Design and Construction of smoke wire apparatus for wind tunnel flow visualization

By

Muhamad Nor Bin Azizi

Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

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Approved by,

_____

(Dr Turnad Lenggo Ginta)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMAD NOR BIN AZIZI

ABSTRACT

Smoke wire apparatus is used to visualize flow pattern across a rigid body for wind tunnel application. For the flow visualization, the smoke wire can illustrate, flow separation, wake region, vortex and recirculation As continuous of previous project design, the objective is to make portable smoke wire apparatus for wind tunnel, and analyze vegetable oil as the alternative to commercial smoke liquid to producing clear image of flow visualization. The design of the portable smoke wire apparatus has been show in this report and all equipment to be used has already been determined. It was found that during this experiment, the smoke flow visualization clarity been determined by the diameter of the wire been used, the type of wire and liquid, speed of wind tunnel, oil flow rate of the liquid that coated to the wire ,voltage and current supplied to the wire. All this parameter has been analyzed theoretically and experimentally. It was best to use two coiled nicrome wire, diameter 0.32 mm coated with the commercial smoke liquid with the voltage around 8v to 11v and current at 1.2 to 2.2 ampere. The wind tunnel speed should be between 0.5m/s and 1.5m/s. The smoke generated by sunflower seed oil is denser and uniform along the wire, which is the best alternative to the commercial smoke liquid for smoke wire technique.

ACKNOWLEDGEMENTS

Alhamdulillah, all praise to Allah S.W.T , The Most Gracious for His blessing and guidance. Thanks to Him for ligthnenig my journey of this final year and giving me the opportunity to complete this dissertation. I would like to extend my gratitute to everybody who involves directly and indirecly towards this project.

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CHAPTER 1
INTRODUCTION

1.1: Project Background

Smoke wire technique been used for flow visualization in wind tunnel at low velocities. The concept lies on using heated wire to evaporate the smoke liquid to form a smoke. This smoke wire technique has been proved to it does not introduce any appreciable disturbance into the investigated flows. The technique has been used for study a wide range of flow visualization. One main advantage using this technique is that, when properly implemented, it does not introduce any appreciable disturbance into investigated flows. Nevertheless for a variety of fluid phenomena, flow visualization via smoke wire remains the preferable technique. However application of smoke wire technique is limited to free stream velocity of about 5m/s

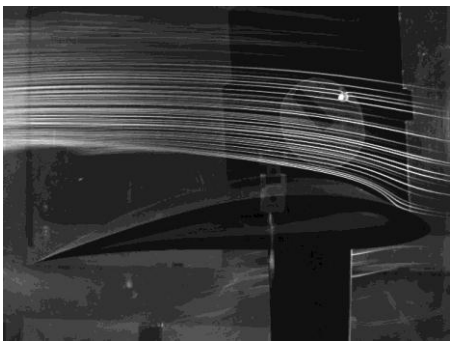

Figure 1: Flow visualization of the aerofoil model

The using of new technologies such as high speed camera and software to analyze the flow visualization based on the stagnation point location, separation line, location of boundary layer transition, characteristic unsteadiness, extent of separation zones, and type of critical point and their location.

In flow visualization, the method mostly used is using tuft wand and smoke generator. For this project, smoke wire is used for flow visualization since it applicable for low speed wind tunnel.

This project has done before by Muhamad Khairun Bin Kamaruzaman. His design is for single operation using nicrome wire, safex smoke fluid for smoke liquid, specified velocities below 5m/s and voltage about 10v. In previous design, the operating speed range of the smoke wire apparatus is not being specified. The apparatus also is not easily to be set up, since user needs to manually find the equipment and install to the wind tunnel.

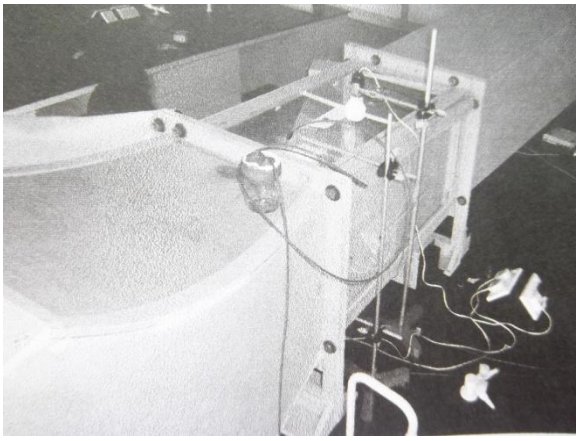

Figure 2: Smoke wire apparatus design by Muhamad Khairun

1.2: Problem Statement

1.21 Problem Identification

This project focuses on design and construction of smoke wire apparatus for wind tunnel flow visualization. To use this smoke wire technique, equipment is needed to be set up. The equipment is bulky since it is heavy and big. Besides that, there are many wiring that need to be ensuring in good position. To achieve the function of smoke wire as visualization medium, there are many parameters need to be determine. The smoke wire should be able to visualize the flow profile passing a bluff object in the wind tunnel test section; UTP has 2 subsonic wind tunnels, however, none of them been equipped with smoke wire apparatus.

To get the good flow visualization using smoke wire apparatus, the liquid known as smoke liquid is needed. However, it is hardly available around the market. Moreover, the price is higher which cost around RM 90 per litter.

1.22 Significance of the project

Smoke wire technique is a good option to be used to visualize flow behavior. However, there are no commercial portable smoke wire apparatus available in the market. Smoke generator has been used for flow visualization. It has advantages of easy to use and install. However, smoke generator can be very expensive and this increase burden of university management to buy new commercial smoke fluid to replenish. Smoke wire technique can be used with the smoke generator to produce good result. Its main component, which is heated wire and smoke liquid, is an important aspect that can be look trough for getting clear view of flow visualization,

The vegetable oil has been known to produce smoke when heated at certain temperature when cooking. It is easily available and cheaper around the market. Smoke been generated by vegetable oil has been analyzed and compared to the commercial smoke liquid.

1.3: Objective & Scope of Study

1. To design portable smoke wire apparatus for wind tunnel flow visualization.
2. To research other type of smoke liquid that has same capabilities to produce same result as the commercial smoke liquid.

1.3.1 The Relevancy of the Project

Even though flow visualization technique is been used by many university researcher around the world, in Universiti Teknologi PETRONAS(UTP), the flow visualization technique is limited by using commercial smoke generator.In this project, the research is made by using the variable of smoke liquid and heated wire, to achieve good visibility of flow visualization with low cost Thus, the smoke wire apparatus can be utilized by student and researcher to get more understanding of the fluid behaviour in the future.

1.3.2 Feasibility of the Project within scope and time frame.

There are a lot of references of studies that can be used for this project as it was already developed so it is actually able to be completed in the period of one year. The equipment and materials needed for the project are readily available in the Mechanical Engineering Lab as well as the chemicals involved. The equipment that needed to buy for this project is the variable of wire, small pump, commercial smoke liquid and vegetable oil. This project can be considered as a feasible project and can be done in the time frame as stated, so there should be no problem across. For this FYP1, the design of the portable of smoke wire apparatus, experimental procedure, location of the smoke wire apparatus and components/software that need to be used has been decided. For FYP2, the fabrication of the portable smoke wire apparatus and the experiment to determine the parameter of smoke wire apparatus been done.

The experiment to determine the vegetable oil that can give same result in terms of smoke generated when compared to commercial smoke liquid also been done.

CHAPTER 2 : LITERATURE REVIEW

2.1 Flow Visualization

Interpretation of fluid flow pattern serve as important tool used to investigate and understand the physics of flow pattern and turbulence. The flow patterns can be display in many techniques. When it involving the air, the smoke is been suggested as the medium to present the flow pattern in wind tunnel.

2.11 Smoke Tunnel

This is one of the equipment uses in flow visualization involving air in a low turbulence wind tunnel. The concept of smoke tunnel is an experimental wind tunnel in which air movements are observed by means of smoke filaments released at suitable points. The are many type of smoke liquid been used to get clear view of flow visualization, however, mostly the type of smoke use are vaporized light oil, kerosene or glycerine and other type of commercial smoke liquid. Smoke tunnel is the best equipment been used to generate good smoke flow visualization. Universiti Teknologi PETRONAS have one of these types of wind tunnel used for flow visualization.

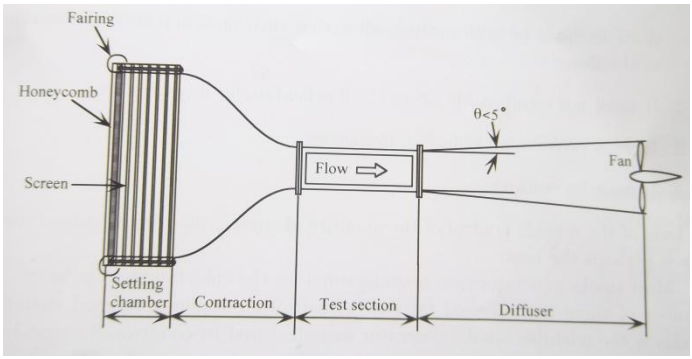

Figure 3: Schematic of smoke tunnel setup

2.13 Smoke Generator

Smoke generator is an equipment been used widely for flow visualization in wind tunnel. This type of equipment will produce smoke particle that sufficiently small that reflect the motion of the flow. This smoke generator was designed to facilitate the observation of air movements and air tracing in many types of air flow situations,

primarily in wind tunnels and air flow visualization. It is a control unit that pumps oil to the tip of a probe. A low-voltage electrical coil at the probe tip heats the oil to produce a fine smoke trail. The smoke moves into the air stream smoothly and steadily. Adjusted control unit in the equipment used to change the smoke strength to suit the air flow conditions." A method reported by Shindo and Brask (1969)[1] that "works at velocities of over 44.7m/s is a vaporized petroleum product called Type 1962 Fog Juice which is used in theatrical production. Smoke generator consists of about 75in of 0.060 in outside diameter stainless steel tubing. To vaporize the fluid, 10-15A is applied ti the stainless steel tubing from the collet to point about 60.0 in a way inside a non-heat conducting handle. The power unit consist of a variac whose output is connected to 230V winding of a 1.5kVA 115:230 transformer. The variac is used to control the temperature on the stainless steel tubing by applying 0-50V. The tubing has 3 ohm resistance, so the current is limited to maximum of 15 A. The fluid reservoir is air tight and has a pressure regulator used to set plant air pressure abot 3oIb/in^2 to feed the fuel to the probe and a needle to control the flow rate. The volume of smoke needed is highly affected by air pressure, fuel flow and voltage"

There are many commercialize smoke generator available in the market. Each of the smoke generator been designed to suit for the wind tunnel application and entertainment.

