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Investigate a Mathematical, Experimental and Finite Element Analysis of Temperature Distribution Through a Brass Metal Pin Fin by Natural Convection

Brass Metal Pin Fin experimental and FEA Analysis

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Abstract—*This research paper represents the experimental study and numerical study of temperature distribution and heat transfer along the length of the brass fin of cylindrical cross section, for that we utilize the Natural and Forced Pin Fin apparatus and utilize ANSYS 15.0 for the thermal simulation and compare the result of experimental setup with the simulation done on ANSYS 15.0, here we consider only natural convection done on the system and calculate the heat transfer coefficient of convection and then find the temperature distribution along the various distance through the fin and compare it with the simulation. We get the nearly same results by comparing the Mathematical Calculation, experimental setup and a finite Element simulation.*

Keywords- *Pin Fin Test Rig, FEA Analysis, Heat Transfer Coefficient, Natural Convection*

I. INTRODUCTION

Fin is used commonly in a reference to a solid that experiences energy transfer by convection and conduction between boundary and surrounding, Fin is basically design to increase the heat transfer along the surface for the body, weather in some component it is require to know that how much temperature can we achieve at what length and in cylindrical fin the temperature gradient can be affected internally in longitudinal direction (X- direction) and at same instant the energy is transferred by convection in atmosphere from its surface temperature.Analysis ofa pin fin performance done by ANSYS 15.0 software. In this thermal analysis, temperature variations w.r.t. distance at which heat flow occur through the fin is analyzed.

II. EXPERIMENTAL SETUP

To study the temperature distribution along the longitudinal fin with circular profile fin made of Brass of circular cross section fitted to the electric resistant coil and calculate the Voltage and Current across the electric coil to regulate the voltage we also use the dimmer, temperature at five points along the length of the fins are measured by the K- TYPE temperature sensors which is connected to the , this setup is fitted in the rectangular duct to reduce interference of the surrounding and also to calculate the forced convection but in this research paper we only introduce the calculation of free convection and compare it with the FEA simulation, We use bellowed specified instruments,

Diameter of fin:	16 mm
Length of fin:	370 mm
Material of fin:	Brass
Control Panel:	Digital Voltmeter (0- 300 V)
	Digital Ammeter (0- 2 A)
	Dimmer Stat (0- 230 A)
	2 A Digital Temp. Indicator (0- 200°C)
	ON/ OFF Switch
	Mains Indicator
Temperature Sensor:	K- type (7 Nos)

(a)

(b)

Figure: 2.1 (a) , (b) Test Rig

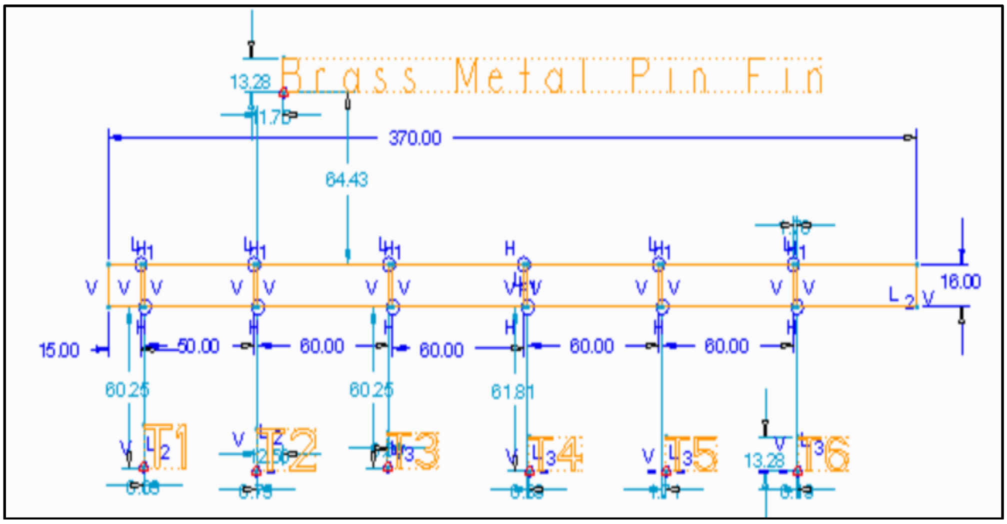


Figure: 2.2 2-D Sketch of Sensor Mounted on Pin Fin (All Dimension are in mm)

