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Air Heater Thermal and Flow Profile Analysis

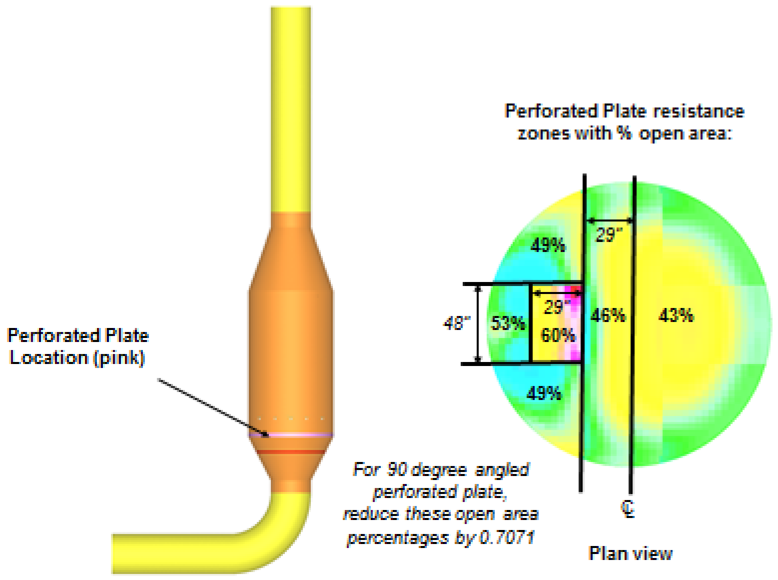
Contents

Introduction

This report outlines the thermal analysis and airflow distribution model as part of an air heater package produced by Zeeco. The first section includes design details of the flow distribution grid applied in the inlet of the heater, located below the duct burners. The grid design was based on a CFD analysis.

The second section includes an analysis performed by Zeeco to determine the final temperature distribution at the exit of the heater. This was accomplished using a program to perform a thermal balance based on flow and temperature on each element. These elements are created by cutting the heater into a number of cross sections at different elevations and overlaying a grid on each section.

Heater Geometry: elevation view looking East



Flow Distribution Grid Design

The flow distribution grid is a device inserted into the inlet of the heater to create a uniform velocity distribution for combustion. In this particular case, air enters the heater after a 90° bend from a horizontal to vertical direction. This change in direction causes a low static pressure region on the inside of the bend, resulting in a variance of velocity and turbulent flow.

The flow distribution grid utilizes five “zones” with different percentages of open areas that restrict flow in high pressure areas and create a uniform velocity distribution across the outlet of the grid. The design goals are as follows:

- Redistribute the air to ensure a velocity distribution of ±5% at the exit of the grid
- Ensure the total pressure drop across the vessel is less than 1 PSI

Thermal Analysis

The objective of the thermal analysis was to determine the final temperature distribution at a cross section located at the outlet of the air heater and controlled heat release (drilling pattern. This ensures that the temperature variance was minimized to meet the specification. Calculations were performed by dividing each cross section into 6”x6” square elements in a grid pattern. This determined the temperatures performed for each element at cross sections every 6” in elevation above the burners, starting at the level of fuel injection. The provided drilling was used to find the heat released at each cell. Calculations were performed until a satisfactory temperature variance was indicated or the top of the heater was reached. The temperature calculations process included taking three iterations at each cross section before the final temperatures were recorded.

Method

The following list outlines each step of the calculation process to find the final temperature distribution in order:

1. *Initial temperature*

The initial temperature listed for each cell is the final temperature from the cross section 6”and below. This temperature is used to calculate the specific heat, C_p. The amount of heat added to the cell will generate a temperature rise. This will be added to this initial temperature to find the 0th iteration final temperature.

2. *C_p calculation*

The specific heat is used to calculate the 0th iteration final temperature. C_p was tabulated based on the initial air temperature for each cell.

3. *Heat Released*

The heat released varies for each cell and elevation. The tip drilling pattern defines the total heat release over the entire flame height for each cell. Once this was determined, the heat released for a particular cell at each elevation was calculated using the following equation:

$$HR_z = HR_{total}\sqrt{\frac{Z}{Z_{max}}} - HR_{z-6}$$

HR= heat released
Z= height of cross section
Z_{max} = total flame length for the cell in question

Note: the heat released is the heat *added* between the previous elevation to the current elevation.