Figure 4 : Smoke generator and delivery wand used for flow visualization in wind tunnel

The smoke is produced by peristaltic ally pumping innocuous, medicinal quality oil to the tip of a probe, where a low voltage electrical coil heats it to produce a dense plume of smoke, at exactly the point where it is needed. White colour smoke generated and follows the airstream of the flow. The probe is shaped to minimize wake generation, ensuring that the smoke can be entrained into the airstream smoothly.

2.13 Smoke Wire Technique

Smoke wire is a technique to produce fine filament of smoke for flow visualization. The smoke been produced by vaporizing the oil from wire heated by an electric current. During the heating time of smoke liquid, it will leave streaks of smoke in the air stream creating a streak like pattern to the flow. This technique allows for the introduction of very fine smoke streamlines into the flow field. The technique had been developing for measure velocity profiles in boundary layer. As describe by (David James Szarko,1993, pg8) " Smoke wire technique been limited to application involving low Reynolds numbers based on the wire diameter"[10] .

Compared to the smoke generator, this technique is inexpensive to implement. It required suitable oil, metal wire and power supply. Most commonly used material for the metal wire is nicrome, stainless steel and tungsten. These types of material have resistivity to heat the oil to boiling temperature which the smoke will produce. For low speed application, smaller diameter wire is recommended as it can produced smoke which is sharper. At higher speed, a larger diameter is better because its larger surface area can maintain higher smoking rate, and since the wires are typically stretched taut, it will able to accommodate required tension at higher temperature. The application of smoke wire is limited to maximum velocity of 6.096 m/s due to"prevent the wake from the wire from disturbing the blow behind the wire and the limit has been determined by experiment "(Jewel B.Barlow, 1999, pg 211)[1].To minimize the flow disturbance, the Reynolds numbers should be less than 2000.

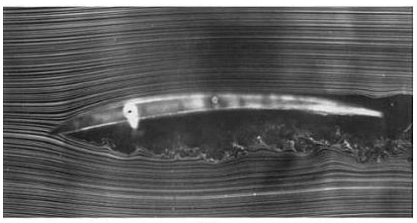

Figure 3: Smoke produced by smoke wire

There are variation of oils which can be used to produce smoke filaments, including kerosene, lubricating oil, kerosene and paraffin. To ensure the smoke is produced uniformly along the length of wire, it's essential that the wire is coated uniformly with the oil. The coating may be applied by gravity feed technique or physically applied using brushes.

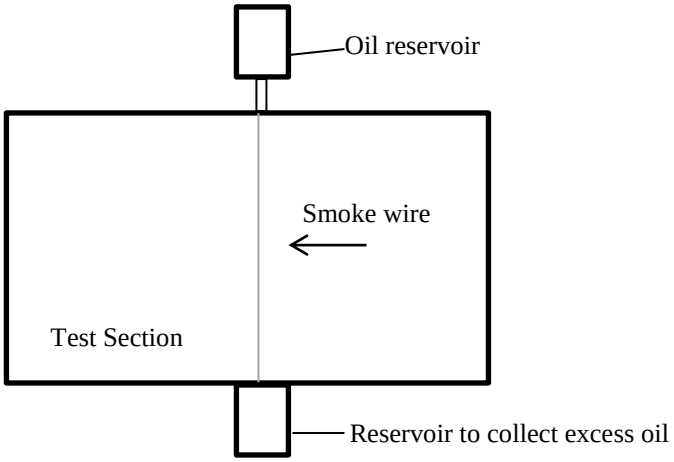

Figure 4: Gravity feed technique

Gravity feed technique has several advantages which easily been installed, however, it not effective as manual coating technique. Using manual coating technique, can control the thickness of the oil been applied to the wire, but it is tedious and troublesome. However, this technique is good to get the result that not affected by different coating thickness of oil.

There are technique been develop by Liu & Ng (1990). The system made of two parts, wire drive system and control circuit. The wire end been connected to the pulley, driven by the stepper motor, other end is attached to the weight to provide with necessary tension [9]. Located outside the test section is the small paint brushes connected to electro-magnetic solenoid actuator. During operation, the stepper motor turns first one way, which pull the wire down, while at same time the upper solenoid is activated to push the brush containing mineral oil against wire. This enables the wire to be coated evenly with the oil. The amount of the smoke produced depends on voltage and current applied to the wire. The whole system is fully operates and control by electronic circuit.

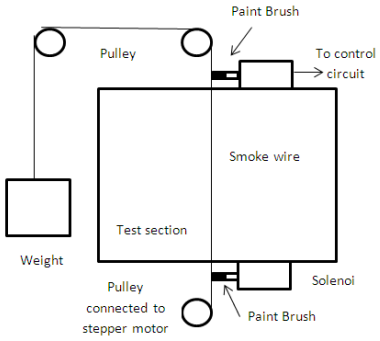

Figure 5: Schematic of an automatic oil coating system used by Liu & Ng (1990)

2.2 Electric resistance

Formula to be used in calculating resistance of wire is

$$R = \frac{p\partial}{A}$$

Where, R= resistance of wire

L = Length of wire

p = Resistivity of wire

From the equation, as the resistance of the wire increase, the diameter decrease and length increases. Therefore, to select suitable wire, the smaller the diameter wire will give higher resistance. Other factor is depend on the wire material been selected.

2.3 Joule heating

Joule heating, also known as ohmic heating and resistive heating, is the process by which the passage of an electric current through a conductor releases heat.[5] At atomic level, Joule heating is the result of moving electron that collide with atoms in conductor where upon momentum is transferred to the atom, increasing its kinetic energy[8]

2.3.1 Joule's Law

Physical law expressing the relationship between the heat generated by the current flowing through a conductor.[2]

$$Q = kI^2Rt$$

Where,

Q= Heat loss (Joule, J)

T= Time (seconds)

I = Current (Amphere, A)

R= Total resistance (Ohm,Ω)

K = The constant of proportionality

2.4 Heat Loss to Force Convection

To heat the wire and the smoke liquid, heat is needed. However, there are lost since convection occurs. The convective heat transfer coefficient is reliant upon the physical properties of the fluid and the physical situation. Usually, the convective heat transfer coefficient for certain flow such as laminar flow is quite low compared to the convective heat transfer coefficient for turbulent flow. . The Zhukauskas correlation on aerofoil blade can be used to determine the overall Nusselt number across the heating wire, the heat loss through force convection to wind tunnel flow also can be predicted.

The coefficient of convective heat transfer is to be determined as below,

$$Nu_d = CPr^n \frac{Pr}{Pr_s}.^{\frac{1}{4}} = \frac{h}{k}D$$

$$\text{h} = (\ \text{Nu}_\text{D}\text{k}\ ).\ D = = (CRe^m Pr^n\ \ \frac{Pr}{Pr_s}.^{\frac{1}{4}}\ \ k)\ /\text{D}$$

Where

Nu_d = Overall Nusselt Number

Re = External flow Reynolds number with wire diameter as characteristic length

Pr = Prandlt number evaluated at temperature of free stream flow

Pr_s= Prandlt number evaluated at surface temperature

K= Conductivity of the fluid (W/m.K0

D= Diameter of wire (m)

Based on (Khairun , 2005) "All properties are evaluated at flow temperature (T) except for Pr_s. Value of constant C and m are dependent of boundary layer Reynold Number across the wire which is based on table 1.[8] For value of n, if Pr is lower than 10, n is equal to 0.37 and if Pr is larger than 10, n is equal to 0.36 "

Table 1: Constant of Zhukauskas correlation for circular cylinder in cross flow

Re	C	M
1-40	0.75	0.4
40-1000	0.51	0.5
10^3 -2 x 10^5	0.26	0.6
2 x 10^5 - 10^6	0.076	0.7

2.5 Flow across Aerofoil Blade

For typical external flows, the most important parameter are the Reynolds number, the Mach number and the Froude number. To differentiate the characteristics of flow, the Reynolds number is widely been used. The number correlation is as follows;

$$Re = \frac{pV\zeta}{\mu}$$

Where

P = external fluid density
V= fluid flows
l = characteristic length
μ = fluid viscosity

The Reynolds number actually represents the ratio of the inertial effects in the flow, to viscous effects in the flow. Inertia itself is the property of an object to remain at a constant velocity, unless an outside force acts on it. When the inertia is bigger, it will resist changing velocity means hard to start and stop. It may cause instabilities in the flow to develop, and thus the flow will become turbulent when inertial effects are dominant, for large Reynolds numbers. For small number or Reynolds, flow always laminar. Critical Reynolds that can cause the flow become turbulent is at 2100. For objects that are no sufficiently streamlined, flow separation is observed

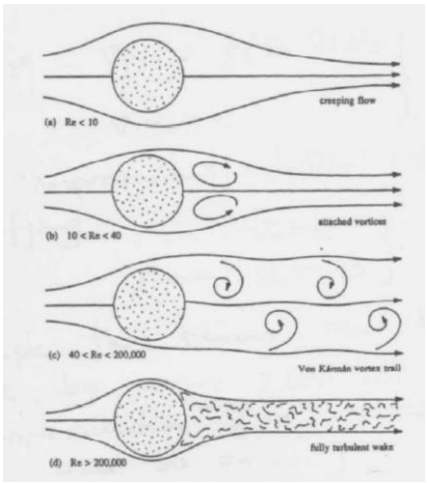

Figure 6: Patterns in fluid flow around a cylinder as a function of the Reynolds number

2.6 Wind Tunnel Universiti Teknologi PETRONAS

Wind tunnel been used in Universiti Teknologi PETRONAS is Subsonic Wind Tunnel. It is a suction type open circuit wind tunnel designed to conduct research experiment related to fluid mechanics and aerodynamics. The model of the object to be tested, called the prototype is placed in the test section of the wind tunnel. Wind tunnel test speeds up to about 60m/s can be obtained. This wind tunnel is chosen to be equipped with smoke wire apparatus, which is been installed to the system. Tunnel operation, control, data acquisition and processing of data are through a computer based system.

