HEAT TRANSFER ANALYSIS IN UNDERGROUND CABLE TUNNEL USING COMPUTATIONAL FLUID DYNAMICS

JANASH A/L S.PATHAMNATHAN

FACULTY OF ENGINEERING

UNIVERSITY OF MALAYA

KUALA LUMPUR

2018

HEAT TRANSFER ANALYSIS IN UNDERGROUND CABLE TUNNEL USING COMPUTATIONAL FLUID DYNAMICS

JANASH A/L S.PATHAMNATHAN

THESIS/DISSERTATION SUBMITTED IN FULFILMENTOF THE REQUIREMENTS FOR THE MASTERS DEGREE OF MECHANICAL ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2018

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Janash A/l S.Pathamnathan

Matric No: KQK 160002

Name of Degree: Degree in Mechanical Engineering

Heat Transfer Analysis in Underground Cable Tunnel Using Computational Fluid Dynamics

Field of Study: Mechanical Engineering – Heat Transfer and Fluid Dynamics

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date:

Subscribed and solemnly declared before,

Witness's Signature Date:

Name:

Designation:

HEAT TRANSFER ANALYSIS IN UNDERGROUND CABLE TUNNEL USING COMPUTATIONAL FLUID DYNAMICS

ABSTRACT

The key concern of this study is to develop an underground cable tunnel ventilation system using the analytical method to determine the best inlet velocity and air flow to create an environment that is close to the outside ambient air. This is done in order for people to occupy the tunnel in for repair and maintenance work. For the analysis of the 90m long tunnel with rectangular and circular manholes, the Computational Fluid Dynamics (CFD)for steady state conditions was be used. The CFD software ANSIS Fluent was used in the analysis of the tunnel system. This tunnel will house the XLPE 132 IC 1200mm^2, the cable will be routed in a trefoil configuration per-circuit and there will be 4 circuits running in this tunnel. Using various airflow configurations, the study was conducted to determine the best internal temperature conditions at peak operation conditions. The heat generated by the cable is calculated to be 58.54^{0}C however for the purpose of the simulation the temperature is assumed to 60^{0}C. The ambient temperature which is given more focus will be 33^{0}C.This is because according to the meteorological department for Petaling Jaya area the average temperature is 33^{0}C. However, there were two other temperatures also was used in the analysis with the same variant of air flows. This was done to observe the effects of the velocity on this various temperature which were higher and lower than the main temperature in question. From the total analysis that was carried out it can be determined that the most suitable inlet air velocity is 4m/s with the air flow of 15000CFM. With this configuration the internal ambient temperature of 34.74^{0}C can be achieved. This temperature is conducive enough for repair and maintenance work to be carried in the cable tunnel.

ANALISIS PEMINDAHAN HABA BAGI TEROWOG CABEL BAWAH TANAH MENGUNAKAN PENGIRAAN DINAMIK BENDALIR

ABSTRAK

Matlamat utama kajian ini adalah untuk membangunkan sistem pengudaraan terowong kabel bawah tanah menggunakan kaedah analisis untuk menentukan halaju masuk udara dan aliran udara yang terbaik untuk mewujudkan persekitaran yang hamper sama dengan udara ambient luar. Ini dilakukan supaya pekerja dapat memasuki terowong untuk kerja pembaikan dan penyelenggaraan. Untuk analisis terowong sepanjang 90m dengan laluan masuk segi empat tepat dan bulat, kaedah Pengiraan Dinamik Bendalir akan digunakan. ANSIS Faluent digunakan dalam analisis sistem terowong ini. Terowong ini akan menempatkan XLPE 132 IC 1200mm2, kabel akan dialihkan dalam konfigurasi trefoil per litar dan akan ada 4 litar yang di alirkan di terowong ini. Menggunakan pelbagai konfigurasi aliran udara, kajian ini dijalankan untuk menentukan keadaan suhu dalaman yang terbaik pada keadaan operasi puncak. Haba yang dihasilkan oleh kabel dikira dan didapati adalah 58.54 ^{0}C bagaimanapun untuk tujuan simulasi suhu itu diandaikan kepada 60 ^{0}C. Suhu ambien yang diberi tumpuan lebih tinggi ialah 330C.Ini kerana menurut jabatan meteorologi untuk kawasan Petaling Jaya suhu purata ialah 33 ^{0}C. Walau bagaimanapun, terdapat dua suhu lain juga digunakan dalam analisis dengan varian udara yang sama. Ini dilakukan untuk melihat kesan halaju udara pada pelbagai suhu yang lebih tinggi dan lebih rendah daripada suhu utama yang dipersoalkan. Daripada jumlah analisis yang dijalankan, dapat ditentukan bahawa halaju udara masuk yang paling sesuai adalah 4m / s dengan aliran udara 15000CFM. Dengan konfigurasi ini suhu ambien dalaman 34.74 ^{0}C boleh dicapai. Suhu ini cukup kondusif untuk kerja-kerja pembaikan dan penyelenggaraan yang akan dijalankan dalam terowong kabel.

ACKNOWLEDGEMENTS

I would like to say thanks to University of Malaya for giving an opportunity to do a research which can improvise my technical career in future.

Therefore, I also thank to my supervisor Professor Madya Ir. Dr. Nik Nazri Bin Nik Ghazali who provided great supervise work and gave lots of useful feedback during progression of my project. His advice, guidance and supports is deeply appreciated. Without his guidance and advice, I would have not successfully completed my research.

Next I would like to express my sincere gratitude to my friends and engineers for helping and guiding me in the process of getting a better understanding of my project requirements and also getting basic information of my project.

Furthermore, thanks to my family member and friends as well who directly or indirectly help me to complete the report. Lastly but not the least thank god.

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

XLPE	:	Cross-Linked Polyethylene Cable
CAD	:	Computer Aided Design
CAD	:	Computational Fluid Dynamics
HV	:	High Voltage
UHV	:	Ultra High Voltage
Q	:	Flow Rate
Vi	:	Inlet Velocity
Vol	:	Volume
k V	:	Kilo Volt
AC/Hr	:	Air Change Per-Hour
$\Delta\theta_s$	:	Difference in surface Temperature
K_A	:	Thermal Conductivity
CFM	:	Cubic Feet Per-Minute
Ft^3	:	Cubic Feet
A	:	Cross Section Area of Tunnel
De	:	Diameter Of Cable

n	:	no of conductor within cable
λ_1	:	Ratio of Losses in Metallic Sheet
λ_2	:	Ratio of Losses in Armor to Conductor
T_1	:	Thermal Resistance Between Conductor and Sheet
T_2	:	Thermal Resistance Between Metallic Sheet and
T_3	:	Thermal Resistance of outer covering
h	:	Heat Dissipation Coefficient
d_a	:	Mettalic Sheet Outer Diameter
W_d	:	Dielectric Losses
U_o	:	Voltage from Phase to Ground
C	:	Capacitance
Di	:	Conductor Outer
ε	:	Insulation Emissivity

CHAPTER 1: INTRODUCTION

1.1 Background

Underground cables tunnels are an essential part of modern city infrastructures this is because all power distribution, communication network and transportation infrastructure cables are laid in this tunnels. This tunnels can run for very long distances. One major problem faced by the engineers designing this tunnels is the dissipation of the heat produced from this cables. Power cables are the most volatile and pose a fire and safety risk. This tunnels are designed so that maintenance and repair work can be carried out underground without the need of excavating buried cables. Therefore, the environment in this tunnels has to be conducive enough for workers to occupy and carry out work regularly inside this tunnels. In order for this to be done a good ventilation and cooling system has to be in place. Normally for the ventilation and cooling of this tunnels one or more blower or tunnel fans will be installed to constantly regulate fresh air in and out of the tunnel. There are also tunnels which a separate pipe to circulate water to cool the cables and the tunnels.

In this case it is found that the heat generated by the power cables can cause the internal temperature of the tunnel to raise up to 70º C. Hence a ventilation system has to be designed for the tunnel so that the inside temperature is cooled close to the outside ambient temperature. This is so that workers can occupy the space for work.

Company J has been awarded the project by a prominent power company to design and build a tunnel, to carry power lines for a new commercial area. This project is to be carried out in the Klang Valley area. The cables will be laid in a 90m tunnel which has rectangular and round manholes on each side. The heat transfer analysis for this design will be done using Computational Fluid Dynamics analysis for steady state conditions.

1.2 Problem Statement

This analysis is to design a ventilated cable tunnel, where 4, 132kV XLPE or cross-linked polyethylene cable is to be laid in a 90m long tunnel with the diameter of 3m. In an underground cable tunnel system heat is created from the cables that are placed in them. This heat that is generated will not allow any maintenance or servicing job to be carried out. Therefore, the design of the ventilation or cooling system must be able to maintain the internal temperature of the tunnel to a temperature where the tunnel can be occupied for work. The temperature has to be close to the ambient temperature of the surface where the tunnel is to be build. Company J has to determine the flow rate of air needed to achieve the outside ambient temperature inside the cable tunnel during full load.

1.3 Objective

To design a ventilated underground cable tunnel where the internal temperature is conducive for workers to occupy and carry out maintenance and repair work. Also to reduce the risk of fire because of the heat generated by the power cables.

a) To design the cable tunnel to lay the power cables for the commercial area using Solid works
b) To carry out analysis using ANSYS Fluent
c) Computational Fluid Dynamics analysis for steady state conditions.
d) To calculate the required volume flow rate of air required for cooling the tunnel
e) To recommend the suitable air flow for the underground cable tunnel system.

1.4 Scope of the Project

The scope of the project is to analyze various air flow rates for Steady State Heat Transfer conditions using Computational Fluid Dynamics. The tunnel will be designed using CAD software for this simulation.

From the study the suitable air flow can be determined. This is because various air flows will be used so that the best air flow can be achieved to dissipate the heat to the outside environment of the tunnel.

For the conclusion all the various air flows and other variable parameters will be tabulated. Recommendation for the most suitable air flow for the underground cable tunnel can be determined. The cross section of the tunnel is shown in figure 1.1 below.

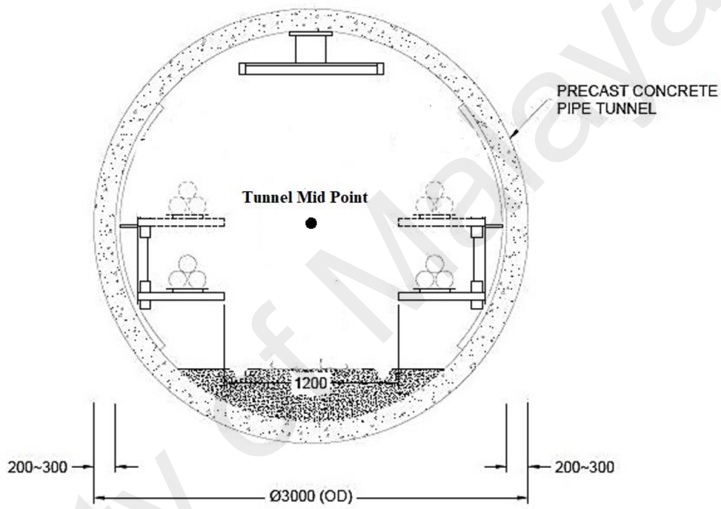


Figure 1.1: Cross Section Of Cable Underground Tunnel

CHAPTER 2: LITERATURE REVIEW

One essential component of an underground cable tunnel is the cooling system; this is to ensure continuous operations. There are mainly two types of cooling system where on will use water to remove the heat from the cables and there is also the cooling system which uses air flow from the surface to cool the cables and also give a good environmental control in the tunnel. There are also bigger capacity tunnels which carry HV and UHV cables which has both this system integrated for a much efficient heat transfer from the tunnels.

