Matityahu Zinn, 3330238, Major Assignment

by Matti Zinn

Major Assignment Report

MMAN4410 FINITE ELEMENT METHODS

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Abstract

This report discusses the analysis procedure undertakn to optimise the geometry of Bromic's Radiative Tungsten Portable Smart Heat heater stand. The heater stand is shown in figure 1.

The geometry was analysed against Australian Standard AS4565 Radiant Gas Heaters for Outdoor and Non-Residential Indoor Use which stipulates the following contraints:

1. 5.6.3.1 The temperatures of surfaces intended to be handled, except those parts that are located in an area where they are obviously hot, shall not exceed 35° above ambient.
2. 5.6.3.3 The temperature of surfacs other than those referred to in Clause 5.6.3.2 that are likely to be accidentally touched... shall not exceed 80° for metals... above ambient.

The analysis considered the following assumptions:

1. Since the analysis does not focus on the heater head itself, the assumption is made that only the heater body needs to be analysed
2. Since Ansys Workbench's Radiation boundary condition does not support symmetry, the whole body is required for thermal analysis [1]
3. Since the front, curved stand is nearest the heater head, it will be the hottest and hence the rest of the body does not need analysing
4. The analysis is to be carreied out at the worst case scenario. This would correspond to an ambient temperature of $30°C$ and zero air velocity around the heater
5. The emissivity applied is 0.9 as the body is painted black
6. The heat conducted from heater head to stand is modelled by assuming the top surface of the heater stand is at $200°C$
7. The whole stand is made of structural steel
8. Radiation from the heater head to the sides of the heater stand is negligible

The imported geometry dimension is shown in figure 2 with a hollow rectangular cross section of $75mm \times 50mm \times 2mm$. The analysis consisted of three parts:

1. Preliminary FEA analysis to ensure the current heater geometry complies with AS4565
2. Analysis of reduction of the stand's cross section dimensions and its effects on the resulting temperatures
3. Structural analysis to ensure the reduced cross section (to the smallest cross section of $50mm \times 25mm \times 2mm$ that was available)

All analyses encompass a discussion and analysis of mesh or dimensional convergence.

The report found that the current stand passes the constraints of AS4565 with temperatures of surfaces that are likely to be touched only reaching $57^\circ\ C$. In addition, the report found that changing the cross section dimensions to the smallest available did not impact these temperatures and did not jeoperdise the stability of the heater stand.

The model could not be validated through a mathematical analysis (although this was attempted) and it is recomended that Bromic validate the analysis with experimental data. If this finds the report's findings invalid, then further work is to be conducted to investigate the roles that conduction heat through mechanical connections may have as well as an investigation of the actual heat flux of the heater.

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1 Introduction

The topic chosen for the major project is design optimisation of a portable heater stand for Bromic Heating. The company specialises in outdoor electric/gas heating solutions and has pioneered innovative designs that attract high end customers from the hospitality industry as well as private consumers. The company has seen significant growth in the market over the past five years and has developed multiple products to accommodate a wide range of environments and needs. The company has recently expanded sales into North America and Europe.

The portable heater stand under consideration in this report is Bromic's Tungsten Smart Heat Portable (see figure 1). The heater is a gas operted raditing heater that is designed to be aesthetically pleasing. The haeter's gas bottle is hidden at it's base (which also serves to lower the heater's centre of gravity) and all connecting pipes are fed through the heater stand's hollow body. The heater head angle can be adjusted to allow the heat to be concentrated on different areas. The heater comes with castor wheels at it's base which allow the heater to be tilted backwards and wheeled to any location necessary.

In order to be sold in the market, the heater and all components must comply with all relevant standards. This analysis is conducted to ensure the current design complies with standards. The analysis focuses on the heater stand itself without the heater head, base, wheels, gas bottle or aesthetic components and is extended to optimise the heater

(a) Heater Overview (b) Heater Dimenstions

Figure 1: Tungsten Smart Heat Portable

body geometry by reducing the cross section. This has the potential of reducing not only manufacturing costs, but costs associated with shipping and freight due to reduction in weight.

2 Design Requirements and Assumptions

2.1 Australian Standards Requirements

Under Australian law, all gas appliances must comply with Australian Standards AS4565 Radiant Gas Heaters for Outdoor and Non-Residential Indoor Use. While many of the specific standards are beyond the scope of this analysis, the following will be directly investigated:

1. 5.6.3.1 The temperatures of surfaces intended to be handled, except those parts that are located in an area where they are obviously hot, shall not exceed 35° above ambient.
2. 5.6.3.3 The temperature of surfacs other than those referred to in Clause 5.6.3.2 that are likely to be accidentally touched... shall not exceed 80° for metals... above ambient.