III. EXPERIMENT PROCEDURE FOR NATURAL CONVECTION AND READING

1. Connect the sensor socket & heater to the fin which to be tested(M.S)
2. Start heating the fin by switching ON the heater element and adjust the voltage up to a certain level by adjusting the dimmerstat.
3. Note down the temp. Sensor readings (1) to (7) when steady state is reached, record the final readings of Temp. Sensor No. 1 to 6 and also the ambient temp. Reading. from temp. Sensor No.7

Table: 3.1 Experimental Observations Reading for Brass Pin Fin

Sr. No.	Temperature Input Value in ℃	Power input W=V X I		Fin Temperature in ℃						Ambient Temp. in ℃
				T_1	T_2	T_3	T_4	T_5	T_6	
		V	I	1.5cm	7.5 cm	13.5cm	19.5 cm	25.5 cm	31.5 cm	T_7
1	214 ℃	118	0.27	214	159	136	114	95	85	46 ℃
2	200 ℃	110	0.25	200	141	126	111	92	83	46 ℃
3	180 ℃	85	0.21	180	133	121	107	87	78	46 ℃
4	160 ℃	70	0.17	160	127	116	101	82	73	46 ℃
5	140 ℃	65	0.14	140	106	92	87	76	68	46 ℃

IV. MATHEMATICAL CALCULATION

4.1 Mathematical equation to be Used

Mean Temp. of the Fin, $T_m = \frac{T_1+T_2+T_3+T_4+T_5}{5}$

Ambient Air Temperature $T_6=T_f$

Mean Fluid Temp. $T_{mf} = \frac{T_m+T_f}{2}$

Properties of air at mean fluid temp. (From material properties handbook)

Density, $\rho = 0.972$ kg/m^3

Viscosity, $\mu = 21.48 \times 10^{-6}$ kg/m s

Kinematic Viscosity, $\nu = 22.10 \times 10^{-6}$ m^2/sec

Thermal Conductivity, $K = 31.28 \times 10^{-3}$ w/m k

Specific Heat $C_p = 1009$ j/kg k

Prandlts's No. Pr= 0.690

$$\beta = \frac{1}{T_{mf}+273.15}$$

Grashoff No. $G_f = \frac{g*\beta*D^3*\Delta T}{V^2}$

Theoretical Temperature Profile within the Fin,

$$\frac{\theta}{\theta_0} = \frac{T_1 - T_f}{T_b - T_f} = \frac{COS\,h\,M(L-X)}{COS\,h\,m\,L}$$

4.2 Mathematical Calculation

4.2.1 General Mathematical Calculation

Mean Temperature of the Fin, $T_m = \frac{T_1+T_2+T_3+T_4+T_5}{5}$ =133.83 ℃

Ambient Air Temperature $T_6=T_f$ =46℃

Mean Fluid Temp. $T_{mf} = \frac{T_m+T_f}{2}$=133.83+46/2 =89.91 ℃

Properties of air at mean fluid temp. (From material properties handbook)

Density, $\rho = 0.972$ kg/m^3

Viscosity, $\mu = 21.48 \times 10^{-6}$ kg/m s

Kinematic Viscosity, $\nu = 22.10 \times 10^{-6}$ m^2/sec

Thermal Conductivity, $K = 31.28 \times 10^{-3}$ w/m k

Specific Heat $C_p = 1009$ j/kg k

Prandlts's No. Pr = 0.690

$$\beta = \frac{1}{T_{mf}+273.15}$$

=1/89.91+273.15 =0.00275

Grashoff No. $G_f = \frac{g*\beta*D^3*\Delta T}{V^2}$

= 9.81 X 0.00275 X0.016^3 X(133.86-46)/(22.10 X 10^{-6})^2

= 19871.01

$\Delta T = (T_m - T_f) = 87.14$℃

4.2.2 Using the Correlation for Free Convection:

Nusselt No. $Nu = 0.53\ (Gr\ Pr)^{0.25}$

$= 0.53(19871.01 \text{x} 0.690)^{0.25}$

$= 5.73$

Free convective heat transfer co eff. $h = \frac{Nu\ K_{air}}{D}$

$h = 5.73 \text{ x } 31.28 \text{ x} 10^{-3} / 0.016 = 11.20$ w/m^2℃

Fin Parameter, m = $\sqrt{\frac{hP}{K_b\ A}} = 5.05$

Thermal Conductivity of brass k_s=110 w/mk

Perimeter, P=π D=3.14 x 0.016 =0.0502 m

Cross sectional area of fin $A = \frac{\pi}{4} * D^2$ =3.14/4 x 0.015^2=0.0002 m^2