2.1 Industrial Application of Tunnel Cooling System.

This kind of cooling system is typically used in many types of tunnel systems. Axial or jet fans are typically used, but there are systems that utilize centrifugal fans. These ventilation systems are widely used in mining tunnels shafts, motorway tunnels and now tunnels that carry power, telecommunication, data and transportation infrastructures. Then there is the water pipe tunnel cooling system this system is used for underground cable tunnels as the heat generated by power cables are greater than the generated in a motorway tunnel. However now this system is more frequently utilized in cables tunnels especially in tunnels that carry power cables. This is because power cables generate high levels of heat and can pose a fire risk. Therefore, if there was an unwanted incident to happen it will not only effect the power grid but also other systems that rely on the tunnels to carry the respective cable lines. This cooling systems ensures the continuous use of all the systems in place without any disruptions.

Mainly for cable tunnel cooling system there are two major cooling systems and they are;

a) Ventilation cooling system

b) Water pipe cooling system

2.2 Ventilation Cooling System for Cable Tunnel

Ventilation Cooling System is a cooling system that has been widely used in tunnels. Normally it will consist of axial fans or centrifugal fans that will create the needed airflow to cater the cooling of the cables and the environment in the tunnels. The cooling rate can be controlled with the speed of the fans. In some cases, the cable is able to perform at optimal conditions at 50ºC therefore without any human interaction in the tunnels the cables can be cooled to about that temperature where the cables would not be effected by the temperature. So the environmental temperature in the tunnel can be maintained at about 50ºC. In the case that there is maintenance or repair work needed to be carried out then temperature in the tunnel can be reduced to the outside ambient temperature. This is done by increasing the airflow in the tunnel so that more heat is carried out and dissipated, this is achieved by just increasing the speed of the fans in the system. This will create an environment where workers can occupy the tunnel and carry out the necessary work. Normally more than one fan will be used in this system. Some tunnels which have long distances will be mounted with fans to supply air into the tunnel at one end and a set of fans to exhaust the hot air out at the opposite end. Normally axial fans are more widely used in this systems. The proposed tunnel ventilation system is shown in figure 2.1 below.

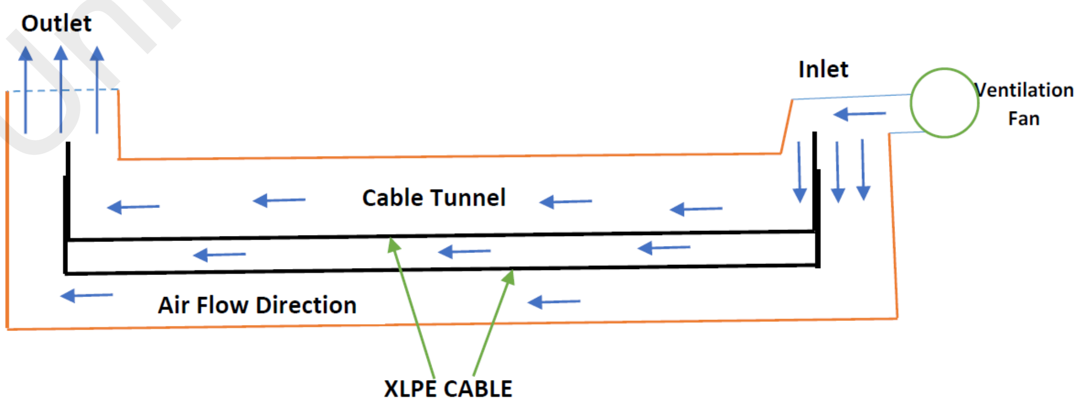


Figure 2.1: Under Ground Cable Tunnel Ventilation Cooling System

For this ventilation systems there are five typical types of systems that widely used. Follows are the five systems;

a) Natural Ventilation
b) Longitudinal Ventilation
c) Semi – Transverse Ventilation
d) Full – Transverse Ventilation
e) Single Point Extraction

a) Natural Ventilation

This type of tunnel depends on the meteorological conditions for the air flow in and out of the tunnel without any additional mechanical support. When said meteorological conditions it mainly depend on the wind and also pressure conditions to create a draft in the tunnels. This system is normally applied in short tunnels in highway systems or rail systems. Because the movement of the vehicles contribute to the pressure difference with the piston effect. Therefore, this system is not suited for underground cable systems where there is no movement of vehicles. Cable tunnels are mostly underground opposed to the transportation system tunnels that are normally above ground and the effect of the surrounding meteorological conditions has a direct impact. This system can only be used for very short tunnel systems. (Aberahm Berhanu, 2016). The typical natural ventilation in a tunnel is shown in figure 2.2

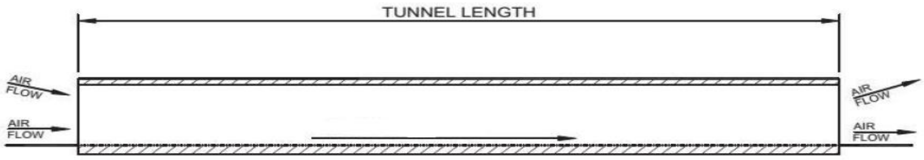


Figure 2.2: Natural Ventilation System (Aberahm Berhanu, 2016)

b) Longitudinal Ventilation

Longitudinal ventilation system uses the same principle as the natural ventilation system. However, the air is mechanically forced in the tunnel using blower fans. The fans are normally installed either in the tunnel, center shaft or in a portal building. This cooling system is normally used in tunnels that does not have extra space above or below the tunnel for the installation of duct work. Hence the tunnel itself becomes a duct carrying the air in and out from one supply end to the exhaust end. This system is typically used in short tunnel system that requires small air replacement. (Aberahm Berhanu, 2016). In figure 2.3 we can see this type of ventilation system

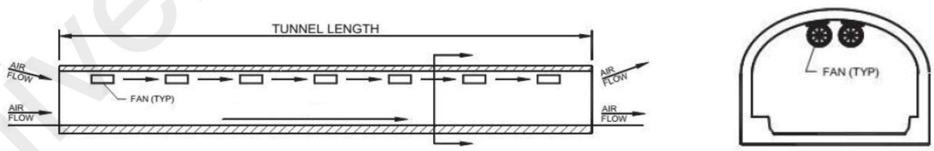


Figure 2.3: Longitudinal Ventilation System (Aberahm Berhanu, 2016)

c) Semi – Transverse Ventilation

For this system the mechanical fans are coupled with duct work. This ducting will be routed along the tunnel network either at the top using suspended ceiling or at the bottom using structural slabs which is placed within the tunnel. Semi – Transverse Ventilation system has a many variation. One of this is where fans are installed supply air fans at both ends of the tunnel and air is supplied into the tunnel and pushed to the center of the tunnel. Then there is the system where reversible fans are utilized either to supply air or exhaust air at one given time. The third variant in this type of system is where half of the tunnel is a supply and the other half is an exhaust system. (Aberahm Berhanu, 2016). Figure 2.4 shows a transverse ventilation system

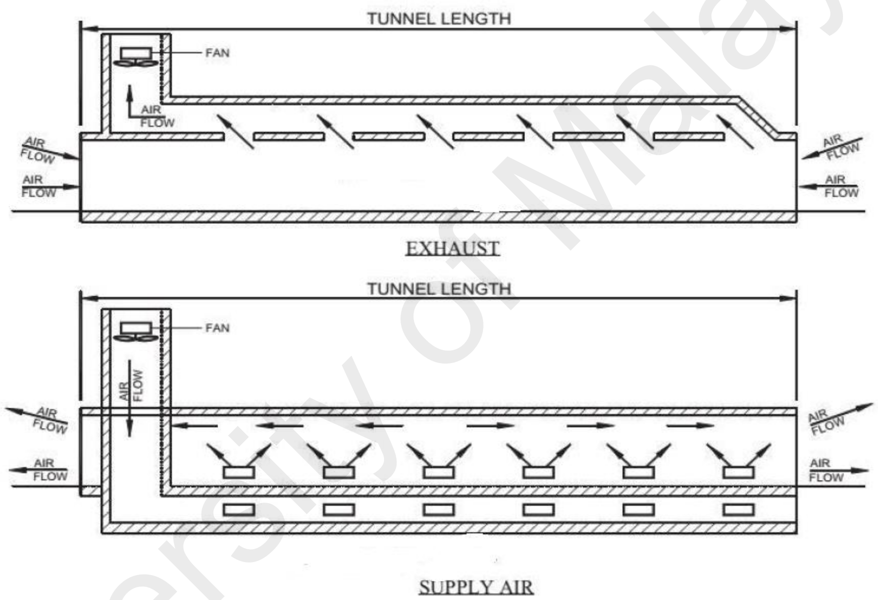


Figure 2.4: Semi – Transverse Ventilation System (Aberahm Berhanu, 2016)

d) Full – Transverse Ventilation

Full – Transverse Ventilation utilizes the same principle as the semi – transverse system, however it incorporates the supply and exhaust air system for the whole length of the tunnel. The presence of air supply system and exhaust system creates a pressure difference between the lower surface and the celling of the tunnel, this will cause the air flow to transverse to the tunnel length hence the air circulation is more frequent. This caters for large air change need in long tunnels. The ducting that is installed on the top and below of the tunnel also can be installed on the sides of the tunnel. (Aberahm Berhanu, 2016). Below in figure 2.5 we can see this kind of ventilation system.

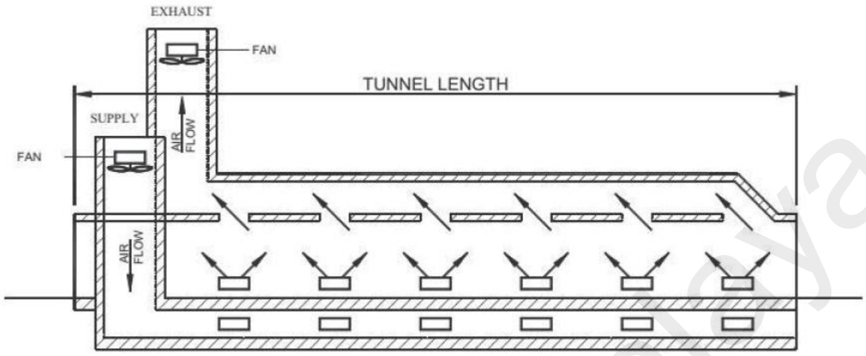


Figure 2.5: Full – Transverse Ventilation(Aberahm Berhanu, 2016)

e) Single Point Extraction

Single point extraction is normally u se with semi or full – transverse ventilation as a fire safety system. In an event of a fire in the tunnel this system is designed to increase air flow, so that the fumes and smoke is carried out of the tunnel. The air flow is increased by allowing some exhaust flues size to increase. This is achieved by opening mechanical louvers in the system. There is also method where part of the celling is constructed from material that would go from solid to gas in a case of a fire. This will provide a bigger opening to accommodate the necessary air flow needed. However, this systems are very expensive. To achieve this results large exhaust ports can be designed in duct work at certain distances. (Aberahm Berhanu, 2016)

2.2.1 Axial Ventilation Fan

Axial ventilation fans or also known as tunnel jet fans are normally fixed on the top of the tunnel. In a long tunnel system this fans will be fixed at the inlet and outlet as supply and exhaust fan. There also when this axial fans are fixed in interval for certain distance, this is normally to ensure continuous air flow in the system. Axial fans normally are used for small air flow application where there is not much draft created. This is why in a long tunnel system it is required to install many axial fans and they will be fixed in interval of certain distance to maintain the required air flow. If there is a need for high air flow in the system centrifugal fans are installed.

