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Faculty of Engineering, Built Environment and Information Technology

MOX 410 Design Project

Portable Braai with Water Heater

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Abstract

To the average South African, participating in recreational outdoor camping is the norm rather than the exception, and in this modern world having the ‘luxury’ of a hot shower during such activities would be beneficial to their overall experience. This study thus aims to bridge the gap between the outdoor life and modernity of the 21st Century by designing a system that accommodates the heating and consequent use of water in a camp-like setting.

Consequently a portable Braaiing Apparatus was deigned (from the inlet to outlet) by which the excess heat from said braai would heat the water for a comfortable shower. The concept selected for the Braaiing Apparatus was simplistic in nature, where heat transfer, fluid flow, and ergonomic aspects were considered to be of most significance. Being such, the design fulfilled all user requirements that had been specified.

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P	Pressure	Pa
V	Velocity	m/s
Z	Height	m
g	gravity	m/s^2
h	head loss	m
r	radius	m
f	Darcy Friction Factor	
L	Length	m
D	diameter	m
K	Secondary Loss Coefficient	
j	Colburn factor	
Gr	Grashoff number	
Pr	Prandtl number	
Re	Reynolds number	
Nu	Nusselt number	
A	Area	m^2
q	Heat Flux	W/m^2
m	Mass Flow Rate	kg/s
k	Conduction Heat Transfer Coefficient	W/mK
h	Convection Heat Transfer coefficient	W/m^2K
T	Temperature	^oC
Cp	Specific Heat Capacity	J/kgK
Q	Heat Transfer Rate	W

Subscripts

b	Bulk Temperature	
e	Exit	
i	Inlet	
s	Surface	
surr	Surrounding	
Convection		
Conduction		
Radiation		

Greek Symbols

P	Density	kg/m^3
ε	Emissivity	
σ	Boltzmann's constant	$m^2\ kg\ s^{-2}\ K^{-1}$
ν	Kinematic Viscosity	m^2/s

1 Introduction

1.1 Background

Camping is a typical recreational activity that many South Africans undergo. Accompanying this is the act of Braaiing, where this culture has been formed as an integral part of South African heritage. Being such, a need arises to bridge the gap between outdoor life and modernity.

In particular, during camping, showers with cold water can only be used as there is no means of heating said water. Being such, since Braaiing generates more heat than what is necessary to cook food, a means of using this excess heat to be transferred to available water for a comfortable shower is needed.

1.2 Problem Statement

A portable Braaiing Apparatus is needed to be designed, which is to utilize the excess heat of the braai to be transferred to the water for a comfortable shower. The Braaiing Apparatus need only be designed, being from the inlet to the outlet (and not the shower itself).

1.3 Objectives

A first-order heat transfer analysis is to be conducted, where a rudimentary radiation analysis is to be undergone as well. That is, an analysis of the heat transfer to the water is to be done, where the designer will ascertain if the Braaiing Apparatus is in accordance to what has been specified by the user. A first-order fluid dynamics analysis of the flow of water through the system is also to be done, so as to ensure if the design of the Braaiing Apparatus is sufficient.

The design in its entirety should take into consideration the Ergonomics aspect, where it should be portable and easily transportable, as well as being able to fulfil what has been specified by the user. In order to ensure correct evaluation of concepts, analyses and overall approach, literature would need to be assessed prior to undergoing any selection of ideas and would need to precede any analysis of the system.

A full mechanical design of the entire unit is to accompany the analyses, where manufacturing drawings will be provided so to ensure all aspects of the design are accounted for.

2 Literature Review

Prior to the design objectives being defined from user stated specifications, a comprehensive study on the particular research pertaining to aiding the design of the braaiing apparatus was conducted. Thus the purpose of the following section is to enlighten the author on the best design approach for said Braaiing Apparatus.

This study is separated into in-depth examinations of each of the Braaiing Apparatus's design aspects, namely Fluid Dynamics Analysis, Heat Transfer Analysis, and its Ergonomic Characteristics. Preceding this is a discussion of its comparability to Industrial Heat Exchangers and moreover, how particular aspects of general Heat Exchanger design can be implemented.

2.1 Heat Exchanger Comparability

A heat exchanger can be defined as a device which facilitates the transfer of thermal energy between a solid surface and a fluid, between solid particulates and a fluid, and most commonly, the exchange of enthalpy (heat) between two or more fluids (Cengel, Ghajar 2015, pp. 647).

In a limited number of heat exchangers, the fluids are in direct contact when exchanging heat, where in most cases the heat transfer occurs through a separating wall. Heat exchangers which exploit this means of heat transfer, where the fluids are separated by a heat transfer surface, where ideally the fluids do not mix (or leak), are titled Direct Transfer Type (Shah, Sekulic 2003, pp. 1). On the contrary, heat exchangers where there exists intermittent heat transfer between hot and cold fluids, by means of thermal energy storage and release via the exchanger surface or matrix, are titled Indirect Transfer Type (Shah, Sekulic 2003, pp.1).

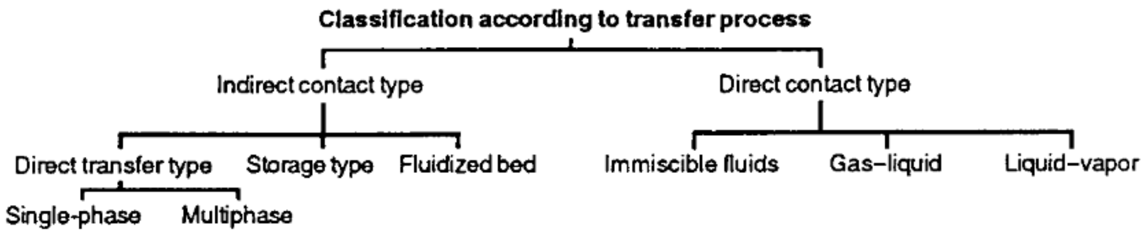


Figure 1: Figure of Classification of Heat Exchangers According to Heat Transfer Process (Shah, Sekulic 2003, pp.2).

Such a classification of heat exchangers is one of the numerous means to classify heat exchangers, where others include Classification according to Surface Compactness, Number of Fluids, Construction, and Flow Arrangements (nptel n.d., pp. 2).

Noticeable, however, is the method of heat transfer related to the classification of heat exchangers which usually involves convection in each fluid, and conduction through the wall separating the fluids. Being such, it is understandable that the majority of heat exchanger literature will be rendered purposeless. This is due to there being no exchange of heat between two (or more) fluids in the Braaiing Apparatus, along with the fact that the means of heat transfer is from a heat flux originating from the specified braai fuel.

Nevertheless, there are aspects of heat exchanger design which can be considered regarding the functionality of the Braaiing Apparatus. Thus the approach of finding these applicable aspects, will be to evaluate how heat exchangers are classified, and then selecting facets of their respective design and applying them to the Braaiing Apparatus.

2.1.1 Surface Compactness

As previously stated, another method of classifying heat exchangers are by their surface compactness.

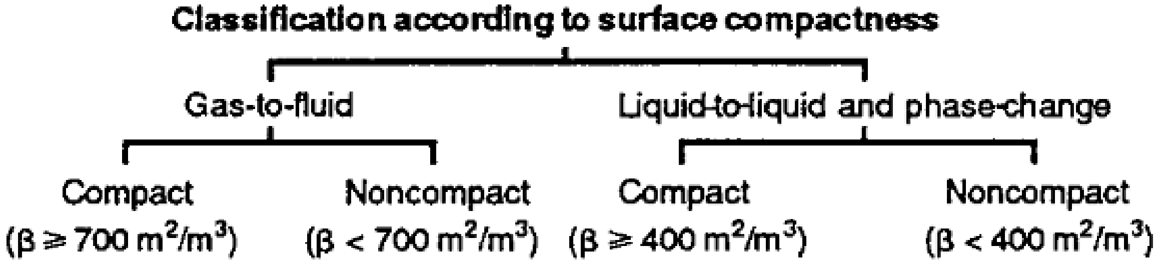


Figure 2: Figure of Classification of Heat Exchangers According to Surface Compactness (Shah, Sekulic 2003, pp.2).

This design consideration is examined to give rise to a large heat transfer surface area per unit volume (defined as area density β [$\frac{m^2}{m^3}$]), and thus achieving a high heat transfer between fluids in a small volume (Cengel, Ghajar 2015, pp. 648). This also results in a reduced weight, space, support structure and footprint, as well as energy requirements and cost (Shah, Sekulic 2003, pp. 8).

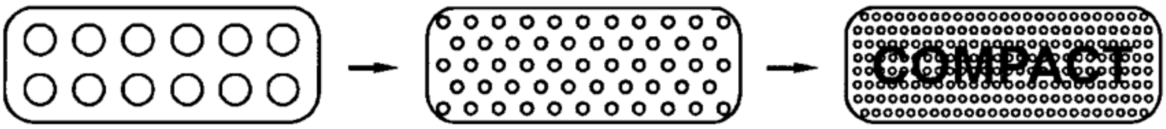


Figure 3: Figure showing the General Notion of Surface Compactness (Shah, Sekulic 2003, pp. 9).

In spite of the fact that the means of heat transfer of the Braaiing Apparatus is different to that of the heat exchanger (as stated prior), the aspect of introducing compactness into the Braaiing Apparatus's design is crucial in order to maximise heat transfer. That is, designing such that there is a large surface area for heat transfer to occur per unit volume, ensuring there is a large enough heat transfer coefficient necessary to heat the water to the specified temperature. Designing such that there are numerous, small diameter tubes would affect flow rates, and will be addressed later.

2.1.2 Construction Features

Secondly, heat exchangers are often characterized according to their construction features.

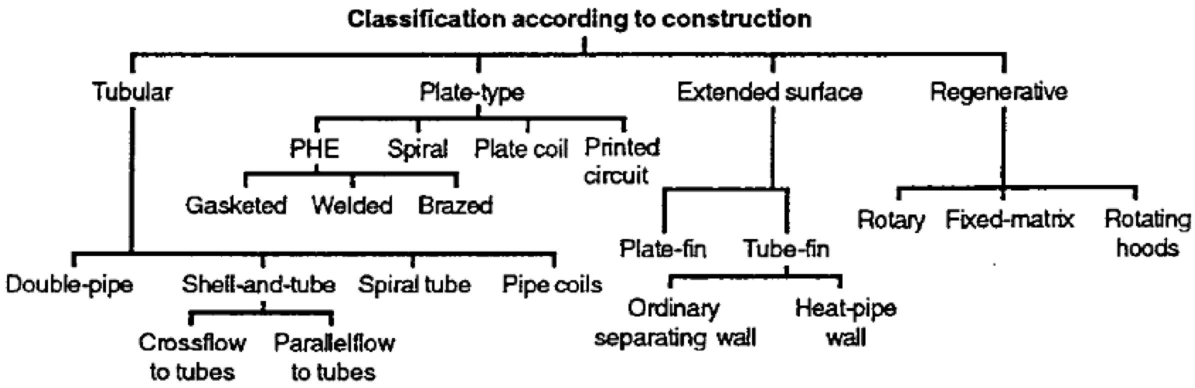


Figure 4: Figure of Classification of Heat Exchangers According to Construction Features (Shah, Sekulic 2003, pp. 2)

With further evaluation of these construction types, assessment of both Plate-Type and Regenerative Heat Exchangers would render a futile effort, seeing as these designs are solely derived from the feature of there being an exchange of heat between a hot and cold fluid. An evaluation can be conducted, however, on the Extended Surface and Tubular Heat Exchangers, as their design features can be implemented with respect to the Braaiing Apparatus.

Extended Surface

A common method of increasing the surface area through which heat transfer occurs, as well as increasing compactness, is to add extended surfaces referred to as fins. An addition fins can increase the surface area by 5 to 12 times the original surface area, conditional on the design (Shah, Sekulic 2003, pp. 37). They are attached to the tubes mainly by a tight mechanical fit, adhesive bonding, brazing, soldering, extrusion or welding (Shah, Sekulic 2003, pp. 41).

Tube-fin heat exchangers are classified as Individually Finned Tube (as seen in Figure 5), Flat Continuous (Figure 6) and Longitudinal Finned (Figure 7).

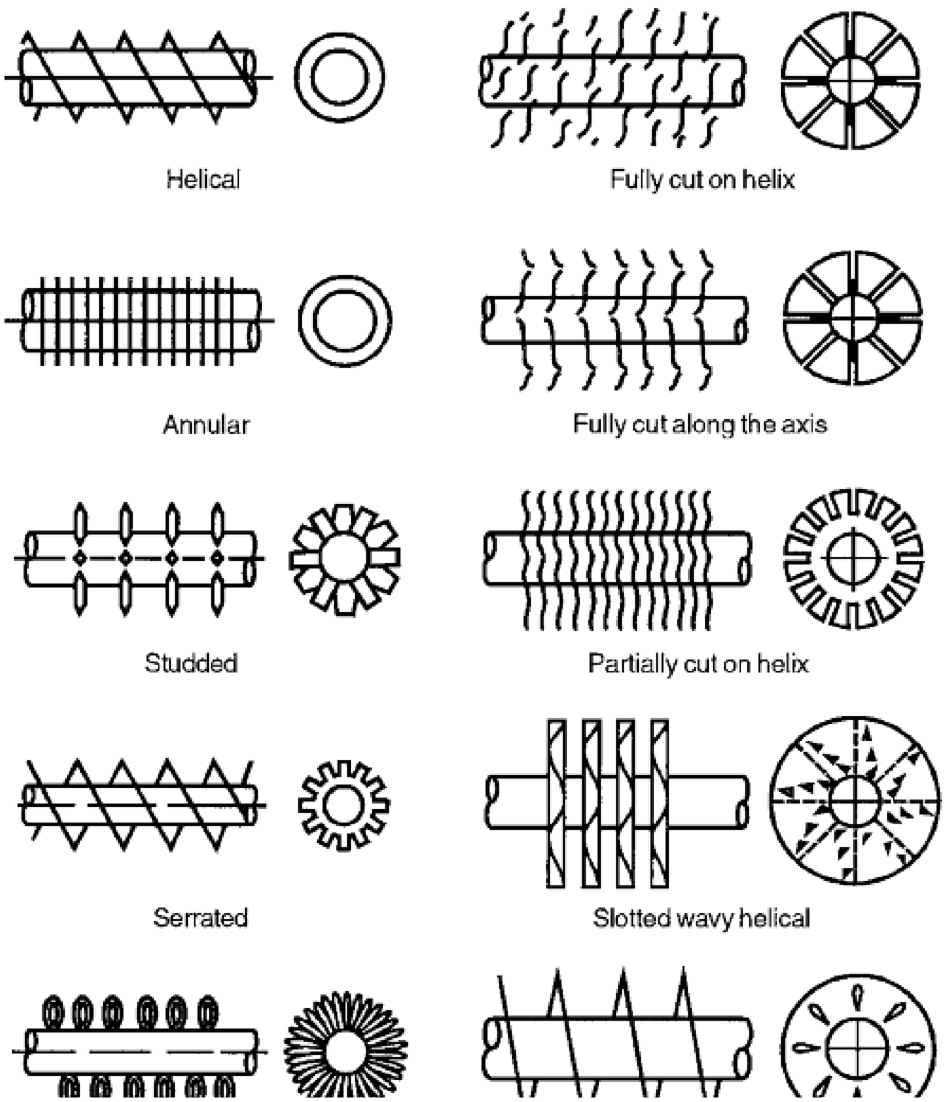


Figure 5: Figure Showing Individually Finned Tubes (Shah 1981).

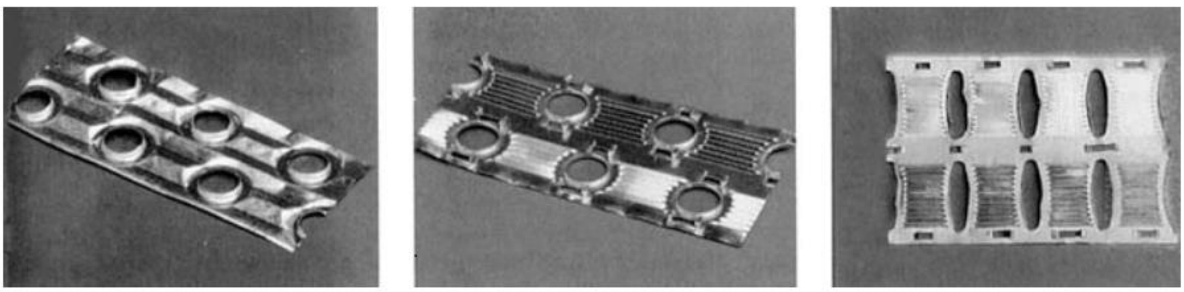


Figure 6: Flat Fins on Round, Flat, and Oval Tubes (Shah, Sekulic 2003, pp. 43).