Figure 7: Subsonic Wind Tunnel UTP

Wind tunnel flow velocity range is between 0 to 50m/s. the overall dimensions of wind tunnel is 6.5m x 1.75m x 2.5m. The isometric view of subsonic wind tunnel been shown in figures 8 below. The design has been drawn using solid works.

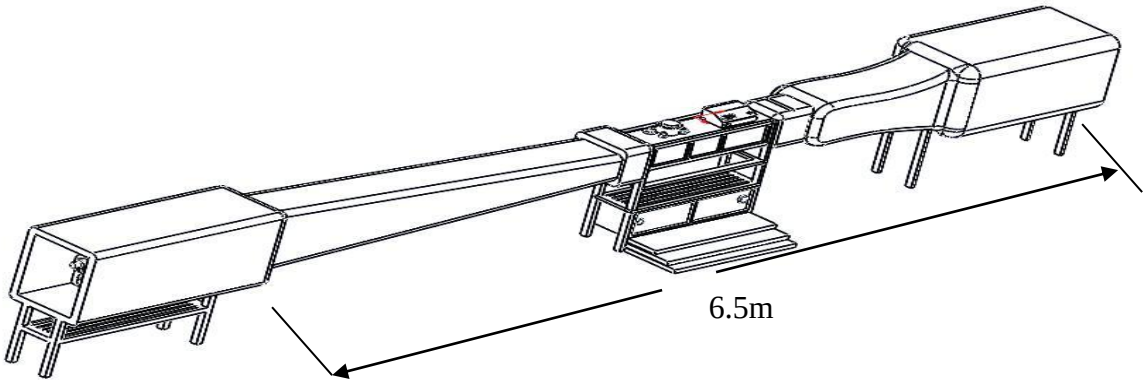

Figure 8: 3D view of subsonic wind tunnel

To ensure the flow visualization by smoke wire apparatus, it is important to ensure the flow profile inside the wind tunnel is qualified as a closed system. Criteria that needed to be follow are

1. Turbulent intensity is low (<1%)
2. Low speed
3. Flow inside the test section is steady

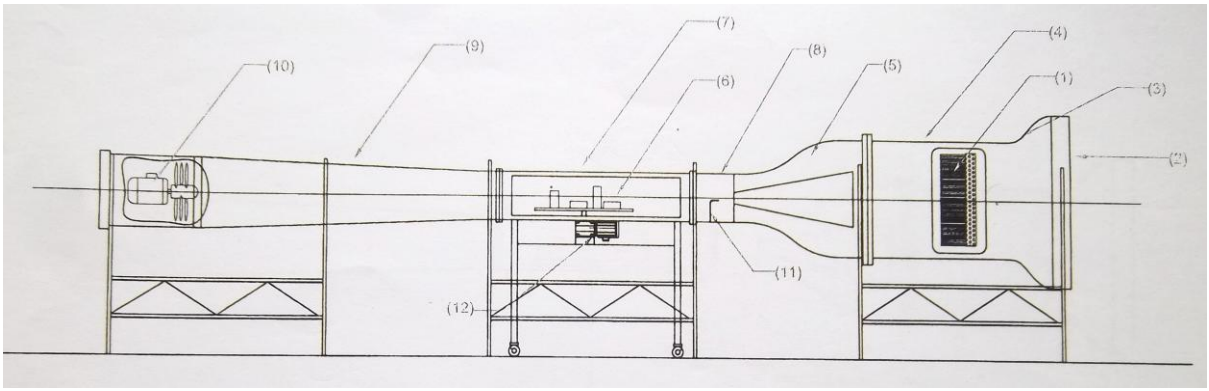

Figure 9: Sub sonic wind tunnel side view

Legend

1. Honeycomb
2. Air entry direction
3. Bell mouth entry
4. Laminar conditioner chamber
5. Contraction chamber
6. Test model
7. Test Section
8. Settling length
9. Diffuser chamber
10. Fan Unit
11. Pitot Tube
12. Turn table with motorize gear unit

CHAPTER 3
METHODOLOGY

Before this project can commence, the basic physical concept governing the process must first be understood. Therefore, thorough research and literature review will be conducted using resources from the library, online journal database and the internet.

3.1 Procedure Identifications

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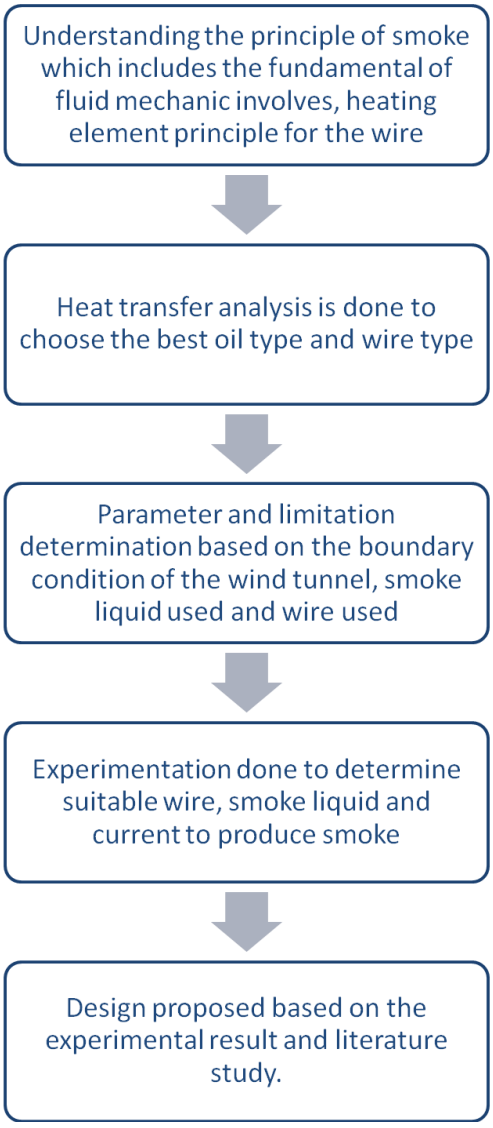


Figure 10 : Step to be used in design and fabricate smoke wire apparatus

3.2 Tools

Experiment need to be done in designing smoke wire apparatus, which involves investigating the flow profile of test section, determining the design parameter, and determining the flow rate of the oil delivered to the heating wire

1. Airflow anemometer
2. Camera
3. Weigh measurement
4. Halogen lamp
5. Air Pump
6. Adjustable voltage regulator (power supply)

3.3 Software

Result of capture image need to be processed using specified software to be analyzed such as the Adobe Photoshop is used to edit the digital photograph captured. Below are the software used in complementing FYP

1. AutoCAD
2. Solid Works
3. Microsoft Excel
4. Adobe Photoshop

3.4 Type of liquid to be used for experiment

3 Fog Liquid Antari (Commercial smoke liquid)

4 Sun Flower Seed Oil

5 Coconut Oil

6 Soy bean Oil

7 Olive Oil

3.5 Type of wire to be use for experiment

1. Nichrome
2. Copper

3.6 Project Activities

3.61 Experiment Set Up

Experiment need to be done to find suitable size of wire to be used, type of smoke liquid and range of speed, to produce technical parameter for producing smoke wire apparatus. The list of experiment been done are:

1. To find suitable wire size(diameter) for producing good smoke visibility
2. To determine the wind tunnel range speed when the smoke wire apparatus in operation
3. To find the best smoke liquid that have same potential as commercial smoke liquid
4. To determine the flow rate of the oil for continuous operation.
5. Smoke flow visualization across Aerofoil blade

From this experiment, the smoke produced been observed to ensure it can give clear view of the flow visualization across Aerofoil blade.

3.62 To find suitable wire size (diameter) for producing good smoke visibility

The different size of wire diameter has been analyzed using Joule formula to find heat release at variable current supplied. Then the experiment has been setup at the wind tunnel. From the analysis, the 12 types of wire been tested

Apparatus been used

1. Adjustable voltage regulator (power supply)
2. Hot wire anemometer (to identify speed in the test section)
3. DSLR Camera / High Speed Camera
4. Halogen lamp

Chemical been used: Commercial smoke liquid (HLZ Antari)

3.63 To determine the wind tunnel range speed when the smoke wire apparatus in operation

The speed of the wind tunnel is key important element need to be identified when the smoke wire apparatus operated. Suitable speed that can produce good visibility of smoke was determined. Chemical been used: Commercial smoke liquid (HLZ Antari)