Fin Diameter, D=16 x 10^{-3} m

Fin Length, L=370 x 10^{-3} m

1) X = 0.015 m

Theoretical Temperature Profile within the Fin,

$$\frac{\theta}{\theta_0} = \frac{T_1 - T_f}{T_b - T_f} = \frac{COS\ h\ m(L - X)}{COS\ h\ m\ L}$$

Tx-46/214-46 =0.930

Tx=202℃at 0.015 m

Taking Base TemperatureTb=T1=214℃

2) X =0.075 m

Theoretical Temperature Profile within the Fin,

$$\frac{\theta}{\theta_0} = \frac{T_1 - T_f}{T_b - T_f} = \frac{COS\ h\ m(L - X)}{COS\ h\ m\ L}$$

Tx-46/214-46 =0.702

Tx=165.34℃ at 0.075 m

Taking Base Temperature Tb = T1=214 ℃

3) X = 0.135 m

Theoretical Temperature Profile within the Fin,

$$\frac{\theta}{\theta_0} = \frac{T_1 - T_f}{T_b - T_f} = \frac{COS\ h\ m(L - X)}{COS\ h\ m\ L}$$

Tx-46/214-46=0.5399

Tx=136.70℃ at0.135 m

Taking Base TemperatureTb = T1 =214 ℃

4) X = 0.0195 m

Theoretical Temperature Profile within the Fin,

$$\frac{\theta}{\theta_0} = \frac{T_1 - T_f}{T_b - T_f} = \frac{COS\ h\ m(L - X)}{COS\ h\ m\ L}$$

Tx-46/214-46 = 0.42

Tx=116.56℃ at 0.195 m

Taking Base Temperature Tb = T1 =214℃

5) X = 0.255 m

Theoretical Temperature Profile within the Fin,

$$\frac{\theta}{\theta_0} = \frac{T_1 - T_f}{T_b - T_f} = \frac{COS\ h\ m(L - X)}{COS\ h\ m\ L}$$

Tx-46/214-46 =0.353

Tx =105.3℃ at 0.255 m

Taking Base Temperature Tb = T1 = 214℃

6) X = 0.315 m

Theoretical Temperature Profile within the Fin,

$$\frac{\theta}{\theta_0} = \frac{T_1 - T_f}{T_b - T_f} = \frac{COS\ h\ m(L - X)}{COS\ h\ m\ L}$$

Tx-46/214-46 =0.313

Tx =98.58˚C at 0.315 m

Taking Base Temperature Tb = T1 =214˚c

Table: 4.1 Natural Convection of Brass Pin Fin Mathematical Result

Sr. No.	Temperature Input Value in ˚c	Method	Fin Temperature in ˚c						Ambient Temp. in ˚c
			T_1	T_2	T_3	T_4	T_5	T_6	
			1.5cm	7.5 cm	13.5 cm	19.5 cm	25.5 cm	31.5 cm	T_7
1	214 ˚c	Mathematical	202	165	137	117	105	99	46 ˚c
2	200˚c		189	155	132	114	103	96	
3	180˚c		171	141	120	105	96	91	
4	160˚c		152	127	109	96	88	84	
5	140˚c		134	114	99	89	82	79	