4. *0th iteration final temperature*

The temperature at this point for each cell is the initial temperature including the rise due to the heat added by the flame. The formula used is the *simplified steady-flow thermal equation* as shown below:

$$q = HR_z = m_{dot}c_p(T_{out} - T_{in})$$

This formula assumes all heat entering a cell results in a change of internal energy in the form of higher temperature. If there is no heat added to a cell, the initial temperature is simply carried over.

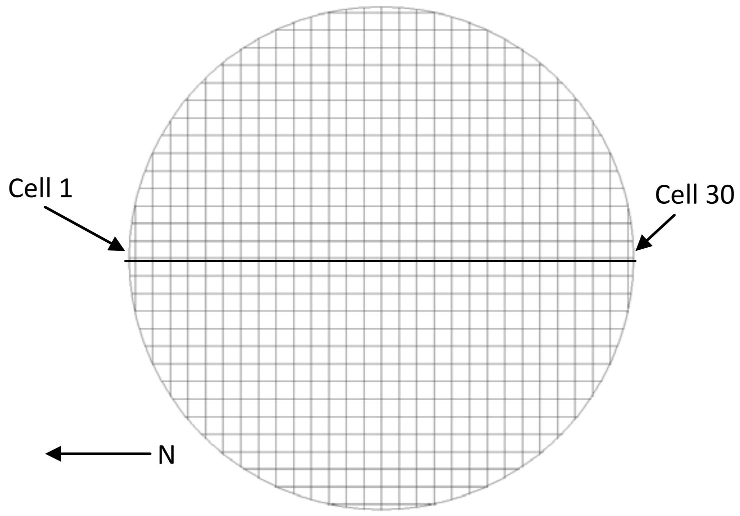


Figure 1: Initial grid with line of symmetry

Note the grid numbering system. Due to the symmetry of the velocity contour plot, calculations were only performed for the east portion of the heater.

5. *First Iteration final temperature*

To model the transfer of heat from hot to cooler grids, cells were combined and averaged, creating a grid of larger squares (12”x12” maximum in Iteration 1). To account for cells around the perimeter with smaller areas and cells with different mass flows, the average was weighted accordingly.

This method assumes the grids have approximately the same compositions and specific heats so that only the cell areas, flow rates, and temperatures factor into the rate of heat transfer to adjacent cells.

To find the mass flow rates through each cell, the velocity contour plot was mapped and entered into each cell. This contour plot was taken at a cross section 14” below the runners in order to avoid localized airflow effects. The velocities for each cell were then averaged and weighted by area to find the overall average velocity. The percentage variance from the average velocity was then obtained from each cell to create a mass flow correction factor. This factor is multiplied by the average mass flow per cell to find the actual mass flow through each cell.

$$\frac{2{,}491{,}200\frac{LBS}{HR}}{688\ Total\ cells}$$

The mass flow of smaller cells was also corrected.

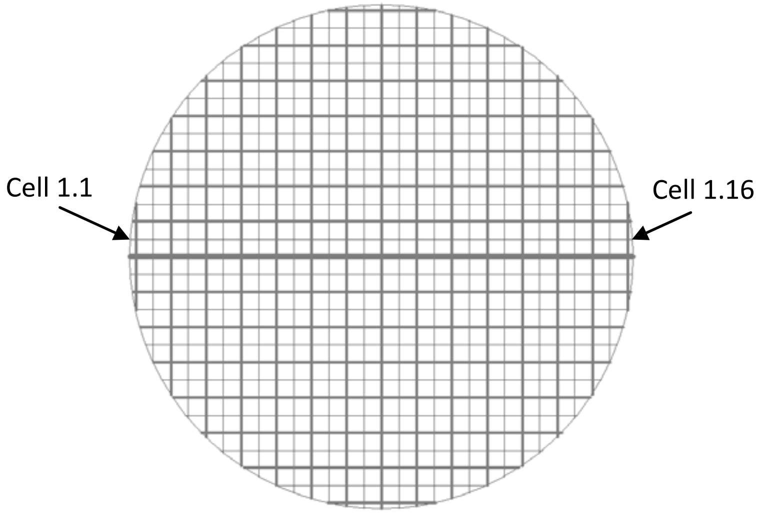


Figure 2: Grid iteration 1 (12”x12”) with initial grid overlaid

The formula to obtain the final temperature for Cell 2, Iteration 1 (Cell 1.2) is as follows:

$$T_{o,1.2} = \frac{m_{dot,2}A_2T_2 + m_{dot,3}A_3T_3 + m_{dot,32}A_{32}T_{32} + m_{dot,33}A_{33}T_{33}}{m_{dot,2}A_2 + m_{dot,3}A_3 + m_{dot,32}A_{32} + m_{dot,33}A_{33}}$$

In this case, since the areas are equal they cancel out.

6. *Second Iteration of final temperature*

Calculation of the final temperature of this iteration follows the same procedure as the previous iteration but with the grid now being spaced 18” apart.

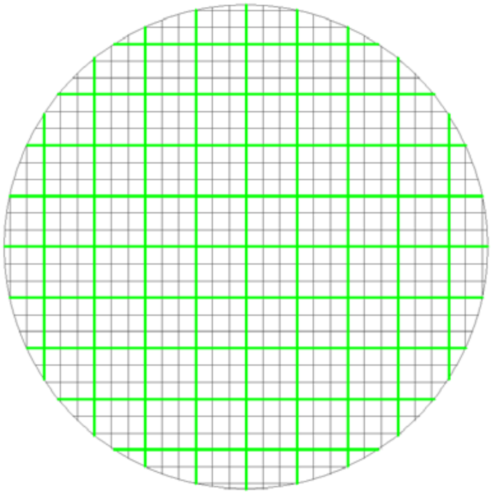


Figure 3: Grid for Iteration 2 (18"x18" max)

7. *Third Iteration of final temperature*

In this case, the grid is 24”x24”, so the grid from the first iteration was used as the basis to average in order for simplifying calculations. Iteration 3 was the final iteration, yet adjacent cells still were not able to transfer heat to each other. To solve this, Iteration 3b was created, which shifts the grid south 6” and east 6”. The method of calculation was switched at every cross section, i.e.: cross section 1 used 3a, cross section 2 used 3b, cross section 3 used 3a, etc.

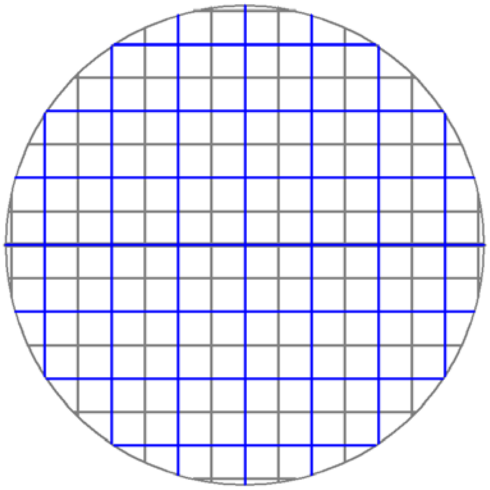


Figure 4: Iteration 3a 24"x24"