The equipment been setup as below

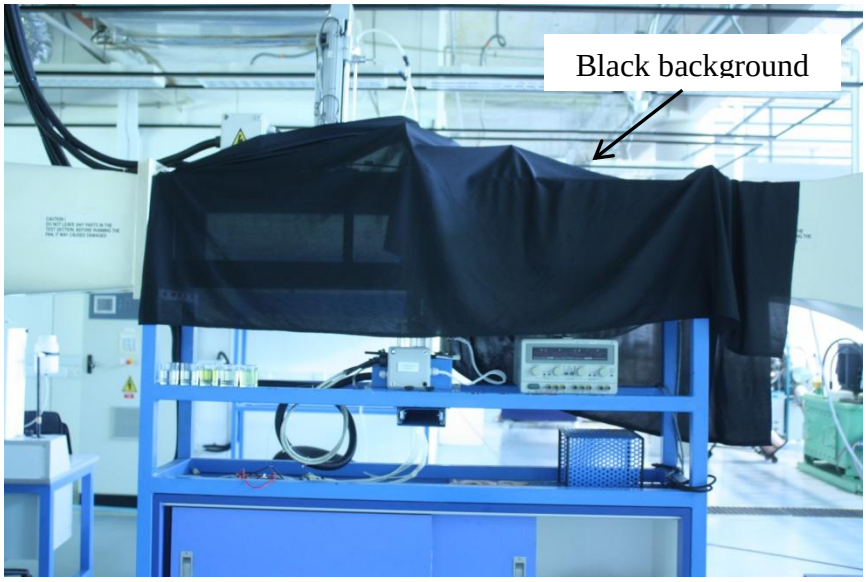


Figure 12: Front view equipment set up

Figure 11: Side view equipment set up

Details of equipment

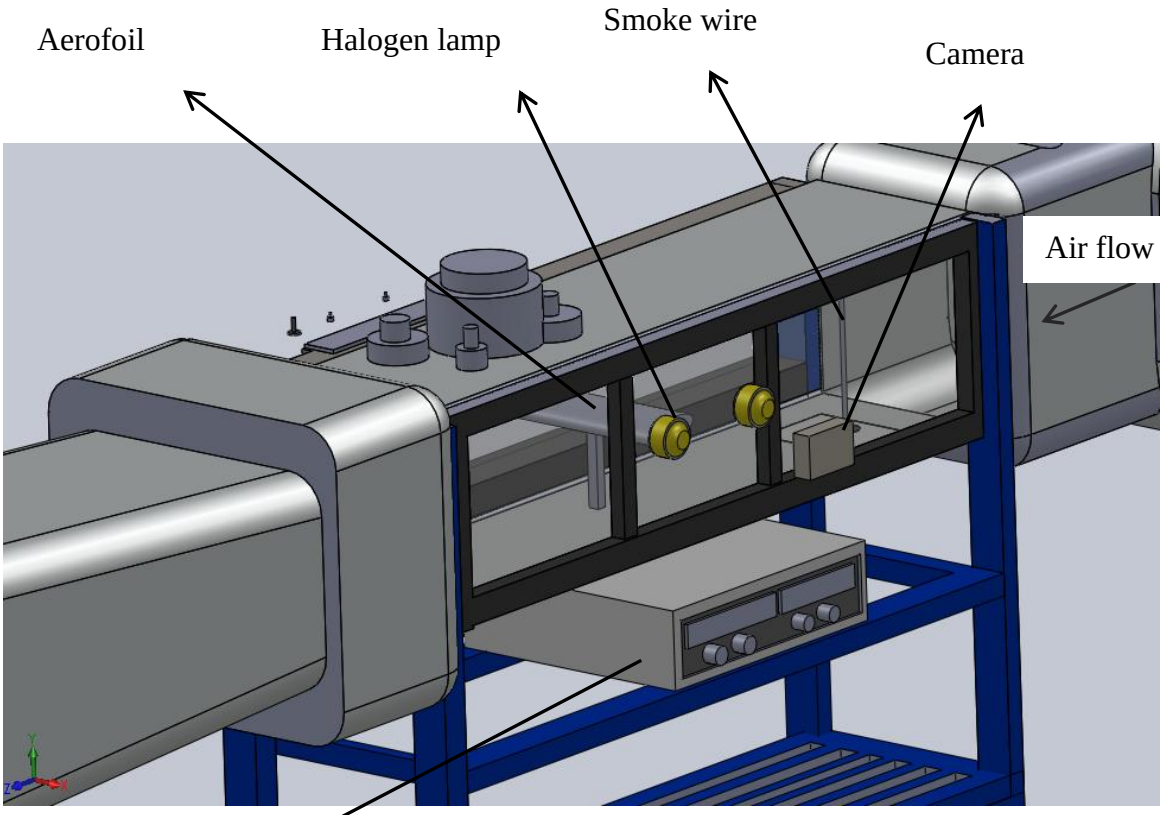


Figure 13 : Experiment Set Up

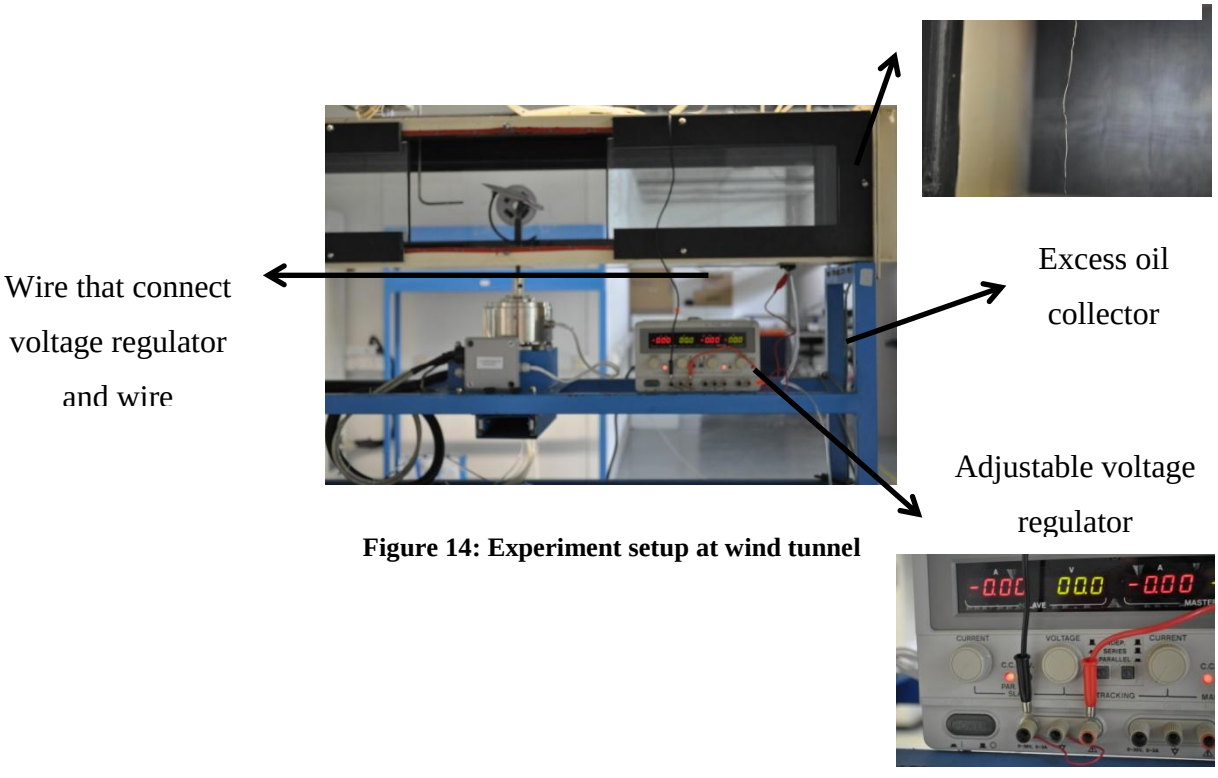


Figure 14: Experiment setup at wind tunnel

3.64 To find the best smoke liquid that has same potential as commercial smoke liquid

Each vegetable oil been used been analyzed using heat transfer concept. The smoke produced by the vegetable oil been observed using eye.

Liquid used

1. Fog Liquid Antari (Commercial smoke liquid)
2. Sun Flower Seed Oil
3. Coconut Oil
4. Soy bean Oil
5. Olive Oil

Figure 15: Vegetable oil used in the experiment

3.65 To determine oil flow rate of the oil for continuous operation.

The oil flow rate of the liquid been used that been supply to the heated wire need to be calculated and determine. The equipment been used has been stated as below

1. Digital weight measurement
2. Air pump
3. Stopwatch

Chemical been used

1. Commercial smoke liquid (HLZ Antari)

The oil reservoir been placed above the test section of wind tunnel. Tube been connected with air pump will create high pressure inside the reservoir and push out the liquid to the heated wire

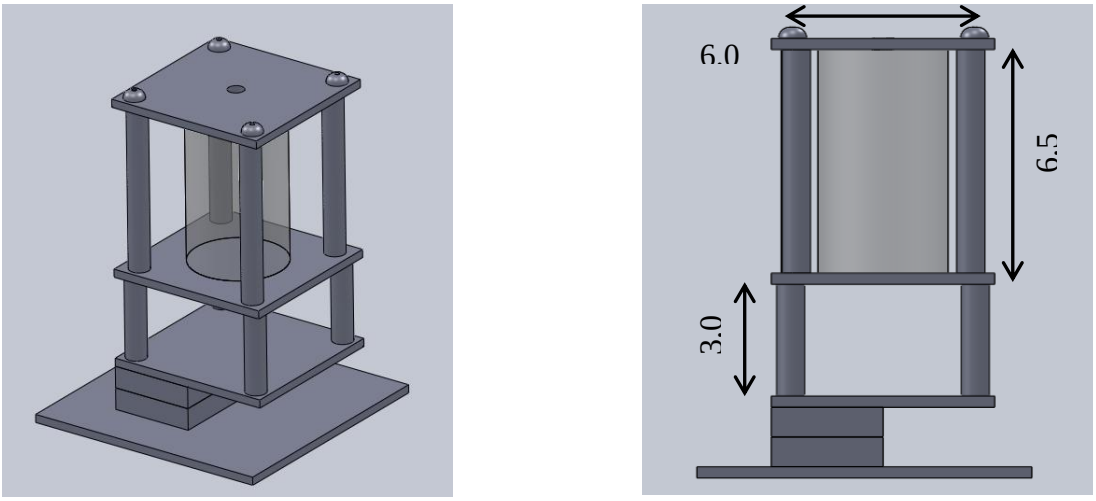


Figure 16: Oil delivery system parameter

Based on figure, the oil reservoir is placed on top of the test section under the portable smoke wire apparatus box. A tube will supply air, which causes high pressure in the cylinder tube, cause the smoke fluid to push out to the heating wire. The principle been used is gravitational positional energy

3.66 Smoke flow visualization across aerofoil blade

The experiment been done to prove the smoke wire apparatus been design and build can produce good visibility of flow visualization across Aerofoil blade. The flow of the smoke across Aerofoil blade had been capture using high speed camera.

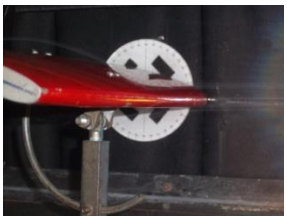


Figure 17: Aerofoil blade

The equipment needed as follow

1. Final design of smoke wire apparatus
2. Hot wire anemometer (to identify speed in the test section)
3. DSLR Camera / High Speed Camera
4. Halogen lamp

CHAPTER 4
RESULT AND DISCUSSION

4.1 Finding

4.1.1 Wire type and diameter

Different wire can produce difference heat release to surrounding. For this experiment there are 2 types of wire been chosen which are copper and nichrome. The wire should able to dissipate the suitable amount of heat supplied at supplied voltage to produce good smoke visibility. The properties of the wire been shown below.