The current heater is compliant with AS4565 and so any preliminary analysis conducted will use this information as a benchmark.

2.2 Assumptions

The analysis took the following assumptions:

1. Since the analysis does not focus on the heater head itself, the assumption is made that only the heater body needs to be analysed
2. Since Ansys Workbench's Radiation boundary condition does not support symmetry, the whole body is required for analysis [1]
3. Since the front, curved stand is nearest the heater head, it will be the hottest and hence the rest of the body does not need analysing
4. The analysis is to be carreied out at the worst case scenario. This would correspond to an ambient temperature of $30°C$ and zero air velocity around the heater
5. The emissivity applied is 0.9 as the body is painted black
6. The heat conducted from heater head to stand is modelled by assuming the top surface of the heater stand is at $200°C$

7. The whole stand is made of structural steel

8. Radiation from the heater head to the sides of the heater stand is negligible

In addiotion, the values shown in table 1, taken from the Bromic website, are assumed. Second, since the analysis focuses on the heat radiated, the analysis does not focus on the maximum stresses or deflections and hence there is no need to optimise the geometry for these constraints. This assumption is also due to the fact that the heater head weighs only 10 kg standing on a 46 kg steel stand. However, this assumption may be relaxed once the heat generated is solved and the geometry optimised for this problem requires verification for stability.

Table 1: Heater Specifications [2]

Gas Supply	LPG
Weight (excluding gas cylinder)	56 kg
Weight (heater head)	10 kg
Heat Output	40.6 MJ
Heater Flame Dimensions	$500mm \times 140mm$
Max Temperature Inside Heater Head	$650°C$
Max Temperature Outside Heater Head	$200°C$

Since the standards specify the temperatures at steady state, it was assumed that a steady state thermal analysis was enough. Lastly, it was assumed that bolt holes, locator tabs, locator holes and other such features are small, and since the analysis does not look at stresses, could be ignored. This had the advantage of making meshing and analysis simpler, without compromising analysis rigor.

2.3 Analysed Geometry

In accordance with the assumptions, the geometry considered in the analsyis is shown in figure 2. The stand has a rectangular cross section of $50mm \times 75mm \times 2mm$.

3 Mathematical Analysis

3.1 Radiation

The radiation heat flux between any two surfaces is given by:

$$q'' = F_{1-2}\epsilon\sigma(T_H^4 - T_a^4) \tag{1}$$

where q'' is the heat flux (W/m^2), F_{1-2} is the view factor between the two surfaces, ϵ is the emissivity, σ is the Stephan-Boltzmann Constant ($\approx 5.670373 \times 10^{-8} W/m^2K^4$), T_H

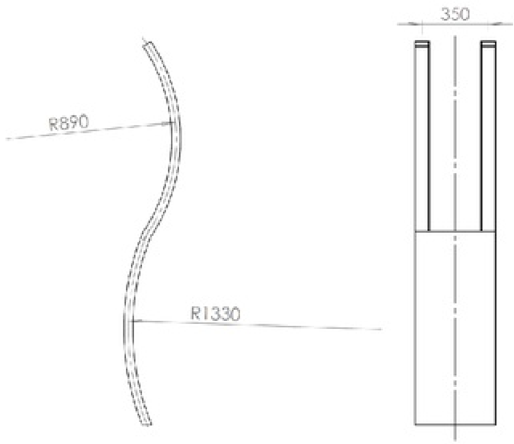


Figure 2: Analysed Geometry Dimensions

is the temperature of the high temperature surface (in $^{\circ}K$) and T_a is the temperature of the low temperature surface (in $^{\circ}K$). In general, the view factor is given by:

$$F_{1-2} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{cos\theta_1 cos\theta_2}{\pi s^2} dA_1 dA_2 \tag{2}$$

where A_1 and A_2 are the areas of the two surfaces, s is the distance between them and θ_1 and θ_2 are the angles between the surface's normal vectors and the line of s. Since equation 2 is too complicated for simple hand calculations, the following analysis assumes a view factor of 1.

For the heater stand, the radiated heat flux between the two surfaces (using $T_H = 923.15^{\circ}K$ and $T_a = 303.15^{\circ}K$) was found to be:

$$q'' = 0.9 \times 5.670373 \times 10^{-8} \times (923.15^4 - 303.15^4) \tag{3}$$
$$= 36\ 632.22\ W/m^2 \tag{4}$$

Multiplying by the heater area (using valued from table 1, $140 \times 500 \times 10^{-6} = 0.07\ m^2$) yields

$$q = 2\ 564.26\ W \tag{5}$$

The results from equation 5 is the maximum heat radiated between the heater head and the stand assuming a view factor of 1. If the view factor between these surfaces was known, the actual heat radiated could be calculated.