2.2.2 Centrifugal Ventilation Fan

Centrifugal fans that are used in tunnel system typically comes with a ducting system. Where the air is supplied in to the tunnel system true this ducts. Normally this fans will be installed at the ground level with duct work to carry air in the tunnels. This fans are bigger in size compared with axial fans. So the fans cannot be mounted in the upper wall of the tunnel like the axial fan. However, with the high capacity less numbers of fans are needed to ventilate a tunnel system. This also can prove to be more energy saving but a specific place would need to be dedicated for this fans to be installed. In some cases, when the tunnels are long axial fans are used alongside with centrifugal fans. Normally a high velocity supply of air is catered in the tunnels by a centrifugal blower but at the outlet of the tunnels axial fans are mounted as exhaust fans. This is done so that there is constant and steady air flow in the tunnels. Which will ensure the heat generated in the cables are carried out at a more efficient rate.

2.2.3 Components of ventilation Cooling System for Cable Tunnel

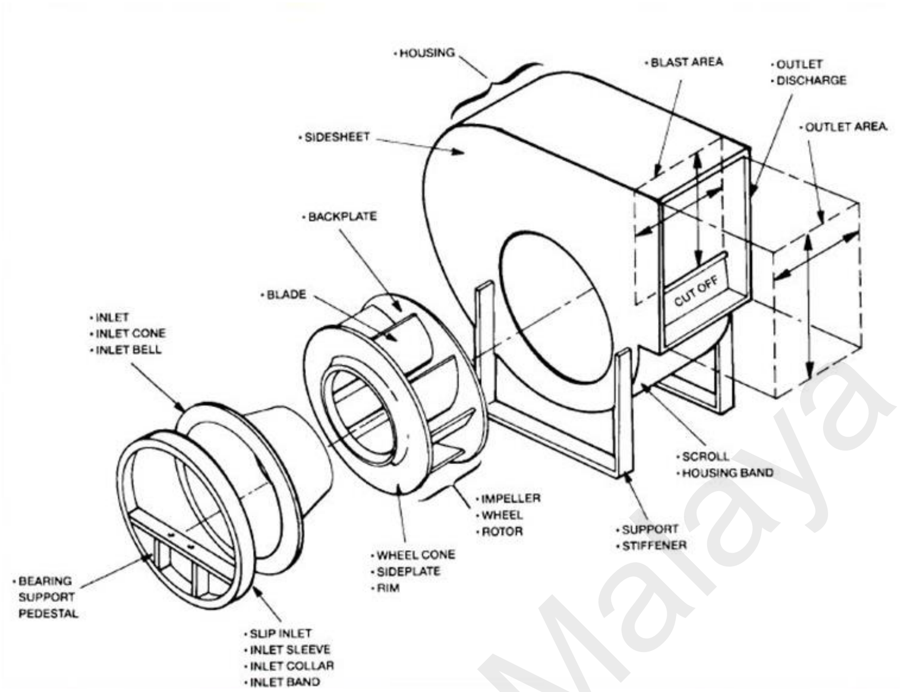


Figure 2.6: Components of a Centrifugal Fan (Waltetr Hilbish, 2016)

Figure 2.7: Centrifugal Fan (Process Enviroment, 1979)

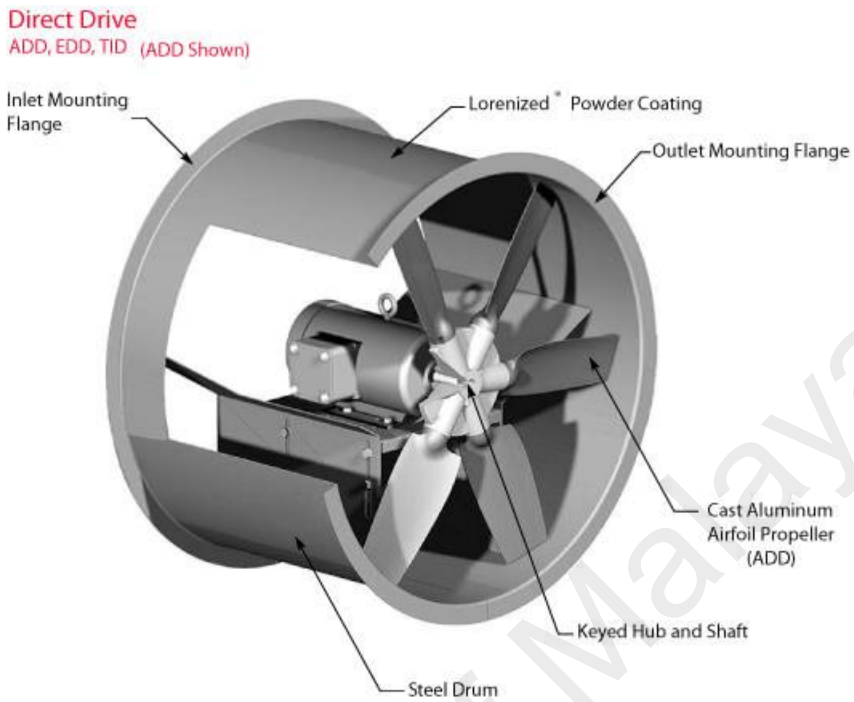


Figure 2.8: Components of Axil Fan (Lorencook, 1941)

Figure 2.9: Example of Ducting Typically used with Centrifugal Fan system (GP Spiral Duct)

Figure 2.10: Jet Fan Installation for Tunnel (**Peter Kenyon, 2015, May 22**)

2.3 Water Pipe Tunnel Cooling System

In a water pipe cooling system water is circulated in pipes which are lain alongside the cables in the tunnel. The water is pump from a cooling tower in to the pipes. The pipes carry the cool water in to the tunnel and extract the heat that is generated by the cables. The water which has absorbed the heat will be circulated back to the cooling tower to be cooled. This cycle is a continuous cycle to ensure continuous operation. Normally the flow is fixed based on the capacity of heat that needs to be removed. This system is more focused on the cable specifically. Removing all the direct heat that is generated by the cables and ensuring a long life span of the cables itself. But the heat in the environment of the cable tunnel is difficult to be controlled with this system. However, use in small tunnel will still create an environment where work is possible to be carried out. For tunnels which have high capacity this system will usually be integrated with a ventilation system. So the cables are cooled to the temperature that it will still operate at optimal when full load. High Voltage Cables can create high levels of heat. In the case of maintenance or repair the ventilation system will ensure that the environmental temperature in the tunnel is suitable for human occupation. In figure 2.11 we can see the water pipe cooling system

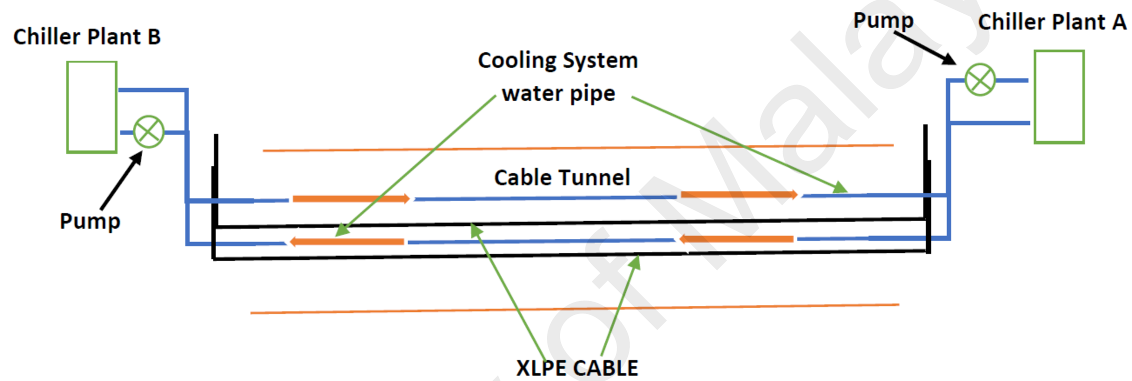


Figure 2.11: Under Ground Cable Tunnel Water Pipe Cooling System For

2.3.1 Cooling Towers

For pipe cooling systems it will come with a cooling tower. The cooling tower is where the heat that is absorbed by the cooling fluid in the pipes is dissipated. This is also the source of the cooling fluid which is normally water for the pipe cooling system in a tunnel. Few of the major components in a wet cooling tower used for this application is axial fan, drift eliminator, water distribution nozzle, cooling fill and cold water basin. Basically the water from the cold water basin which is normally at the bottom of the cooling tower will be pumped out using a water pump in the pipes that run along the cables in the tunnel. This water will collect the heat generated by the cables are return to the cooling tower and enter the cooling tower true the water distribution nozzle at the same tie the axial fan which is mounted at the top of the cooling will create an air flow in the cooling tower to cool the hot water that has entered. The nozzle will spray the hot water onto the cooling fill. When this waster moves true the cooling fill to the cold water basin the air flow will cool the water by removing the heat collected from the tunnel. This cool water then will be re circulated into the pipes and this process will repeat. This is a continuous process as this cooling system will ensure continuous supply of electricity

2.3.2 Components of Water Pipe Tunnel Cooling System

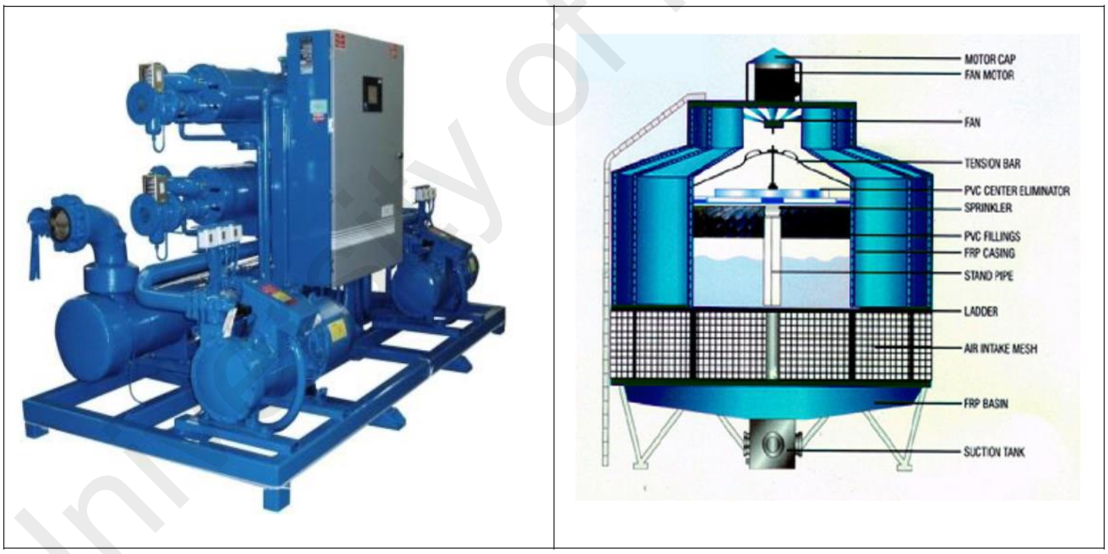


Figure 2.12: Cooling Tower (Berg, 2003)

Figure 2.13: Centrifugal Water Pump For Water Cooling System (Weiku, 2011)

2.4 XLPE – Cross-Linked Polyethylene Cables

For this study and for the tunnel project a 132kV XLPE cable system is proposed to be used. XLPE or Cross – Linked Polyethylene Cable are suitable to be used in an underground environment it is also applicable in high voltage and high temperature applications. This is because XLPE material has a very good resistance to chemical, moisture and heat. This is the reason it is one of the mainly used insulation material or components for high tension cables. The XLPE cable consist of the solid metal inner core which is usually copper or aluminum which will be wrapped with a layer of metallic sheath which acts as a conductive earthed layer. In an event of a leak the electricity is conducted away from damaging the insulation layer. Them the insulation layer consist of a semiconductor layer of tape that wraps the core followed by a solid insulation layer followed by an outer semiconductor layer and the outer insulation. This layer is all extruded in one process to create the insulation layer for the XLPE cable (ABB, 2010, April). In figure 2.14 is shown a cut section of a XLPE cable.

