$$DATA1 := \begin{pmatrix} 26 \\ 27 \\ 28 \\ 30 \\ 34 \\ 41 \\ 52 \\ 69 \\ 61 \\ 58 \\ 65 \\ 78 \\ 72 \\ 73 \\ 94 \\ 97 \\ 105 \\ 99 \\ 71 \\ 49 \\ 40 \\ 35 \\ 31 \\ 29 \\ 28 \end{pmatrix}$$

First experiment in notebook

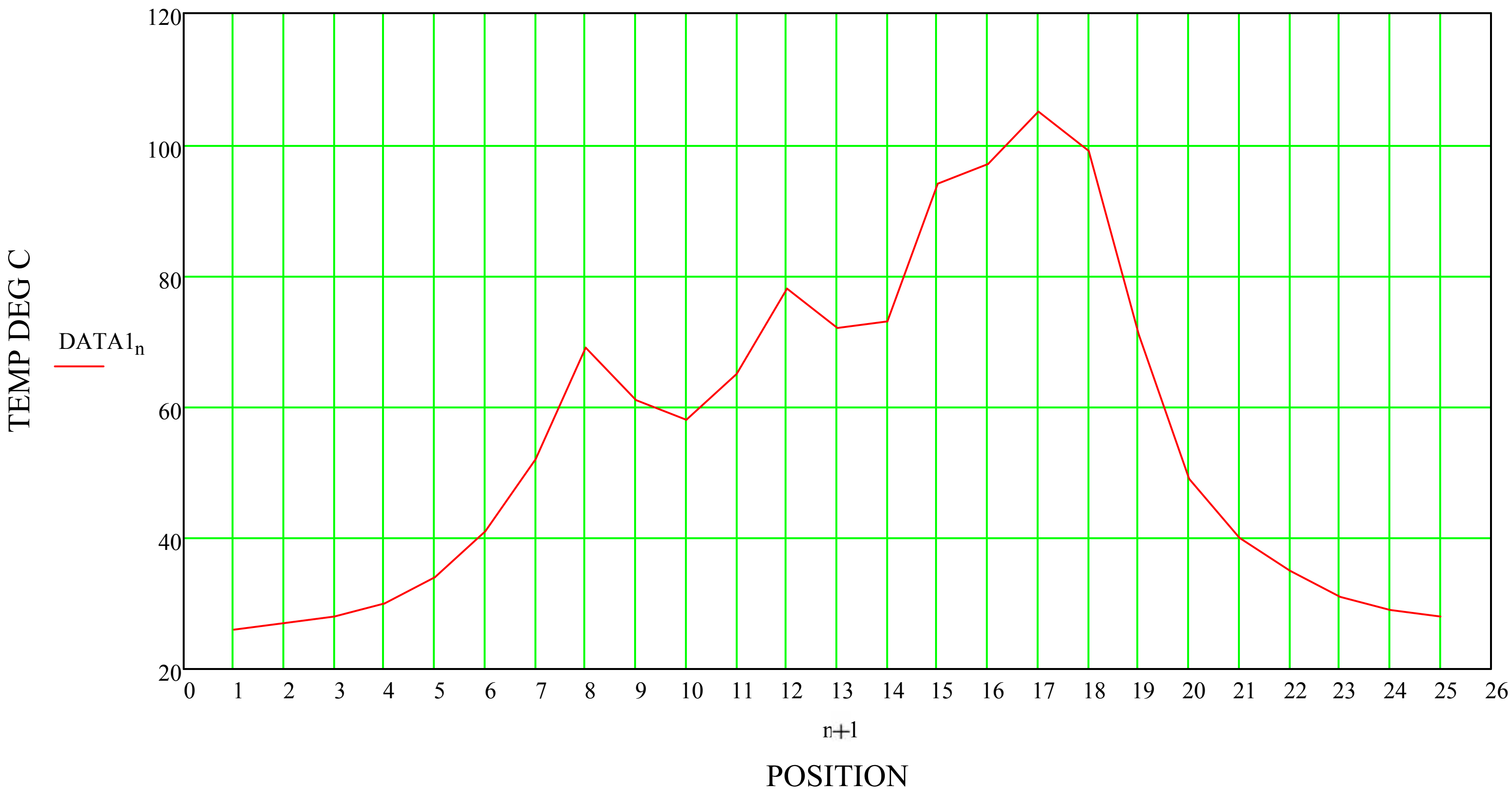
$n := 0..25$

wires at 8,12,15,17,18

2.6amps 13V, 1500 mm wire, 280mm each leg

$13 \cdot 2.6 \cdot \frac{280}{1500} =$ ▮ watts per leg

TEMP PROFILE, WIRES AT 8,12,15,17 and 18 CM, AT EQUILIBRIUM



assuming the wires are evenly spaced and equal amounts flow each direction, then between two wires we have

$$\text{heatdens}(Pw, L, G) := 2\cdot\frac{\frac{Pw}{2}}{L\cdot G}$$

between wires 1 and 2

$$\text{heatdens}(6.309, 28, 4) = 0.056 \qquad \frac{W}{cm^2}$$

between 2 and 3

$$\text{heatdens}(6.309, 28, 3) = 0.075$$

between wires 3 and 4

$$\text{heatdens}(6.309, 28, 2) = 0.113$$

between wires 4 and 5

$$\text{heatdens}(6.309, 28, 1) = 0.225$$

thermal_wizzard.com predicts for heat up from a plate...

105 degC plate, 25 degC ambient, 100 cm^2 plate, 13.9W	.139	$\frac{W}{cm^2}$
280 cm^2, plate, 37.0W	.132	

Second Experiment

Glass is a 14 inch round mirror, 0.187 thick

Two evenly spaced grids, 20 CM gap and 30 CM gap
each section used 750mm 22 ga Nichrome wire
30cm section was 5 wires of 126mm each
20cm section was wires of 134mm each. The windings
were in series and a ~12 supply was used

TimeData :=

0	25	25
1	32	31
2	38	35
3	44	41
4	48	44
5	53	46
6	58	50
7	62	52
8	64	55
9	68	57
10	70	59
11	72	61
12	74	62
15	80	67
20.5	87	72
25	90	77
30	92	78
45	95	79
60	95	80
75	95	81