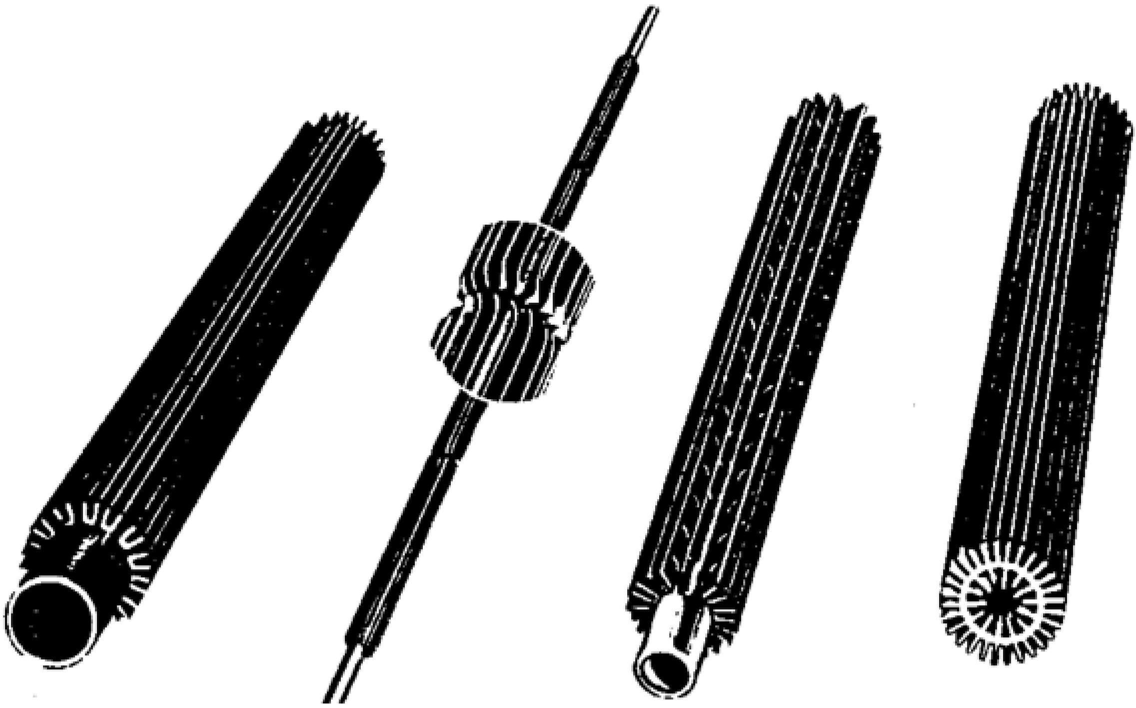


Figure 7: Longitudinal Fins on Individual Tubes (Shah, Sekulic 2003, pp. 44).

Tubular

In particular, certain facets of design implemented into Shell-and-Tube Heat Exchangers can be addressed, despite the Heat Exchanger's functionality being different to that of the Braaiing Apparatus, i.e. Shell-and-Tube Heat Exchangers contain a large number of tubes packed in a shell with axes parallel to the shell, where heat transfer occurs as one fluid flows inside the tubes while the other fluid flows outside the tubes through the shell (Cengel, Ghajar 2015, pp. 650).

The tubing implemented may be seamless or welded. The former is created in an extrusion process, while the latter is produced by rolling a strip into a cylinder, after which welding the seam. Intuitively, the welded tubing is more cost-efficient (H&C Heat Transfer Solutions, n.d.).

Tube Shapes. Various shapes of circular cross-sectioned tubes are used in the Shell-and-Tube Heat Exchanger, with the most customary being straight and U-tubes (Figure 8). Serpentine, helical and bayonet shapes are also employed occasionally in the design of Shell-and-Tube Heat Exchangers (Figure 9) as higher heat transfer rates are associated with said shapes in comparison to straight tubes (Shah, Sekulic 2003, pp. 22). Furthermore, shapes such as Sine-Wave Bend, J-Shape, L-Shape and Hockey Stick Shapes are also implemented, though mainly in Advanced Nuclear Heat Exchangers to accommodate large thermal expansion (Shah, Sekulic 2003, pp. 16).

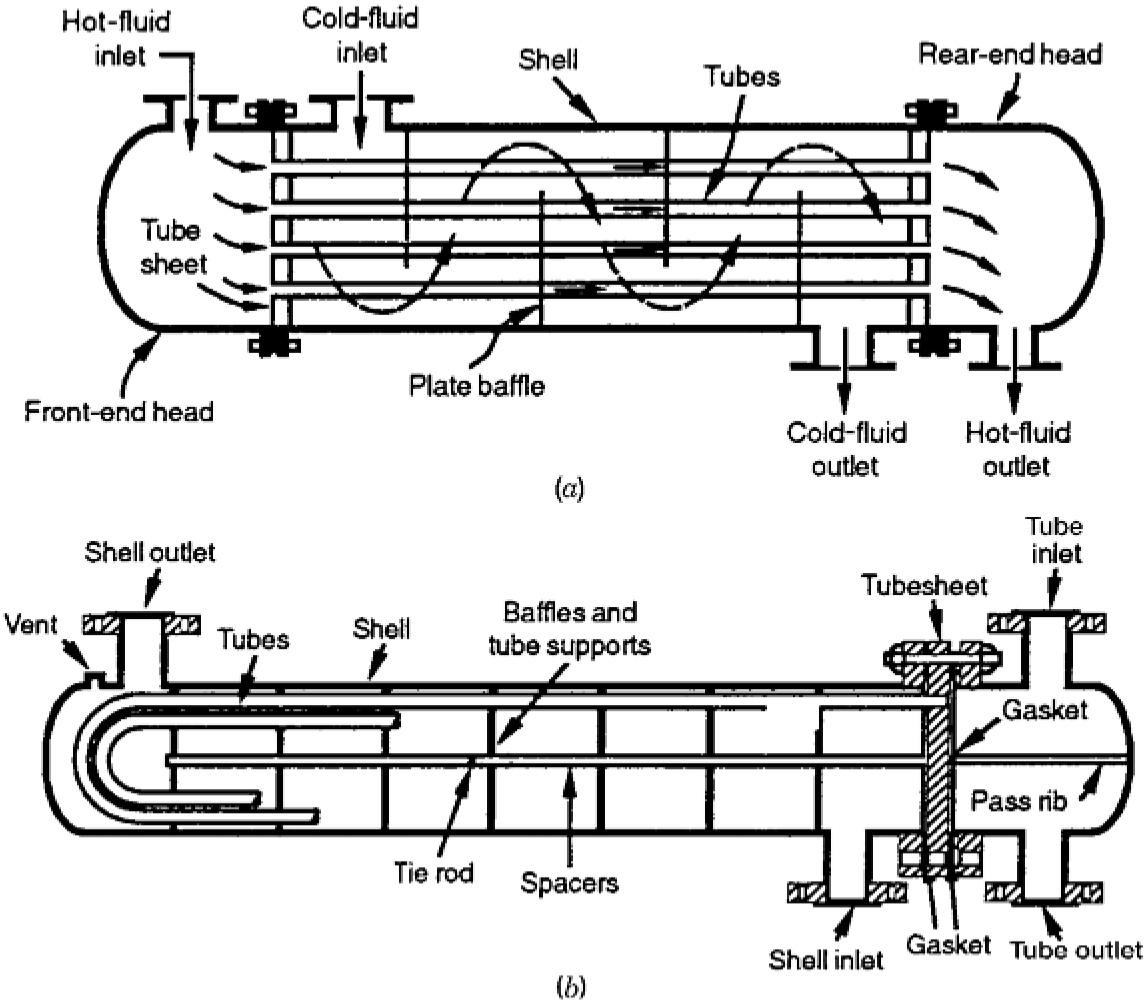


Figure 8: Shell-and-Tube Heat Exchangers: a) Straight Tubes; b) U-Tubes (Shah, Sekulic 2003).

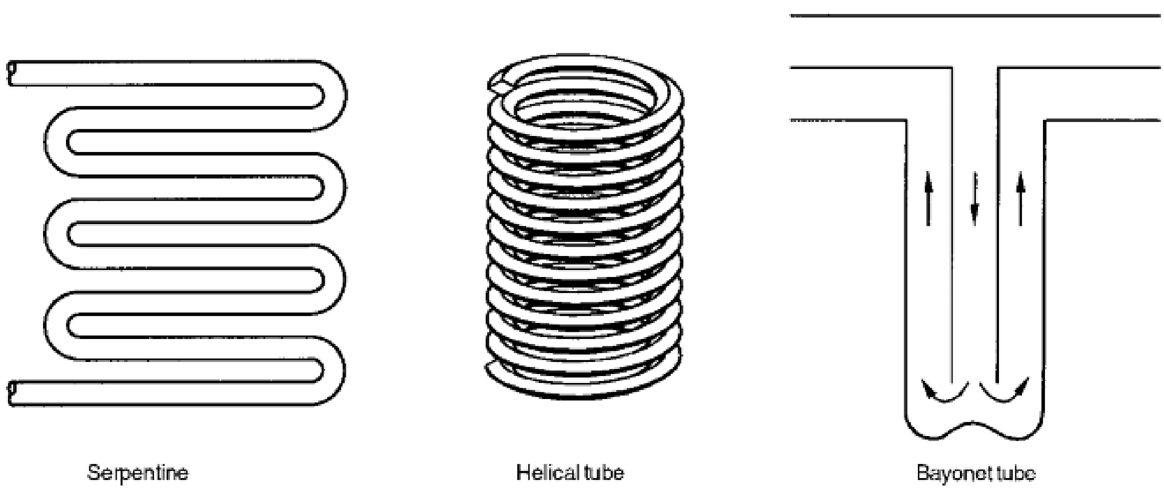


Figure 9: Other Shell-and-Tube Heat Exchanger Tube Shapes (Shah, Sekulic 2003).

Tube Thickness. The tube thickness of a Shell-and-Tube Heat Exchanger should be sufficient so as to withstand internal pressure with an adequate corrosion allowance (nptel n.d., pp. 8). Birmingham Wire Gauge (BWG) is the most common means of expressing tube thickness, where normal tube wall thickness varies from 12 BWG (2.769mm) to 16 BWG (1.651 mm). Thin-walled tubes (which can be expressed as a range of 18 to 20 BWG) are implemented when the tubing material in question is relatively expensive (H&C Heat Transfer Solutions, n.d.).

Tube Passes. These passes can be considered as a "layering" of tubes inside the heat exchanger, and are employed in the design as a means of increasing the heat transfer co-efficient. In Shell-and-Tube Heat Exchangers, tube passes can vary from one to sixteen, where one, two and four tube passes are the most customary in industrial application (nptel n.d., pp. 9).

It should be noted however, that while implementations with regard to maximizing heat transfer are important, the fluid dynamics aspect of the Braaiing Apparatus design is equally significant and thus in general all design aspects should be considered congruently. In particular, from what has already been addressed apropos of heat transfer, implementations with respect to tube diameter, number of tubes, tube shape and number of tube passes all have an influence on the flow rates, and should be considered in unison with the fluid dynamics.

2.2 Fluid Dynamics

The subsequent section will focus on the tubing and fitting analyses for the Braaiing Apparatus in order to create optimum performance with regards to flow rates and to ensure minimal wastage. In this regards, entrances and exits as well as elbow and bends will be analysed numerically to facilitate a fitting analysis.

2.2.1 Tubing Analysis

A vast range of fluid behaviour exists; being such, there is no effective general analysis of fluid flow. This can be attributed to a profound change in the fluid behaviour which occurs at moderate Reynolds numbers (a dimensionless number representing the ratio of inertial to viscous forces) (White 2016, pp. 307). Highly ordered fluid motion illustrated by smooth layers of fluid is called laminar flow, while highly disordered fluid motion occurring at high velocities is referred to as turbulent flow (Cengel, Ghajar 2015, pp. 383). The transition between these two flows occurs at a critical Reynolds number of between 2100 to 2300 in ducts (White 2016, pp. 311).

Subsequently, determining the type of analysis suitable to the proposed application is crucial, where one would need to accommodate typical Reynolds numbers adequately. Designing tubing for the Braaiing Apparatus consists of a rather simplistic modelling of fluid flow through a duct. Being such, certain justified approximations would need to be established. Furthermore, one can approximate the fluid flow to be steady and incompressible, implying the properties of the liquid do not change with time, and most importantly, the liquid's density.

Moreover, following from the notion of the tubing system being rudimentary, and by employing the use of a control volume analysis, including the aforementioned one-dimensional continuity relations, the steady flow-energy equation (referred to as the Bernoulli Equation) can be reduced to (White 2016, pp. 164):

$$\left(\frac{P}{\rho g}+\frac{V^2}{2g}+z\right)_{in} = \left(\frac{P}{\rho g}+\frac{V^2}{2g}+z\right)_{out} + h_{friction} \quad (1)$$

After centuries of rigorous fluid dynamics experimentation, and extensive data collection, the term $h_{friction}$ can now be computed as (White 2016, pp. 345):

$$h_{friction} = \frac{V^2}{2g}\left(f\frac{L}{d}+ \Sigma K\right) \quad (2)$$

The Darcy friction factor, f (also referred to as Moody-type friction), is a function of the Reynolds number (Re) as well as relative roughness ($\frac{\varepsilon}{d}$), where ε is the wall roughness in millimetres. This dimensionless parameter can either be obtained by reading off the Moody Chart-plotting the friction factor as a function of the Reynolds number (Re) and relative roughness ($\frac{\varepsilon}{d}$). Or by implementing the Haaland formula, defining an explicit formula for the Moody Chart and only varying by 2% (White 2016, pp. 329).

2.2.2 Fittings Analysis

An adept assessment of the tubing layout would need to be undergone prior to selecting fittings necessary to sustain optimum performance of the Braaiing Apparatus, which can include: Pipe Entrances and Exits, Bends and Elbows.

Being such, in order to maintain this flow efficiency, the fittings will be specifically designed for to accommodate 'minor losses' (also referred to as 'local losses') that are induced as a result of the installation of the respective fittings (White 2016, pp. 344-345).

These Local losses are commonly measured experimentally, due to the theory associated with flow patterns in fittings being quite poor, and are correlated to the pipe flow parameters. The ratio of head loss (h_m) through the duct to velocity head, gives rise to the measured local loss (White 2016, pp. 345):

$$Loss\ Coefficient\ K = \frac{h_m}{V^2/2g} = \frac{\Delta p}{\frac{1}{2}\rho V^2} \quad (3)$$

The tubing system may have a number of fittings, and thus with the accompanying local losses. Furthermore, as the $Loss\ Coefficient\ K$ is correlated to the term $V^2/2g$, a summation of all these terms into a single total system loss results in Equation (2) above.

Entrances and Exits

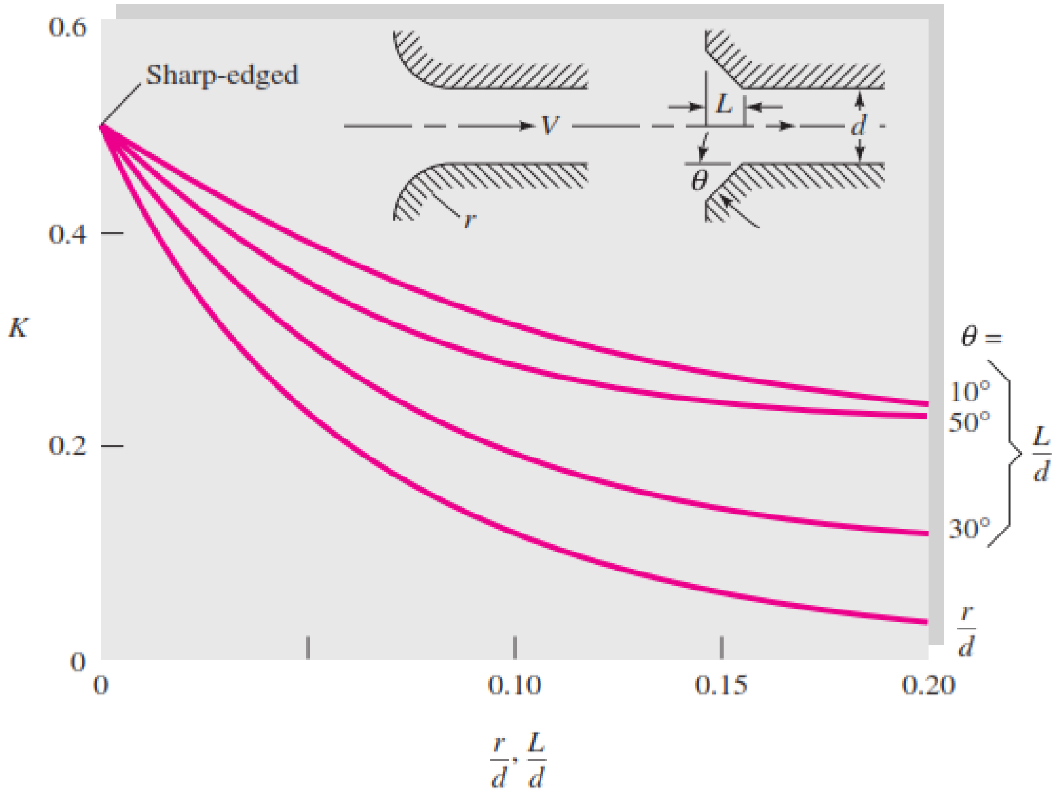


Figure 10: Entrance and Exit Loss Coefficients (K) (White 2016, pp. 349).

The geometry of the entrance (where the fluid enters the tubing system) is highly influential on the extent of entrance losses, as illustrated in Figure 10. Geometrical protrusions in general, as with sharp edges, existent in the entrance region gives rise to large zones of flow separation and results in vast minor losses (White 2016, pp. 349).

Additionally, as seen in Figure 10, minute rounding of the entrance geometry can significantly reduce minor losses, where a well-rounded entrance (r = 0.2d) has approximately a negligible loss coefficient of K = 0.05.

For exits immersed in fluid, the fluid merely flows out of the tube, and due to viscous dissipation, loses all its velocity head (White 2016, pp. 349). Therefore, the loss coefficient K = 1.00 for all submerged exits, regardless of exit geometry.

Bends and Elbows

Due to flow separation on curved walls and swirling "secondary flow" caused by centripetal acceleration, a bend (or curve) in tubing results in larger local losses in comparison to mere straight tubed Moody friction loss (White 2016, pp. 348). Flow separation and therefore local losses are reduced as the ratio of bend radius to tube diameter decreases (an exception being minute ratios tending to 0), as illustrated in Figure 11. The same principle can be applied to Elbows, as illustrated in Figure 12.