Figure 2.14: Construction of a XLPE – Cross – Linked Polyethylene Cable

(Brugg Kabel, 2005)

2.5 Modeling and Analysis

In this study of the underground cable tunnel ventilation system the main focuses are the internal temperature of the tunnel. The point that is taken as the reference is the middle of the tunnel. To determine the tunnel temperature focus is given on the different ambient temperature and ventilation velocities. To analyses this parameter, the numerical modeling method is used as this method is very much more economical and flexible. It is flexible because all the varying parameters can be changed and controlled and by doing so various air flow has been analyzed and the effects of it on the internal temperature of the cable tunnel can be determined. The ventilation velocities are calculated based on the air change per hour (AC/Hr). For the modeling of the tunnel, a simplified geometrical model of the proposed underground cable tunnel was modeled using Solid Works. The analysis of the flow rate and heat transfer out of the tunnel caused by the airflow was conducted using ANSYS Fluent. By using both this software`s it has made it possible to accurately determine the correct air flow needed to achieve the necessary ambient temperature for occupation of workers for repair and maintenance work.

Solid works is a CAD software which allows direct 3D modeling. This software has a wide application in architecture, construction and manufacturing. This is because if its wide range of use and versatility when modeling. Using Solid works enables a wide range of geometrical control of the model that is to be designed. In this study this software was utilized to create an accurate scale model of the tunnel to be analyzed.

ANSIS Fluent is a computational fluid dynamics (CFD) software which has a broad range of capabilities needed to model flow, heat transfer, turbulence, and reactions. This software is widely used in industrial application. For example, it can be used to analyze the heat transfer from a cooling fin on a computer mother board to air flow over a car. Using this method, the need of a scaled of full scale physical model is eliminated. Therefore, it is a more convenient and cost efficient method to carry out analysis of system or product. This software is also accurate in simulating the scenarios given the geometrical modeling and numerical calculations are accurate.

In this study the geometrical model of the 90m long tunnel with the diameter of 3m for the XLPE cables was done using CAD software Solid Works. This allowed the model to be done to scale. All the necessary numerical calculations were done to determine all the essential parameters. However, when all the data from the numerical modeling methods was obtained. The Geometrical model and the numerical results were simulated in ANSYS Fluent to determine the necessary air flow rate to achieve the desired temperature. Below in table 2.1 is shown all the properties and parameters of the study.

Table 2.1: Properties and parameter of study

Specifications	
Tunnel Length	90m
Tunnel Diameter	3m
Tunnel Material	Precast Concrete
Circuit	4 Cables
Cable Type	132kV 3x1Cmmsq Cu
Cable Arrangement	Trefoil
Cable diameter	193mm
Cable Insulation	XLPE
Ambient temperature	30ºC to 33ºC
Maximum Core Temperature of Cable	90ºC
$\Delta\theta$ (Assumption)	60ºC

CHAPTER 3: METHODOLOGY

3.1 Data Collection and Design Considerations

The data for this project study is collected from the requirement of power supply needed for the commercial area from the customer. The length, diameter of the tunnel, the construction material of the tunnel has been already predetermined. As well as the cable layout and type of cable that is to be laid. From the technical data obtained and using a mathematical model and using mathematical models the head generated in the system can be determined. With all the necessary mathematical results an analysis using Computational Fluid Dynamics (CFD) software ANSIS – Fluent can be conducted to determine the air flow needed to cool the inter temperature of the tunnel so that it is suited for human occupation for work purposes.

- Mathematical calculation and development of a mathematical model of the tunnel system. Using the given parameters and Heat Transfer Equations
- Analyze the tunnel system and it heat transfer using CFD software with the results from the mathematical modeling and parameter of the project.
- Different air flows and ambient temperature has been analyzed.
- To determine the needed airflow in the tunnel to disperse the heat generated by the cables.

3.2 Numerical Modeling and Calculations

3.2.1 Fixed Design Parameter

These parameters are the design that was already. This analysis is done on the basis of this parameters. Where the design of the tunnel has already been determined for the analysis of the heat transfer at a steady state was done. The tunnel in question is a 90-meter-long tunnel with an air inlet of 1.5m in diameter. This tunnel has a round and square manholes at each ends of the tunnel. The cable that was used in this analysis is a XLPE 132 kV 1C 1200mm^2. The diameter of the cable is 193mm and is laid in a trefoil layout with a 4 cable circuit. This type of cables generates a core temperature of up to 90 ^{0}C. The ambient temperature is taken to be 33 ^{0}C and this is determined based from the meteorological date for the area where the cables is to be laid in the tunnels. This is because the ambient air will be circulated in the tunnel without any external cooling involved.

3.2.2 Calculation of Cable Surface Temperature

Excess Cable surface temperature is given by, $\Delta\theta_s$. This is the difference in temperature between the ambient temperature and the cable surface temperature. $\Delta\theta_s$ may be calculated iteratively using the equation below.

Equation 3.1

$$(\Delta\theta_s)_{n+1}^{1/4} = \left[\frac{\Delta\theta + \Delta\theta_d}{1 + K_A(\Delta\theta_s)_n^{1/4}}\right]^{0.25}$$

Since, $\Delta\theta_d = 0.0002227$ and $\Delta\theta = 60$, $K_A = 0.476844549$,

$$(\Delta\theta_s)_{n+1}^{1/4} = \left[\frac{60 + 0.0002227}{1 + (0.476844549)(\Delta\theta_s)_n^{1/4}}\right]^{0.25}$$

Iteration to stop when, $(\Delta\theta_s)_{n+1}^{1/4} - (\Delta\theta_s)_n^{1/4} \le 0.001$

Table 3.1: Iteration to determine surface temperature

Iteration	Initial $(\Delta\theta_s)^{1/4}$	New $(\Delta\theta_s)^{1/4}$	Error |New-Initial|/ Initial
1	2	2.354096992	17.70%
2	2.354096992	2.305814313	2.05%
3	2.305814313	2.312109887	0.27%
4	2.312109887	2.311284127	0.04%
5	2.311284127	2.311392354	0.00%
6	2.311392354	2.311378168	0.00%

Therefore, the iteration is stopped with:

Equation 3.2

$$(\Delta\theta_s)^{1/4} = 2.311284127$$

$$\Delta\theta_s = 28.54^o C$$

Solving, results with:

$$\theta_s = 28.54 + 30.0 = 58.54^o C$$

The steady state cable surface temperature is expected to be 58.54 ^oC with a core temperature of 90 ^oC and an ambient temperature of 33 ^oC.

3.2.3 Design Calculations

For this project the design calculation is based on the Air Change Per Hour (AC/Hr). The AC/Hr is calculated based on the Volume of the tunnel that can be obtained from the design drawing of the tunnel. As various assumptions were done on the air change that will be suitable for the tunnel system. Few AC/Hr was calculated for this project to determine the most suited AC/Hr for this cable tunnel system

Below is the formula to calculate Air Change Per Hour

$$AC/Hr = \frac{60\ X\ CFM}{Vol}$$

The Volume that was determined from the design is

Volume = 40368.98 ft^3

From the volume that was obtained from the design the air change per hour can be determined by assuming few AC/Hr and obtaining the Q, Flow rate and followed by the velocity.

$$CFM = \frac{AC/HrX\ Vol}{60min}$$

From this equation the air flow was determined followed by and the equation below is the equation to determine the Q. which also can be used to obtain the Velocity.

$$CFM = V\ X\ A\ X\ 2118.88$$

$$V = \frac{CFM}{A\ X\ 2118.88}$$

Table 3.2: Air Change Per-Hour, Flow Rate and Velocity

AC/Hr	Q (ft^3/min) or CFM	Velocity of Air at Inlet (m/s)
2.00	1345.63	0.36
6.00	4036.90	1.08
15.00	10092.25	2.70
22.00	14801.95	3.95
28.00	18838.86	5.03
33.00	22202.94	5.93

Above is the table shows various air change per hour for the inlet diameter of 1.5m. The respective air change was assumptions done to determine the air flow and followed by the velocities. These velocities are then used to input into ANSYS to determine the mid-point temperature. From the mid-point temperature, the most suitable velocity and air flow can be determined

Calculating K_A

Equation 3.3

$$K_A = \frac{\pi D_e^* h}{(1 + \lambda_1 + \lambda_2)} \left[\frac{T_1}{n} + T_2 \ (1 + \lambda_1) + T_3 \ (1 + \lambda_1 + \lambda_2) \right]$$

D_e^* = 110.86mm = 0.11086m

n = 1 (single conductor within cable)

λ_1 = 0.0041998

$\lambda_2 = 0$

$T_1 = 0.4233$ K.m/W

$T_2 = 0$ K.m/W

$T_3 = 0.07808$ K.m/W

h = 2.740446

$K_A = 0.476844549$

Calculating $\Delta\theta_d$

Equation 3.4

$$\Delta\theta_d = W_d \left[\left(\frac{1}{1+\lambda_1+\lambda_2} - \frac{1}{2} \right) T_1 - \frac{n\,\lambda_2\,T_2}{1+\lambda_1+\lambda_2} \right]$$

$W_d = 1.061\text{x}10^{-3}$ W/m

$\lambda_1 = 0.0041998$

$\lambda_2 = 0$

$T_1 = 0.4233$ K.m/W

$T_2 = 0$

$\Delta\theta_d = 2.227\text{x}10^{-4}$ ^{o}C

λ_1 = ratio of losses in metallic sheath to conductor = 0.04575/10.89337

λ_1 = 0.0041998

λ_2 = ratio of losses in armor to conductor

in this case, with no armor installed, λ_2 = 0.

T_1 = Thermal Resistance between one conductor and sheath

$$T_1 = \frac{\rho_T}{2\pi} \ln\left[1 + \frac{2t_1}{d_c}\right]$$

Thermal resistivity for XLPE, ρ_T = 3.5 K.m/W

Thickness of layer between conductor and metallic sheath, t_1 = 0.0247m

Conductor Diameter, d_c = 0.0434m

T_1 = 0.4233 K.m/W

T_2 = Thermal Resistance between metallic sheath and armor

In this case, with no armor installed, T_2 = 0.