Table 2: wire properties

Material	Nicrome	Copper
Diameter	0.28 and 0.16	0.16
Resistivity	17.1 x 10^-6	1.5 x 10^-6
Composition	99% copper	80% nickel , 20% chromium
Melting point	1084.62^{o}C	1350^{o}C

When current been applied to the wire, there will be potential difference that cause the free accelerated and gain kinetic energy. As the electron move through the wire, they will collide with the positive ion and transfer the kinetic energy to them. Increasing thermal energy of lattice will increase temperature of the conductor cause it been release into heat.

The amount of heat produced in time t is

$$\text{Heat: } I^2Rt = V^2t/R$$

Resistance is dependent of length of wire, resistivity of wire and cross section area. The correlation shown as equation

$$R = pl / A$$

Where, R = Resistance of wire, L = Length of wire p = Resistivity of wire

Several constraints have been determined to investigate the effect of resistance to the heat loss of wire.

Wire length = 0.33 m	Voltage supplied: 0-30V

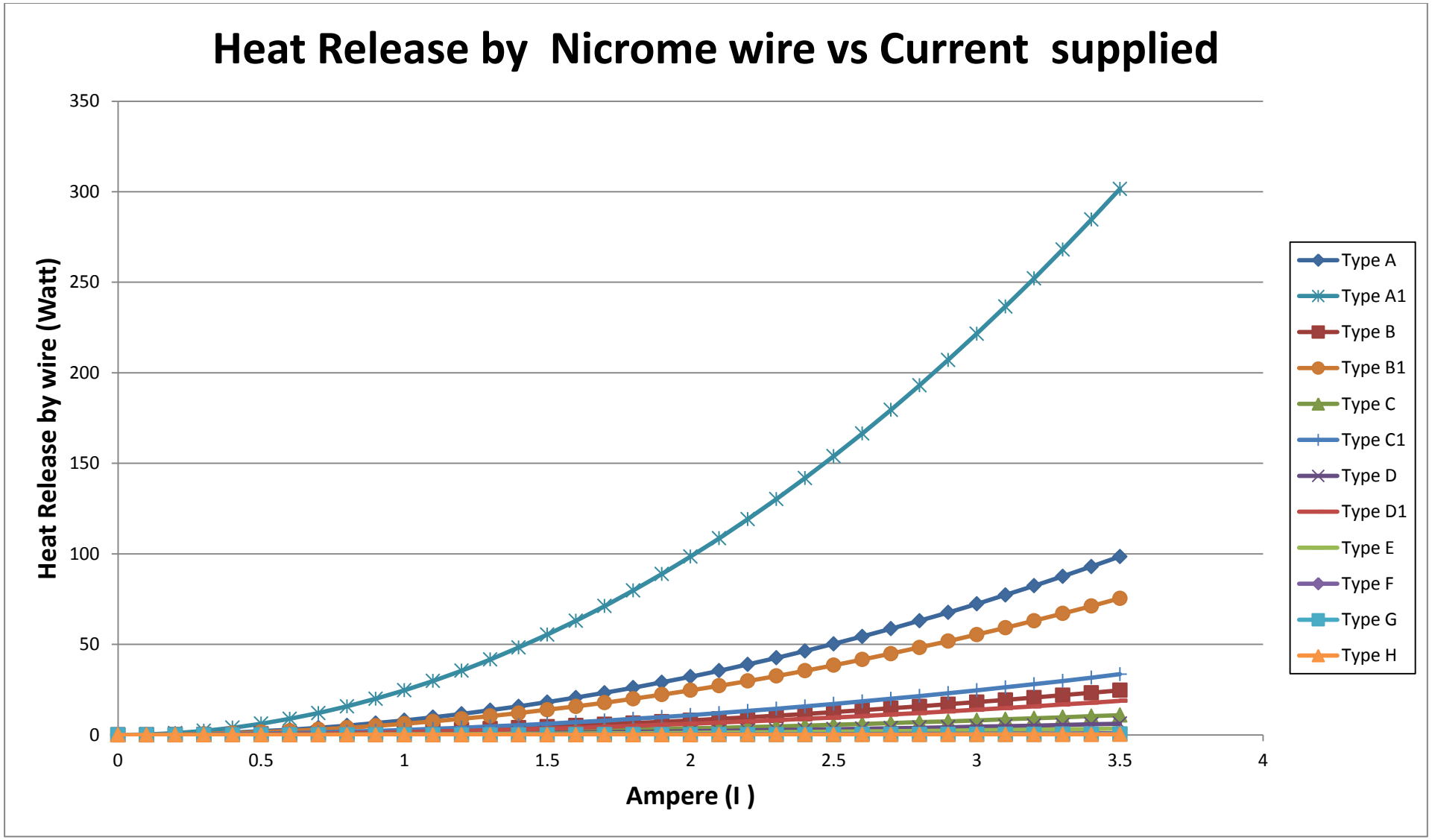
To increase the diameter of the wire, the 2 or 3 wires has been coiled to become one wire. Different diameter will give different resistance as the resistivity is constant.

The calculation been done using Microsoft Excel, and the result has been plotted to identified the heat loss from wire as supplied ampere. To find the heat loss, the equation Joule's Law equation has been used

Table 3: wire type and resistance on selected material

Material	Type	Design	Diameter(mm)	Resistivity (Ωm)	Resistance (Ω)
Nicrome wire	Type A	Single Wire	0.28	$1.5x10^{-6}$	8.04
	Type B	2 coiled wire	0.56		2.01
	Type C	3 coiled wire	0.84		0.89
	Type D	4 coiled wire	1.12		0.50
	Type A1	Single Wire	0.16		24.62
	Type B1	2 coiled wire	0.32		6.15
	Type C1	3 coiled wire	0.48		2.74
	Type D1	4 coiled wire	0.64		1.54
Copper Wire	Type E	Single Wire	0.16	$17.1x10^{-6}$	0.28
	Type F	2 coiled wire	0.32		0.07
	Type G	3 coiled wire	0.48		0.03
	Type H	4 coiled wire	0.64		0.02

From the graph, nicrome wire diameter 0.16 (type A1) release the highest heat compare to other type of wire. As the diameter increase, the heat release by the wire also reduced.



Graph 1: Heat release by different wire type

4.1.2 Chemical liquid analysis

The liquid that will be used in this experiment is vegetable oil and commercial smoke liquid (fog liquid Antari HLZ-1). Vegetable oil has higher boiling rate that and capable to produce good smoke visibility. Several assumptions been made:

- There are about 15% heat release/ dissipated by the wire loss through radiation
- The 85%, remaining heat is transferred to liquid been used, to surpass the latent heat of vaporization, and force convection to the wind tunnel flow (assuming all heat is transferred to the fluid)
- Surface temperature (T_s) is same as boiling point (T_b) of oil by assuming the surface of heated wire is all covered by the oil
- The analysis is done at 1.5m/s wind tunnel velocity to compare with the experiment done.
- The room temperature is between 21^{o}C to 25^{o}C. (use 23^{o}C)

Based on the assumption above, the heat transfer for the system is as below

$$0.85IR^2 = mc_p(T_b-T_0) = mh_v + hA(T_s-T_0)$$

M = mass flow rate of oil (kg/s)

Cp= Specific heat capacity at constant pressure (KJ/kg.K)

Hv = Latent heat of vaporization

H = convective coefficient (W/m2.k)

A = Surface area (m2)

T_b= Boiling points of oil

The equation can be used when the flow is affected with convection. Evaluate as forced convection since the flow is imposed by fan, the convective coefficient is obtained from Zhukauskas correlation on circular cylinder in cross flow as shown by equation before. The convection heat transfer is been valued at 296K. (23^{o}C)

Table 4: Properties of air at 296K

Constant	Value (At temperature 296K)
Dynamic air viscocity	1.826x10-5 Ns/m2
Air density	1.164kg/m3
Fluid conductivity	25.98x10-3W/m.K
Prandlt number	0.708

There are 6 different fluid has been used to tested as the smoke liquid. The liquid has been analyzed and checked the boiling points of the liquid. Most of the vegetable oil, do not have exact value of boiling points, but have specific value of smoke point. Smoke points refer to the temperature when oil start to breakdown glycerol and free fatty acids and produce bluish smoke. The glycerol then starts to further breakdown to acrolein which is a component of smoke. From this point, the smoke will generate..

Table 5: Properties smoke liquid

No	Type	Classification	Smoke Point (K)	Boiling Point (C)	Latent heat of vaporization (J/g)
1	Sun flower seed	Vegetable Oil	539	~	321
2	Coconut Oil		505	~	360
3	Olive Virgin		472	~	450
4	Soybean Oil		511	~	342

4.2 Experimental Work

4.2.1 To find suitable wire size (diameter) for producing good smoke visibility and determine the wind tunnel range speed when the smoke wire apparatus in operation

Using Adjustable voltage regulator and hotwire anemometer, the experiment been tested as procedure in appendix. 1.1

Table 6: Smoke generated by different wind tunnel velocity and wire type

Wind Tunnel Velocity (m/s)	Smoke Properties A1 (wire diameter 0.16)	Smoke Properties A (wire diameter 0.28)	Smoke Properties B1 (wire diameter 0.32)	Smoke Properties B (wire diameter 0.56)
0.5	The smoke clearly visible, and sharp along the wire.	The smoke generated is very light and visible in short duration.	. The smoke is not sharp as when using wire diameter 0.28mm. The smoke generated is clear and uniform along the wire	The smoke visible in short duration and non-uniform at early stage of the smoke produce along the wire.
	4.1V, 0.64A	5.8V, 0.79A	5.9V,1.01A	8.3v, 2.18A
	8 seconds	8 seconds	12 seconds	14 seconds