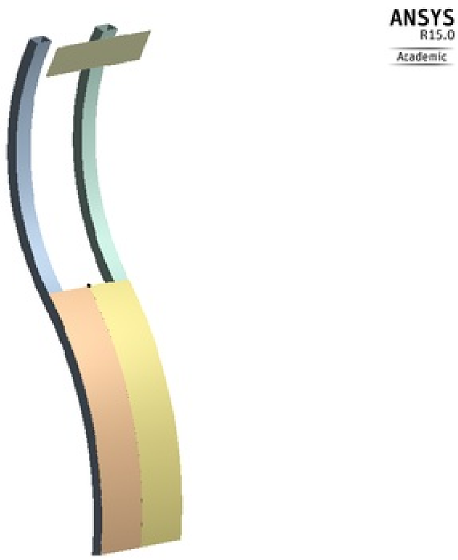


Figure 3: ANSYS Model

3.2 Conduction

The conductive heat flux through a uniform cross section length is given by:

$$q'' = -k\frac{dT}{dx} \tag{6}$$

where k is a material dependent thermal conductivitiy coefficient ($\approx 60.5\ W/mC$), dT is the change in temperature and dx is the change in length. Since this equation is a differential and only applies to regular one-dimensional geometries, it is not easily applied to this problem and hence not solved.

4 Preliminary FEA Analysis

The model was imported into ANSYS under the Steady State Thermal Analysis. In order to model the heater area, a plane with dimensions of $150mm \times 500mm$ (in accordance with values in table 1) was created and placed where the heater head front area would be if modelled. in addition, its angle to the vertical axis was constrained to $105°$ which corresponds to the lowest heater head angle.

As figure 3 shows, five parts were modelled: two stands, heater head front area and the front plate which was split in two. This split ocurred because the model was created by mirroring one stand and one plate so that parametrising and re-dimensioning could be done more easily. In order to make sure the split did not affect the results, the front plate parts were combined into one part. In addition, in order to use the radiation boundary

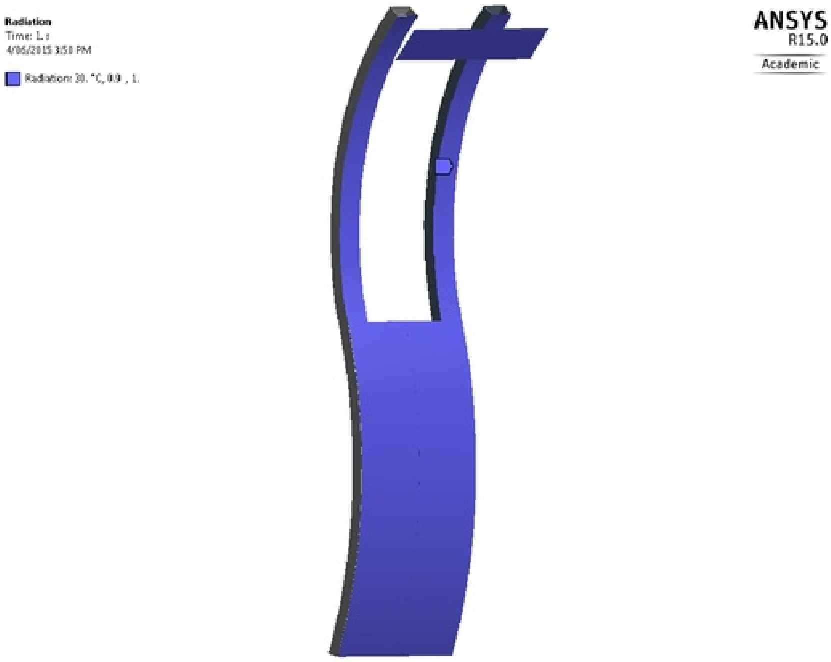


Figure 4: Radiation Boundary Condition

condition, the heater head plane was converted into a body with $1mm$ thickness.