T_3 = Thermal resistance of outer covering (serving)

$$T_3 = \frac{\rho_T}{2\pi} \ln\left[1 + \frac{2t_3}{d_a}\right]$$

Thermal resistivity for XLPE, ρ_T = 3.5 K.m/W

Thickness of XLPE jacket, t_3 = 0.00725m

Metallic sheath outer diameter, d_a = 0.09636m

T_3 = 0.07808 K.m/W

Heat dissipation coefficient, h

$$h = \frac{Z}{\left(D_e^*\right)^g} + E$$

For three cables in trefoil, installed on non-continuous brackets, ladder supports or cleats with D_e^* not greater than 0.15m (case under study = 0.11086m).

Z = 0.96

E = 1.25

g = 0.20

D_e^* = 0.11086m

h = 2.740446

Dielectric losses, $W_d = CU_o^2 \tan\delta = 1.061 \times 10^{-3}$ W/m

Voltage from phase to ground, U_o = 76,210 V

$\tan\delta$ = 0.001

Capacitance, $C = \dfrac{\varepsilon}{18 \ln\left(\dfrac{D_i}{d_c}\right)} 10^{-9} = 1.8275 \times 10^{-10}$ F/m

Insulation outer diameter, D_i Conductor outer diameter, d_c = 0.0434m

Insulation emissivity, ε = 2.5

3.3 CAD Modeling with Solid Works

The underground cable tunnel was modeled using Solid works software. All the parameters of the proposed tunnel were used in this model so that when the simulation is done in ANSIS – Fluent the results will be same or very close to the actual situation after the tunnel is build. It can be seen from figure 3.1, 3.2 and 3.3.

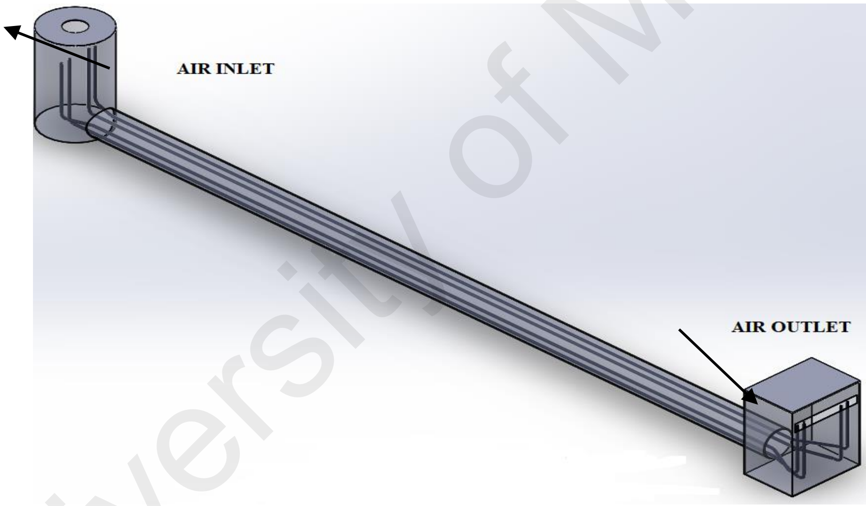


Figure 3.1: CAD model of underground tunnel

Figure 3.2: Top View

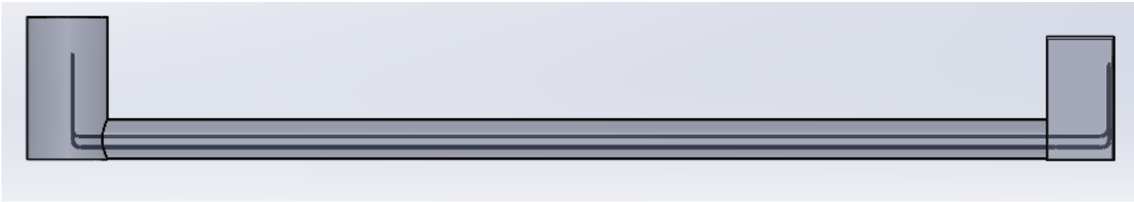
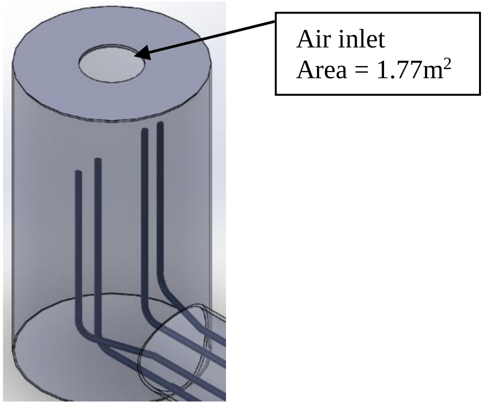


Figure 3.3: Side View



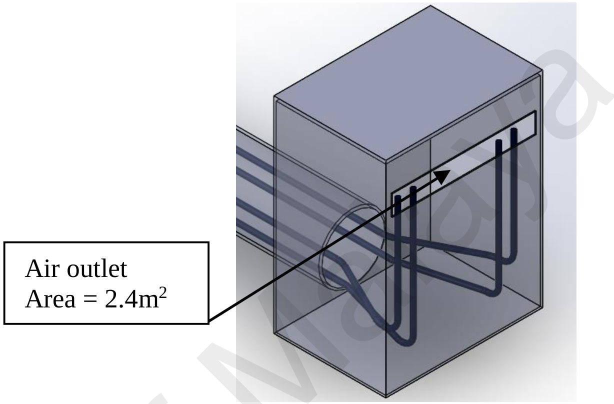


Figure 3.4: Tunnel Inlet

Figure 3.5: Tunnel Outlet

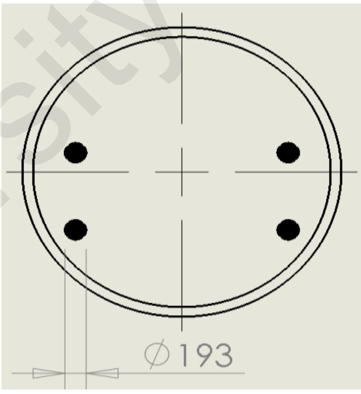


Figure 3.6: Cross section of tunnel with cables

Area of cable cross-section = $Area = \frac{\pi d^2}{4}$

Diameter Of Cable = 110.86 mm

Cross-section Area of Cable = 9652.5 mm^2

Cross-section of cable in trefoil arrangement (Area x 3) = 28957.5 mm^2

Estimated Diameter of Cable for simulation = 193 mm

3.4 Simulation Using Computational Fluid Dynamics (CFD)

Once the data collection, design and mathematical modeling was done. All the data was obtained was compiled and a few analysis models with various velocities and ambient temperature was simulated using ANSIS Fluent. In order to obtain the best possible result for the tunnel ventilation system the ambient temperature and velocity way inputted into fluent. In order to do that the design was exported into ANSIS fluent and a mesh was created for the tunnel so that the analysis can be carried out in the software. The first step is meshing

3.4.1 Meshing of the design

To start the min and maximum size and maximum face size had to be set and it is as follows

Table 3.3: Meshing Configuration

Number of Nodes	560,941
Number of Elements	2,850,839
Min Size (m)	0.1
Max Size (m)	0.1

After all this parameter were set for the meshing and generated. The meshing is as follows in figure 3.7.

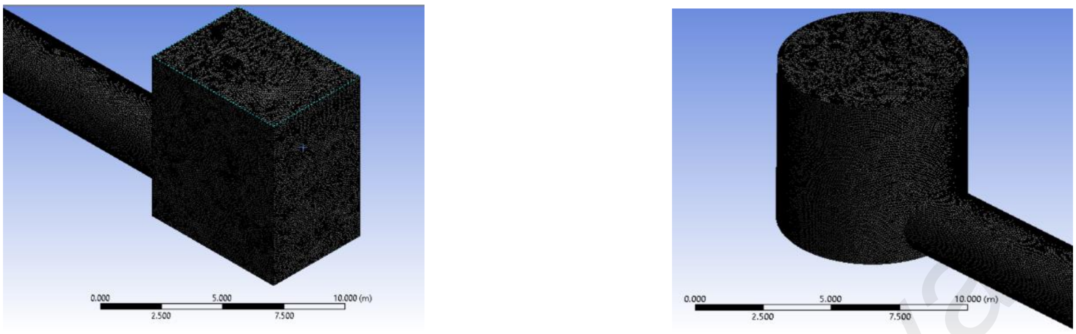


Figure3.7: Mesh Generated for Underground Cable Tunnel

3.4.2 Analysis

Once the mesh was setup the next step is the analysis of the system in fluent. For this analysis there was a few set of temperatures and velocities used to determine the best design for the underground tunnel. There are 3 ambient temperatures and 5 different velocities was used.

Analysis 1: Ambient temperature @ 30^0C

Table 3.4: example fixed parameters for analysis

Velocity m/s	Inlet Diameter m	Area m^2
2	1.5	1.7671
4	1.5	1.7671
6	1.5	1.7671
8	1.5	1.7671
10	1.5	1.7671

For the analysis 1 the inlet temperature is set at 30^0C with 5 varying velocities with the inlet size that is fixed. This is done to find the midpoint temperate of the cable tunnel. This temperature is then compared with the inlet temperature which is the ambient temperature. From here we have determined which flow rate is able to cater a temperature closest to the ambient temperature at the lowest velocity. In Figure 3.8 we can see the focal point of the study.

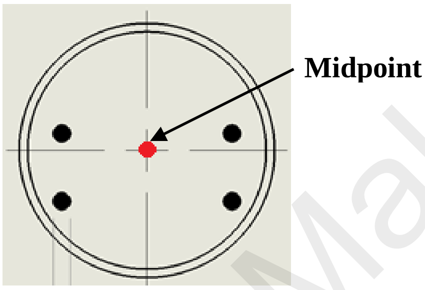


Figure 3.8: Midpoint where the tempreature is analyzed

For analysis 2 and 3 the temperature used for the analysis was 33^0C and 36^0 C using all the velocities in the table above. To determine the best velocity to be used at the respective ambient and inlet temperature.