ProfileData :=

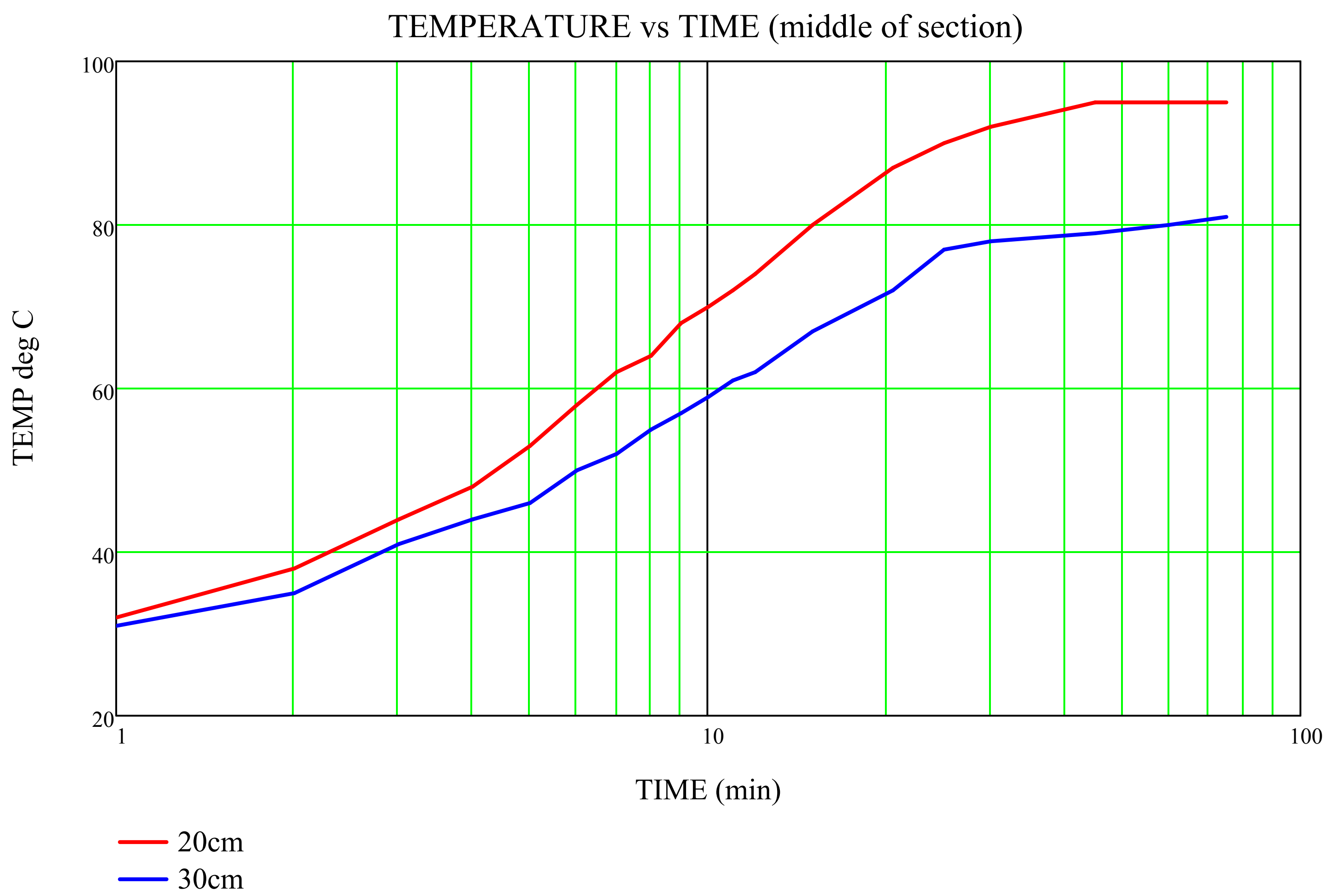
1	53
2	68
3	85
4	89
5	96
6	93
7	96
8	92
9	94
10	87
11	85
12	63
13	49
19	36
22	45
23	55
24	73
25	73
26	73
27	82
28	76
29	72
30	81
31	79
32	75
33	84
34	80
35	73
36	79
37	72
38	53