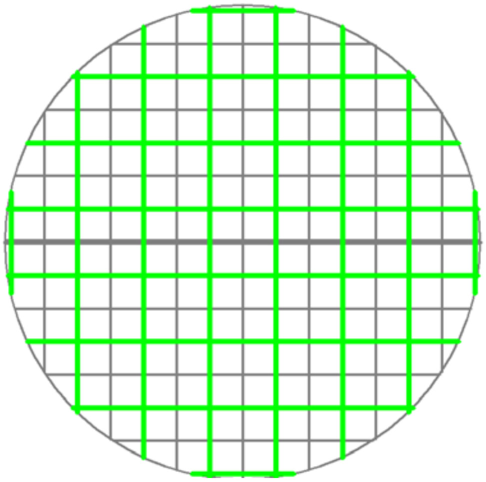


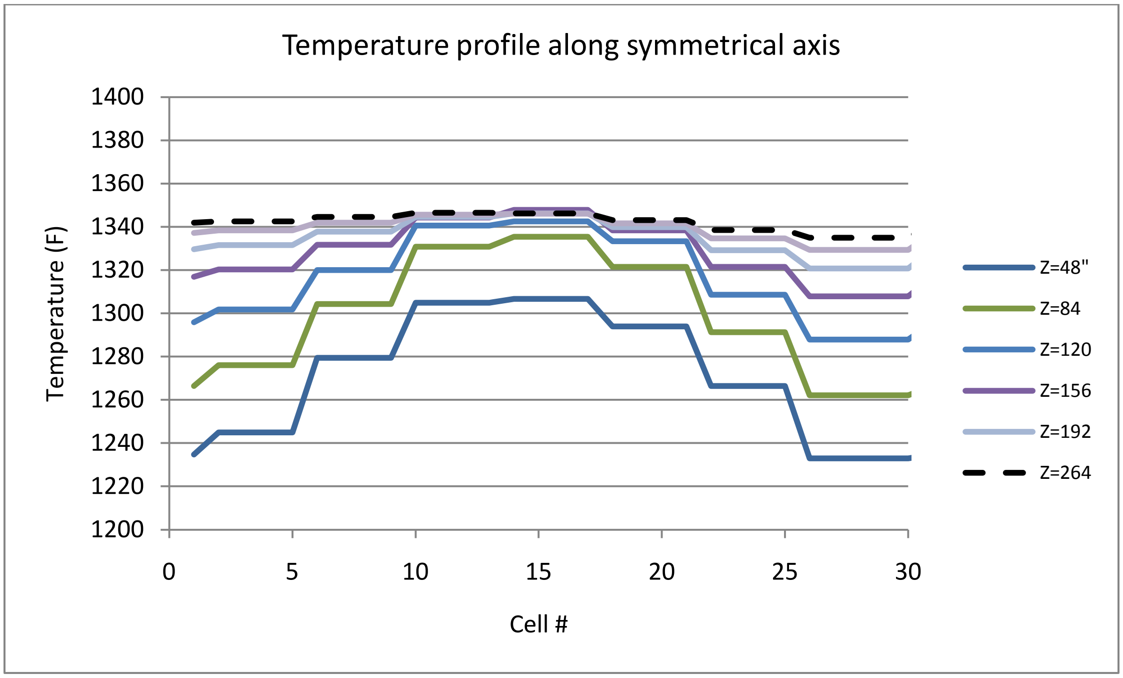
Figure 5: Iteration 3b (24"x24")

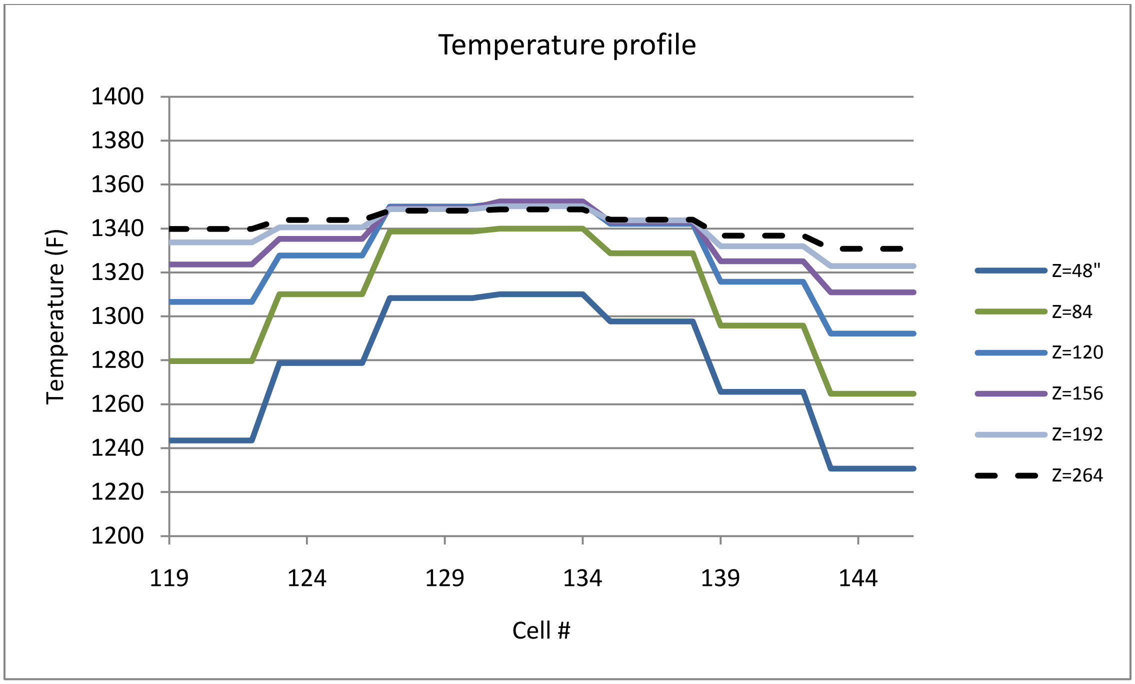
The final temperature from Iteration 3 or 3b was the final calculation for a cross section.

