING, INC.
One Omega Drive Box 4047 Stamford Connecticut 06907