1.0	Smoke is too thin and hardly visible to see.	. Smoke generated clearly visible, and thin. Smoke duration is around 12s.	**Smoke becomes thin from previous. Smoke generated clearly visible, dense and uniform**	Smoke generated visible, and uniform.
	Smoke generated: 5.2V,0.9A	Smoke generated: 6.1V,0.9A	**8.8V, 1.5A**	9.2V, 1.34A
	Duration : 7 seconds	Duration : 10 seconds	**Duration :14 seconds**	Duration : 16 seconds
1.5	Smoke is hardly visible to see as the smoke become too thin to see.	The shorter duration of smoke.. At this speed, the smoke is hardly visible.	Smoke is hardly visible to see as the smoke become to thin for flow visualization.	Smoke is hardly visible to see.. At this speed, the smoke become thin, but can be clearly see.
	6.5V, 0.98A	8.6V,1.64A	8.8V,2.46	10.3V, 2.95A
	Duration : -	Duration : -	Duration : -	Duration : 12 seconds
2.0	At 2m/s, the type A1,is unpractical to be used, since the smoke is hardly to see.	At this speed, the smoke is become too thin to be seen.	At this speed, the smoke is become too thin to be seen	At this speed, the smoke is hardly visible.
	7.8v,1.3A	8.68V,1.93A	9.68V,2.34A	11.1V,2.66A

Wind Tunnel Velocity (m/s)	Smoke Properties C1 3coiled wire (wire diameter 0.48)	Smoke Properties C 3 coiled wire (wire diameter 0.84)	Smoke Properties D1 4 coiled wire (wire diameter 0.64)	Smoke Properties D 4 coiled wire (wire diameter 1.12)
0.5	The smoke visible in short duration and non-uniform at early stage of the smoke produce along the wire.	The smoke visible in long duration and it produce thin smoke.	Smoke generated visible, and dense.	. The smoke generated is dense, not uniform.
	8.3V,2.18A	9.6V,2.18A	10.1V,1.92A	10.1V,2.1A
	Duration : 12 seconds	Duration : 17 seconds	Duration : 16 seconds	Duration : 20 seconds
1.0	. Smoke generated visible, and uniform.	Smoke generated clearly visible, and uniform.	Smoke generated dense and thin	the smoke is too dense and the smoke not uniform
	9.2V,1.34A	9.8V,2.56A	8.6V,2.6A	9.1V,3.1A

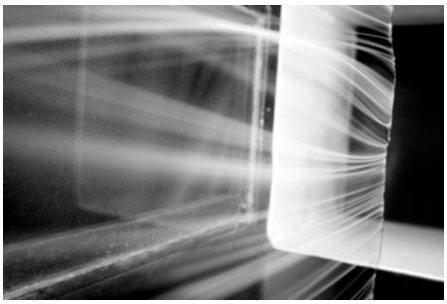
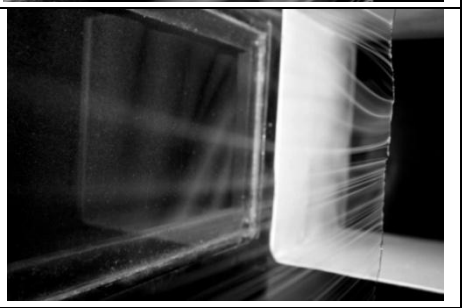
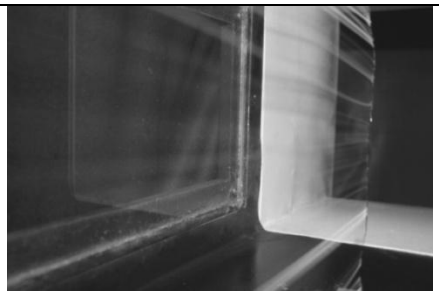
	Duration : 16 seconds	Duration : 19 seconds	Duration : 18 seconds	Duration : 22++ seconds
1.5	Smoke is hardly visible to see.. At this speed, the smoke become thin, but can be clearly see	.. At this speed, the smoke become thin, but can be clearly see.	Smoke generated visible, dense and thin. Uniform along the wire.	the smoke become thin, but can be clearly see and produce good visibility. Not uniform
	10.3V,2.95A	10.8V,2.84A	10.5V,3.17A	11.8V,3.4A
	Duration : 12 seconds	Duration : 15 seconds	Duration : 20	Duration : 20 ++
2.00	At this speed, the smoke is hardly visible	. At this speed, the smoke is hardly visible.	Smoke generated clearly visible, and uniform.	.The smoke is steady but to thin. Uniform along the wire
	11.1V,2.66A	11.5V,3.16A	11.5V,1.34A	11.85V,3.46A
	Duration : -	Duration : -	Duration :25	Duration : -

For copper wire, no smoke generated at any voltage and ampere. This may due to low resistance of copper which provide insufficient heat to boil smoke liquid.

Based on the result above, the best wire design are type B1(Ø0.32mm) , B(Ø0.056mm) and C2(Ø0.84mm) since they generate clear, uniform smoke. For the purposed of the flow visualization, wind tunnel velocity of 1m/s is chosen by considering the smoke visualization.

Since only nicrome wire can generate the smoke, the experiment is repeated to wire design type B1, B and C2 at wind tunnel speed 1m/s

Table 7: Image smoke generated by wire type B2,B and C2

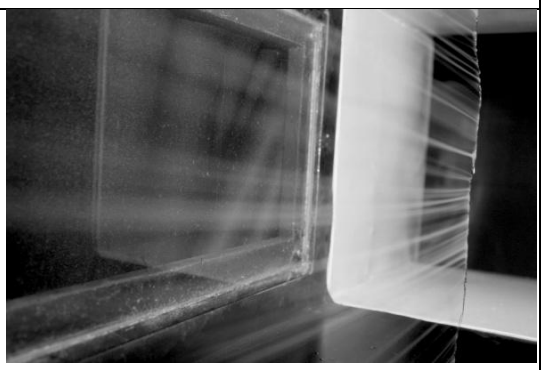
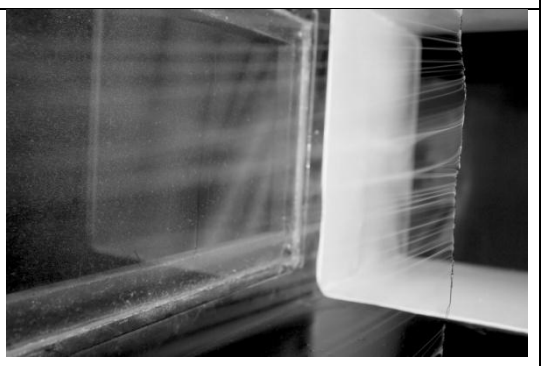
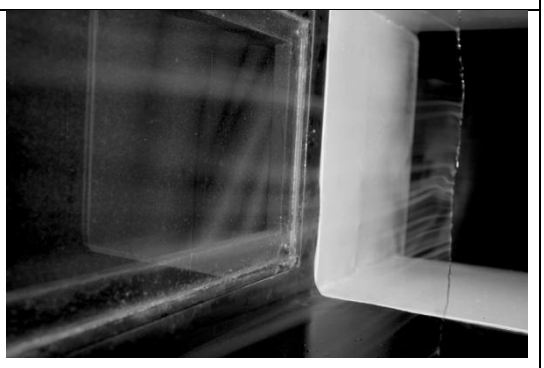
Wire Type	Smoke Property	Image
B1(Ø0.32mm)	Smoke been generated is uniform, and dense. Short duration of smoke	
B(Ø0.56mm)	Smoke been generated is uniform but smaller than wire type B1. Short duration of smoke	
C1(Ø0.84mm)	Smoke been generated is bit thinner than type B because it have lower resistance. Long duration of smoke	

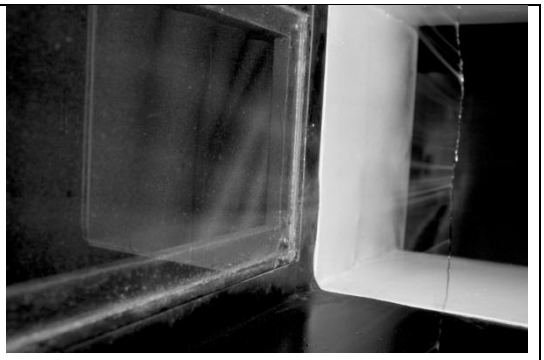
From the table above, the suitable type of wire to be used is type B1, because it produces dense and uniform smoke during the experiment. The current supply to the wire is 8.8v and 1.5A.Since the experiment been affected by surrounding temperature and liquid, the range to of current supply to the wire is 8 to 11v and current at 1.2 to 2.2 ampere.

4.2.2 To find the best smoke liquid that has same potential as commercial smoke liquid

Using wire type B1 and power supply at 11.6V, 2.8A, vegetable oil been tested as procedure in appendix. 1.2

Table 8: Smoke generated by different liquid

	Smoke Property	Picture
Sunflower Seed Oil	The smoke bit denser at beginning till the end.	
Coconut Oil	The smoke generated by coconut oil is thinner than sunflower seed oil.	
Olive virgin Oil	The smoke generated by olive virgin oil thinner than coconut oil	

Soybean Oil	The smoke generated by soybean oil is hardly visible to see.	
Fog Liquid Antari HLZ-1	Clear smoke generated for any wire design.	

From the table 8 above, the liquid that have capabilities same as smoke commercial liquid is Sun Flower seed oil and Coconut oil.

Ranking clarity of the smoke generated from vegetable oil

1. Sun Flower Seed Oil
2. Coconut Oil
3. Olive Virgin Oil
4. Soy Bean Oil

. 4.2.3 To determine oil flow rate for continuous operation

Figure 18: Oil delivery system

Oil delivery system has been tested, and the result as below.

- Volume : 50 ml
- Mass : 31.94 g
- Density : 0.6388 g/cm^3
- Mass one drop : 0.0436g – 0.0039g = 0.0397g
- Temperature room : 24.1 C
- Oil flow rate : 1 drop/s

To produce continuous oil flow during this experiment, several calculations has been made to analyze the duration of the liquid reservoir can withstand.

Oil Flow rate: 1 drop in 1 second

Volume of reservoir = 50 cm^3

Figure 19: Digital weight measurement

Flow rate of the oils is 0.0397g/s. Duration of the oil can be supplied to the heated wire is

Mass of oil in reservoir = V reservoir / Density

= $50cm^3$/ $0.6388g/cm^3$

= 78.27g

Continuous smoke duration

= V reservoir / flow rate

= 78.27g / 0.0397g/s

= 1971.54s

= ***32 minute 51 seconds***

The duration of smoke produce is 32 minute 51 seconds.