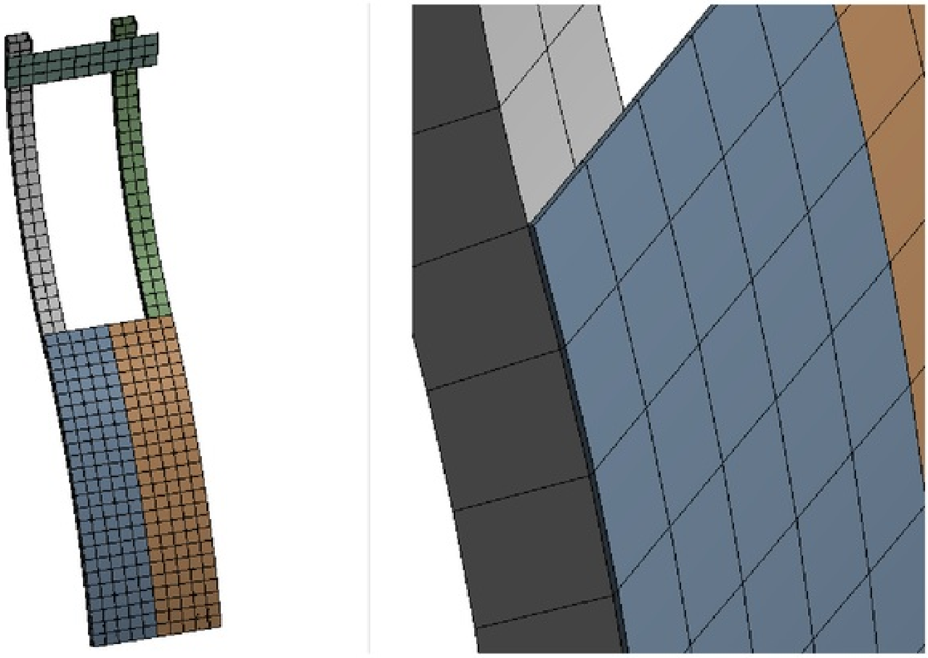
4.1 Boundary Conditions

The following boundary conditions have been applied:

1. Initial temperature of 30° C
2. Temperature of heater head plane of 650° C
3. Temperature of the top surfaces of heater stands of 200° C
4. Perfectly insulated on the back face and edges of the heater head plane

While boundary condition 1 is imposed in line with the worst case scenario assumption, boundary conditions 2 and 3 were added to mimic the heater head temperatures for radiation and conduction. Lastly, boundary condition 4 was added to stop the heater head plane from emitting heat to ambient through those surfaces.

In addition, a radiation boundary condition was applied between surfaces on the front face of the heater head plane and the whole front face of the heater stand at an ambient temperature of 30° C and an emissivity of 0.9. The applied radiation boundary condition can be seen in figure 4. This boundary condition was applied only on the front face of the heater stand in line with the assumption that radiation to the sides of the stand are



(a) Heater Mesh (b) Example of Matching Nodes

Figure 5: Heater Body Mesh, Body Sizing = $40mm$

negligible. In addition, a fluid-solid interface condition was not necessary in line with the assumption that the air velocity around the heater is zero.

Since the analysis does not look at structural conditions, no forces or supports were required.

4.2 Mesh

All bodies were meshed using one body sizing. Since all bodies are regular, the mesh was structured and regular by default. An example of the mesh using a body sizing of $40mm$ is shown in figure 5a. In addition, figure 5b show that this body sizing method assures all nodes are correctly matching.

4.2.1 H Convergence

An H convergence was conducted to ensure the results were independent of the mesh. Since only one body sizing was used, it was allowed to change from $10mm$ through to $100mm$ and the design point followed was the maximum temperature measured on the heater front plate (due to the boundary conditions imposed on the top surface of the heater stands, the heater stands would always reach $200° \ C$ regardless of the mesh sizing).

As figure 6 suggests, the maximum temperature on the front plate converges at a mesh size of $40mm$ to a value of $58.138° \ C$.