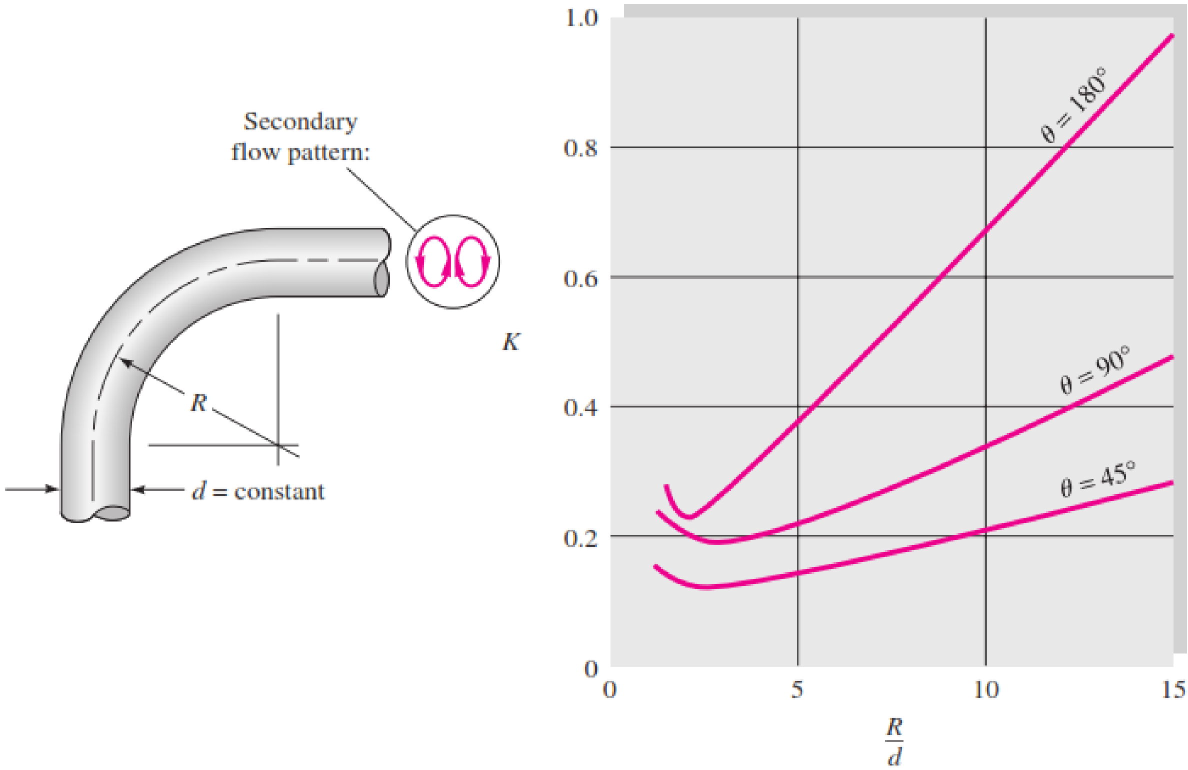


Figure 11: Graph Showing the Correlation between Loss Coefficient K and Ratio of Bend Radius to Diameter (R/d) for 45°, 90° and 180° Bends (White 2016, pp. 348).

An approximation of the Loss Coefficient K for 90° bends is given as (White 2016, pp. 348):

$$Loss\ Coefficient\ K \sim 0.388\alpha \left(\frac{R}{d}\right)^{0.84} Re_D^{-0.17} \tag{4}$$

Where

$$\alpha = 0.95 + 4.42 \left(\frac{R}{d}\right)^{-1.96} \geq 1 \tag{5}$$

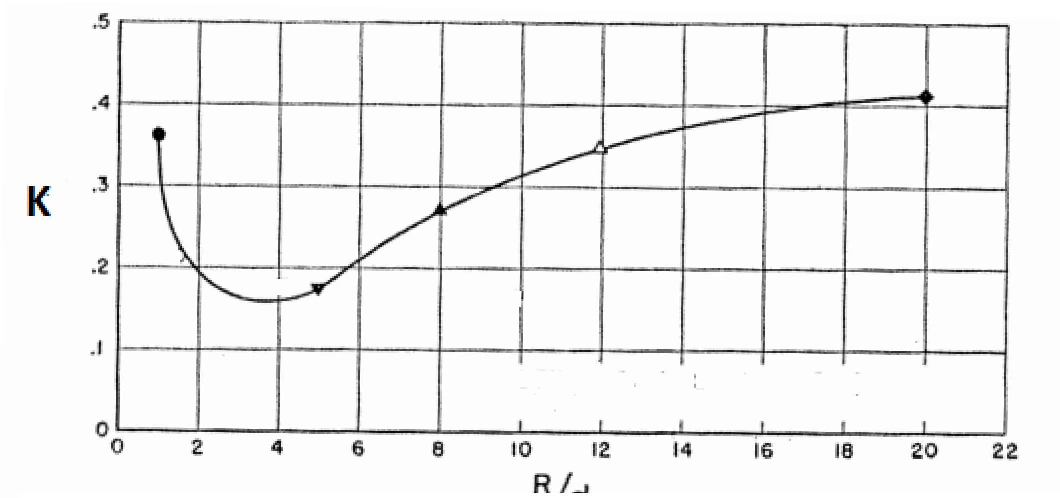


Figure 12: Graph showing correlation between Resistance Coefficient (K) and the Ratio of Bend Radius to Diameter (R/d) for 90^{0} Elbows (U.S. Department of Commerce, 1938).

2.3 Heat Transfer

The effective transfer of heat in the Braaiing Apparatus is a crucial element in its design. Thus the following section will show in-depth analyses with regard to convection and radiation, both being important aspects in heat transferal.

2.3.1 Convection Analysis

The heat transfer approach implemented for the Braaiing Apparatus, and more specifically the heat exchange between its respective tubes and the braai fuel, will not be adapted from typical heat exchanger design.

Such heat exchanger design methodology entails computing an Overall Heat Transfer Coefficient from the known geometry of the tube. Although heat exchangers have somewhat similar characteristics to the Braaiing Apparatus as addressed prior, adopting the heat exchanger heat transfer approach would not be entirely ideal. The core reason being that said approach has been modelled to accommodate typical heat exchangers, where this usually involves convection in each fluid (hot and cold), and conduction through the wall separating the fluids.

Being such, a Reynolds Analogy (or Chilton-Colburn Analogy) approach will be implemented with respect to the Braaiing Apparatus. Where equations have been derived from experimental data collected, presenting the relationship between the Darcy friction factor,f (also referred to as Moody-type friction) and heat transfer in smooth horizontal circular tubes in laminar, transitional, quasi-turbulent and turbulent flow regimes, as seen in Figure 13.

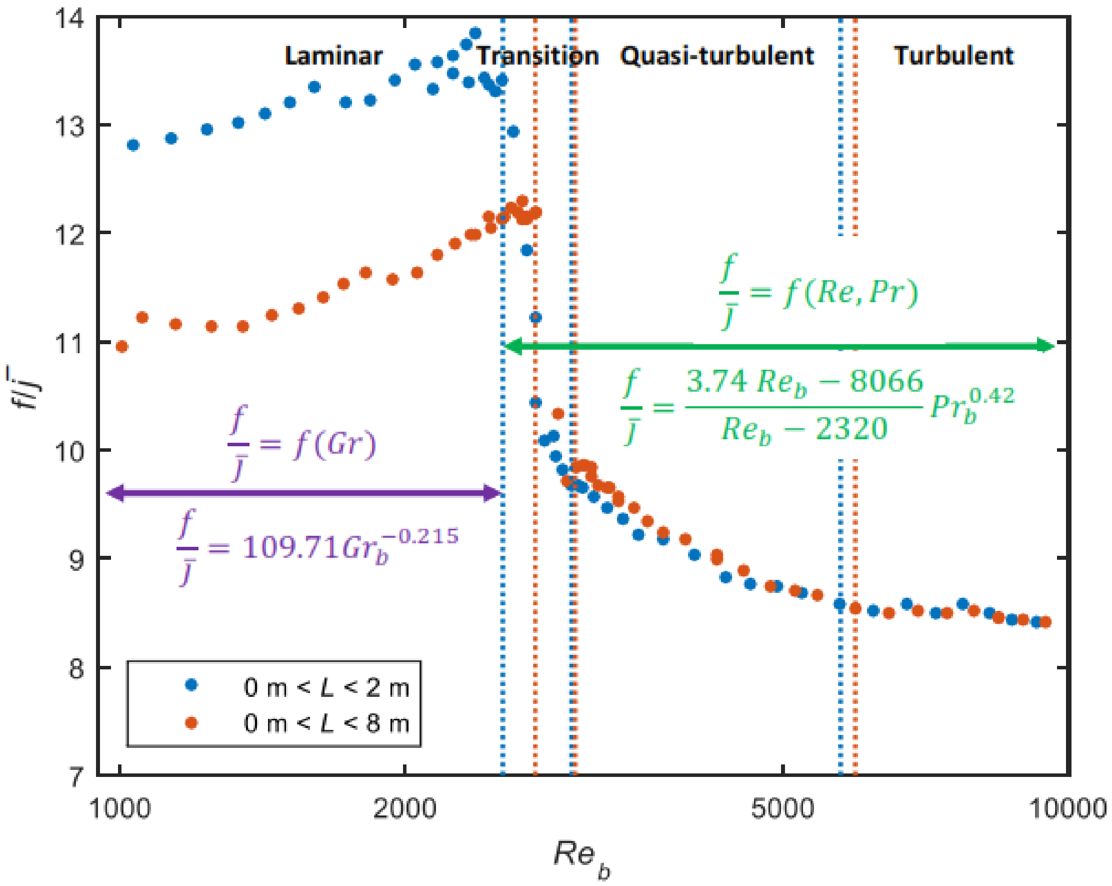


Figure 13: Graph Showing Relationship Between the Ratio of Moody-Friction Factor to the Average Colburn j-factor, and the Bulk Reynolds Number for Smooth Circular Tubes 0 m < L < 2 m and 0 m < L < 8 m at a Constant Heat Flux of 3 kW/m^2 (Everts, Meyer 2018, pp. 1250).

Furthermore, the Average Colburn j-factor will need to be determined to initiate the heat transfer analysis, and following from Figure 13, it can be seen that the Ratio of Moody-Friction Factor to the Average Colburn j-factor is solely a function of the bulk Grashof number Gr_b during laminar flow (Everts, Meyer 2018, pp. 1250):

$$\frac{f}{j} = 109.71\, Gr_b^{-0.215} \tag{6}$$

Where

$$Gr_b = \frac{g\beta(T_s - T_\infty)d^3}{\nu^2} \tag{7}$$

And during turbulent flow, the Ratio of Moody-Friction Factor to the Average Colburn j-factor is a function of the bulk Reynolds and Prandtl number (Everts, Meyer 2018, pp. 1250:

$$\frac{f}{j} = \frac{3.74\, Re_b - 8066}{Re_b - 2320} {Pr_b}^{0.42} \tag{8}$$

Where the Bulk Reynolds number Re_b will be calculated from the fluid dynamics of the Braaiing Apparatus, and the Prandtl number Pr_b is a known constant of the fluid flowing through the tubes.

After which, the analysis is quite rudimentary, where the following equations will be used to complete the analysis and determine the heat flux necessary to obtain the specified temperature difference between the inlet and outlet of the Braaiing Apparatus:

The Reynolds (Chilton-Colburn) Analogy (Cengel and Ghajar 2015, pp. 406):

$$Nu = j\, Pr_b^{\frac{1}{3}}\, Re_b \tag{9}$$

$$h = \frac{k\, Nu}{d} \tag{10}$$

If the tubing of the Braaing Apparatus is modelled to be subject to a constant heat flux brought about by the braai fuel, the outlet temperature will be calculated as (Cengel and Ghajar 2015, pp. 479):

$$T_e = T_i + \frac{qA_s}{mC_p} \tag{11}$$

However, if the tubing is modelled as having a constant surface temperature, the exponential decay of the temperature difference between the fluid and the surface temperature must be accounted for. Thus the outlet temperature must be computed as (Cengel and Ghajar 2015, pp. 481):

$$T_e = T_s - (T_s - T_i)e^{\frac{-hA_s}{mC_p}} \tag{12}$$

2.3.2 Radiation Analysis

Radiation can be described as energy emitted by electromagnetic waves due to changing electron configurations, which do not require the presence of a medium to travel through. Any body which has a temperature above absolute zero, will emit a type of radiation called thermal radiation (White 2015, pp. 27). Thermal radiation can potentially be an extensive source of heat generation, and is essential to be considered.

The core governing equation for radiation heat transfer is (White 2015, pp. 29):

$$Q_{radiation} = \varepsilon \sigma A_s (T_{surr}^4 - T_s^4) \tag{13}$$

(This equation is rudimentary, and does not take into account the emissivity of the surrounding surface, and thus is merely an approximation)

2.4 Ergonomics

It is imperative that factors relating to the ease of human use must be addressed, that is, factors which can improve human efficiency should be considered during the design of the Braaiing Apparatus. The subsequent section focuses on the materials of the apparatus, where the weight and maintenance aspect will be elaborated on.

2.4.1 Material

There is a vast selection of materials available with regards to the components of the Braaiing Apparatus. The selection of material, however, must be congruent on the respective properties (physical and mechanical) which the materials offer.

The core physical property for the material to have would be a high heat transfer co-efficient. It is essential for both the tubing and fins to have a high thermal conductivity, such that there is efficient heat transfer from the material to the water. Another physical property of the material that should be addressed is that of a low thermal expansion coefficient though this would only be of significance if there were vast temperature differences present in the Braaiing Apparatus (Rodriguez 1997, pp. 62). Lastly, the final physical property that should be addressed is the density of the material, where a low density material would signify a lighter and a more ergonomic Braaiing Apparatus.

The materials chosen throughout the Braaiing Apparatus must also have a melting point above that of the temperature at which the braai fuel burns. This includes the material used for the tubing and fins, as well as for the material which makes up the Braaiing Apparatus's outer and inner vessel.

Mechanical properties must be looked at to ensure ease of maintenance of the Braaiing Apparatus. Being such, the tubing and fin material need to exhibit good fatigue, corrosion fatigue and creep-fatigue behaviour. The material should also possess a low corrosion rate to ensure corrosion allowance is minimized (Rodriguez 1997, pp. 62).

The final material to address is the insulation material, which is essential to be implemented in the design, so as to ensure heat dissipation to the outside of the Braaiing Apparatus. This lack of heat transfer is vital for ergonomic reasons, as it would be impractical for users to efficiently handle the apparatus if the outer vessel was at a high temperature. Insulation material to be considered will need to have a low thermal conductivity, as well as being reasonably priced.

2.4.2 Braai Fuel

There exists a need to produce vast amounts of heat for not only the cooking of food, but additionally, for the heating of the water. This source of heat is conventionally brought about by charcoal or wood. Seeing as wood as a braai fuel need not be elaborated on, as it is a fairly rudimentary source of heat, charcoal as a braai fuel can potentially be complex. Charcoal is created by burning wood in the presence of oxygen. Fundamentally, there exists two types namely lump charcoal and briquettes.

Lump charcoal is charcoal without the presence of any chemical additives and is charcoal in its purest form. It lights quicker when compared to briquettes, as well as burning hotter and producing little ash. It is however, fairly expensive (Bousel 2008).

Briquette charcoal are manufactured from by-products of wood, and are compressed with chemical additives to aid in the lighting and consistent burning of the charcoal. They are significantly cheaper than lump charcoal, as well as burning longer. They however, produce more ash and have a chemical smell (Bousel 2008).

Coal gas can burn up to 2000 ^{o}C under 100% air conditions (Avallone 2006). During a braai, however, the apparatus is subject to large amounts of air which will decrease the temperature of the burning coals vastly (Rebuilding Civilization n.d.), such that temperature of the charcoal can reach a temperatures ranging from 300 ^{o}C to 550 ^{o}C (Vanaparti 2016, pp. 39).

3 Specifications

The following are set by the needs of the user (customer requirements) and additionally, technical specifications set forth by the designer, which were not specified by the user, and are necessary to ensure efficient functioning of the system.

The Specifications are presented in a table-like format, which will "run" congruently with 4 Functional Analysis that is, the listed specifications will reference the functions in the subsequent section.