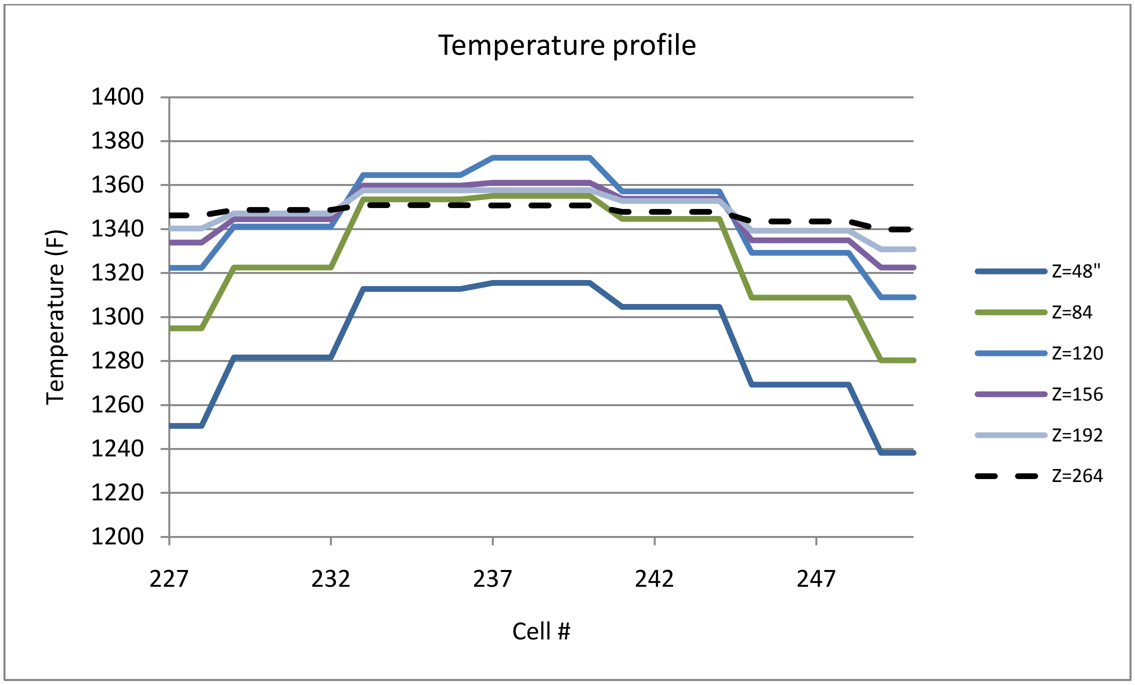
Results

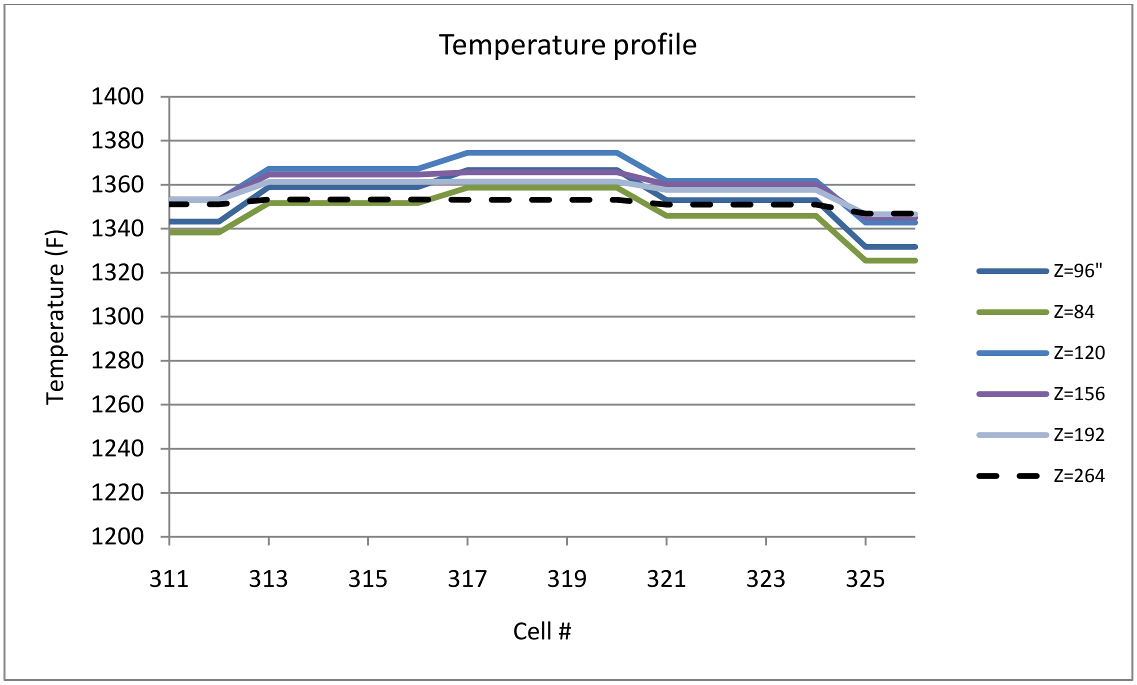
After the thermal analysis and airflow distribution model results have been reviewed, the heater temperature distribution is reported is sufficiently uniform (less than 1% variance from average) when the heater begins to neck down at the outlet. This result is due to the increased air mixing and time to reach equilibrium.

The following charts take the temperatures along several chords parallel to the North-South line of symmetry at several elevations. The elevations chosen are all at 12” apart so that all charts utilize the same formula for the 3rd Iteration. Z=264” is the final elevation shown, just below the point where the heater begins to neck down at the outlet.




Temperature profile
Temperature (F)
1400
1380
1360
1340
1320
1300
1280
1260
1240
1220
1200
119
124
129
134
139
144
Cell #
Z=48"
Z=84
Z=120
Z=156
Z=192
Z=264


Temperature profile
Temperature (F)
1400
1380
1360
1340
1320
1300
1280
1260
1240
1220
1200
227
232
237
242
247
Cell #
Z=48"
Z=84
Z=120
Z=156
Z=192
Z=264