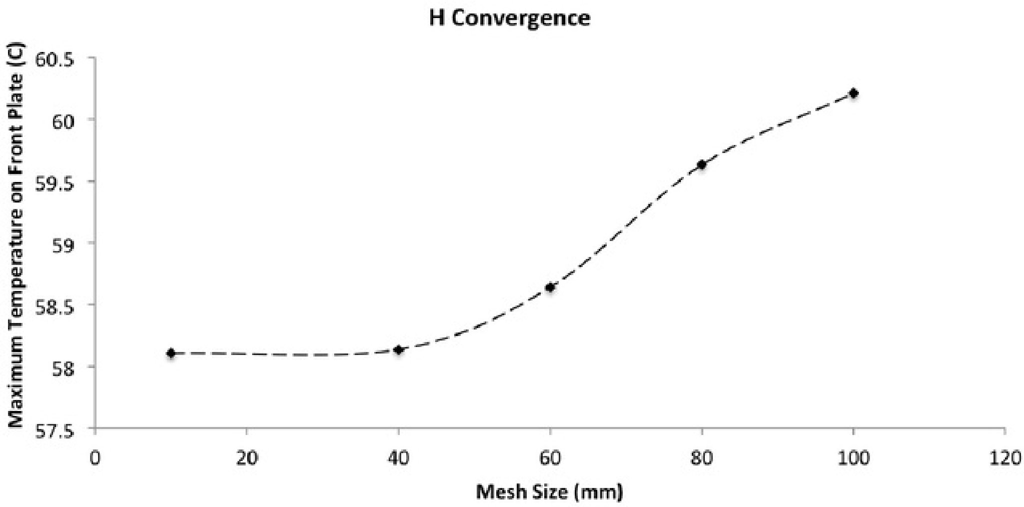
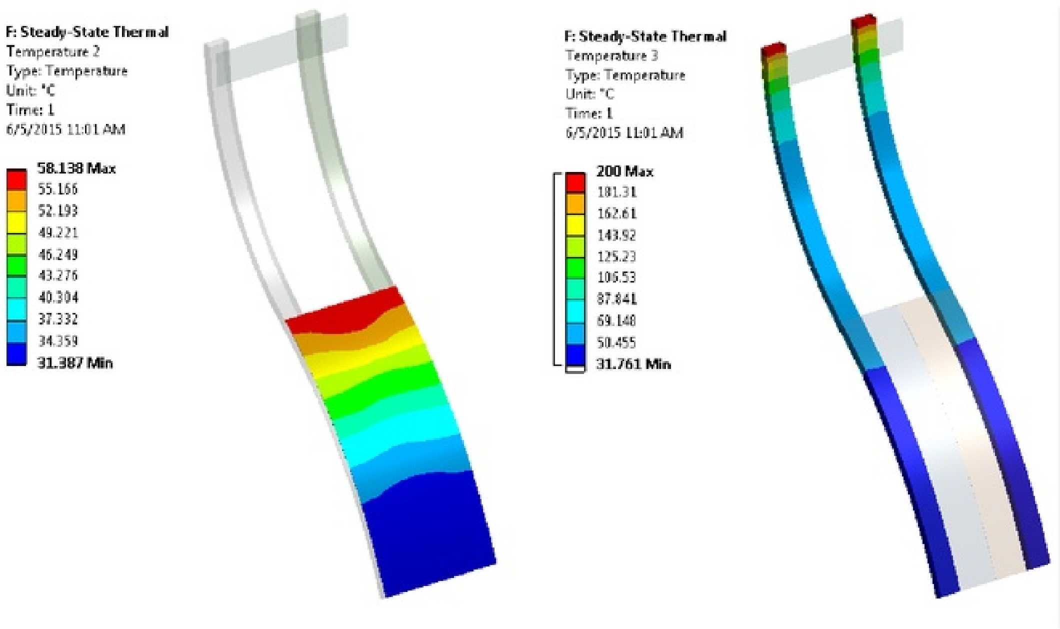


Figure 6: H Convergence

4.3 Preliminary Results

The results suggest that at the worst case scenario, the heater front plate reaches a maximum of 58.138° C while the stands vary in temperatures from 200° C at the top to 58.138° C at the interface with the front plate. The results are shown in figure 7.

A radiation probe was used to compare against the mathematical analysis. The probe



(a) Front Plate (b) Stands

Figure 7: Preliminary Results

was only applied when the boundary condition on the top surfaces of the heater stands was supressed so that only the radiation from the heater head is accounted for (without the added conduction). Under these circumstances the radiation emitted was measured to be 2 563.6 W while the incident radiation was found to be 367.58 W.

4.3.1 Preliminary Discussion

The results are as expected: very hot at the top of the stands near the heater head and slowly dissipating at areas of the heater likely to be touched. The results are also in compliance with AS4565 as temperatures of surfaces intended to be handled are below 35° C above ambient and, in additionm, the top of the stands are not intended to be hot and therefore the fact that they reach above 80° C above ambient is acceptable.

In addition, the radiation emitted is correct to within 0.026% of that found in the mathematical analysis. In addition, if the method shown in appendix A.1 is valid, then the view factor can be approximated as

$$F_{1-2} = \frac{367.58}{2563.6} \quad (7)$$

$$= 0.1434 \quad (8)$$

which is small, as expected. In addition, this can be used to compute the actual heat radiation for the mathematical analysis to find that:

$$q = 2564.26 \times 0.1434 \quad (9)$$

$$= 367.71\ W \quad (10)$$

Although these results cannot readily be validated (Bromic has not released data on the heater stand temperatures), the H-convergence and radiation validity, along with the results being acceptable according to AS4565, allow the results to be taken as indicative for a worst case scenario. The analysis did not allow for fluid flow around the heater and used a high ambient temperature so that these results are expected to be well above the real values obtained if the experiment were to run on a real heater stand.

Another point to consider is that since the model only used radiation between heater head plane and the front faces of the heater then the temperatures would not vary greatly if the front face of the heater stands isn't changed.