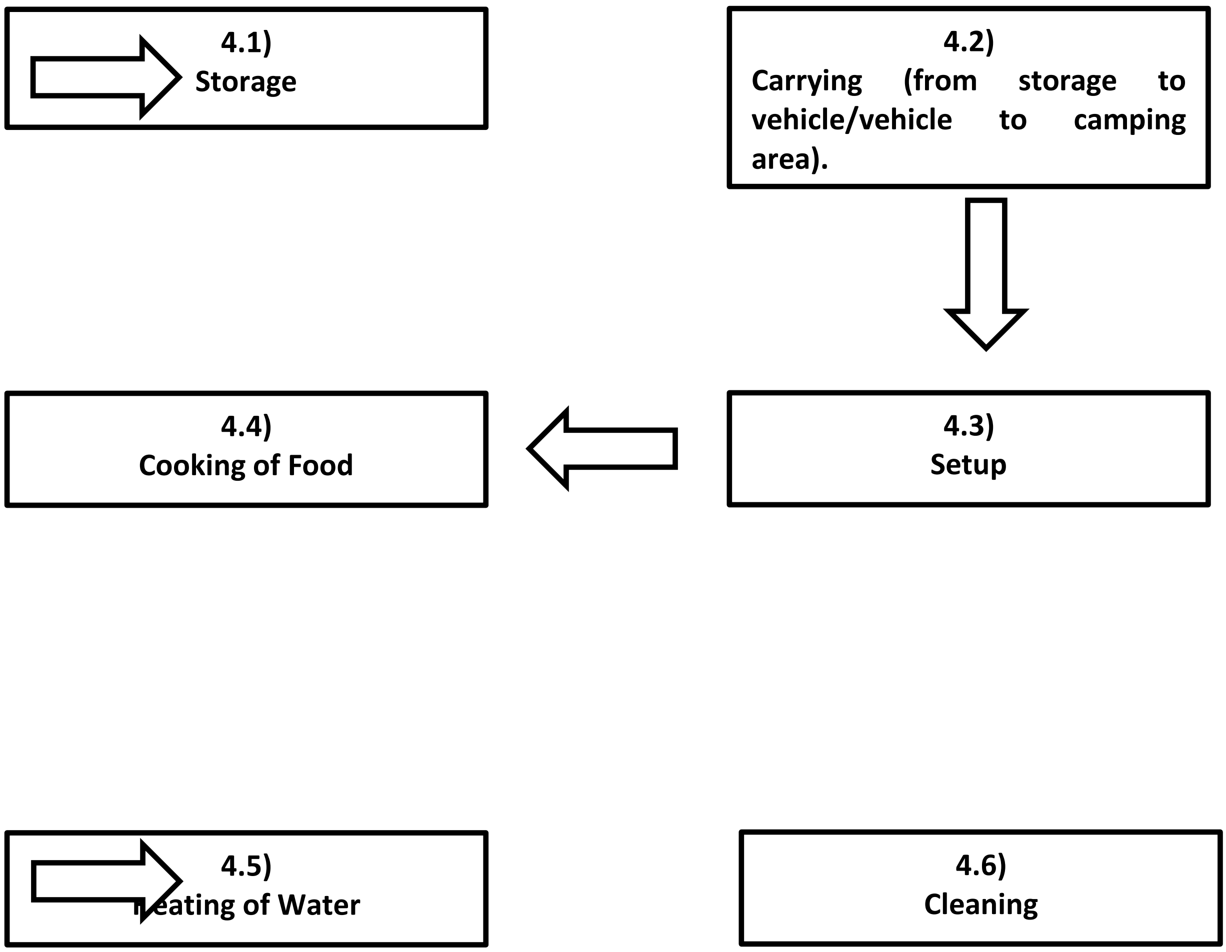
Specification	Value	Functional Analysis Reference
Detachable "legs".	Maximum Height = 1 metre	4.1)
Detachable grill.	N/A	4.1)
Maximum occupy-able area/spacing (without "legs").	Maximum Length = 1 metre Maximum Width = 0.5 metres Maximum Height = 0.25 metres	4.1)
Store in non-moist/non-wet environment, preferably room temperature or dryer.	N/A	4.1)
Weight	Maximum 10 kilograms	4.2)
Users (encompassing all gender, age etc.).	2	4.2) 4.3)
Normal hosepipe connector to be used as inlet/outlet.	N/A	4.3) 4.5)
Braai fuel to be used is charcoal (lump or briquette charcoal, where any brand is useable).	N/A	4.3)
Apparatus to be used only on flat surface/ground.	N/A	4.3)
Apparatus to be used only in customary braaiing environment ie. non-moist/non-wet weather.	N/A	4.3)
Apparatus to have customary braaiing capabilities.	N/A	4.4)
Water temperature increase.	Minimum $10^{o}C$	4.5)
Water source available at domestic pressure.	N/A	4.5)
Water inlet temperature.	$15^{o}C$	4.5)
Shower to be had after Cooking of Food, not during.	N/A	4.5)
A fair amount of braai fuel must still be present in the Braai after cooking. That is, braai fuel	To be designed for	4.5)

must be distributed on all applicable areas of the Braai.		
Braai fuel must be fully ignited and burning prior to shower.	N/A	4.5)
Additional braai fuel may be added if necessary to meet requirement.	N/A	4.5)
No storage of water necessary, as water will be used immediately from hosepipe.	N/A	4.5)
No electricity available	N/A	4.5)
Customary discard of braai fuel must be employed.	N/A	4.6)
Rudimentary wipe of inlet/outlet after each use.	N/A	4.6)

4 Functional Analysis

The subsequent section was undergone to facilitate an efficient design process, whereby the problem at hand was fully addressed. An analysis of the Braaiing Apparatus in its entirety was performed, where specific functions of the system were identified, to reduce the complexity of the problem.

4.1 Functional Analysis Flow Diagram



4.1)
The main component of the Braaiing Apparatus will consist of 2 parts, namely the body of the apparatus and detachable legs. These ‘detachable’ legs will have a maximum height of 1 metre. The storage unit of the apparatus will have measurements of 1 metre in length, 0.5 metres in width and 0.25 metres in height. These will constitute the maximum specifications for the unit. This unit must be stored in a non-moist/wet environment, preferably at room-temperature or dryer.

4.2)

To accommodate the ease of carrying the apparatus by the users, the Braaiing Apparatus will have a maximum weight of 10 kilograms. Thus, users of encompassing all genders and ages will be able to use this apparatus with convenience.

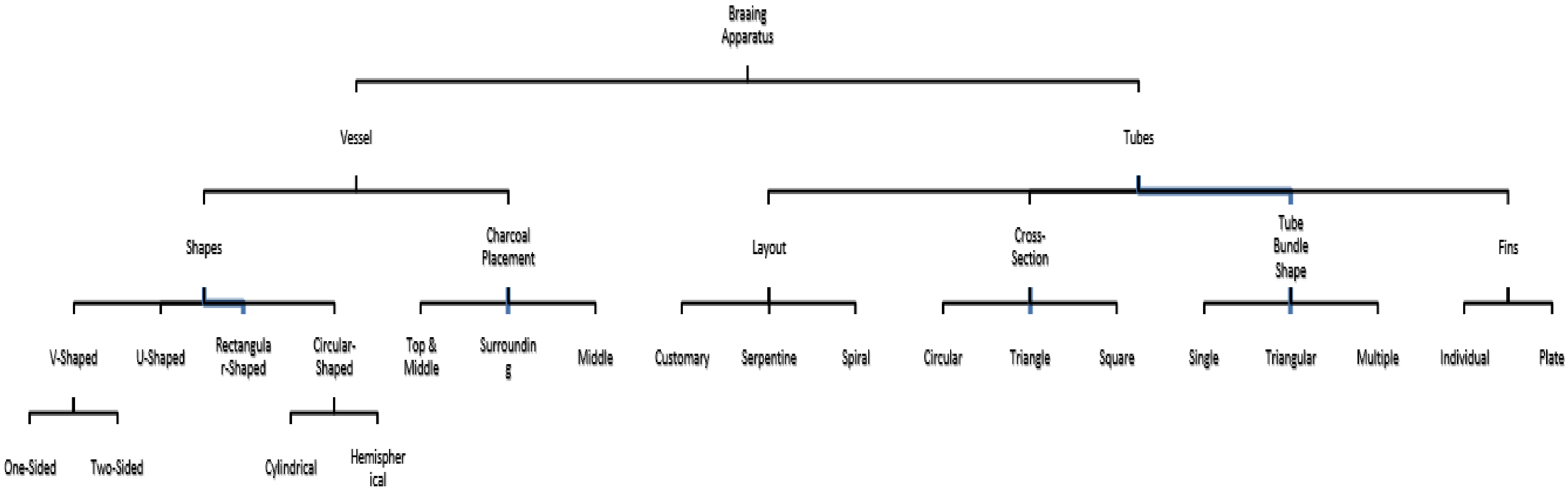
4.3)
With regards to the setup, again this will be made convenient to all users regardless of age or gender. A normal hosepipe connector will be used as the inlet and outlet, and this will be the means of transporting the water from a water source to the apparatus. The braai fuel to be used is charcoal; lump or briquette charcoal, where any brand is suitable. In terms of the suitability of use, this apparatus is most suited for a customary braaiing environment (i.e. non-moist/wet weather) and on a flat surface (i.e. level ground).

4.4)
As all braais have the ability to cook food on a grill, so will the Braaiing Apparatus have this same capability.

4.5)
The water temperature at the outlet must have at least a 10 degrees Celsius difference from the water temperature at the inlet. Braai fuel must be fully ignited and burning prior to the shower. Additional braai fuel may be added if necessary to meet requirement. In this regard the water can only be used after cooking is done and not during the process. A fair amount of braai fuel must still be present in the Braai after cooking. That is, braai fuel must be distributed on all applicable areas of the Braai for the heating of water to occur. Additionally, the flow rate of the water at the outlet must be of adequate standards to allow for a comfortable shower.

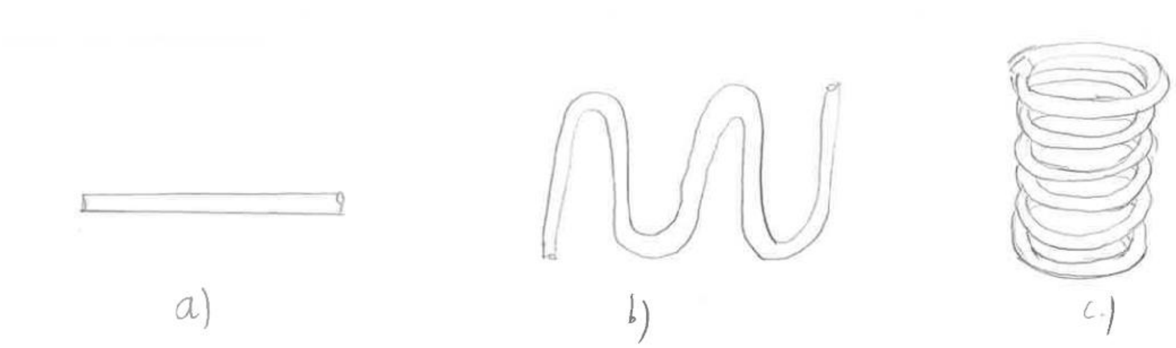
4.6)
In terms of cleaning the Braaiing Apparatus, a considerable amount of time must pass before one can handle the unit. The braai fuel must be discarded as customary to other braais as well as a wipe down of the outlet/inlet undergone.

4.1.1 System Level Diagram



5 Concept Generation

The approach with regards to the generation of concepts pertaining to the Braaiing Apparatus will be to initially evaluate the Functional Analysis, after which, determining which focal points of the entire apparatus needs to be designed. Namely, the Tube Layout will be addressed, with subsequent designs of the Braaiing Apparatus in its entirety, and moreover, which tubing layouts are applicable. The followed by propositions of design with respect to Tube Bundles, Tube Cross-Section, and lastly Tube Fins.



5.1 Tube Layout

These tube layouts can only be implemented to certain Braaiing Apparatus vessels, where this will intuitively depend on the shape and space to accommodate said tubes, and will be addressed later (See 2.1.2 Tube Shapes). Heat transfer capabilities increase from a) to c), as the compactness of the design highly influences the tubes ability to transfer enthalpy. However, losses due to friction are amplified in this order as well, the core reason being that there are increased local losses due to the additional bends.

Figure 14: Tube Layouts: a) Customary; b) Serpentine; c) Spiral

5.2 Braaiing Apparatus Vessel

5.2.1 U-Shaped Vessel

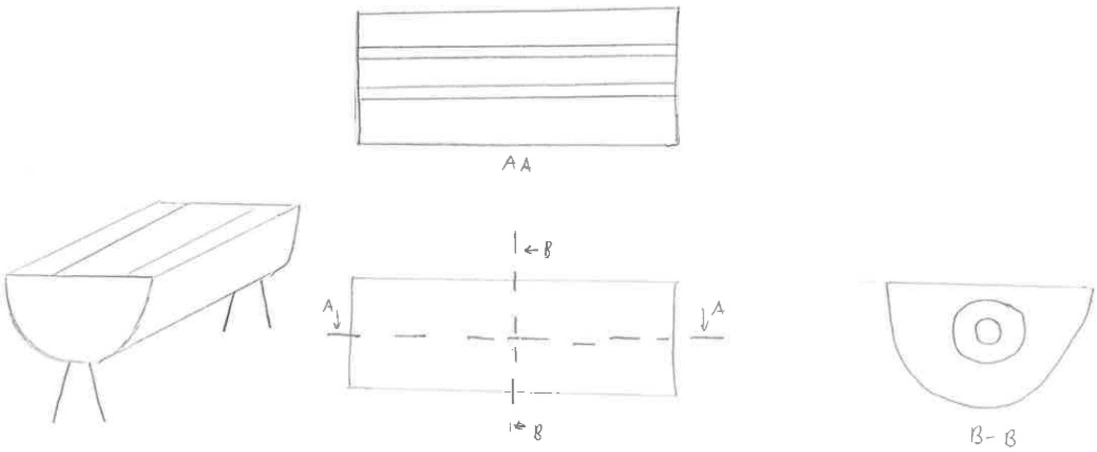


Figure 15: Figure of U-Shaped Vessel.

The Customary and Spiral Tube Layout can be implemented in this design. A disadvantage of this design is that the time taken for the water to flow through these tubes is not significantly large and could pose a problem with regards to the heat transfer (the time taken to heat the water to +10^{o}C), even though the Charcoal is place all around the centre cylinder which runs longitudinally through the vessel. This design would most likely be lighter when compared to the other designs, due to the single longitudinal cylinder in the centre.

5.2.2 V-Shaped Vessels

Two-sided Tubing

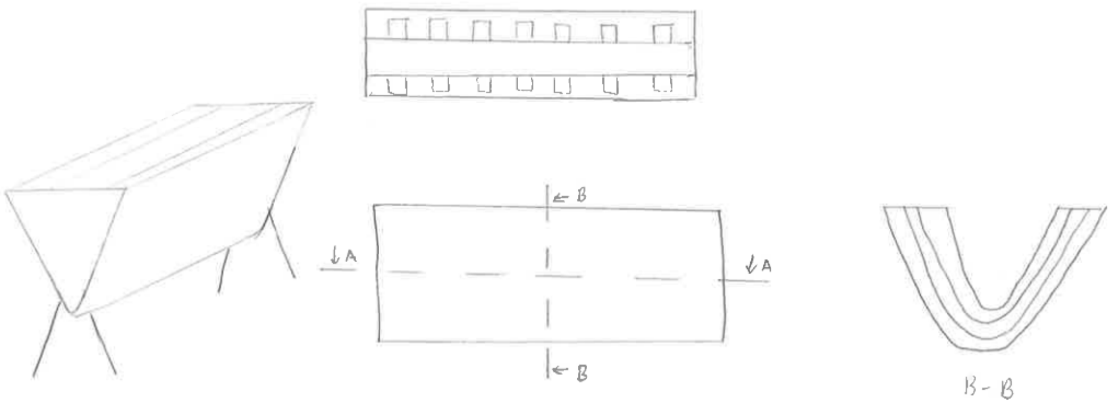


Figure 16: Two-Sided V-Shaped Vessel.

Only the Customary Tube Layout can be employed in this design, where the tubing "runs" from one top end of the 'V' to the opposite top end of the 'V'. Immediately upon evaluating, one can ascertain that there probably will be an issue with the flow rate caused by the local losses sustained by the large V-shaped bend. There shouldn't be an issue with regards to heat transfer, as the charcoal is placed in the centre of the 'V', where there is a heat flux being applied to both sides. Weighting issues could be a problematic due to the excess tubes.

One-sided Tubing

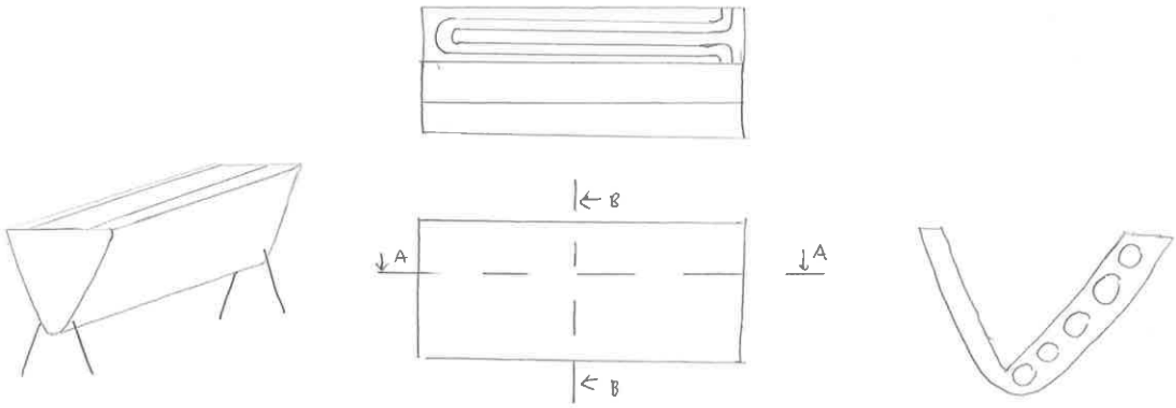


Figure 17: One-Sided V-Shaped Vessel.

Following from the previous V-Shaped Vessel, the Customary Tube Layout can only be used in this design, where a serpentine like shape is formed on a single side of the 'V'. There could possibly be a lack of heat exchange between the charcoal and the tubes as there would only be a heat flux from a single side. Balancing difficulties could also be encountered.