$V := 13.3$

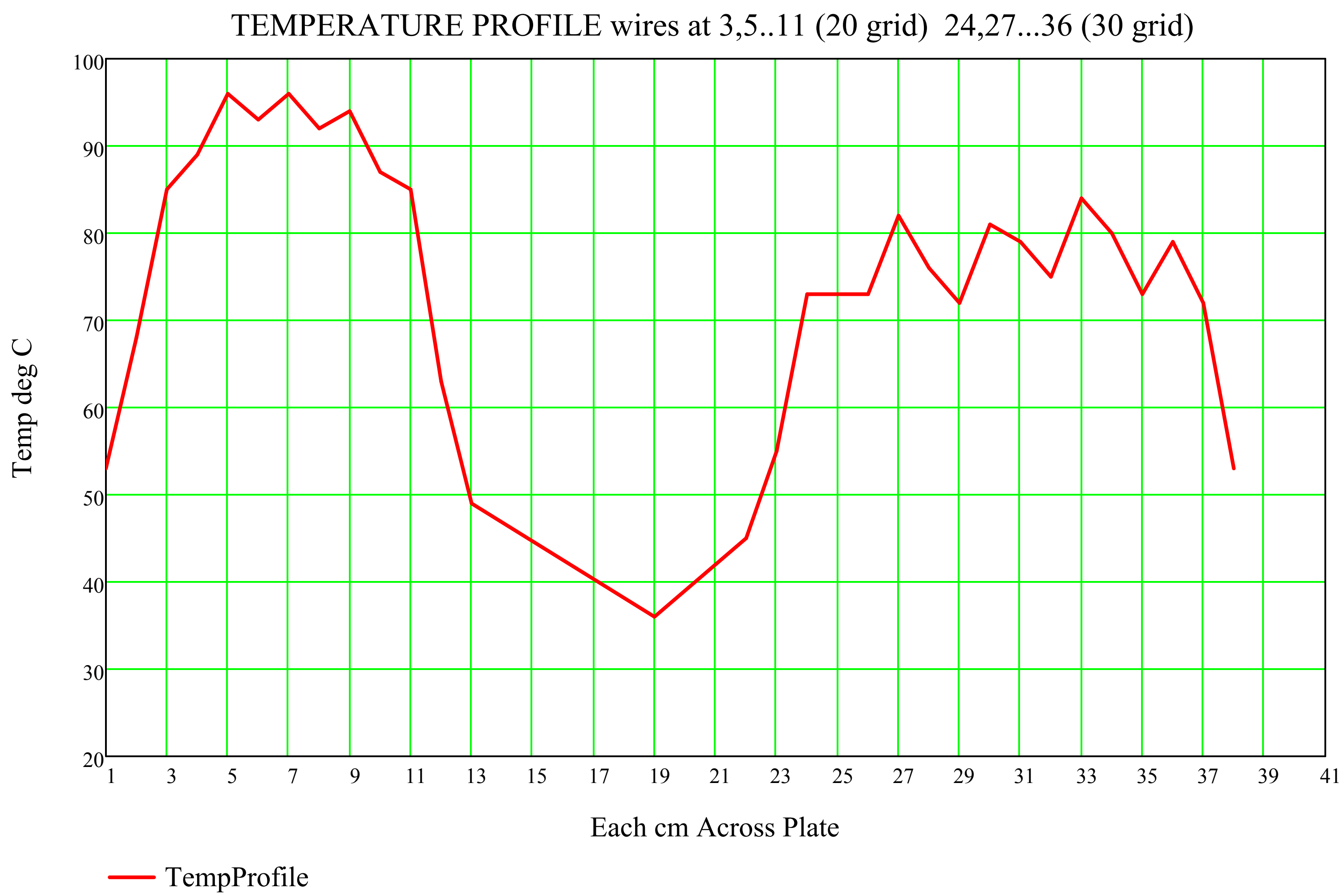
$Icold := 2.6$ $\quad Pcold := Icold \cdot V$ $\quad Pcold = 34.58$

$Ihot := 2.5$ $\quad Phot := Ihot \cdot V$ $\quad Phot = 33.25$

Second experiment in notebook



TEMPERATURE vs TIME (middle of section)
TEMP deg C
100
80
60
40
20
1
10
100
TIME (min)
20cm
30cm


TEMPERATURE PROFILE wires at 3,5..11 (20 grid) 24,27...36 (30 grid)
Temp deg C
100
90
80
70
60
50
40
30
20
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
Each cm Across Plate
TempProfile

Transient Analysis

The temperature change of the plate as a function of time should follow an exponential expression

$$T(T) = TA + T\Delta\cdot\left(1 - e^{\frac{t}{\tau}}\right)$$

temperature as a function of time = initial temperature + final change x exponential expression, where τ is the time constant of the thermal circuit

The thermal circuit looks like a parallel RC circuit, being charged by a current source. TΔ is Q*thermal resistance, τ is heat capacity*thermal resistance.

estimate thermal resistance..