5 Design Optimisation

The model shown in section 4 was used to optimise the geometry for weight reduction. This was done by maintaining the heater head area while individually changing the cross section width and breadth (from the current size to 25mm, the smallest dimensions for

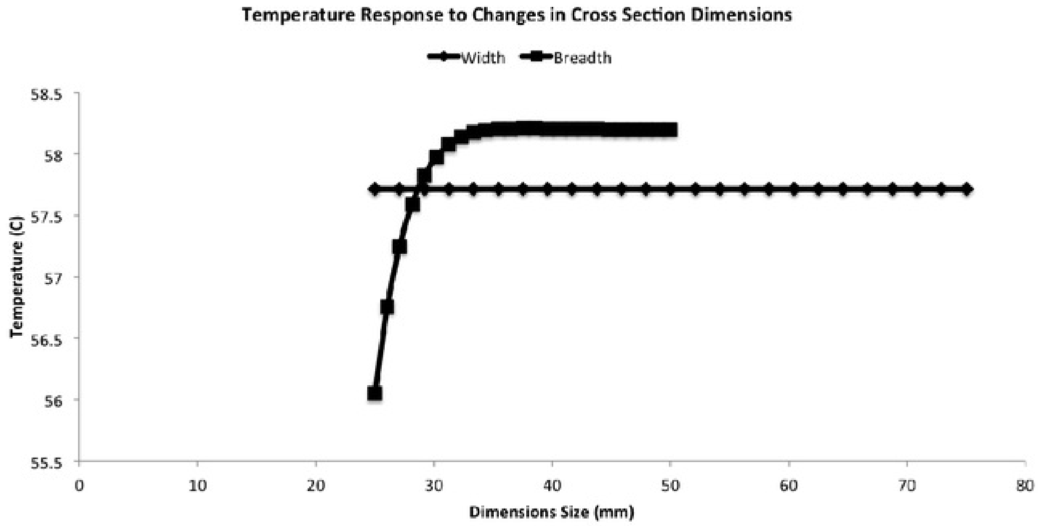
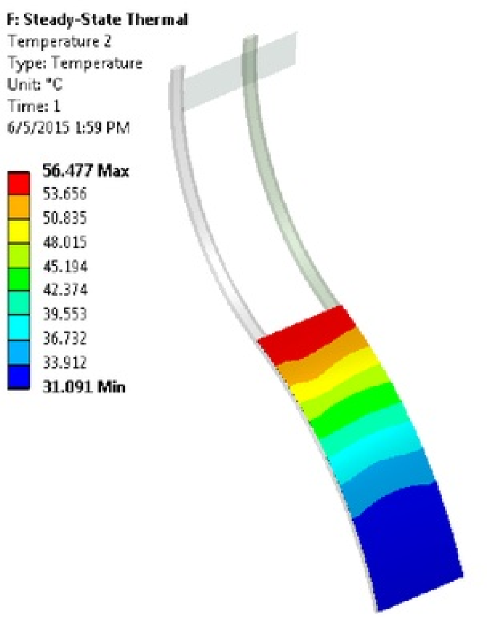


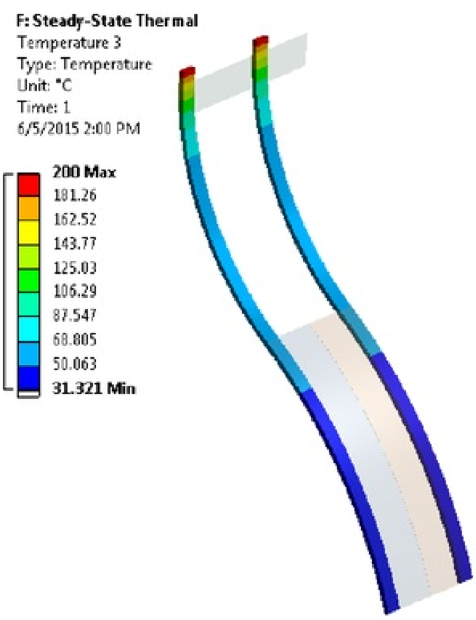
Figure 8: Temperature Response to Changes in Dimensions

standard hollow rectangular tubes [5]) using Ansys's Response Surface tool. The temperature response of the front plate to the changes was monitored and the results are shown in figure 8.

The results suggest that reducing the width of the stands from $75mm$ to $25mm$ has no



(a) Front Plate



(b) Stands

Figure 9: Results After Cross Section Reduction

effect on the measured temperature while reducing the breadth from $50mm$ to $25mm$ can see a reduction in temperature when the breadth is reduced to values lower than $30mm$

In order to see these effects, the simulation was run with the smalles standard size available with dimensions $50mm \times 25mm \times 2mm$. As figure 9 shows, the reduction in the stand's cross section bears little effect on the heater stand temperatures.