5.2.3 Rectangular-Shaped Vessel

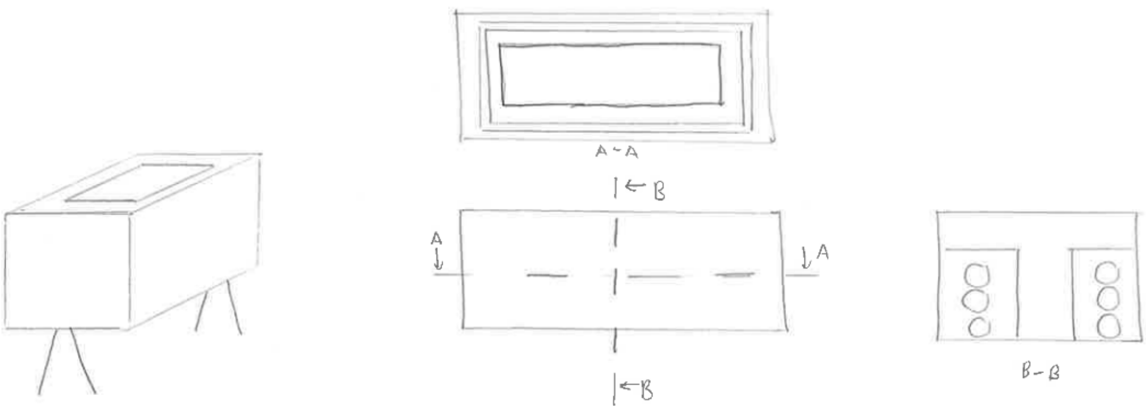


Figure 18: Rectangular-Shaped Vessel.

This design structure was inspired by an ordinary Braaiing Stand. A simplistic network of tubes encompass the charcoal, which is centrally placed. All three Tubing Layouts are applicable, where a layering of tubes will be employed as they encircle the charcoal. The only possible issue after initial assessment could be the weight, as there are numerous tubes utilized.

5.2.4 Circular-Shaped Vessels

Cylindrical

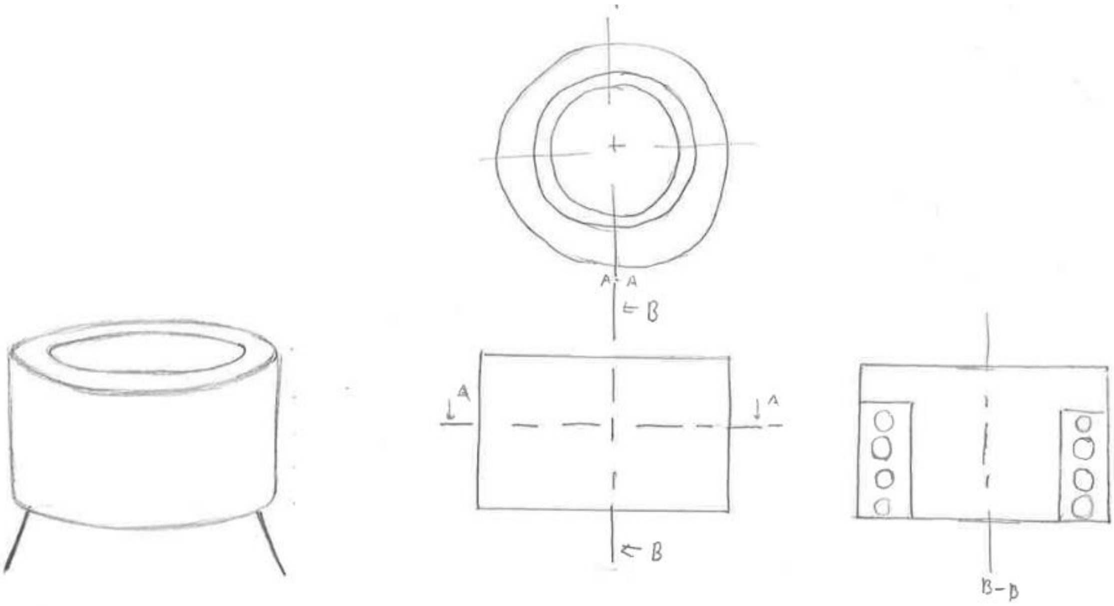


Figure 19: Cylindrical Circular-Shaped Vessel.

The tubes in this design surround the charcoal placed in the centre, and somewhat form a spiral around said heat source. The excess bends formed by the spiral in this design could cause flow rate difficulties. The only applicable Tube Layout in this design is Customary.

Hemispherical

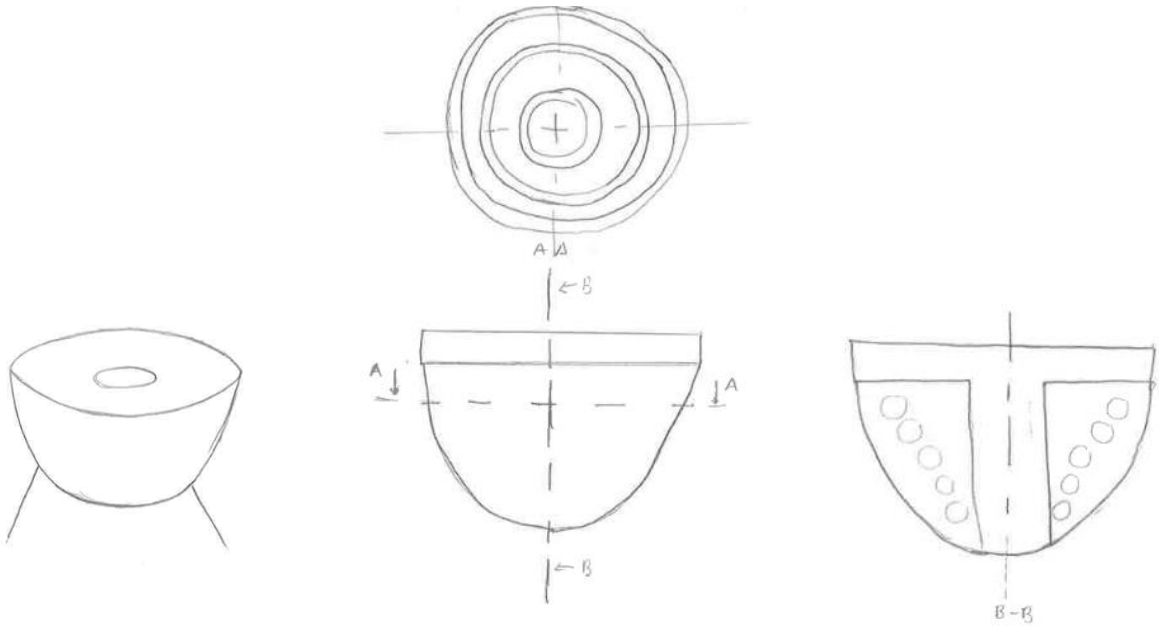
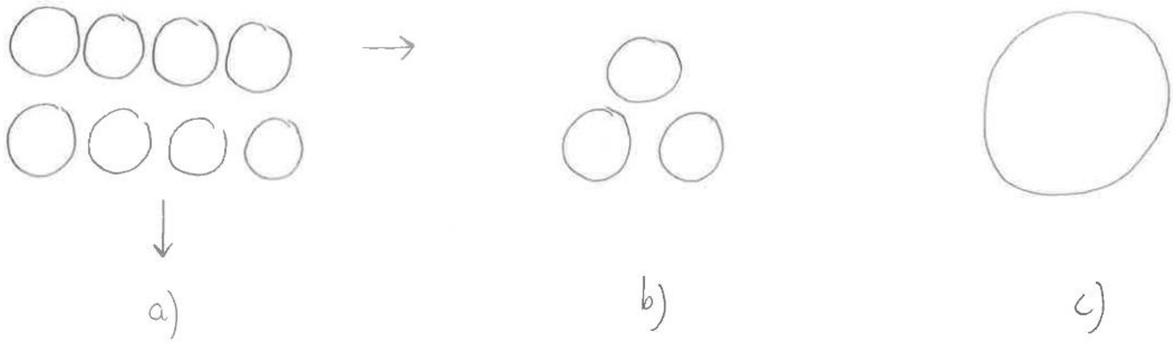


Figure 20: Hemispherical Circular-Shaped Vessel.

This design is identical to the previous Circular-Shaped Vessel, however the cylindrical piece is replaced by a hemisphere. The core reason being to alleviate weighting issues, as there would be less tubing implemented, though this could be at the expense of the heat transfer being insufficient. Furthermore, heat transfer could be influenced negatively as there is less time allowed for heat exchange. Flow rates could be advantaged however, as the bend radius of the tubes decrease which correlate to lower local losses.



5.3 Tube Bundle Shape

The Tube Bundle Shape directly influences the extent of tubing compactness, hence extent of heat transfer (See 2.1.1 Surface Compactness). Where the more compact the tubing, the greater the heat transfer. However, the notion of compactness could bring about cost and complexity difficulties with respect to manufacturing, as well as introducing weighting issues.

5.4 Tube Cross-Sectional Shape

Figure 21: Tube Bundle Shapes: a) Multiple; b) Triangular; c) Single

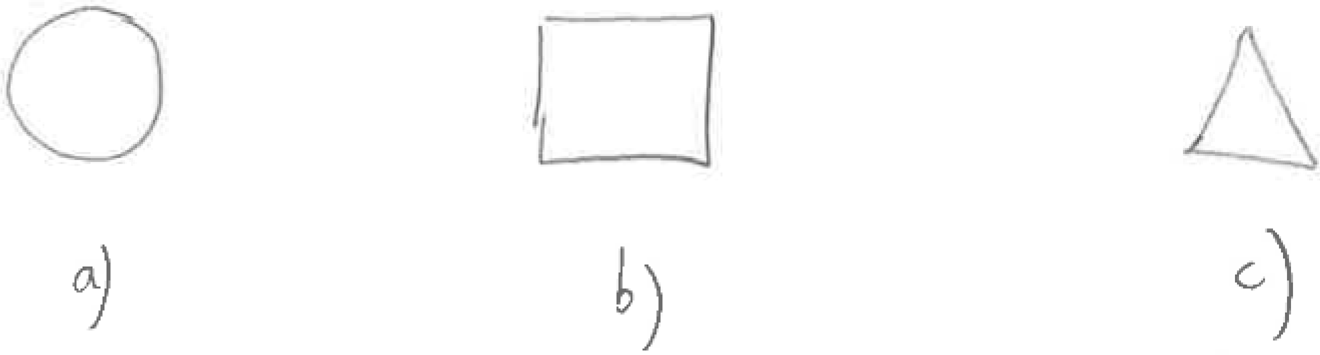


Figure 22: Tube Cross-Sectional Shape: a) Circular; b) Square; c) Triangle

The most customary choice of tubing is tubing with a Circular-Shaped cross section, where limited theory of Square and Triangle cross- sectioned tubes exist.

5.5 Tubing Fins

As explained in the literature (See 2.1.2 Extended Surface), Fins are an essential element to have with regards to heat transfer, and additionally, storage of heat. An assessment would have to be made initially whether Plate or Individual Fins would best suit an already specified Braaiing Apparatus Vessel Design.

5.5.1 Plate Fins

Figure 23: Figure of Plate Fins with an Accompanying Side View.

5.5.2 Individual Fins

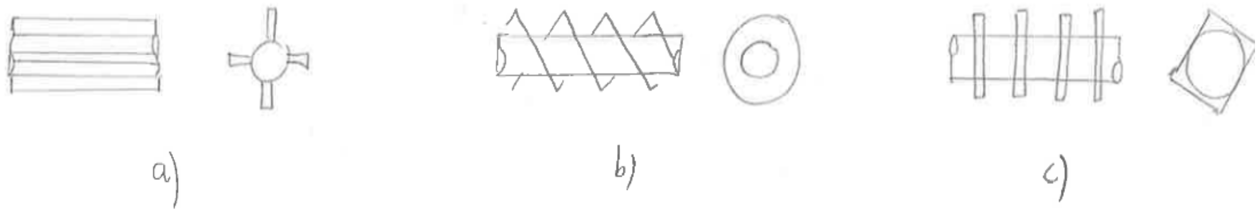


Figure 24: Individual Fins: a) Customary; b) Rhombus; c) Diamond

These specific Individual Fins have been addressed as they are the simplest to manufacture, and are the most simplistic when compared to the other Individual Fins addressed in the literature.

6 Concept Selection

The following section will entail describing the concepts selected, as well as justifying the particular selection. (The concepts can best be visualized with the aid of the Manufacturing Drawings in a subsequent section.)

Outer Vessel

The outer vessel selected was the Rectangular-Shaped Vessel, due to its simplicity as well as being able to utilized most of the allowed space (See “4.1 Storage”). Its ability to ensure the greatest amount of space was utilized was the primary reason for its implementation in comparison to other Outer Vessel Designs in “5.2 Braaing Apparatus Vessel”.

The charcoal will thus be placed in the centre of the apparatus (referred to as the Inner Vessel) as well as on the top to ensure maximum heat transfer capabilities so both the cooking of food and the heating of water is sufficiently undergone (See “4.4 Cooking of Food” and “4.5 Heating of Water”).

The Outer Vessel in its entirety will be made from AISI 304 Stainless Steel due to its advantageous mechanical properties such as fatigue and corrosion resistance which is ideal as Braai Stands are frequently subject to harsh environments. Stainless steel also has a low thermal conductivity so as to ensure the outside of the Braaiing Apparatus does not reach high temperatures, as well as having a high melting point to ensure adequate functioning if subject to these high temperatures. ASIS 304 is one of the most common types of stainless steel, and was implemented due to it being widely available.

The Outer Vessel is composed of a Top and Bottom plate, as well as side plates to enclose the Braaiing Apparatus.

Tube Layout

The tubes implemented were customary straight tubes, where tubes such as Serpentine or Helical would have been too complex to implement corresponding to the chosen Outer Vessel. Although greater heat transfer could be a result of other implementations such as with the Serpentine or Helical tube layout, a loss due to excess friction in the tube due to additional bends would have resulted, and affected the flow rate greatly (See “4.5 Heating of Water.”)

The tubes are placed in the Braaiing Apparatus such that it encompasses the charcoal placed centrally, where the tubes touch the inner vessel to ensure maximum conduction heat transfer from the burning coals to the tubing.

The use of Pure Copper will be implemented for the manufacturing of the tubing. Although costly, the designer thought it necessary to ensure a material with an extensively high thermal conductivity to be implemented, as there is limited time for the water to be heated as it flows through the apparatus.

The tubes itself will have an inner diameter of 2cm, and due to copper being expensive, Birmingham Wire Gauge Thickness of 18 will be employed (thickness of 1.245mm) (See “2.1.2 Tube Thickness”).

Tube Bundle Shape

In order to ensure tubing compactness, and thus sufficient heat transfer to occur in the limited amount of time through which water flows through the Braaiing Apparatus, it was imperative to implement multiple thin tubes that are within close proximity to each other to increase the surface area through which heat transfer occurs. Although this gives rise to manufacturing difficulties, these multiple thin tubes are placed vertically along the outer wall of the Inner Vessel (which encompasses the charcoal) so as to ensure sufficient heat transfer to the water (See "4.5 Heating of Water").

Tube Cross Section
The customary implementation of tubes with a circular cross section was employed as it is the most common type of tubing, which results in an ease of manufacturing as well as cost efficiency in comparison to other cross sectional shapes. There is also limited theory available on other cross sections such as Square and Triangle, and would have made an analysis difficult.

Fins
Although Fins, a means of extended surface, has been extensively addressed prior, it was decided that its implementation would be futile since such components do not apply in the proposed Braaiing Apparatus design. Although Fins do serve as a means of increasing surface area through which heat transfer occurs as well as a storage of heat, it is not necessary in this design, as the core means of heat transfer to the tubes occurs through conduction from the Inner Vessel (which stores the burning charcoal). Storage of heat would also not be beneficial, as the water is needed to be heated in the limited time that it flows through the apparatus. It is also not ergonomic to store heat in the Braaiing Apparatus as the users will need to handle the apparatus after use (See "4.2 Transport" and "4.3 Setup" in Functional Analysis).

Inlet/Outlet
The means of entry and exit of water flow through the apparatus is merely a fitted hole on either of the sides, so as to ensure a hosepipe can adequately transfer water into, as well as remove water from the Braaiing Apparatus. The Inlet and Outlet is sufficient size to accommodate the front nozzle and inlet of an ordinary hosepipe (See "3 Specifications").

Inner Vessel
The Inner Vessel provides a means of storing the burning charcoal, as well as providing a means of heating the tubing through conduction on its outside wall. Being such, the material which is ideal for the manufacturing of the Inner Vessel would be Brass (CuZn10) due to its versatility, strength and corrosion resistance. Brass also has a high thermal conductivity, a vital property in being able to transfer heat from the burning coals to the tubing. CuZn10 Brass has the highest melting point in comparison to other brass alloys, so as to ensure adequate functioning as the Inner Vessel is directly in contact with the burning coals.

Insulation
Insulation is vital to be included in the design so as to ensure adequate handling of the apparatus by the user. In order to ensure a dissipation of heat to the outside of the Braaiing Apparatus, the material chosen must have the lowest possible thermal conductivity. The designer considered this aspect to be of great significance and thus selected Fibre-reinforced glass due to its extensively low thermal conductivity and high melting point, at the expense of cost efficiency. Fibre glass is also readily available and easily manufacturable, and will be placed in sheets on the inside wall of the Outer Vessel. More so, this implementation conforms to "4 Functional Analysis", with regards handling of the apparatus in "4.2 Carrying", "4.3 Setup" and "4.6 Cleaning".

Legs

As required in “3 Specifications”, removable legs were to be implemented. Being such, a simple means to support the apparatus was designed which can easily be placed into the bottom plate of the Outer Vessel during use as in “4.3 Setup”, as well as when the apparatus is being transported as in “4.2 Carrying”.

The legs will be manufactured with AISI 1018 Mild/Low Carbon Steel due to its toughness and strength, all ideal properties to ensure acceptable support of the Braaiing Apparatus.

7 Detail Design

The subsequent section consists of calculations and corresponding analyses required to ensure the Braaiing Apparatus can perform sufficiently, as well as to ascertain whether it conforms to what was required in “3 Specifications”.

7.1 Calculations

A Fluid Dynamics and Heat Transfer Analysis were conducted, which were facilitated by sections “2.2 Fluid Dynamics” and “2.3 Heat Transfer” in the literature.