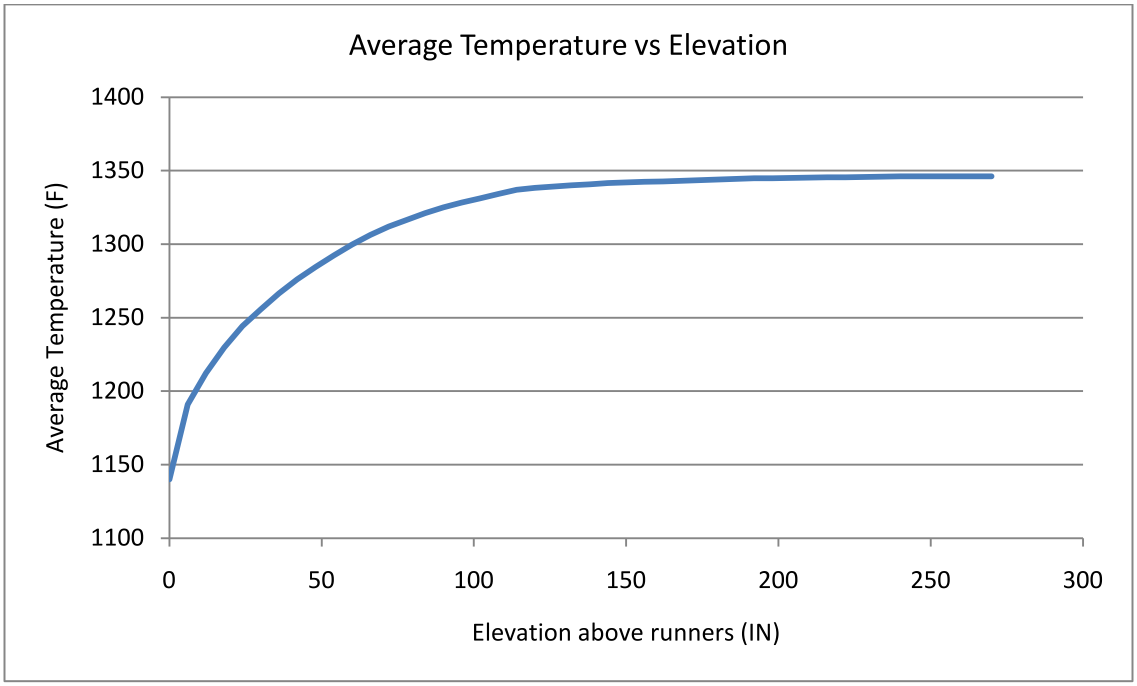


Figure 6: Average temperature (area weighted) at each elevation

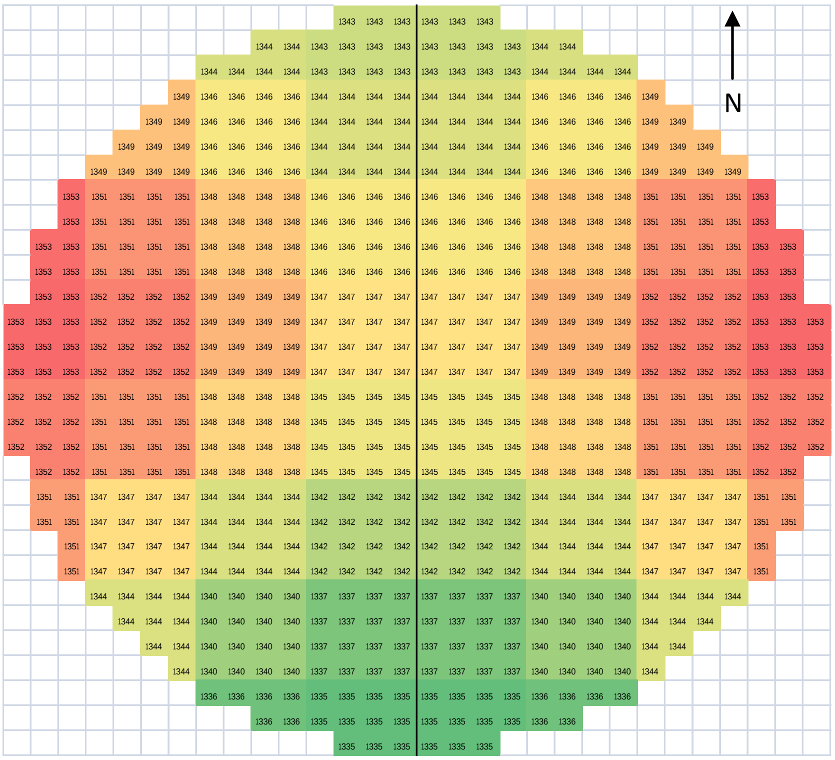


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Figure 7: Final Temperature Distribution at Z=270"

Largest	1353.199	F		
Smallest	1335.492	F		
Average	1346.098	F		
Variance	0.787854	% (variance from average)		
	10.60529	F (variance from average)		

Figure 8: Temperature distribution at Z=270"