6 Mechanical Stability

The analysis concludes by ensuring a reduction in the cross section of the stands will not compromise the design structurally. To do this, the model was imported into Ansys's Static Structural tool. However some assumptions have been made to make this analysis simpler. Namely:

1. The design is symmetrical and hence only one stand needs to be analysed
2. The front plate is not structural and hence can be ommitted
3. The yield stress of structural steel is 250 MPa
4. The locator holes and tabs are ignored as the stress concentrations are outside of the scope of this study.

No mathematical analysis was used since the stand body is curved and the mathematics is unclear in this respect. The analysed geometry is shown in figure 10a.

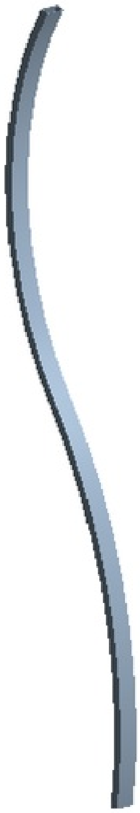
6.1 Boundary Conditions

The boundary conditions used in this analysis are a fixed support on the bottom face and a 10 kg weight on the top surface (simulating the heater head). The fixed support assumption comes from assuming that under normal conditions, the gas bottle and weight of the structure would cause the stand to be fixed at the bottom.

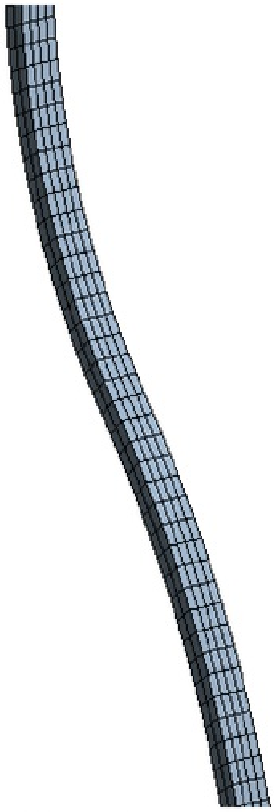
6.2 Mesh

Since the geometry is regular, the mesh used was the default structured mesh. The mesh sizing was set as a parameter with the maximum equivalent Von-Mises Stress as the output parameter. A response surface was created after allowing the element size to grow from $5mm$ through to $80mm$. The results are shown in figure 11.

The results show that the maximum equivalen Von-Mises stress in the heater stand converges to nearly 13 MPa at an element size of $40mm$. The final mesh with a body sizing of $25mm$ is shown in figure 10b.



(a) Stand



(b) Mesh, Body Sizing $25mm$

Figure 10: Structural Analysis

6.3 Structural Results

The reults of the stress analysis is shown in figure 12. As can be seen, the maximum stress developed is 11.2 MPa which is well below the yield stress of 250 MPa.

7 Results

The analysis suggests that the current heater stand passes Australian Standard AS4656 with temperatures of surfaces likely to be handled only reaching $27° \ C$ above ambient. In addition, the stand would pass the standard even if the cross section were to be reduced the a hollow rectangular cross section of dimensions $50mm \times 25mm \times 2mm$. Lastly, the structural analysis suggests the heater stand would maintain its structural integrity even with a reduced cross section with maximum stresses reaching 13 MPa at most which is much below the yield stress of 250 MPa.

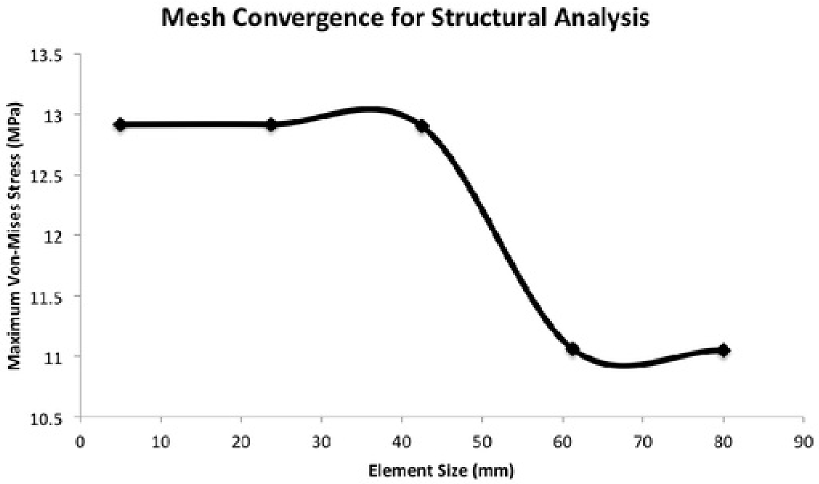


Figure 11: Mesh Convergence for Structural Analysis

8 Discussion

While the analysis took care to make valid assumptions, there are some that need verifying. For example, the assumption that the conduction of heat through the top surface of the heater stand is not sound as the conduction would occur where the mechanical connections between the heater head and heater stand exist. Thus this assumption is an over simplification of the real world problem. Second, the assumption that locator holes and tabs can be eliminated for the thermal analysis but were not relaxed for the structural analysis (although considering how low the resulting stresses were, the factor of satefy is over 19 which may allow for the structural integrity of the heater stand to be considered appropriate). Similarly,the emissivity was assumed to be 0.9 but as the heater stand surfaces are black, the emissivity could be higher which would result in higher temperatures. Lastly, the assumption that radiation from heater head to the sides is negligible is not necessarily correct and could be added in further studies.