7.1.1 Fluid Dynamics

The flow rate of the Braaiing Apparatus tubing was calculated, as well as the various fittings which accompany the tubing, namely the Tubing Bends and Tubing Entrances and Exits.

Flow Rate

With the aid of Equations (1) and (2) in Section “2.2 Tubing Analysis” in literature, and after proficient evaluation of the tubing layout from the Concept Selection, quantitative values could be ascertained for the unknown variables. The procedure of utilizing the governing equations are complex and require a multitude of iterative steps, therefore, digital software was employed to aid in the computation of the flow rate.

The governing equations were applied to the inlet and outlet of the Braaiing Apparatus. The various approximations of the inputting variables as well as the code used to generate the iterations are addressed in “Appendix A: Part A”.

It was found that the minimum flow rate of the heated water, needed to ensure efficient functioning of the Braaiing Apparatus was approximately 5.7 L/min. Seeing as the minimum supply of basic water in South Africa is 10 L/min (Department of Water Affairs 1997), the Braaiing Apparatus should provide a sufficient flow rate for a reasonably comfortable shower, as is only approximately 40% lower than the Municipal standard.

Furthermore, the Reynolds number was calculated to be in the turbulent regime ($Re > 2300$), and the Darcy friction factor was calculated as 0.036, where both values will be utilized in the Heat Transfer calculations.

Fittings Design

After an appraisal of the Braaiing Apparatus design layout, there existed a need to design for two types of tube fittings to ensure a minimization of secondary losses, namely Entrances and Exits and a means by which the heated water is able to flow through 90^{o} turns, that is, 90^{o} Bends. To reiterate, there was an essential need to design for these fittings in manner that will induce the least possible secondary loss coefficients so to ensure efficient flow of water.

Entrances and Exits

Following from Section “2.2.2 Entrances and Exits” in the literature, it is known that rounding the entrances of the inlet of the Braaiing Apparatus will result in lower losses induced. Being such, an optimum entrance bend radius to tube diameter (r/d) was needed to be computed. With the tube diameter being a known variable, the entrance bend radius was only needed to be calculated. It is apparent from Figure 10 (“2.2.2 Entrances and Exits”) that the lowest losses are induced when the ratio r/d equals 0.2. Being such, the tubing entrance bend radius was computed (“Appendix A: Part B”).

Consequently, the entrance bend radius of the tubing inlet was determined to be 4mm.

Elbows

An equivalent approach was adapted as with the previous section, where a calculation of a sufficient Bend Radius (R) which correlates to a sufficient bend radius to diameter ratio (R/d) of a 90^{o} bend, which induces the lowest possible secondary loss coefficient, needed to be conducted. It is clear from Figure 11 (“2.2.2. Elbows”) that in order to fulfil this requirement, the R/d ratio must be equal to 4. With the tubing diameter known, the bend radius of the 90^{o} bend was computed (Calculation in “Appendix A: Part B”).

Subsequently, the bend radius (R) for the 90^{o} bends were calculated to be 8cm.

7.1.2 Heat Transfer

With respect to Section ‘3 Specifications,’ the tubing of Braaiing Apparatus was to be examined so as to ensure if its heating capabilities were congruent with what had been specified. Additionally, the outlet temperature of the water was determined, as well as an evaluation of the radiation transfer.

The latter part focuses on approximating the thickness of the insulation utilized in the Braaiing Apparatus so as to ensure weight and cost efficiency.

Heating Capabilities

It was specified prior, that the heating operation of the water was to occur after the cooking of food and not during (3 Specifications), and being such, a Steady State approach was employed, where the tubing surface temperature was assumed to be constant and not change with time.

Convection Heat Transfer

Seeing as the flow through the tubing was turbulent (7.1.1 Flow Rate), Equations (8) to (10) were employed to determine the convection heat transfer coefficient from ‘2.3.1 Convection Analysis’ in literature. The computation of the outlet temperature was conducted with the aid of Equation (12), as it was assumed the surface temperature of the tubing to be constant. Said computation, along with the approximations of variables is explained in “Appendix B: Part A: Convection Heat Transfer”.

It was calculated that the outlet temperature of the water 38 ^{o}C, which is roughly a 50% higher outlet temperature than what was required in ‘3 Specifications’.

The heat transfer rate was subsequently computed to be 9.4 kW.

Radiation Heat Transfer

To ascertain to what extent radiation heat transfer improves the Braaiing Apparatus's heat transfer capabilities, an evaluation of the heat transfer rate of radiation was evaluated, where the use of Equation (13) was employed (Calculation and assumptions in "Appendix B: Part A: Radiation Heat Transfer").

It was determined the radiation heat transfer rate to be 1.5 kW, and thus is less than 16% of the heat transfer rate brought about by convection. Therefore, it can be concluded that the assumption of radiation heat transfer to the water being negligible, was fair.

Insulation Design

The thickness of the insulation required for the Braaiing Apparatus to fully facilitate human operation was designed for, where it was approximated that the only means through which heat transfer would occur would be conduction (The computation, including other assumptions are explained in "Appendix B Part B").

It was determined that the insulation thickness would be approximately 5mm.

8 Manufacturing Analysis

The manufacturing process for two components, namely the Tubing and Bottom Plate is explained in its entirety, so as to ensure correct manufacturing of these core components.

8.1 Tubing

The tubing to be implemented is created by rolling a strip into a cylinder, and subsequently welding the seam (Shielded Metal Arc Welding SMAW). This method is also cost-efficient compared to alternatives such using an extrusion process to manufacture the tubing. The corresponding bends in the tubing is to be conducted in the same manner where all the components are subsequently welded to each other to create the shape specified in the Manufacturing Drawings (Surface Finishes and Geometric Tolerances can be viewed in the Manufacturing Drawings as well).

8.2 Bottom Plate

The Bottom Plate consists of two pieces namely the Base and the Inner Vessel. The base is to be manufactured by merely rolling available ASIS 304 Stainless Steel to achieve required thickness and subsequently through a milling machine to achieve required dimensions (as specified in the Manufacturing Drawings).

The Inner Vessel will consist of four brass (CuZn10) parts (one for each of the four corners of the Inner Vessel), which will be manufactured using the same process as mentioned prior. Each brass part will be bent to achieve the desired bend radius. After which, the four pieces are to be welded together (SMAW)

The Inner Vessel will be attached to the Bottom Plate through welding the outer and inner edges of the Inner Vessel to the plate (SMAW).

9 Maintenance Analysis

The maintenance and upkeep of the Braaiing Apparatus is not considered to be of great significance with regards to the amount of effort the user needs to undergo. That is, the designer specifically chose materials which have great longevity (at the expense of cost efficiency), especially with regard to corrosion and fatigue resistance in all components of the Braaiing Apparatus. This decision is justified by a user requirement in “3 Specifications”, where a rudimentary “wipe down” of the apparatus was to be conducted after use.

However, fouling, which is the accumulation of deposits on heat transfer surfaces which introduce additional resistance, may occur with time (the most common type being precipitation fouling i.e. solid deposits in a fluid, especially the case in areas where the water is “hard”). This would deteriorate the Braaiing Apparatus’s heat transfer capabilities, and therefore might not be able to meet specified user requirements in the long-term.

10 Impact of Design

The subsequent section focuses on the implications this design has on the health and safety of the public, the environmental effects and other social ramifications.

Social Impact

Using the Braaiing Apparatus will have both negative and positive impacts for both the users and environment alike. Benefits include the social aspect that is brought about when users cook on the grill as well as the ability to take a hot shower in an area where this usually would not be possible. Secondly, this apparatus can be seen as very convenient to the users because it is a "two-in-one" system as the user can both cook and use this same heat to heat water. Lastly a major benefit of the Braaiing Apparatus is that it has no need for any electricity which means lower costs for the users and the convenience of not having to find a plug point or electricity source. However, there are still negative consequences of using this system especially in a 'public' area. The smoke from the fire could be a cause for irritation to people in close proximity to the apparatus.

Health and Safety

This smoke could also be a health hazard especially to young children. Not only could the smoke irritate the eyes and lungs in the short term, there have been numerous studies that have concluded that in the long-term it could be very dangerous for the health and some go as far as to say that it could cause cancer. This is due to the coals producing carbon-monoxide. Another health and safety concern would be the possibility that the braai could cause a fire. The cause of the fire could be very unpredictable, while some reasons could include cooking oil dripping on the grill or the leg stands tipping over. There could be an even higher risk when young children are around the area. Not only is this dangerous for the users but also for the environment around them.

Environmental Impact

The environment would not only be impacted by both the fumes from the braaiing fuel but also negligence on the part of the users could result in a fire as mentioned before. Secondly, negligence of the users when it comes to cleaning the apparatus could damage the environment considerably especially when the braaiing fuel (charcoal) is discarded. Some users could "dump" the used coals in forested area or even in water that would be harmful to the vegetation as well as animals in the area.

Legal Impact

Legally there should be some areas that have legislation in place that would limit this type of apparatus. There could be some areas that have a limit to the amount of braais that are used in order to protect the environment and the surrounding people. Users must keep in mind to only braai in areas that a designated for this type of activity. The ignorance of these rules could lead to confiscation of the apparatus or a possible fine having to be paid.

11 Recommendations

Although the Braaiing Apparatus design is sufficient in its performance, other design improvements or innovations could be implemented in future designs.

A storage aspect of the water could be addressed, where instead of limited time given for heat transfer to occur to the water as it flows through, it could instead be left inside the apparatus for a longer period of time. This would ensure greater time for heat transfer to occur, resulting in higher outlet temperatures of the water, though will be at the expense of weighting and flow rate issues which could arise.

A more efficient method of cooling the outside of the Braaiing Apparatus down could be looked at, where the amount of insulation used could be decreased to save money.

With regards to long-term considerations, a removable top plate should be implemented instead of permanent welding. This is in the case of decreased performance of the Braaiing Apparatus, where the copper tubing would need to be removed to be cleaned, repaired or replaced.

An improved means of providing support to the Braaiing Apparatus should also be considered, where although the removable legs are sufficient in acting as a foundation, better solutions could be adopted to ensure greater sturdiness of the system.

12 Conclusion

In order to bridge the gap between the camping lifestyle, and the modernity of the 21st Century, a need arose which required the designer to utilize the excess heat produced from a braai (often used during camping) to heat water to be used in a shower.

The task was propagated by a means of examination of literature, to acquire concept design ideas, as well as a means of ascertaining an approach with regards to the heat transfer and fluid dynamics analysis. All of which, to ensure user requirements were achieved, as well as to design for other components of the system which were required.

A simplistic design concept was ultimately chosen due to its efficiency in all areas, which had a substantial flow rate in comparison in to Municipal standards, as well as being able to achieve an outlet temperature of water 50% greater than what was required by the user.

The complete design was concluded by a Maintenance and Manufacturing Analysis, as well as Manufacturing Drawings to aid in the manufacturing of core components. The social, environmental and legal impact of the design was also evaluated so as to ensure a comprehensive look from "all angles".

13 References

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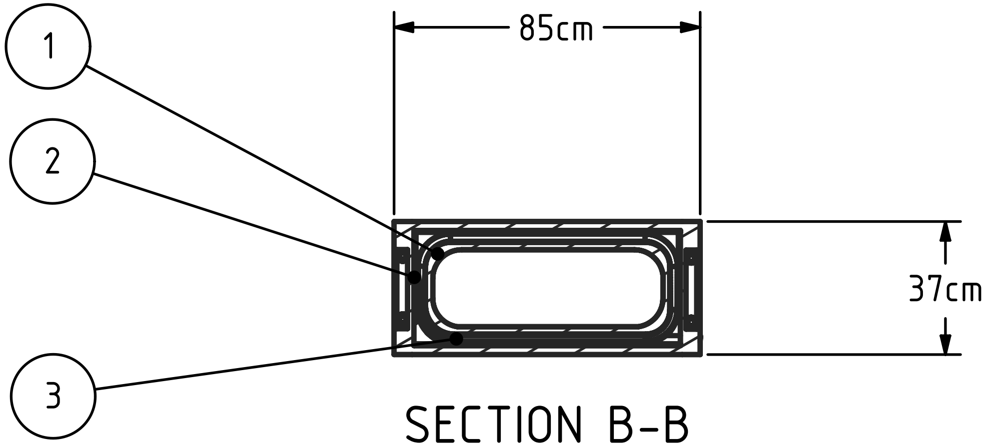
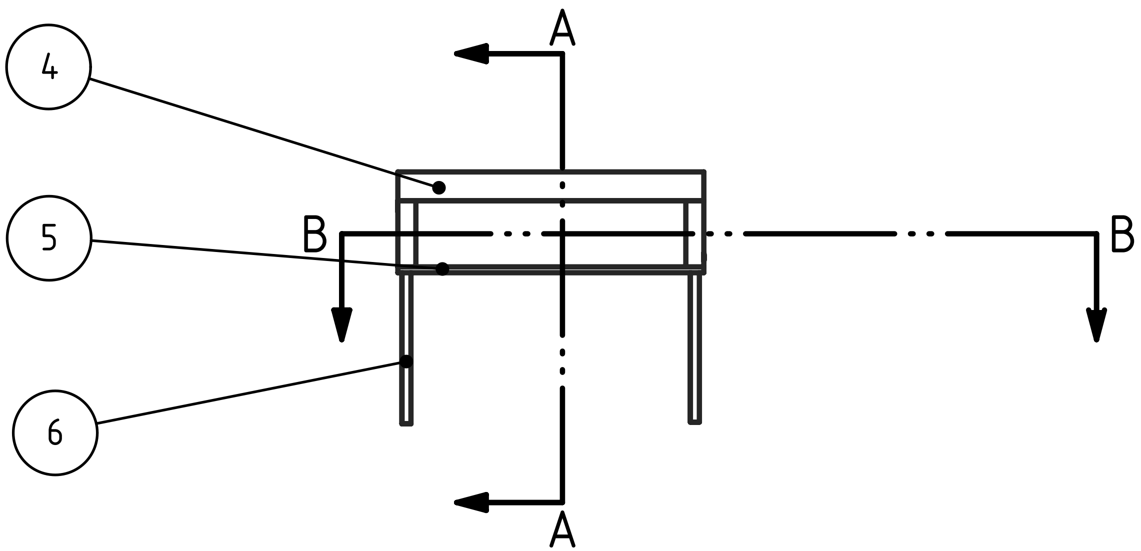
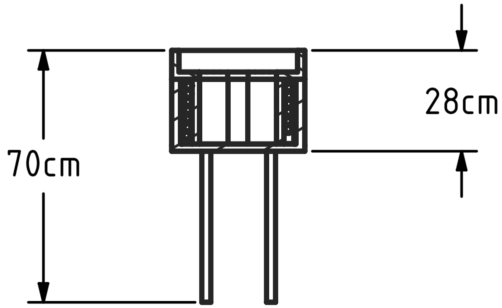
14 Manufacturing Drawings



SECTION B-B





SECTION A-A

ITEM NO.	PART NUMBER	MATERIAL	QTY
1	Inner Vessel	Brass (CuZn10)	1
2	Insulation	Fibre-reinforced Plastic	4
3	Tubing	Copper	1
4	Upper Plate	AISI 304 Stainless Steel	1
5	Bottom Plate	AISI 304 Stainless Steel	1
6	Legs	AISI 1018 Mild/Low Carbon Steel	2

TOLERANCES FROM - TO	+/-
0 - 6	0.1
6 - 30	0.2
30 - 100	0.3
100 - 300	0.5
300 - 1000	0.8
1000 - 3000	1.2
3000 - PLUS	2.0
ANGLES	1°

ITEM NR / ITEM NO — AANTAL / QUANTITY — BESKRYWING / DESCRIPTION — MATERIAAL / MATERIAL — ONDERDEEL NR / PART NR

VAN / SURNAME — VOORLETTERS / INITIALS — TITEL / TITLE

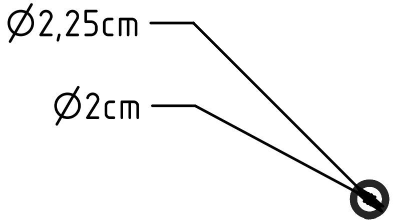
STUDENTE NO / STUDENTE NR — RIGTING / DISCIPLINE — TEKENING NR / DRAWING NR

PROJEKSIE / PROJECTION — UNIVERSITEIT VAN PRETORIA / UNIVERSITY OF PRETORIA — A3 — SKAAL / SCALE 1:1 — DATUM / DATE

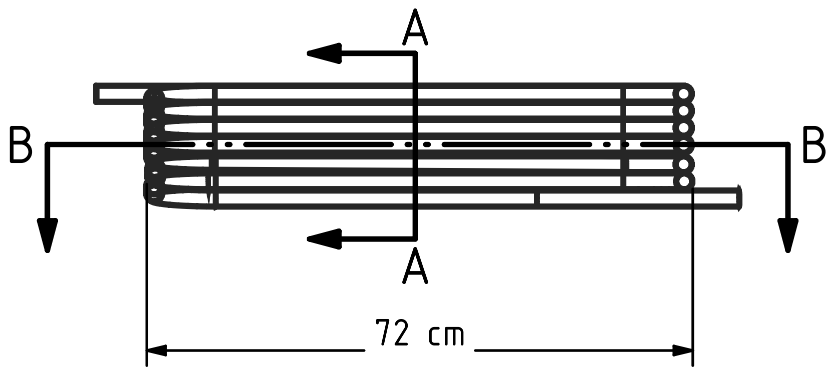
VOLTOOI TITELBLOK IN SWART INK/COMPLETE TITLEBLOCK IN BLACK INK

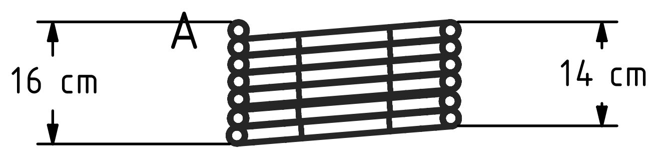
Material: Pure Copper
All Fillets and Rounds = R8