The graphical results from the analysis in ANSIS is as follows;

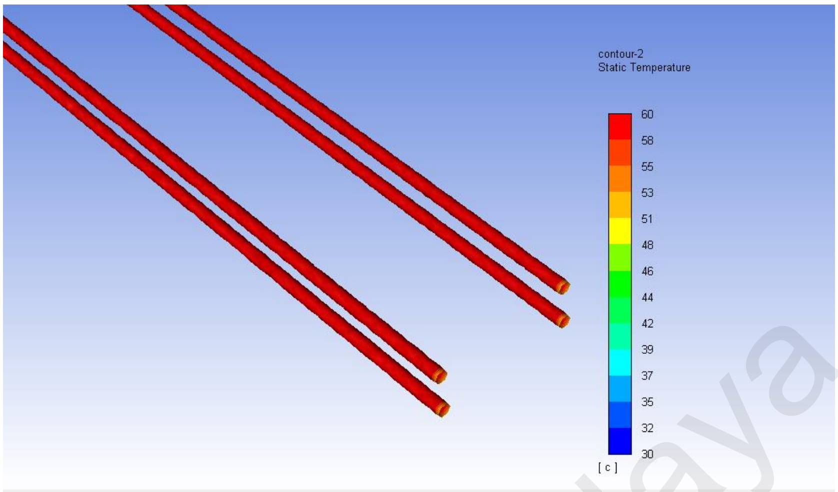


Figure 3.9: Heat generated by cables

Figure 3.9 is showing the internal cables that are the primary source of the heat generated at a tempreature of 60^0C

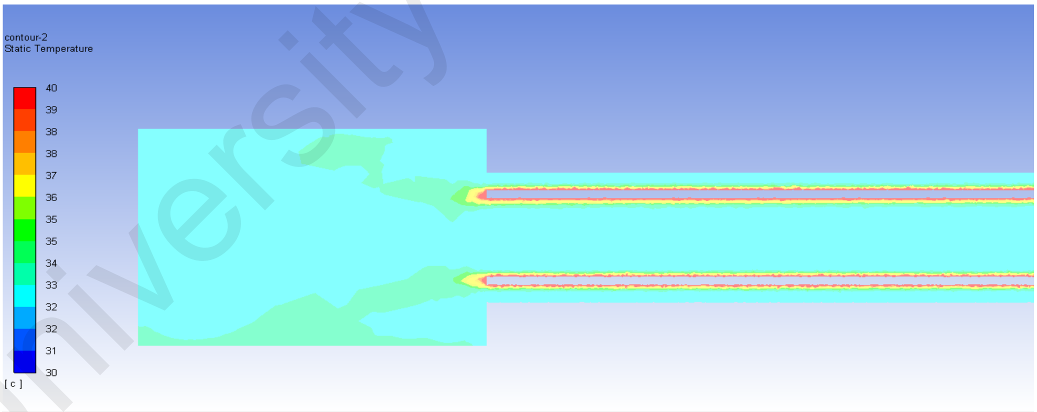


Figure 3.10: Heat contours

Figure 3.10 is the top view of the tunnel which shows the temperature variance from the source of the heat generated and the surroundings. This is for an ambient inlet temperature of 33^0C and inlet velocity of 4 m/s. The temperature scale is set from 30^0C to 40^0C to show a more detailed temperature variance true the top view cross section.

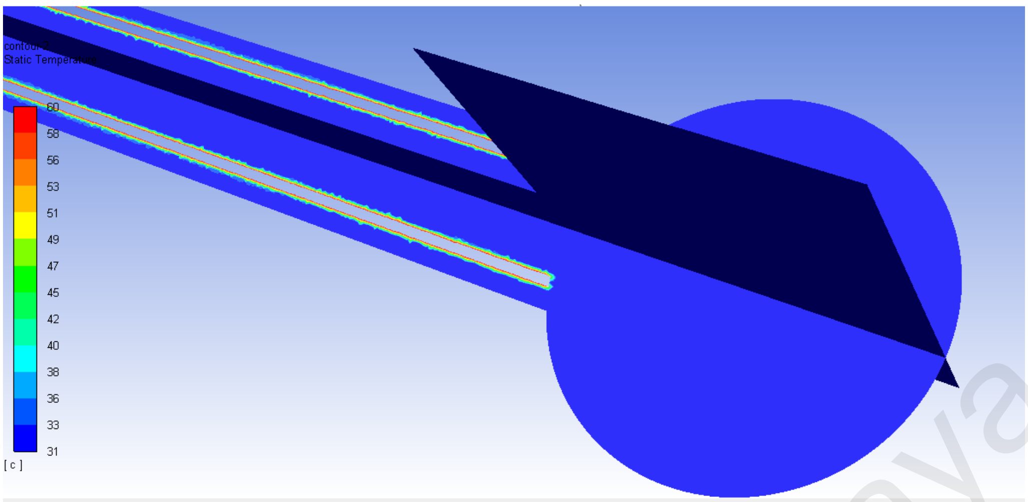


Figure 3.11: Heat generation and surrounding temperature at mid-point axis's

Figure 3.11 shows the cross-section of the tunnel from the side and top axis where the tunnel is cut for the purpose of the analysis. This is for an ambient inlet temperature of 33^{0}C and inlet velocity of 4 m/s

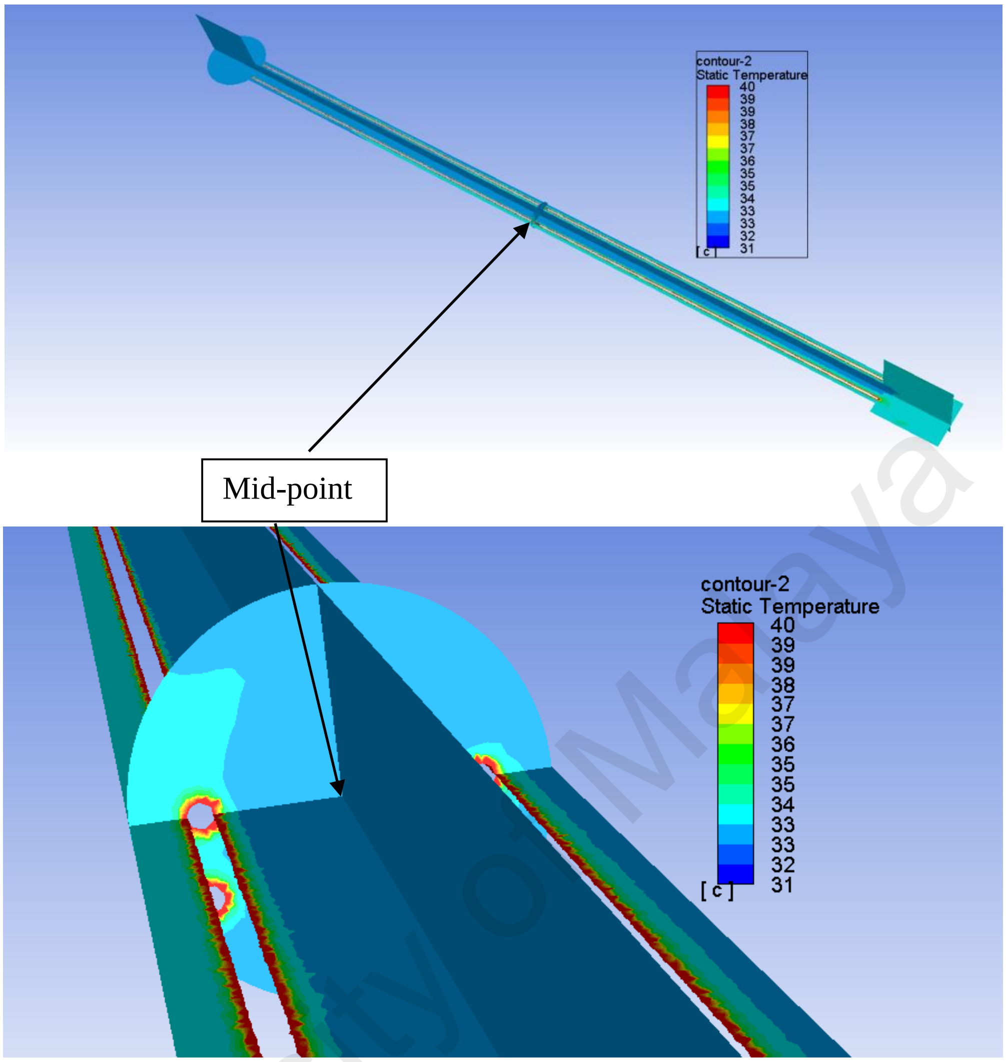


Figure 3.12 Midpoint where the analysis focuses with planes

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Results

In total there were 3 different ambient temperature conditions that were analyzed. This temperature is 30^0C, 33^0C and 36^0C with 5 different velocities that were analyzed for each of the temperatures. The study is done in various temperature because in tropical climates the temperature can change abruptly. That the analysis was carried out on a temperature that is lower and higher than the set temperature of 33^0C which was set based on the information from the Malaysian meteorological department for Klang Valley are specifically Petaling Jaya. Figure 4.1 shows where the analysis was carried out.

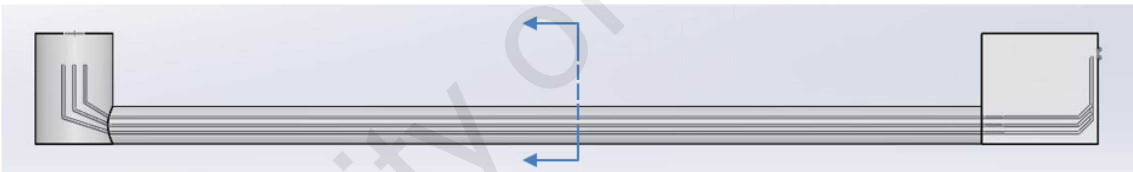


Figure 4.1: Cut section of temperature contour where the results are analyzed

Analysis 1: Ambient temperature set at 30°C

Table 4.1: Temperature at mid-point for various velocities at 30°C

Velocity of Air at Inlet (m/s)	**Diameter of Inlet (m)**	**Flow Rate of Air at Inlet (ft^3/min)**	**Temperature of Air at Midpoint (°C)**	**Temperature Difference (°C)**
2	1.5	7400.98	32.88	2.88
4	1.5	14801.95	32.01	2.01
6	1.5	22202.95	31.93	1.93
8	1.5	30276.74	31.90	1.90
10	1.5	37677.71	31.86	1.86

Temperature contours at cross section of tunnels at the maximum temperature of 60^0C for the ambient temperature of 30^0C. Below is the analysis results from ANSIS Fluent. It shows the temperature variance from 30^0C to 60^0C. Where the temperature difference can be observed clearly for ambient temperature of 30^0C. This temperature was analyzed to simulate a lower temperature then the main temperature to be analyzed to show the effects of air flow on various ambient temperature.