V. FINITE ELEMENT ANALYSIS

5.1 3-D Model of Brass Metal Pin Fin developed in Creo 2.0

Dimension of Pin Fin

Diameter, D = 16 mm

Length, L = 370 mm, Material = Brass

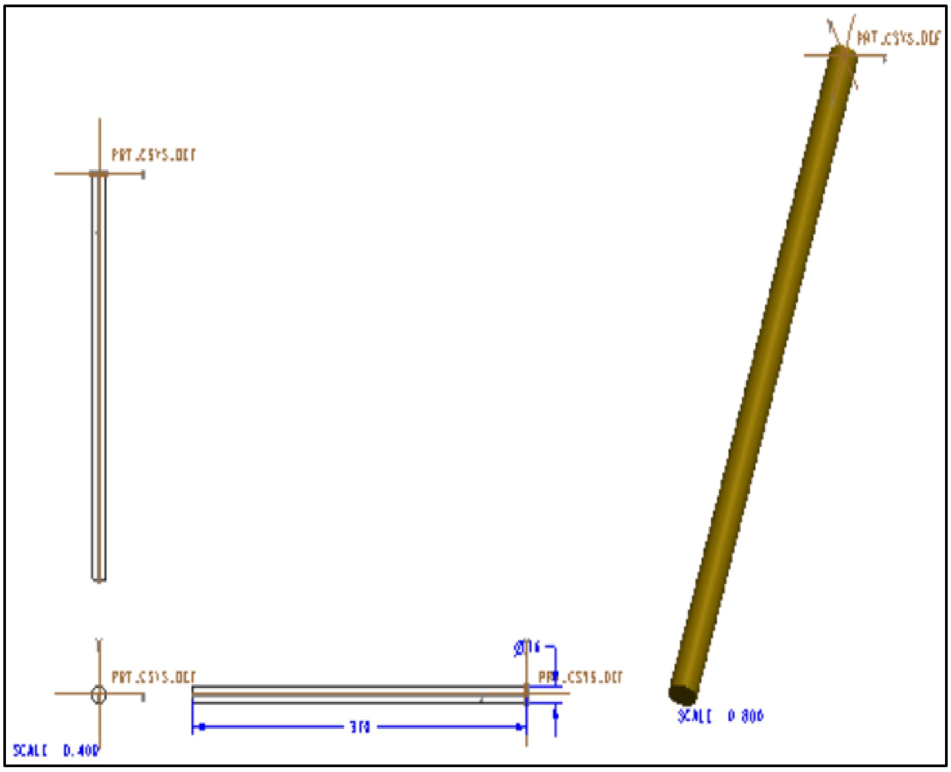


Figure:5.1 3-D Model of Brass Metal Pin Fin Developed in Creo 2.0

5.2 Finite Element Analysis

5.2.1 Finite Element Analysis Step

1. Create 3-D CAD model in Ansys 15.0/Creo2.0
2. Open in Ansys 15.0 Workbench
3. Select a static structural Analysis
4. Open geometry/Import IGES file in Ansys workbench
5. Mesh generation (1 mm)
6. Select boundary condition
7. Select solution type (Temperature Distribution)
8. Click on solver

5.2.2 Finite Element Project Schematic in Ansys 15.0

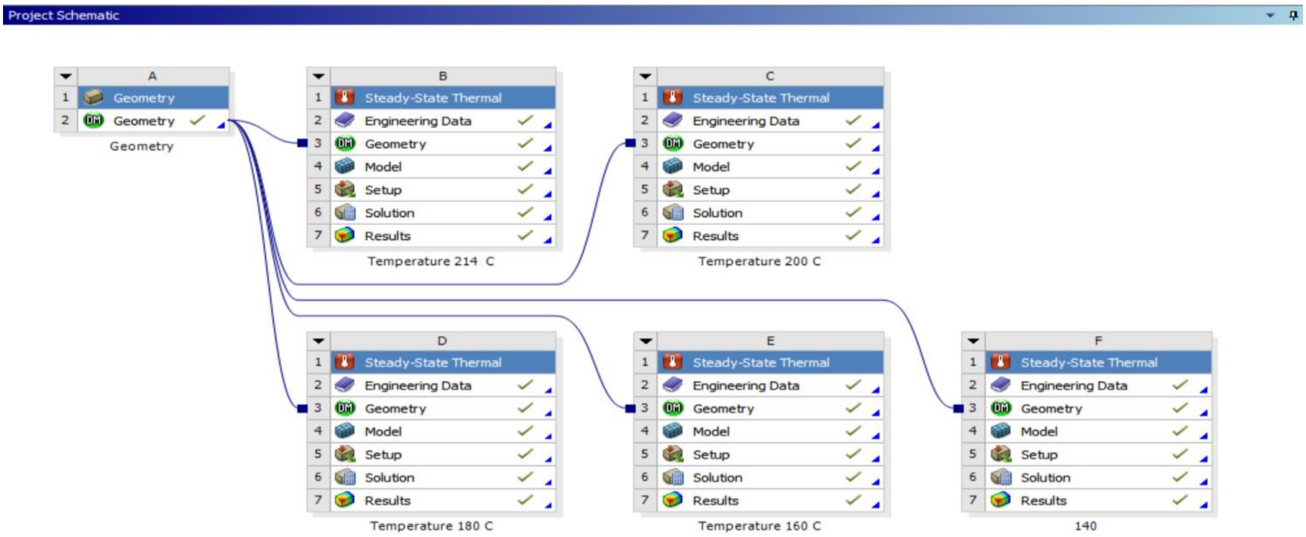
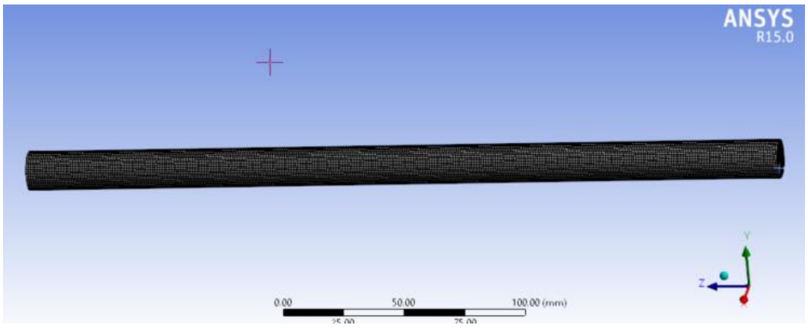
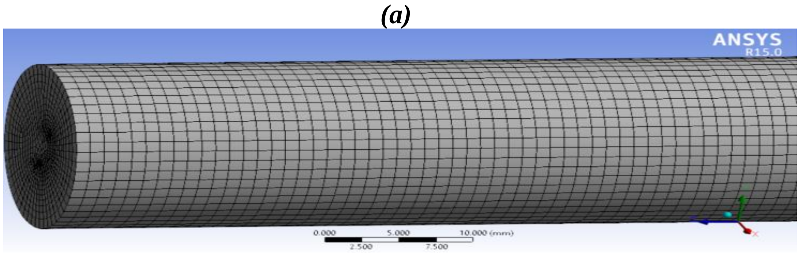