SECTION B-B



DETAIL A
SCALE 1:5

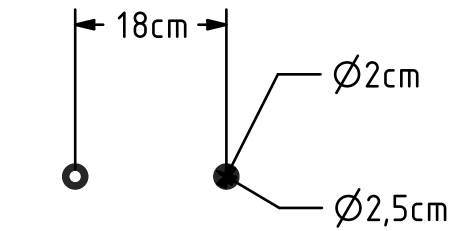




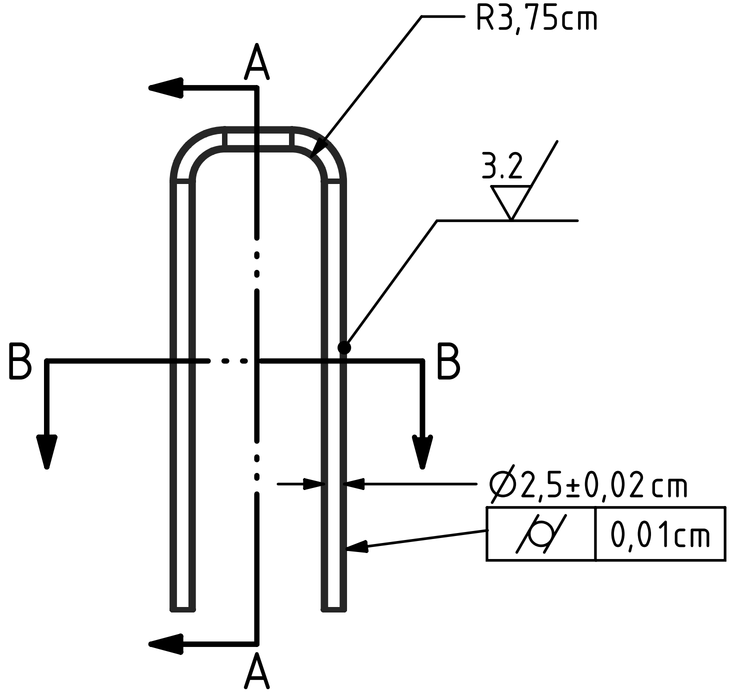
SECTION A-A

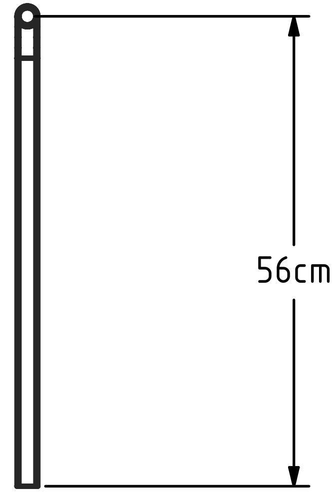
TOLERANCES		ITEM NR / ITEM NO	AANTAL / QUANTITY	BESKRYWING / DESCRIPTION	MATERIAAL / MATERIAL	ONDERDEEL NR / PART NR
FROM - TO	+/-	VAN / SURNAME		VOORLETTERS / INITIALS	TITEL / TITLE	
0 - 6	0.1	STUDENTE NO / STUDENTE NR		RIGTING / DISCIPLINE	TEKENING NR / DRAWING NR	
6 - 30	0.2	PROJEKSIE / PROJECTION	UNIVERSITEIT VAN PRETORIA / UNIVERSITY OF PRETORIA	A3	SKAAL / SCALE 1:1	DATUM / DATE
30 - 100	0.3					
100 - 300	0.5					
300 - 1000	0.8					
1000 - 3000	1.2					
3000 - PLUS	2.0					
ANGLES	1°					

VOLTOOI TITELBLOK IN SWART INK/COMPLETE TITLEBLOCK IN BLACK INK



SECTION B-B



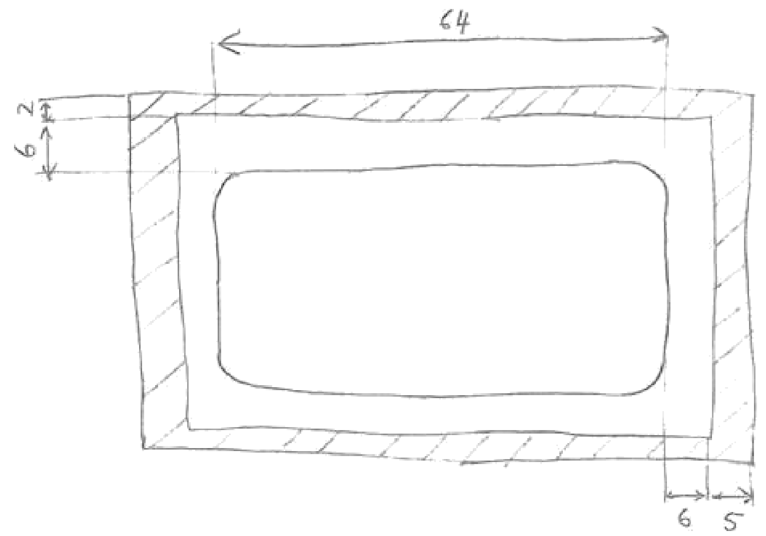


SECTION A-A

TOLERANCES FROM - TO	+/-
0 - 6	0.1
6 - 30	0.2
30 - 100	0.3
100 - 300	0.5
300 - 1000	0.8
1000 - 3000	1.2
3000 - PLUS	2.0
ANGLES	1°

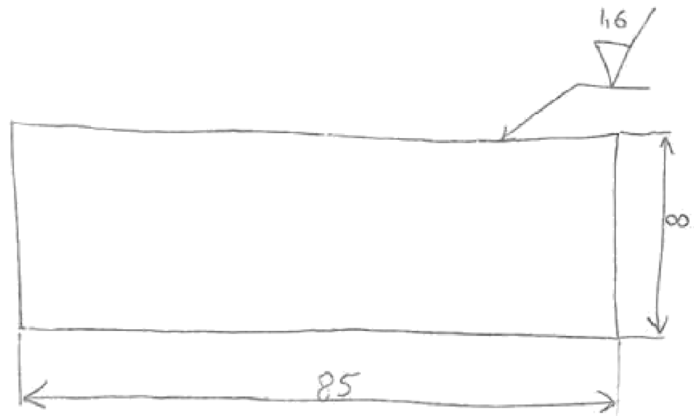
ITEM NR ITEM NO	AANTAL QUANTITY	BESKRYWING DESCRIPTION	MATERIAAL MATERIAL	ONDERDEEL NR PART NR
VAN SURNAME		VOORLETTERS INITIALS	TITEL TITLE	
STUDENTE NO STUDENTE NR		RIGTING DISCIPLINE	TEKENING NR DRAWING NR	
PROJEKSIE PROJECTION	UNIVERSITEIT VAN PRETORIA UNIVERSITY OF PRETORIA	A3	SKAAL 1:1 SCALE	DATUM DATE

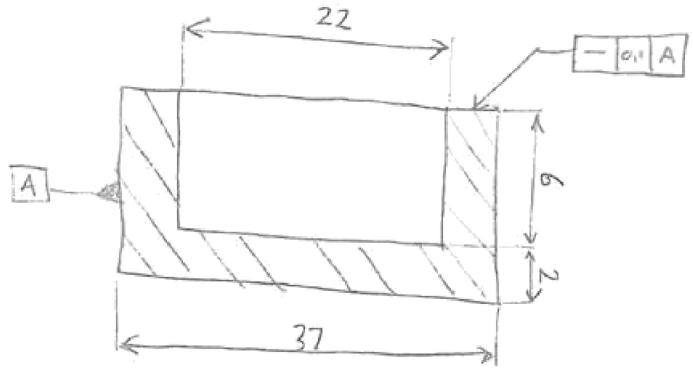
VOLTOOI TITELBLOK IN SWART INK/COMPLETE TITLEBLOCK IN BLACK INK



ALL FILLETS AND ROUNDS = R8

MATERIAL: AISI 304 STAINLESS STEEL

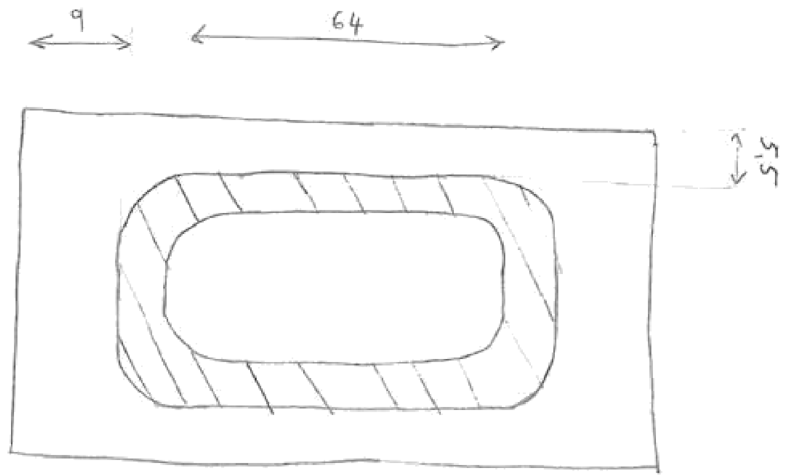




TOLERANCES FROM - TO	+/-
0 - 6	0.1
6 - 30	0.2
30 - 100	0.3
100 - 300	0.5
300 - 1000	0.8
1000 - 3000	1.2
3000 - PLUS	2.0
ANGLES	1°

ITEM NR ITEM NO	AANTAL QUANTITY	BESKRYWING DESCRIPTION	MATERIAAL MATERIAL	ONDERDEEL NR PART NR
VAN SURNAME		VOORLETTERS INITIALS	TITEL TITLE	
STUDENTE NO STUDENTE NR		RIGTING DISCIPLINE	TEKENING NR DRAWING NR	
PROJEKSIE PROJECTION	UNIVERSITEIT VAN PRETORIA UNIVERSITY OF PRETORIA	A3	SKAAL SCALE 1:1	DATUM DATE

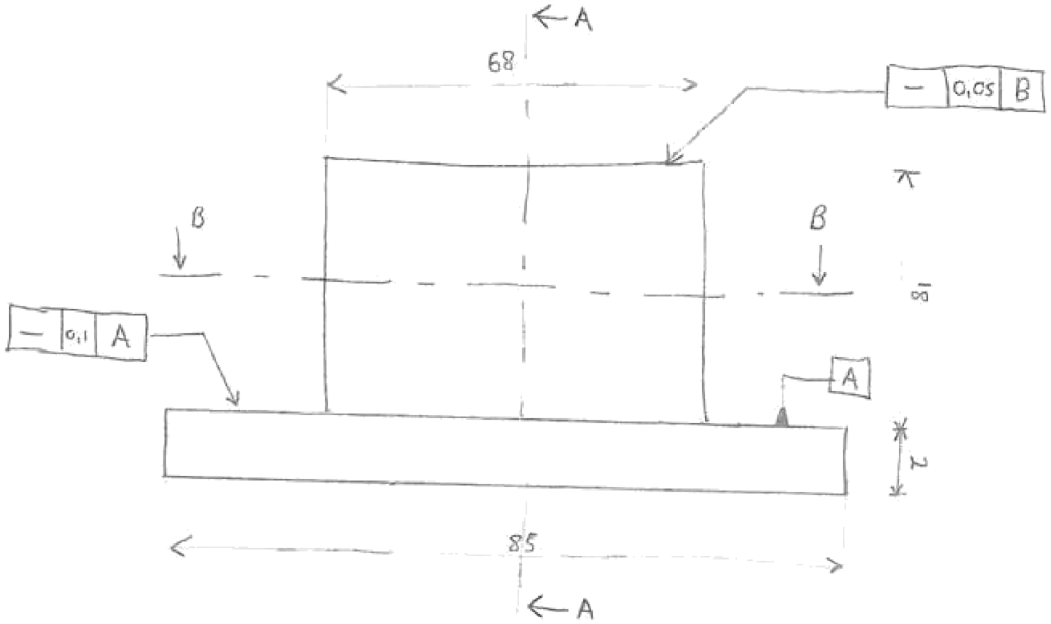
VOLTOOI TITELBLOK IN SWART INK/COMPLETE TITLEBLOCK IN BLACK INK

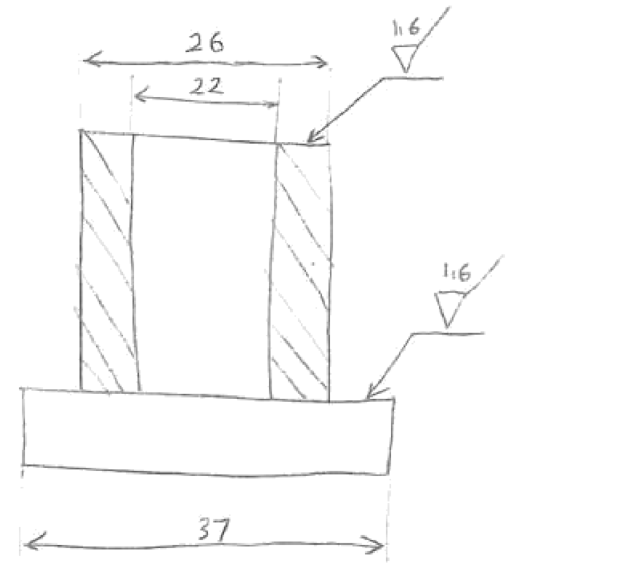


SECTION B-B

ALL FILLETS AND ROUNDS = R8

MATERIAL : AISI 304 STAINLESS STEEL





SECTION A-A

TOLERANCES FROM - TO	+/-	ITEM NR / ITEM NO	AANTAL / QUANTITY	BESKRYWING / DESCRIPTION	MATERIAAL / MATERIAL	ONDERDEEL NR / PART NR
0 - 6	0.1	VAN / SURNAME		VOORLETTERS / INITIALS	TITEL / TITLE	
6 - 30	0.2	STUDENTE NO / STUDENTE NR		RIGTING / DISCIPLINE	TEKENING NR / DRAWING NR	
30 - 100	0.3	PROJEKSIE / PROJECTION		UNIVERSITEIT VAN PRETORIA / UNIVERSITY OF PRETORIA	A3	SKAAL / SCALE 1:1
100 - 300	0.5					DATUM / DATE
300 - 1000	0.8					
1000 - 3000	1.2					
3000 - PLUS	2.0					
ANGLES	1°					

VOLTOOI TITELBLOK IN SWART INK/COMPLETE TITLEBLOCK IN BLACK INK

Appendix A

Part A

Inputting values, for the inlet and outlet, for Equation (1), (15) and (16):

- Pin = Pout. An approximation was proposed, where the difference in pressure was considered to be negligible.
- Vin = Vout. Justified by conservation of momentum, that is, the flow rate will remain constant, and the tubing diameter from inlet to outlet is unchanged.
- Zin = 0.2 m. This is accurate if Zout is used as the reference value (ie. 0m). Zin was approximated as being the total height of the tubing in the Braaiing Apparatus.
- g = 9.81 m/s^2. Gravitational Acceleration.
- L = 15m. An approximate length of the entire Braaiing Apparatus tubing.
- d = 0.02m. The inside diameter of an individual tube.
- ν = 1.005e-6. The kinematic viscosity of water at 1 atm, 20 ^{o}C (White 2015)
- ε = 0.0013 mm. Surface roughness of copper (Spray.com n.d.)

- ΣK = 15. An overestimate of the Total Minor Loss Coefficients (all losses are taken as the highest K value):

Loss	**Amount**	**K**	**Total K**
90 ^{o} Bends (Figure 11)	24	0.5	12
Exit	1	1	1
Entrance (Figure 10)	1	0.5	0.5
			13.5

An iterative approach was employed, whereby an initial "guess" of the friction factor (f = 0.03) was used to compute an initial flow rate, by rearranging substituting Equation (2) into (1) and rearranging:

$$\frac{\left(\frac{4Q}{\pi d^2}\right)^2}{2g}\left(\frac{fL}{d} + \Sigma K\right) = z_{in} - z_{in} \tag{14}$$

And the Reynolds number:

$$Re = \frac{4Q}{\pi d \nu} \tag{15}$$

Was used to aid the computation of the friction factor (f), with the use of the Haaland formula (White 2016, pp. 329):

$$\frac{1}{f^{1/2}} \sim -1.8 \log\left(\frac{6.9}{Re} + \left(\frac{\frac{\varepsilon}{d}}{3.7}\right)^{1.11}\right) \tag{16}$$

(If however, the Reynolds number was calculated as less than or equal to 2300 (Re_{cr}), then f = Re/64).

This friction factor value was then substituted back into Equation (14), where the process was repeated until a substantial error was achieved.