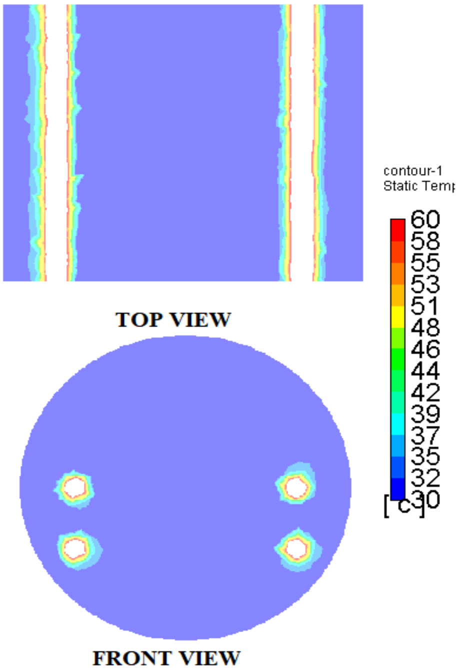


Figure 4.2: V_i = 2m/s at 30°C

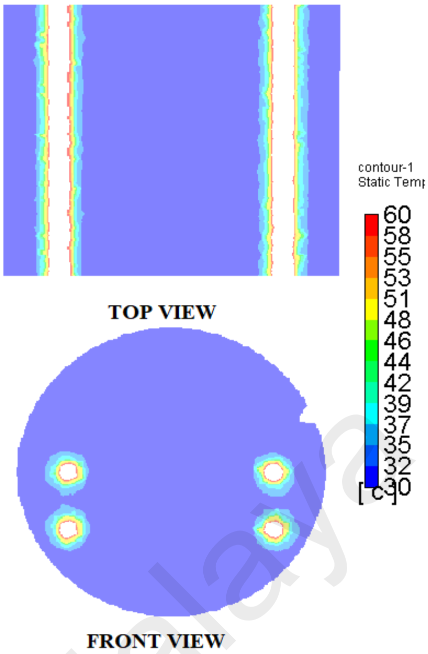


Figure 4.3: V_i = 4m/s at 30°C

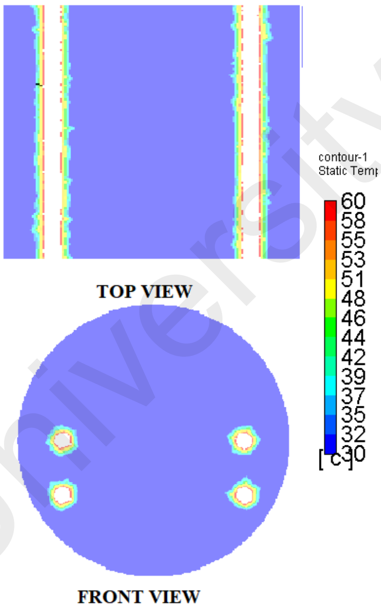


Figure 4.4: V_i = 6m/s at 30°C

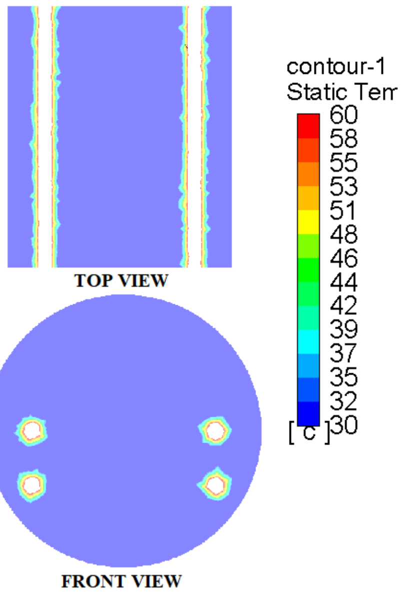


Figure 4.5: V_i = 8m/s at 30°C

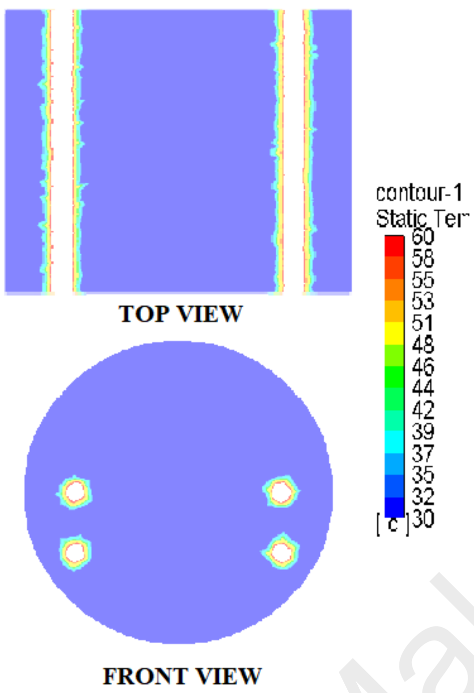


Figure 4.6: V_i = 10m/s at 30°C

Analysis 2: Ambient temperature set at 33°C

Table 4.2: Temperature at mid-point for various velocities at 33°C

Velocity of Air at Inlet (m/s)	Diameter of Inlet (m)	Flow Rate of Air at Inlet (ft^3/min)	Temperature of Air at Midpoint (°C)	Temperature Difference (°C)
2	1.5	7400.98	35.54	2.54
4	1.5	14801.95	34.74	1.74
6	1.5	22202.95	34.71	1.71
8	1.5	30276.74	34.69	1.69
10	1.5	37677.71	34.66	1.66

Temperature contours at cross section of tunnels at the maximum temperature of 60^0C for the ambient temperature of 33^0C. Below is the analysis results from ANSIS Fluent. It shows the temperature variance from 33^0C to 60^0C. Where the temperature difference can be observed clearly for ambient temperature of 33^0C. This temperature is the reference temperature because this will be the average ambient temperature in the area of the tunnel project which was obtained from the meteorological department.

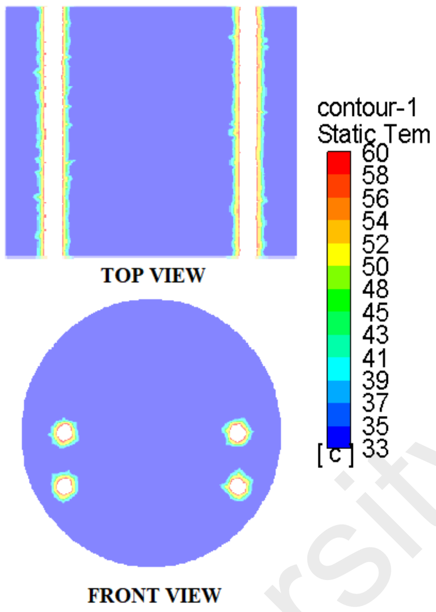


Figure 4.7: **V_i = 2m/s at 33°C**

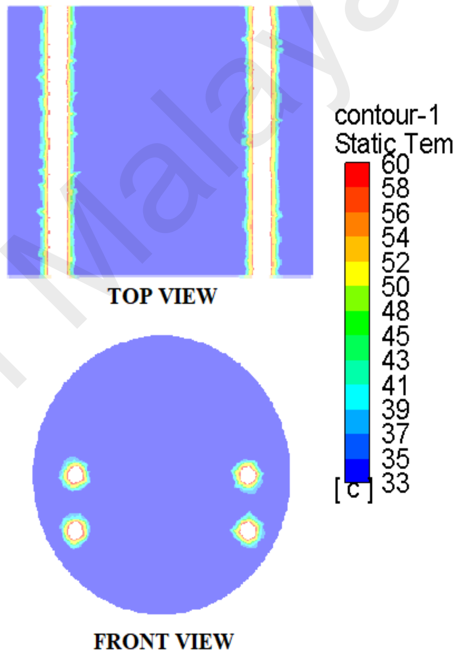
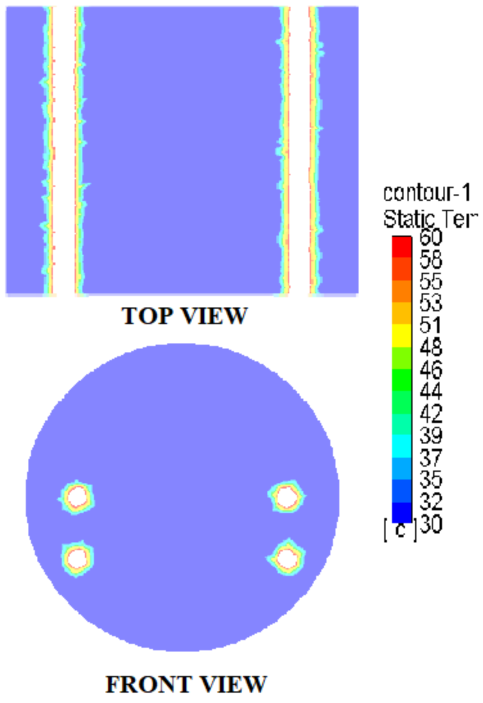


Figure 4.8: **V_i = 4m/s at 33°C**



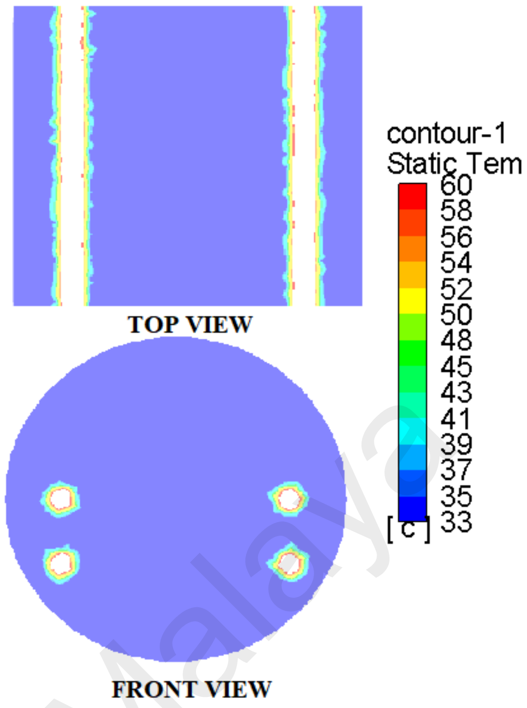


Figure 4.9: $V_i = 6m/s$ at 33ºC

Figure 4.10: $V_i = 8m/s$ at 33ºC

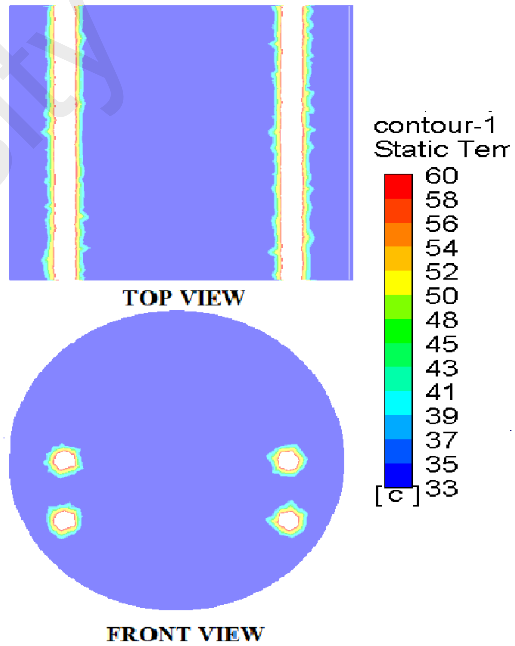


Figure 4.11: $V_i = 10m/s$ at 33ºC

Analysis 3: Ambient temperature set at 36ºC

Table 4.3: Temperature at mid-point for various velocities at 36ºC

Velocity of Air at Inlet (m/s)	**Diameter of Inlet (m)**	**Flow Rate of Air at Inlet (ft^3/min)**	**Temperature of Air at Midpoint (^OC)**	**Temperature Difference (^OC)**
2	1.5	7400.98	38.72	2.72
4	1.5	14801.95	37.89	1.89
6	1.5	22202.95	37.78	1.78
8	1.5	30276.74	37.76	1.76
10	1.5	37677.71	37.72	1.72

Temperature contours at cross section of tunnels at the maximum temperature of 60^0C for the ambient temperature of 36^0C. Below is the analysis results from ANSIS Fluent. It shows the temperature variance from 36^0C to 60^0C. Where the temperature difference can be observed clearly for ambient temperature of 36^0C. Here we can observe that the temperature higher and the temperature profile has more contours because of the smaller temperature gradient and generally higher temperature.