The two H-Convergence studies serve to add to the validity of the model however without experiment data the whole analysis is unvalidated as the mathematical model was too simplistic. Similarly, it is unknown whether the contacts and new part formations could ahve distorted the results and more analysis is required in this respect.

9 Conclusion and Recommendations

The report found that the current heater stand meets the requirements of AS4565 even at the worst case scenario. Crucially, the report found that reducing the heater stand's cross sectional area to a hollow rectangular tube of $50mm \times 25mm \times 2mm$ would also

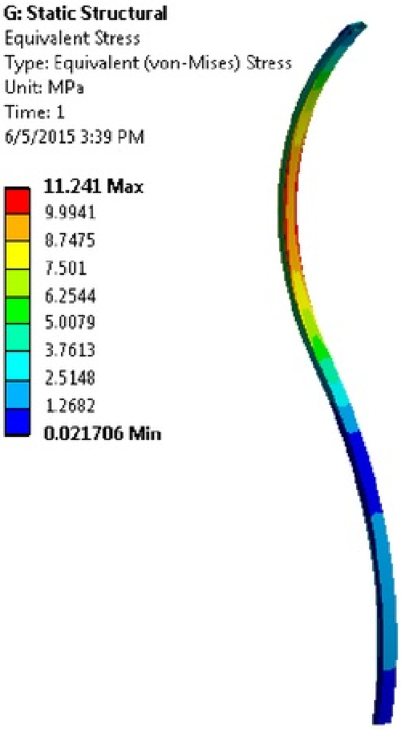


Figure 12: Maximum Stress Results

pass the standard. The analysis found that temperatures of surfaces likely to be handled only reached 27° C above ambient (30° C). Lastly, the report found that the stand, even at a reduced cross, section would be stable and able to hold the load of the heater head without deformation.

It is recommended that more analysis is carried out, specifically to validate the current analysis. This should be done by measuring actual heater stand temperatures and comparing to those found in the report's simulations. Once this has ocurred, the model should either be refined by investigating the role that contacts have had on the front plate or the role that locator holes and tabe would have the stability of the stand with a reduced cross section. Similarly, investigation is required to capture the effects that conduction of heat from heater heat to the stand through mechanical connections is required.

10 References

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A Appendices

A.1 Radiation View Factor Analysis

In this section, a brief analysis was conducted to see how the view factors may be calculated from Ansys' radiation probe. For this analysis a known geometry with a known view factor was analysed in Ansys and results compared to those known.

Theory

It is well known that the view factor for two square surfaces radiating heat between each other is [4, 3]

$$F_{1-2} = 0.1998 \tag{11}$$

if the length of the square sides is equal to the distance between the two surfaces.

Ansys Simulation

The geometry analysed in Ansys Workbench in Steady State conditions is shown in figure 13. Each plate had side lengths of $30mm$ and the distance between them is $30mm$ as well.

The boundary conditions imposed were radiation between the two surfaces and a temperature on one of the surfaces of $650^\circ\ C$. The backs of each plate was set as thermally insulated and the initial temperature to $22^\circ\ C$.

The radiation probe results show that total heat emitted is $3.586 \times 10^{-7}\ W$ and the incident radiation to be $7.7653 \times 10^{-6}\ W$. Taking the ratio between these two numbers yields a ratio of 0.2165. This only yields an 8% to the view factor known from theory and therefore could give an indication of the actual view factor.

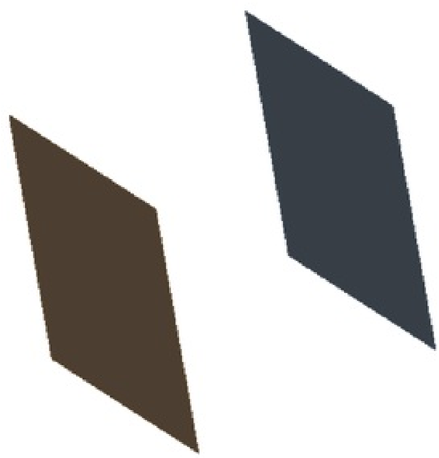

Figure 13: Flat Plates Geometry

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GENERAL COMMENTS

Instructor

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