Python 3 code follows:

```
from math import pi
from math import log
run = 0
f = 0.03
rho = 998
flist = [f]
error = 10
while error > 1e-3:
   Q = 0
   g = 9.81
   L = 15
   K = 15
   d = 0.02
   RHS = 0.2
   error = 10
   while error >  1e-2:
      Q = Q +0.000001
      equation  =( (( (4*Q) / (pi*(d**2)) )**2) / (2*g) ) * ( ( (f*L)/d )  + K  )
      error = abs (RHS - equation)
   nu = 1.005e-6
   Re = (4*Q) / (pi*d*nu)
   rel_roughness = 0.0013e-3/d
   f = (  1/( -1.8 * log( ( (6.9/Re)   +  (rel_roughness / 3.7)**1.11 ), 10   ) )    )**2
   flist.append(f)
   error = abs(f- flist[run])
   run = run + 1

print ("Q [m^3/s] = {}".format (Q))
print ("Q [L/s] = {}".format (Q/0.001))
print ("Q [L/min] = {}".format (Q *60/0.001))
print ("m [kg/s] = {}".format(Q*998))
print ("Re = {} ".format(Re))
print ("f = {}". format(f))
```

```
Q [m^3/s] = 9.499999999999983e-05
Q [L/s] = 0.09499999999999982
Q [L/min] = 5.6999999999999895
m [kg/s] = 0.09480999999999982
Re = 6017.798843275634
f = 0.03574165602169852
```

Part B

Entrances and Exits

Tubing Entrance Bend Radius (r), calculated from the ratio of Entrance Bend Radius to Tubing Diameter (r/d):

Following from Figure 10 of '2.2.2 Entrances and Exits', it is apparent that r/d = 0.2 to induce the lowest loss coefficient.

r = d*0.2 = 2cm * 0.2 = 0.4 cm (0.004 m)

Bends

Bend Radius (R), calculated from the ratio of Bend Radius to Tubing Diameter (R/d):

Following from Figure 11 of '2.2.2 Elbows', R/D = 4 to ensure least possible loss coefficient.

Appendix B

Part A

Convection Heat Transfer

Inputting values for Equations (8) to (10):

- f = 0.036. Darcy friction factor obtained from '7.1.1 Flow Rate'
- d = 0.02 m. The internal diameter of the tubing.
- Re = 6017. Approximate Reynolds number from '7.1.1 Flow Rate'
- T_b = 20 ^oC. The bulk temperature, is the average of the inlet and outlet water temperatures ie. (Tin+Tout)/ 2 = (15+25)/2 = 20. (Tin and Tout were specified in '3 Specifications')
- Pr_b = 7.01. The Prandtl number of water based on the bulk temperature (ie. at 20 ^oC) (Cengel and Ghajar 2015).
- k = 0.598 W/mK. The thermal conductivity of water based on the bulk temperature (ie. at 20 ^oC) (Cengel and Ghajar 2015).

Therefore rearranging Equation (8) and substituting:

$$j = 0.033/\frac{3.74\,(6017) - 8066}{(6017) - 2320}(7.01)^{0.42}$$

$$j = 3.729 \times 10^{-3}$$

Computing the Nusselt number from Equation (9):

$$Nu = (3.729 \times 10^{-3})(7.01)^{\frac{1}{3}}(6017)$$

$$Nu = 42.95$$

Computing the convection heat transfer coefficient from Equation (10):

$$h = \frac{(0.598)(42.95)}{0.02}$$

$$h = 1284.17\, W/m^2K$$

Lastly, the heat flux supplied by convection from Equation (12), where it was approximated that the tubing thickness was negligible (such that the inner and outer surface temperature would be equal):

- ρ = 998 kg/m^3. Density of water taken at 20 ^oC (Cengel and Ghajar 2015).
- Cp = 4182 J/kgK. Specific Heat of water at 20 ^oC (Cengel and Ghajar 2015).
- m = 0.0948 kg/s. Mass flow rate calculated as ρ*Q = (998*9.5e-05) (Q obtained from '7.1.1 Flow Rate)
- As = π(0.02)*15 = 0.942 m^2
- Ts = 40^oC. The approximated surface temperature taken as 10% of the average temperature the burning coals can reach in '2.4.2 Braai Fuel.' (313K)

$$T_e = 40 - (40 - 15)e^{\frac{-1284.17*0.942}{0.0948*4182}}$$

$$T_e = 38.82\ ^0C$$

Heat Transfer rate can be calculated using:

$$Q_{convection} = mCp(T_e - T_i) \tag{14}$$

$$Q_{convection} = 0.0948 * 4182 * (38.82 - 15)$$

$$Q_{convection} = 9435.6\ W$$

Radiation Heat Transfer

- Tsurr = 400^{o}C. The temperature of the charcoal, taken as the average of the temperatures exhibited in '2.4.2 Braai Fuel' in the literature (673K)
- ε = 0.15. The emissivity of copper (commercial) taken at 300 K (Cengel and Ghajar 2015).
- σ = 5.67 x 10^-8. Boltzmann's constant.

Employing the basic radiation equation such as in Equation (13):

$$Q_{radiation} = (0.15)(5.67 \times 10^{-8})(0.942)(673^4 - 313^4)$$

$$Q_{radiation} = 1566.66\ W$$

Part B

Prior to determining the thickness of insulation to be employed, one must ascertain the heat transfer rate through the insulation. This value was approximated as being equal to the heat transfer by conduction, from the burning charcoal, through the brass inner vessel, and to the tubing surface.

Utilizing the basic steady state conduction formula:

$$Q_{conduction} = kA_s \frac{\Delta T}{L} \tag{15}$$

And substituting:

- k = 52 W/mK. The thermal conductivity of the inner vessel made from brass (Cengel and Ghajar 2015).
- As = 0.36 m^2. The surface are through which heat transfer occurs through the tubes (Reference the geometry of the Braaiing Apparatus model).
- ΔT = 360 ^{o}C. The temperature difference of the burning charcoal and the surface temperature of the tubing surface.
- L = 0.02 m. The thickness of the brass inner vessel.

$$Q_{conduction} = 52 * 0.36 * (\frac{360}{0.02})$$

$$Q_{conduction} = 336960\ W$$

The thickness of the insulation can now be solved for by assuming the temperature difference to be the difference between the temperatures of the burning charcoal and ambient temperature, and by substituting:

- k = 0.038 W/mK. The thermal conductivity of glass fibre (Cengel and Ghajar 2015).
- As = 0.575 m^2. The surface are through which heat transfer occurs through the insulation (Reference the geometry of the Braaiing Apparatus model).
- ΔT = 380 ^{o}C. The temperature difference of the burning charcoal and ambient temperature.

And by rearranging Equation (15):

$$L = 0.038 * 0.575 * (\frac{380}{336960})$$

$$L = 2.46\ x\ 10^{-3}$$

Appendix C

Design Project Protocol

Problem Statement

A portable braaiing apparatus will be designed, which is required to use the excess heat of a braai, to heat water to be used for a shower. The braaiing apparatus need only be designed, this being from the inlet to the outlet of water, and not the shower itself.

Project Scope

- Water flow:
  Design will compensate for the heating area of water. Either by a means of storage, which will temporarily store the water until it is heated, although there will be difficulties in designing for a reasonable pressure at the outlet. Or a piping system in which the water travels from inlet to outlet, having no complications with pressure at the outlet, but rather if there is sufficient time for the water to be heated.

  Storage:
  Amount of water (in litres) that is able to be heated while being ergonomic will be needed to be looked at, that is, the size of the temporary storage.
  Will the water, which is heated during the braai and until the burning coals or wood dissipate (gas is not to be used), be sufficient for 1-4 people to shower or will the storage need to be regularly filled?
  Consideration of how long the water needs to be in the storage to heat to +10^{o} C.
  How long after the heating source is removed will the water be able to retain +10^{o} C?

  Piping system:
  Size of pipe to allow for maximum heat transfer rate to the water will need to be considered.
  Geometry, length, distribution of the piping system will need to be designed to allow for a heating of +10^{o} C.

- Ergonomics:
  Braai needs to be used by 1-4 people. Consideration of the apparatus being light, durable easily to carry, setting up time, will all need to be addressed.

- Heat transfer analysis:
  Heating will be from any direction, dependent on the placement of storage or piping system (steady state approximation, or transient heat flow analysis will need to be decided on). Extending knowledge from previous Fluid Mechanics modules.
  Simple radiation analysis will be undergone.

- Fluid Analysis:
  Flow rates, piping losses, pressure drops will all be calculated. Bernoulli's equation with Local Losses will most likely be used.

- Further Detailed Analyses

CFD, combustion processes, detailed radiation analysis will be considered low priority, and will only be done if time is available, or if content taught in the semester's modules aid in the process.

- Mechanical Design
  A full mechanical design (needs to be a structural design) of the braai unit will be undergone. Main assembly will be drawn on CAD, where four detailed components (2 on CAD, 2 hand drawn) of the braai will also need to be completed.

Specifications

- A water temperature increase of at least 10°C.
  A water storage will most likely be able to easily achieve this. However, utilizing a piping system, where the water is transferred from inlet to outlet in a matter of seconds, will require an in-depth design, more so than the storage option, in order to meet this specification.

- A water source is available at normal domestic pressure (at the inlet).
  No specification has been given for a specified pressure at the outlet. Being such, outlet pressure will still be addressed, as it adds to the Ergonomics of a 'comfortable' shower, where it would be impractical to have a shower with no water pressure.
  Using a water storage will pose an issue with maintaining this pressure, being such, design will need to be implemented to achieve just this. Using a piping system should have no problem in fulfilling this.

- No electricity is available.

- The safety of the user must be taken into consideration.
  Brief instructions will be given if the design and use is not intuitive or overly complicated. If necessary, an Instruction Manual (User Guide) will be attached in report if time allows.

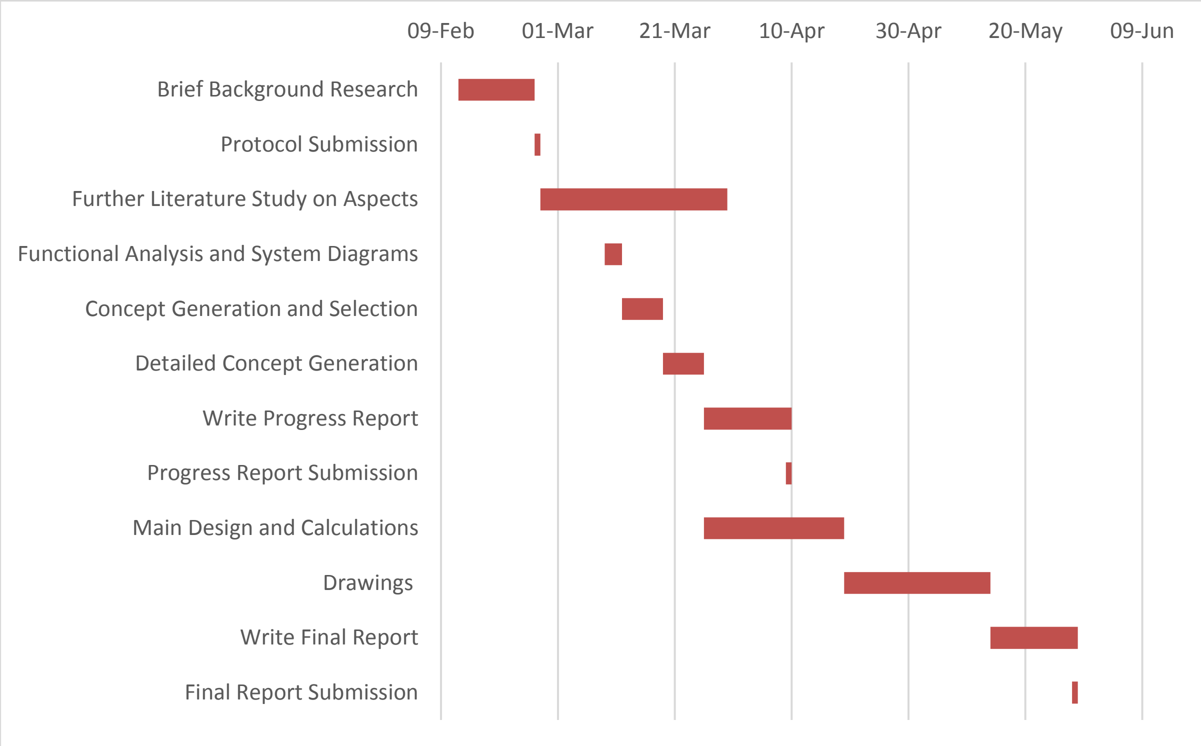
- A normal hosepipe connector can be used for water inlets and outlets, it is not necessary to design the shower.

- The device must be suitable for the use of 1-4 people.

- No specifications on pricing given, however anything more than a few thousand rand would be excessive (aesthetics are secondary to the braai fulfilling its specifications). No cost analysis has been specified either, being such, intuition will be used to determine an estimate price.

Gantt Chart

(Subject to change)



	Start Date	End Date	Duration
Brief Background Research	12-Feb	25-Feb	13
Protocol Submission	25-Feb	26-Feb	1
Further Literature Study on Aspects	26-Feb	30-Mar	32
Functional Analysis and System Diagrams	09-Mar	12-Mar	3
Concept Generation and Selection	12-Mar	19-Mar	7
Detailed Concept Generation	19-Mar	26-Mar	7
Write Progress Report	26-Mar	10-Apr	15
Progress Report Submission	09-Apr	10-Apr	1
Main Design and Calculations	26-Mar	19-Apr	24
Drawings	19-Apr	14-May	25
Write Final Report	14-May	29-May	15
Final Report Submission	28-May	29-May	1

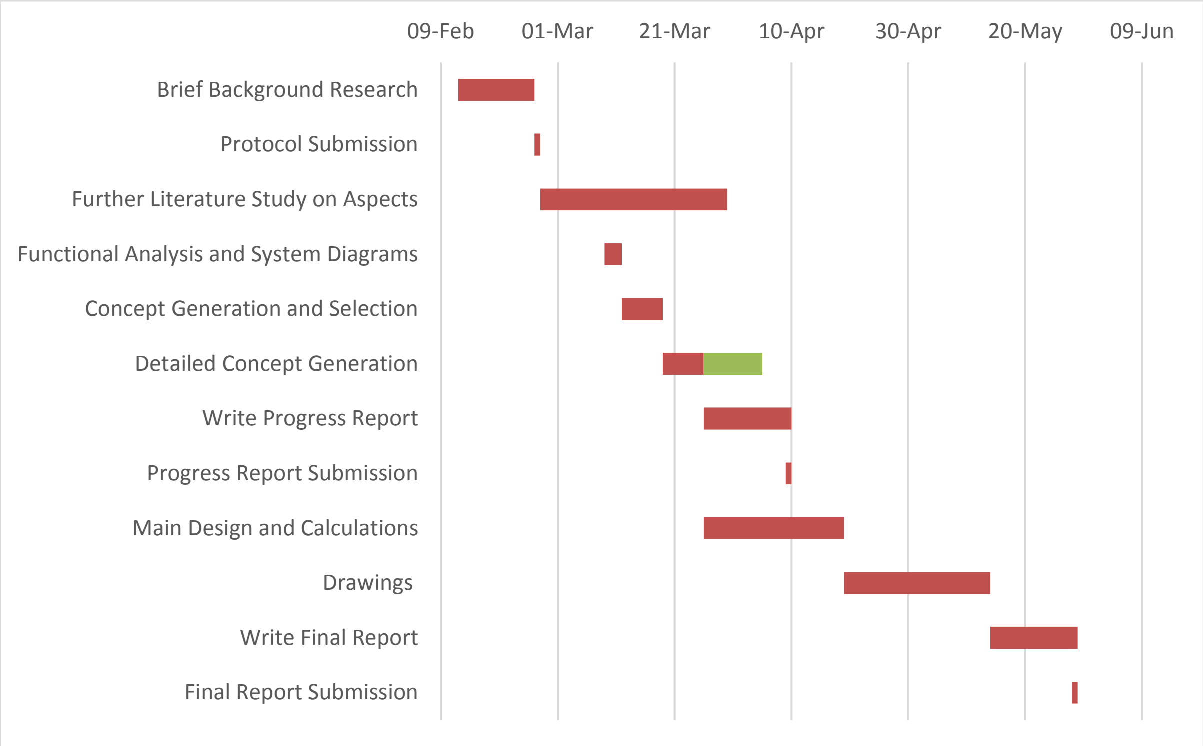
MOX 410 Progress Report

CERG#2: Portable braai with water heater

Jared Neil Lakhani 15125344

Progress report includes the Literature Review up until Concept Selection. A few difficulties arose with regard to the Literature Review, the problem being what information should be included and excluded. This will be addressed continuously where certain aspects will be removed, or different information will be added, and is in a way a 'living document'.

I still feel the need to add more to the Specifications, to make the section as precise as possible. The Functional Analysis seems lacking in content, and will be addressed further.



I am only behind on Detailed Concept Design, although I have started this. I have also started on other sections that I have not included in the report as they are currently incomplete, though still on schedule with regards to these.

Appendix A – Meeting Log Card

DESIGN PROJECT - MOX 410

MEETING LOG CARD

Student Jared Neil Lakhani **Student. no.** 15125344

Design project Portable Braai Stand With Water Heater

Date	Student signature	Supervisor signature	Comments
13 Feb			(For example, Initial meeting) Initial Meeting
20 Feb			DPP Discussion
27 Feb			Q + A meeting
06 Mar			Q + A meeting

ADDITIONAL COMMENTS:

Appendix C – Drawings for evaluation

This form is available for download on ClickUP.

DESIGN PROJECT - MOX 410

DRAWINGS FOR EVALUATION

Student Jared Neil Lakhani **Student. no.** 15125344

Design project Braai with Water Heater

The following drawings must be submitted:

- One assembly drawing consisting of at least four different components as agreed upon between study leader and student.
- 2 x detailed CAD drawings of two different component indicating all necessary manufacturing detail to ensure correct functioning and assembly.
- 2 x detailed hand drawings of the other two components each indicating all necessary manufacturing detail to ensure correct functioning and assembly.

Drawings must be submitted on the due date for the deliverables stated in the study guide in the following formats:

- In an appendix as part of the two hardcopies and electronic copy as specified in section 9.3. Deliverables, in the study guide of this module and,
-

Drawing	Description
Assembly drawing	Braai Stand
Detail CAD 1	Tubing
Detail CAD 2	Leg
Detail Hand 1	Top Plate
Detail Hand 2	Bottom Plate

Date 16/05/2018

Signatures:

Student

Client