$A20 := (13.4 + 1)\cdot(2.0\cdot 4 + 1)$ $A20 = 129.6$ cm^2 approximate area that significant heat flows out of

$A30 := (12.6 + 1)\cdot(3.0\cdot 4 + 1)$ $A30 = 176.8$ cm^2

$Q := \frac{13.3\cdot 2.5}{2}$ $Q = 16.625$ watts per section

$THr20 := \frac{(90 - 25)}{Q}$ $THr20 = 3.91$ degC per Watt

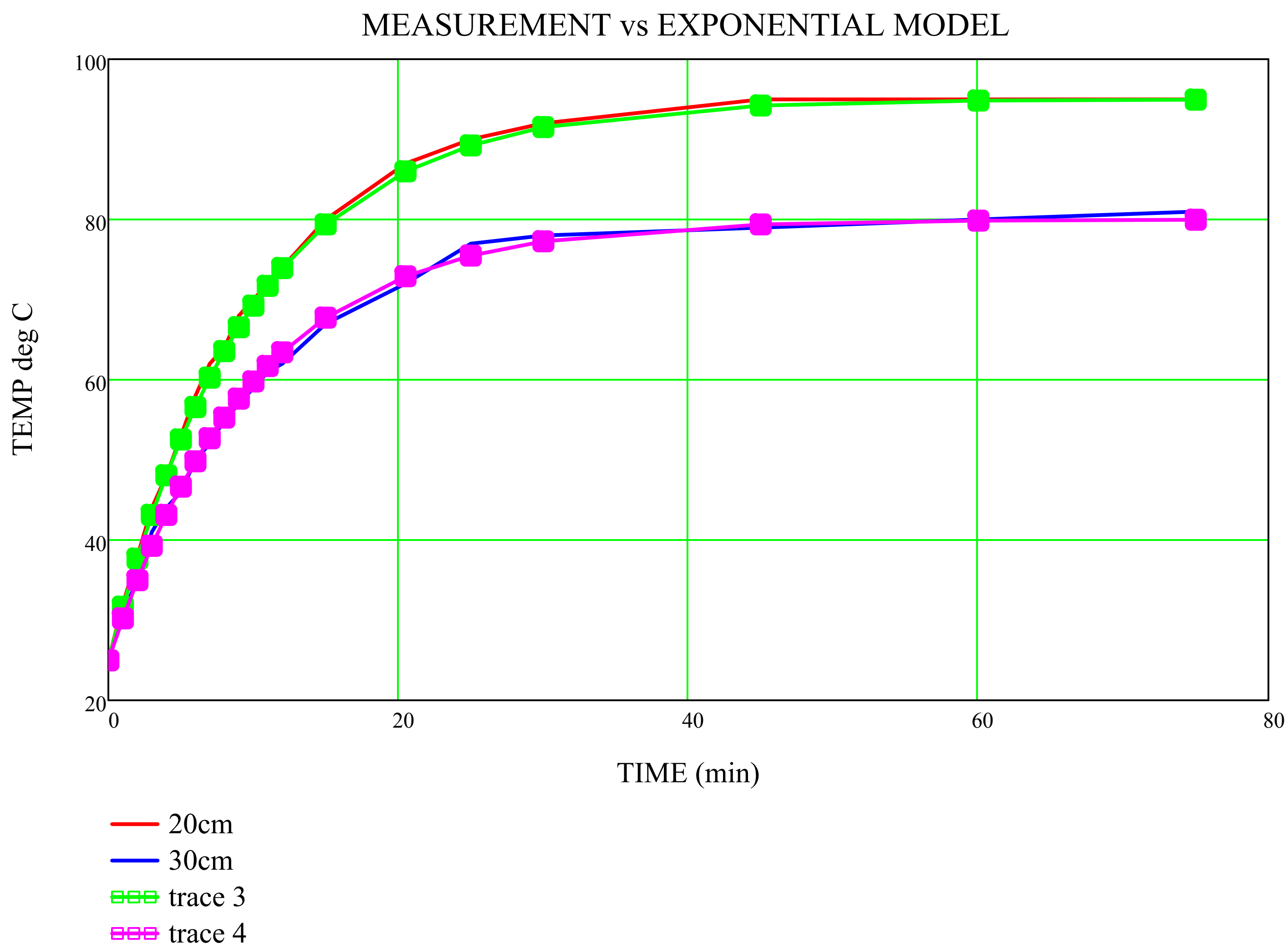
$THr30 := \frac{(75 - 25)}{Q}$ $THr30 = 3.008$ degC per watt Based on eyeball averaging of the temperature across the sections profile