Figure:5.2 Project Schematic

5.2.3 Meshing of Pin Fin Model



(a)



(b)

Figure:5.3 (a), (b)1 mm Meshing of Pin Fin 3-D Model

5.2.4 Thermal Analysis Result of Pin Fin

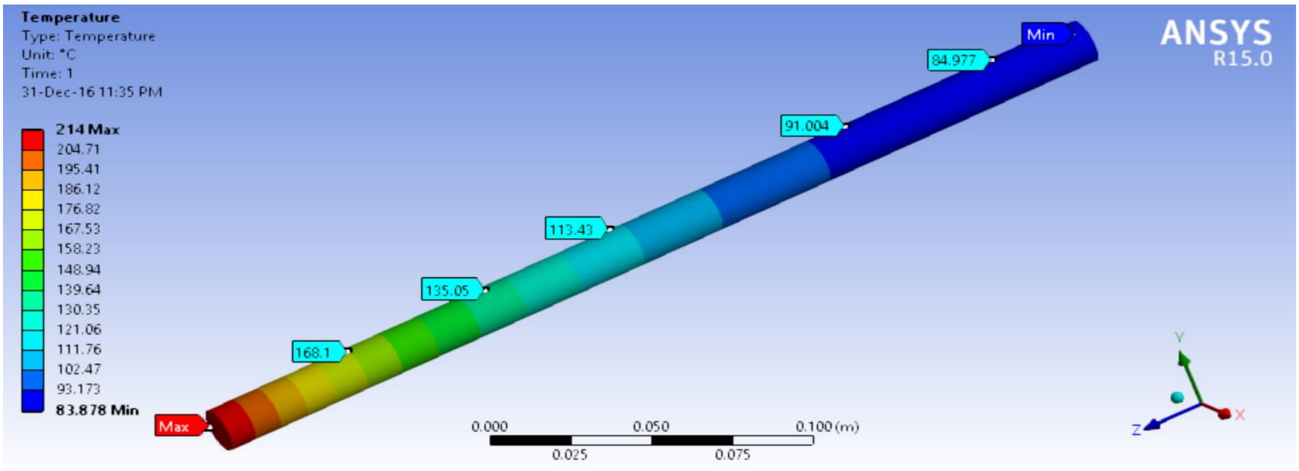


Figure: 5.4 Temperature Distribution of Pin Fin at 214 °C

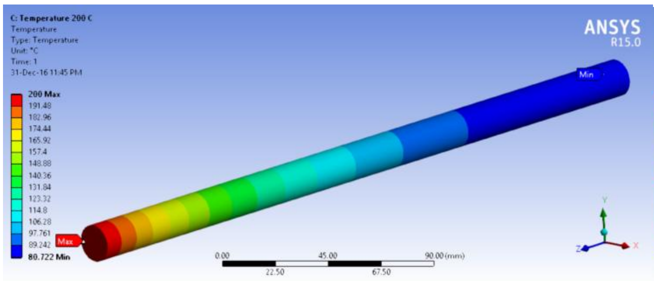


Figure: 5.5 Temperature Distribution at 200 ºC

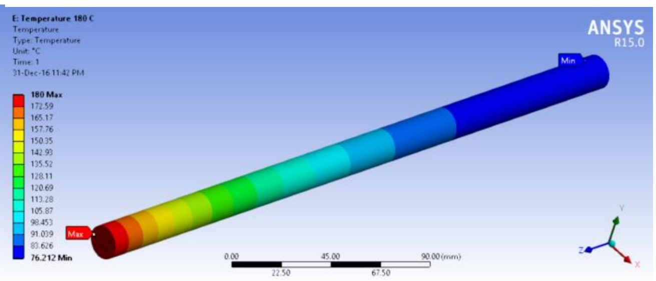


Figure: 5.6 Temperature Distribution at 180 ºC

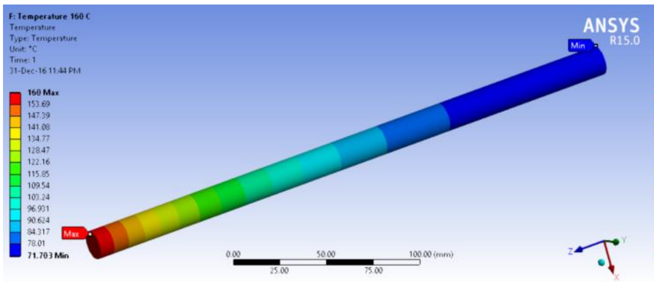


Figure: 5.7 Temperature Distribution at 160 ºC

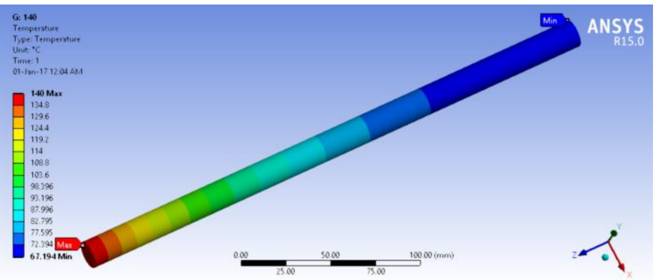


Figure: 5.8 Temperature Distribution at 140 ºC

VI. CONCLUSION

Here we done mathematical, experimental and FEA simulation on the Brass Pin Fin and compare their results with each other and finally conclude that in each method we have face some issue like in mathematical calculation we have to take some assumptions, in experimental setup we have to wait till we get the actual temperature and steady state condition but we have to take care to set the proper time for it here we wait for 20 minutes to achieve steady state condition. Finally we done the FEA simulation and apply the proper boundary conditions and get the nearly same results in the simulation. So we finally get that by applying the proper boundary conditions we can get the nearly same