Duration of smoke is very long. So the oil can be flow to the wire nonstop for 32 minutes. To avoid wasting the liquid, excess oil can be collected and recycle to the system

4.2.4 Smoke flow visualization across aerofoil blade

The experiment been done at different speed of wind tunnel. Which are 0.5/s, 1m/s, 1/5m/s and 2.0m/s .The result has been shown below. Flow pattern captured are as follow

At 0.5 m/s

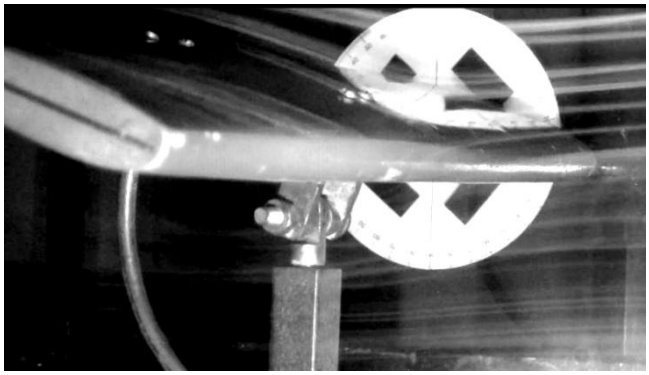


Figure 20: Flow pattern at 0.5m/s

At 1.0 m/s

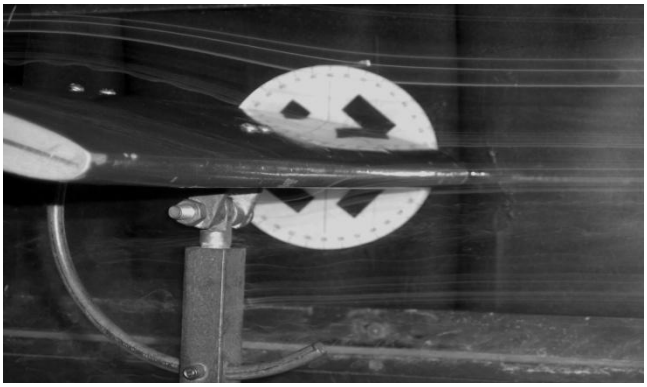


Figure 21: Flow pattern at 1.0m/s

At 1.5m/s

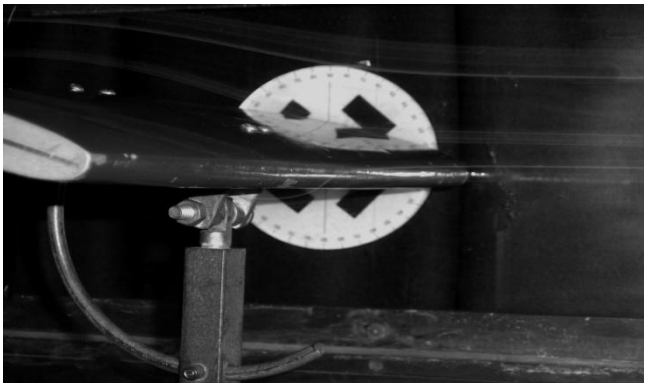


Figure 22: Flow pattern at 1.5m/s

At 2.0m/s

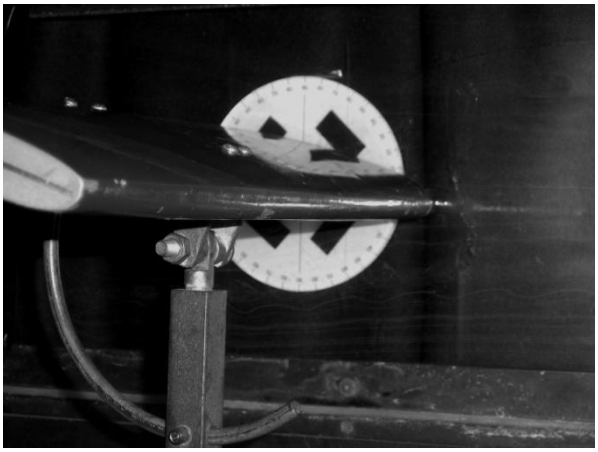


Figure 23: Flow pattern at 2.0m/s

Reynolds Number at different speed

External fluid density: 1.164kg/m3

L : characteristic length : 0.02

U : fluid viscosity = 1.826 x 10^-5

Table 9: Reynolds Number for different wind tunnel speed

Speed(m/s)	Reynolds Number	Type of flow
0.5	637.46	Laminar
1	1274.92	Laminar
1.5	1912.38	Laminar
2	2549.84	Laminar + Turbulent

Analysis of flow at 0.5m/s

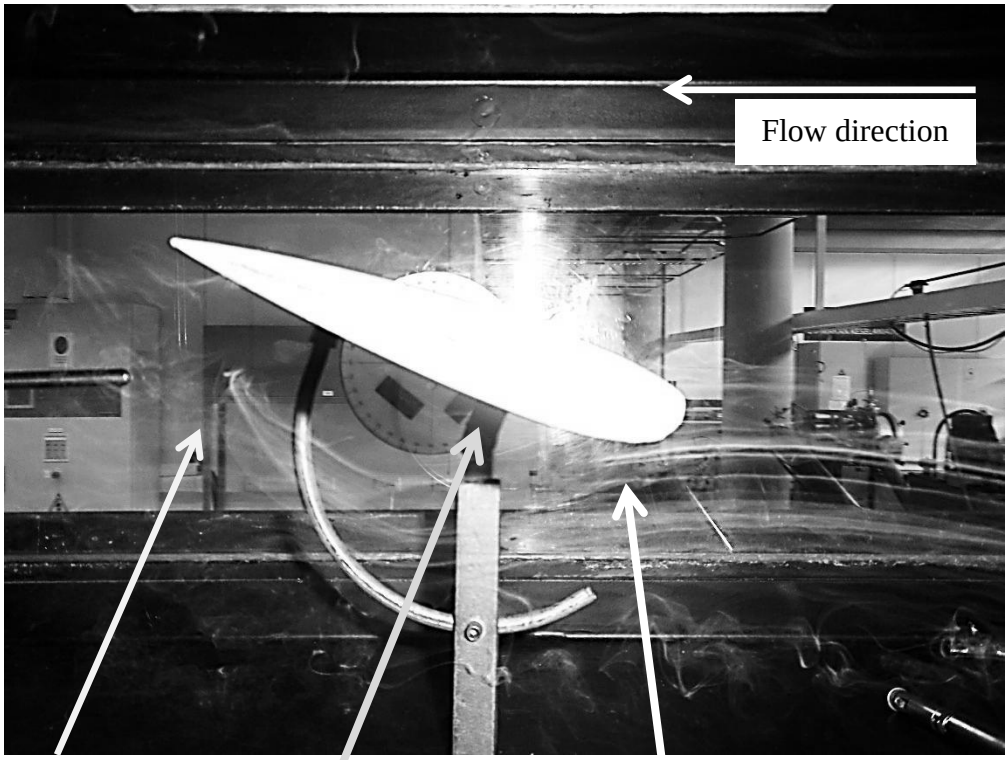


Figure 24: Flow pattern across blade

As smoke passing the aerofoil blade, the smoke been separated to several region. There are wake region, flow separation point, vortex, and recirculation can be seen in this experiment. At 0.5m/s, the flow is visualized by eye without needed any software to analyze the flow. However, at 1.5 m/s speed of wind tunnel, the smoke is hardly visible, since, the smoke become thinner and need to be capture by camera to be analyze in Adobe Photoshop software .

4.3 Discussion

Flow visualization is a method been used to generate smoke in filament that been used in wind tunnel. At low wind tunnel speed, the Reynolds numbers is low, and the flow will become laminar during the experiment take place. At this speed, its suitable to use smoke wire technique, as the smoke been generated is uniform along wire and give good flow visualization

The concept that lies during this experiment take place, is using the concept of fluid mechanic, heat transfer and thermodynamic. First law of thermodynamic stated, the heat release by the heated wire is absorbed by the oil to increase its temperature to boiling points which is equal to heat required to surpass the latent heat of vaporization and heat loss through convection to wind tunnel flow. Based on the theory, 15% of heat release been lost due to the radiation and the remaining, been absorbed by the liquid that coating the wire. The wind tunnel speed is important aspect to the smoke generated, as the higher the speed, the higher the heat loss through the convection cause the higher voltage and ampere needed to boil the liquid.

As the important requirement in designing the smoke wire apparatus is the diameter of the wire, type of wire, flow rate of liquid and type of liquid. From the table 7, the 2 coiled nicrome wire type B1(Ø0.32mm), can give good smoke flow visualization. It is follow the analysis been done in graph 1, where the B1 wire can produce high heat release compare to other wire because it have high resistance. The range of speed of wind tunnel to operate is between 0.5m/s to 1.5m/s, As the higher speed will cause the smoke been produce is hardly visible to see by human eye.

For vegetable oil, the sunflower seed oil is the best smoke liquid to be used as alternative for the commercial smoke liquid. During the experiment, current that been supplied to the wire is constant, the sunflower seed oil can gives denser smoke compared to other vegetable oil. It is because; the sunflower seed oil has the highest smoke points. Smoke points refer to the temperature when oil start to breakdown glycerol and free fatty acids and produce bluish smoke. The glycerol then starts to further breakdown to acrolein which is a component of smoke.

Final Design Specification

The design should be able to produce good flow visualization when the system has been operated.

Table 10 : Proposed design description

No	Component	Description
1	Frame	The frame is constructed from Perspex. The material do not conduct any electricity and easy for assemble.
2	Wire	Based on the experiment and theoretical analysis done, the most suitable wire is 2 coiled nicrome wire (B1(Ø0.32mm) as it give great smoke visualization From the theory, as the wire diameter increase, the resistance of the wire will decrease, and the heat been release also decrease. The smaller wire diameter will give high resistance, and high heat release, however, the smoke been generated is sharp and dense. The proper selection of the wire diameter based on the experiment also depends on the liquid and current been supplied to wire.
3	Smoke liquid	From experiment result, Fog Liquid Antari (Commercial smoke liquid) is the best smoke liquid to be used. All cooking oil can produce smoke, however the fest alternative for the commercial smoke liquid is Sun Flower seed oil and Coconut oil, which give good smoke visualization. Mostly, the smoke liquid depends on its boiling mass flow rate which influence by its property, and thermodynamic properties.
4	Oil delivery system	The design using gravity feed technique, which been provided with air supply as the liquid viscosity that higher, will cause the liquid not moving to the smoke wire.