$$T\Delta(t, Q, THr, Hc) := \frac{Hc \cdot Q \cdot t^2}{Hc \cdot THr \cdot t^2 + 2}$$

$$Tm20(t) := 25 + 70 \cdot \left(1 - e^{\frac{-t}{\frac{40}{4}}}\right)$$

$$Tm30(t) := 25 + 55 \cdot \left(1 - e^{\frac{-t}{\frac{40}{4}}}\right)$$

These models are just eyeball fits based on the assumption that it follows an exponential model, and it shows a very good fit. A good rule of thumb is "nearly up in 4 time constants". These plots are nearly up in 40 minutes, hence 40/4, or 10



heat capacity of glass

$Qcg := 0.84 \quad \frac{J}{g \cdot K}$ Joules per gram-Kelvin

from http://hyperphysics.phy-astr.gsu.edu/hbase/tables/sphtt.html

$Mp := 930$ g (by measurement)

$Vp := 35^2 \cdot \frac{\pi}{4} \cdot .39$ cm^2 by measurement

$Ap := 35^2 \cdot \frac{\pi}{4} \qquad Ap = 962.113$

$Qc20 := Qcg \cdot Mp \cdot \frac{A20}{Ap} \qquad Qc20 = 105.23 \quad \frac{J}{K}$ Joules per degree K, (a Joule is a W-s. so a W is a J/s)

$Qc30 := Qcg \cdot Mp \cdot \frac{A30}{Ap} \qquad Qc30 = 143.555 \quad \frac{J}{K}$

$Qc20 \cdot THr20 = 411.427$ J/K x K/J/s, or s

$Qc30 \cdot THr30 = 431.745$

These time constants are in seconds, whereas the "by inspection" time constants above are minutes

$\frac{Qc20 \cdot THr20}{60} = 6.857$ Minutes So the calculated time constants are about 7 minutes and the measured time constant is about 10 minutes.

$\frac{Qc30 \cdot THr30}{60} = 7.196$ Minutes

Estimate the time constant of the plate

from thermal wizard, 90 deg C rise, 310mm square plate (962 cm^2) requires 132 W, for .682 degC/W

$Qcg \cdot Mp = 781.2 \qquad \frac{J}{K}$ heat capacity of plate

$\frac{Qcg \cdot Mp \cdot 0.682}{60} = 8.88$ estimated time constant of plate.

$8.88 \cdot \frac{10}{7} = 12.686$ fudge it up by the ratio of measured to calculated

$\tau p := 12.7$

Now we want to solve for the final temp that will heat the plate in 10 minutes. The way we heat the plate faster is to provide extra heat flow over that required to keep it hot. Then when the plate reaches the desired temperature the controller starts running the heater with a duty cycle..
If the controller didn't, the plate would get much hotter.

$$110 = 20 + TP \cdot \left(1 - e^{\frac{-t}{\tau p}}\right)$$

$$TP(\tau p, t) := -\frac{90}{e^{-\frac{t}{\tau p}} - 1}$$

$TP(\tau p, 10) = 165.145$

Range of maximum temperatures

$TP(8.88, 10) = 133.193$

$$Wheat(\tau p, t) := \frac{TP(\tau p, t)}{.688}$$

$Wheat(\tau p, 10) = 240.037$

$Wheat(10, 10) = 206.945$

$Wheat(8.88, 10) = 193.594$

3 estiamates of the power to heat the plate in 10 minutes, calculated, fudged time constant, experimental time constant, calculated time constant