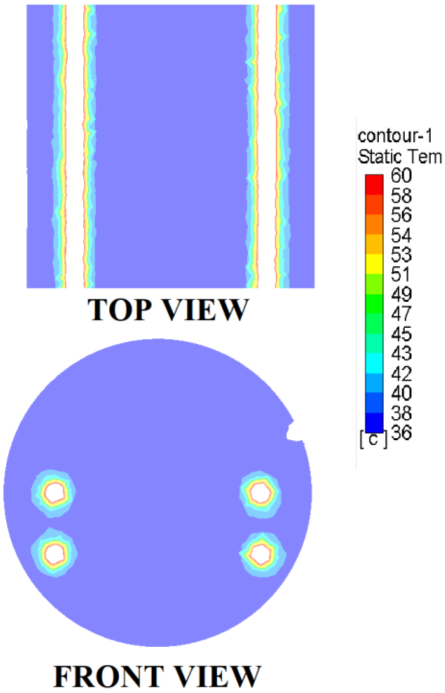


Figure 4.12: V_i = 2m/s at 36°C

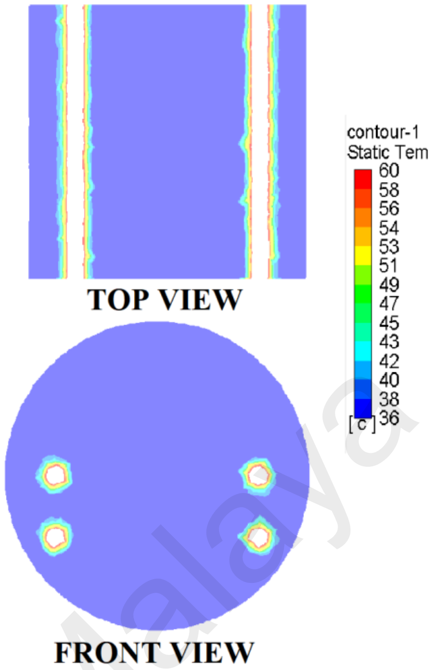


Figure 4.13: V_i = 4m/s at 36°C

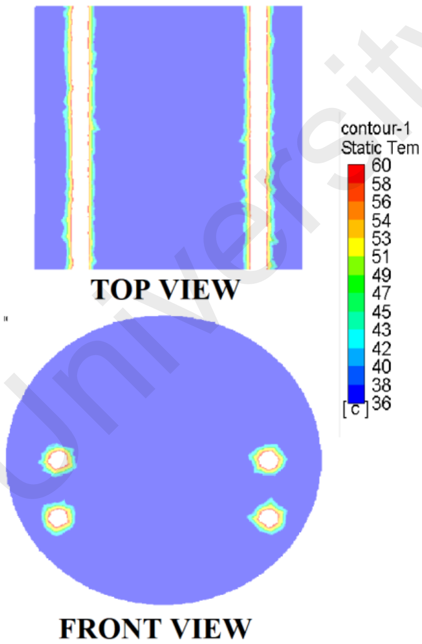


Figure 4.14: V_i = 6m/s at 36°C

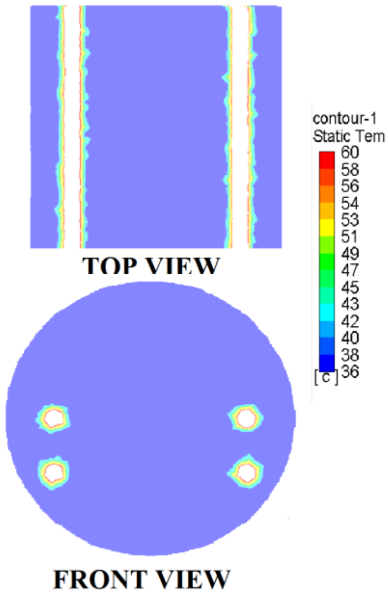


Figure 4.15: V_i = 8m/s at 36°

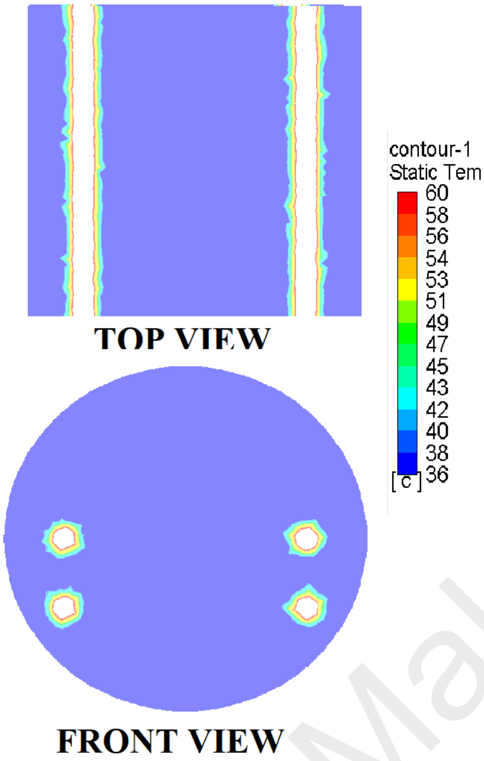


Figure 4.16: **V_i = 10m/s at 36°C**

Table 4.4: Velocity properties with Air Change Per-Hour

Velocity of Air at Inlet (m/s)	**Volume ft^3**	**Q (ft^3/min) or CFM**	**AC/Hr**
2	40368.98	7400.98	11
4	40368.98	14801.95	22
6	40368.98	22202.95	33
8	40368.98	30276.74	45
10	40368.98	37677.71	56

Table show all the air change per hour for the all the velocities that are analyzed.

If AC/Hr = 22, at ambient temperature = 33^0C;

Table 4.5: 22 Air Change Per-Hour and its parameters at 33^0C

Q (ft^3/min) or CFM	14801.95
Volume (ft^3)	40368.98
Velocity of Air at Inlet (m/s)	3.95
Temperature of Air at Midpoint (^{O}C)	34.74
Temperature Difference (^{O}C)	1.74

Shown in table 4.5 is the data analyzed and it can be determined that the most suitable air change per-hour is 22 AC/Hr for the ambient temperature of 33^0C.The ambient temperature of 33^0C was selected based on the meteorological data for the Klang Valley area which is around 33^0C. This data can be found in the table 4.5 below,

Table 4.6: Meteorological data (Malaysian Meteorological Department ,2018, March)

48674	Mersing	23.4	24.9
96449	Miri	26.2	35.5
48649	Muadzam Shah	22.5	32.9
96448	Mulu	24.6	37.6
48648	Petaling Jaya	25.2	33.4
96469	Ranau	22.2	31.6
96491	Sandakan	25.5	31.6
48679	Senai	23.7	33.9
48650	Sepang (KLIA)	24.4	31.7
96421	Sibu	25.0	34.4

48620	Sitiawan	23.7	33.4

Based on this data it can be determined that the analysis results at the temperature of 33^0 C is taken as the most accurate data for this study. The other 2 ambient temperatures are used for comparison and analysis

Table 4.7: Temperature difference between ambient temperature and mid-point temperature for velocity of 4m/s

No	Ambient Temperature (°C)	Temperature of air at mid-point (°C)	Temperature Difference (°C)
1	30	32.01	1.82
2	33	34.74	1.80
3	35	37.81	1.79

CFM: Recommended CFM is 15,000 CFM.

Temperature: The temperature can be maintained at 34.7ºC at the mid position in the tunnel.

Velocity: Inlet velocity is about 4 m/s.

Air Change Per-Hour: 22 AC/Hr

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusio

a) Cable tunnel was designed based on the specifications given and to cater the housing of the cables.

b) Analysis was done using ANSIS for steady state conditions and results were obtained for various ambient temperatures.

c) Based on the analysis various airflows were determined for the various ambient temperatures analyzed.

d) Below is the recommendations and conclusion

Based on the data collected and analyzed using Computational Fluid Dynamics analysis for steady state conditions in ANSIS fluent software for the underground cable tunnel. The optimal airflow and inlet velocity was able to be concluded for the 90m long XLPE 132kV 1C 1200mm^2 tunnel. However, the analysis was not only done for other ambient temperature of 33^{0}C, because being a tropical climate country the temperature can change from day to day. Hence in total 3 temperatures were analyzed which is 30 ^{0}C, 33 ^{0}C and 36^{0}C. The velocities used were 2m/s, 4m/s, 6m/s, 8m/s, and10m/s. Among this 3 temperatures, 33 ^{0}C has been given more emphasis because that would be the average ambient temperature in the area where the tunnel is proposed to be build. This data was obtained from the meteorological department. In conclusion from the research based on the air change per-hour it can be determined that a temperature of 34.74 ^{0}C can be obtained at the mid-section of the tunnel where the analysis was focused on. This temperature is obtained with the inlet velocity of 4 m/s at a volume flowrate Q, of 15,000 CFM. This temperature has a variant of 1.74^{0}C from the ambient temperature. Even when the inlet velocity and air flow is increased the variance of temperature is around the same. Using the inlet velocity of 4m/s would cater to the need of the internal tunnel temperature to be conducive for human occupation for maintenance and repair work. This velocity would be the most efficient on basis of cost and system design. From the analysis also it can be concluded that the velocity of 4 m/s will cool the environment of the cable tunnel quiet efficiently for the range of ambient temperature of 30 ^{0}C to 36^{0}C. Being a tropical climate country the ambient can vary very rapidly therefore this proposed system can cater to the constantly varying needs of the changing temperature.

5.2 Recommendations

For the ambient temperature of 33^{0}C based on the Air Change Per hour the recommendations are as follows.

- Velocity of air at inlet = 4 m/s
- Air flow based on AC/Hr = 14801.95 CFM
- Air flow recommended = 15000 CFM
- Mid tunnel temperature = 34.74 ^{0}C
- From the results and discussions, it is recommend that the velocity and air flow that is used for the ambient temperature 33^{0}C can be used for variant temperature gradient that is not too high above the analyzed temperature

REFERENCES

Aberahm Berhanu (2016, September). CFD ANALYSIS OF A RAIL WAY TUNNEL VENTILATION.Retrievedfromhttp://etd.aau.edu.et/bitstream/handle/123456789/12402/Aberahm Berhanu.pdf;jses – 2nd February 2018

Process. Enviroment.(1979) (n.d.). BIDW Industrial Air Technology Backward Inclined Double Wide Fan. Retrieved from http://www.processenvironments.com/shopItem.php?cid=72&catid=57&picid=124&category=&sub_category=&scid= - 2nd February 2018

Waltetr. Hilbish. (2016). Understanding fan operation and performance. Retrieved from http://slideplayer.com/slide/6521166/ - 2nd February 2018

Lorencook (1941). Propeller Inline: Tube Axial Fans. Retrieved from http://www.lorencook.com/propellerinline.asp -8th February 2018

GP Spiral Duct. (n.d.). Spiral Round Duct System. Retrieved April 14, 2018, from http://www.gpspiralduct.com/ducting-system.html - 9th February 2018

Peter Kenyon (2015, May 22). Preparing Presidio Parkway for opening. Retrieved April 1, 2018, from https://tunneltalk.com/USA-22May2015-San-Francisco-Presidio-Parkway-final-preparations.php - 9th February 2018

Weiku (2011). Centrifugal water pump. Retrieved from http://www.weiku.com/products/9459954/centrifugal_water_pump.html

Berg. (2003). Retrieved from The Science Behind Refrigeration: https://berg-group.com/engineered-solutions/the-science-behind-refrigeration/ - 11th March 2018

ABB. (2010, April). XLPE Land Cable Systems 2GM5007GB rev 5.pdf. Retrieved from https://library.e.abb.com/public/ab02245fb5b5ec41c12575c4004a76d0/XLPE Land Cable Systems 2GM5007GB rev 5.pdf - 11th March 2018

Brugg. Kabel. (Ed.). (2005). HIGH VOLTAGE XLPE CABLE SYSTEMS Technical User Guide. Retrieved from http://nepa-ru.com/brugg_files/02_hv_cable_xlpe/03_web_xlpe_guide_en.pdf -11th March 2018

Malaysian Meteorological Department . (2018, March). Observations of Surface -Minmaxtemperature. Retrieved April, 2018, from http://www.met.gov.my/en/web/metmalaysia/observations/surface/minmaxtemperature - 2nd April 2018.