results as the experimental. Here FEA simulation is done in Ansys 15.0 software. Here an investigation a result ofmathematical, experimental and finite element analysis is shown in table 6.1. Experimental and FE Analysis has a high precise results and then it is concluded that finite element analysis is used for this problem is more suitable and rapid processing.

Table: 6.1 Result Mathematical vsExperimentalvs FE Analysis

Sr. No.	Temperature Input Value in ℃	Method	Power input W=V X I		Fin Temperature in ℃						Ambient Temp. in ℃
					T_1	T_2	T_3	T_4	T_5	T_6	
			V	I	1.5 cm	7.5 cm	13.5 cm	19.5 cm	25.5 cm	31.5 cm	T_7
1	214 ℃	Mathematical	-	-	202	165	137	117	105	99	46 ℃
		Experimental	118	0.27	214	159	136	114	95	85	
		FEA	118	0.27	214	158	135	113	91	84	
2	200 ℃	Mathematical	-	-	189	155	132	114	103	96	46 ℃
		Experimental	110	0.25	200	141	126	111	92	83	
		FEA	110	0.25	200	139	124	109	90	81	
3	180 ℃	Mathematical	-	-	171	141	120	105	96	91	46 ℃
		Experimental	85	0.21	180	133	121	107	87	78	
		FEA	85	0.21	180	132	120	105	85	76	
4	160 ℃	Mathematical	-	-	152	127	109	96	88	84	46 ℃
		Experimental	70	0.17	160	127	116	101	82	73	
		FEA	70	0.17	160	125	115	99	81	72	
5	140 ℃	Mathematical	-	-	134	114	99	89	82	79	46 ℃
		Experimental	65	0.14	140	106	92	87	76	68	
		FEA	65	0.14	140	105	91	86	75	67	

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