	Oil collector	This oil collector been placed below the heating wire (outside test section) to collect the drops of excess oil

Table 11: Proposed parameter of the smoke wire apparatus to operate (constant smoke wire and oil flow rate)

No	Parameter	Description
1	Wind tunnel speed	The wind tunnel speed is important measurement need to be considering when smoke wire apparatus operated. The suitable range of the speed of wind tunnel speed to produce good smoke flow visualization is between 0.5m/s to 1.5m/s. The suitable speed is at 1m/s. As the speed increase, the smoke become too thin to been observed
2	Voltage and current	The voltage of the wire is variable based on the temperature of surrounding, liquid and the wire. There are no specific voltage and current to produce good flow visualization. The range is between 8v to 11v and current supplied at 1.2 to 2.2 ampere.

The location of the smoke wire apparatus been install is above the test section of the wind tunnel.

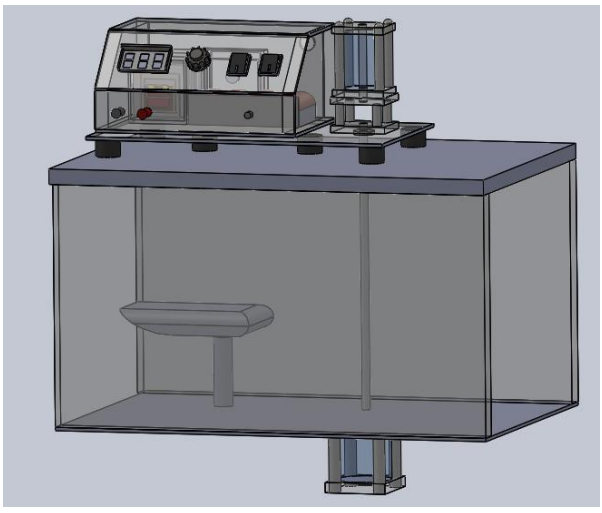


Figure 25: Location of smoke wire apparatus been install

Final design of smoke wire apparatus

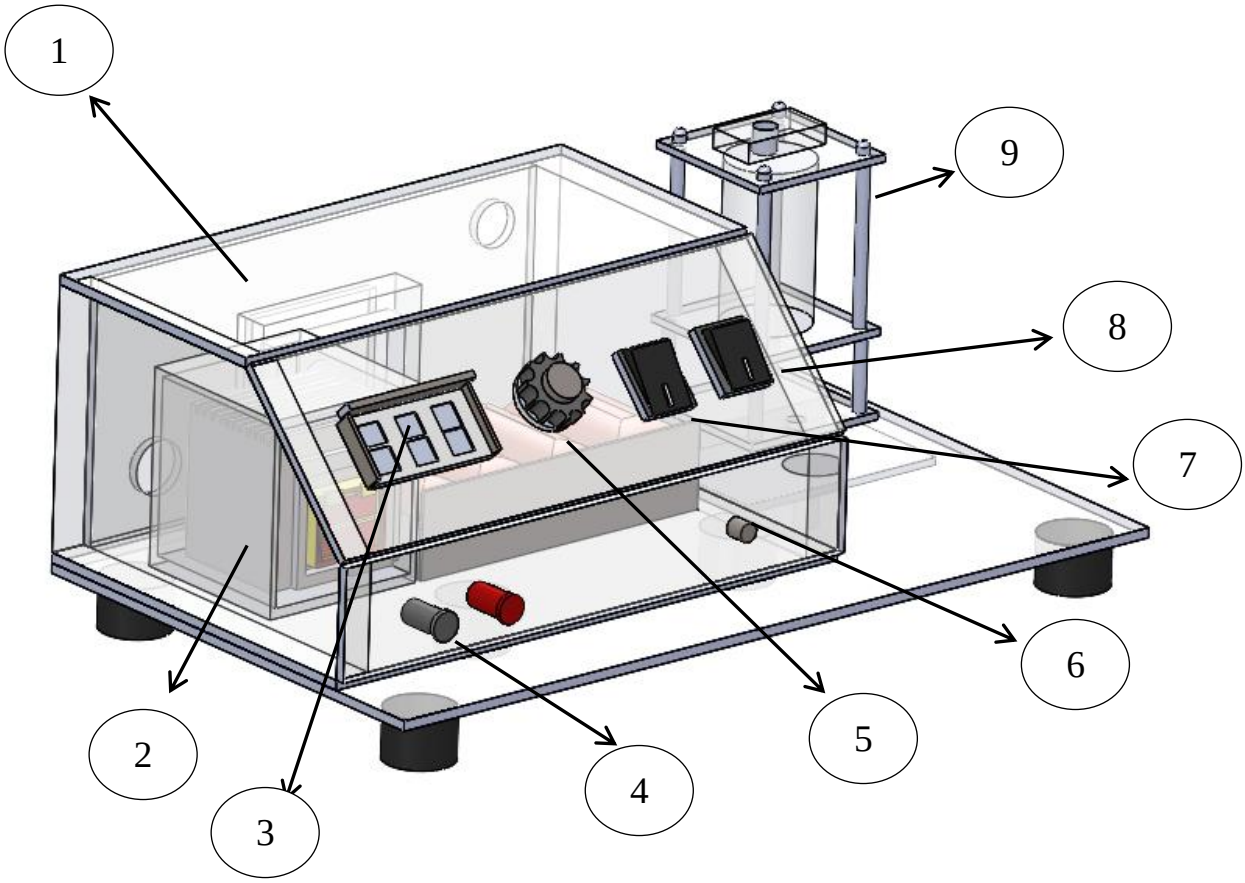


Figure 26: Final design smoke wire apparatus

Table 12: Final design component used

Part No	Name	Function
1	Frame	To protect the components inside
2	Transformer	To step down 240v to lower voltage
3	Voltage meter	To display voltage to be used
4	DC Current	To be connected to the heated wire (DC current)
5	Adjusted Voltage Regulator	To control voltage to be used
6	Air Pump	To provide pressure to oil delivery system
7	On/Off Switch Voltage	To turn “on” and “off” voltage /current used
8	On/Off Switch Pump	To turn "on" and "off" air pump
9	Oil delivery system	Oil reservoir

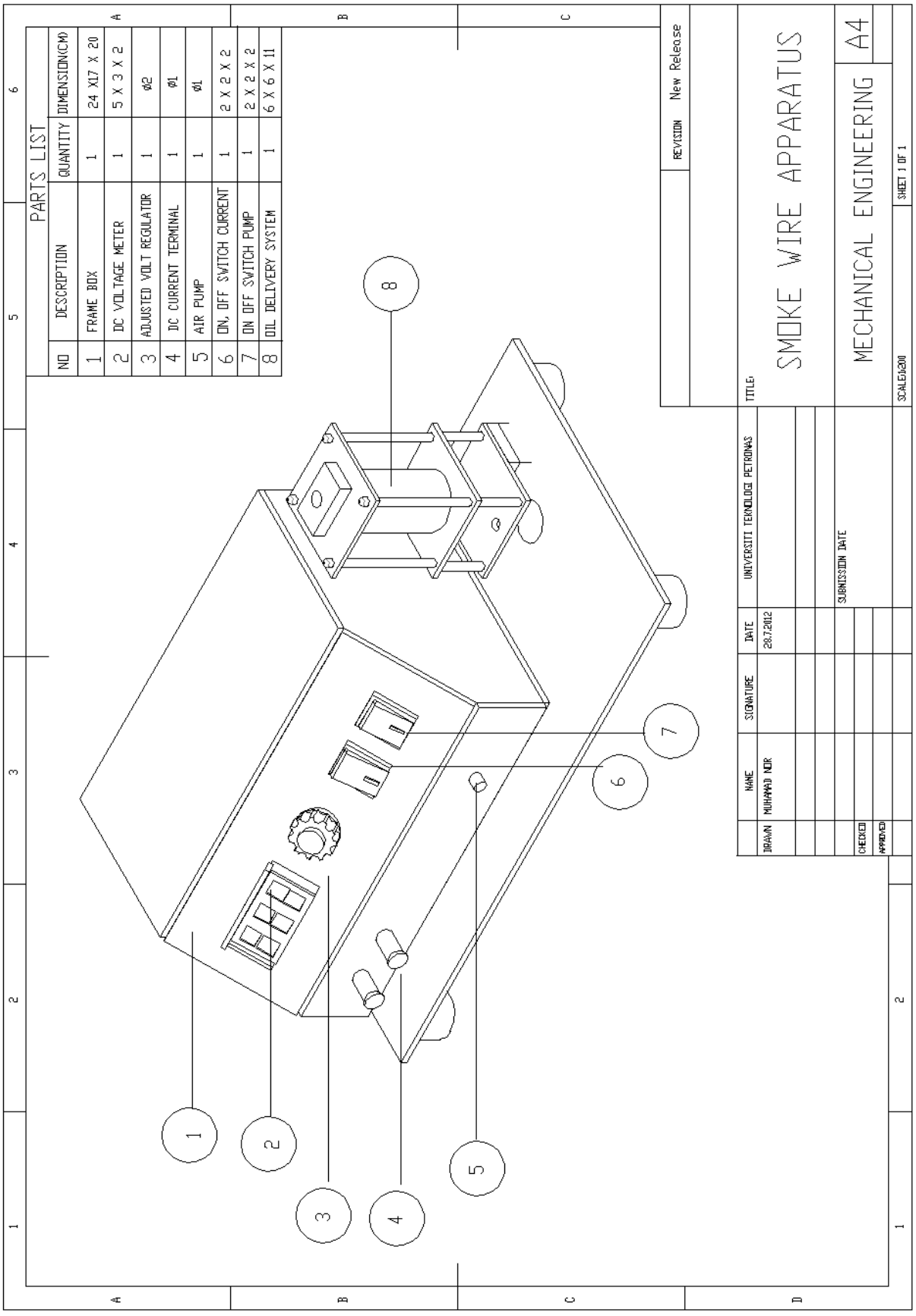


Figure 27: Technical drawing Smoke wire apparatus

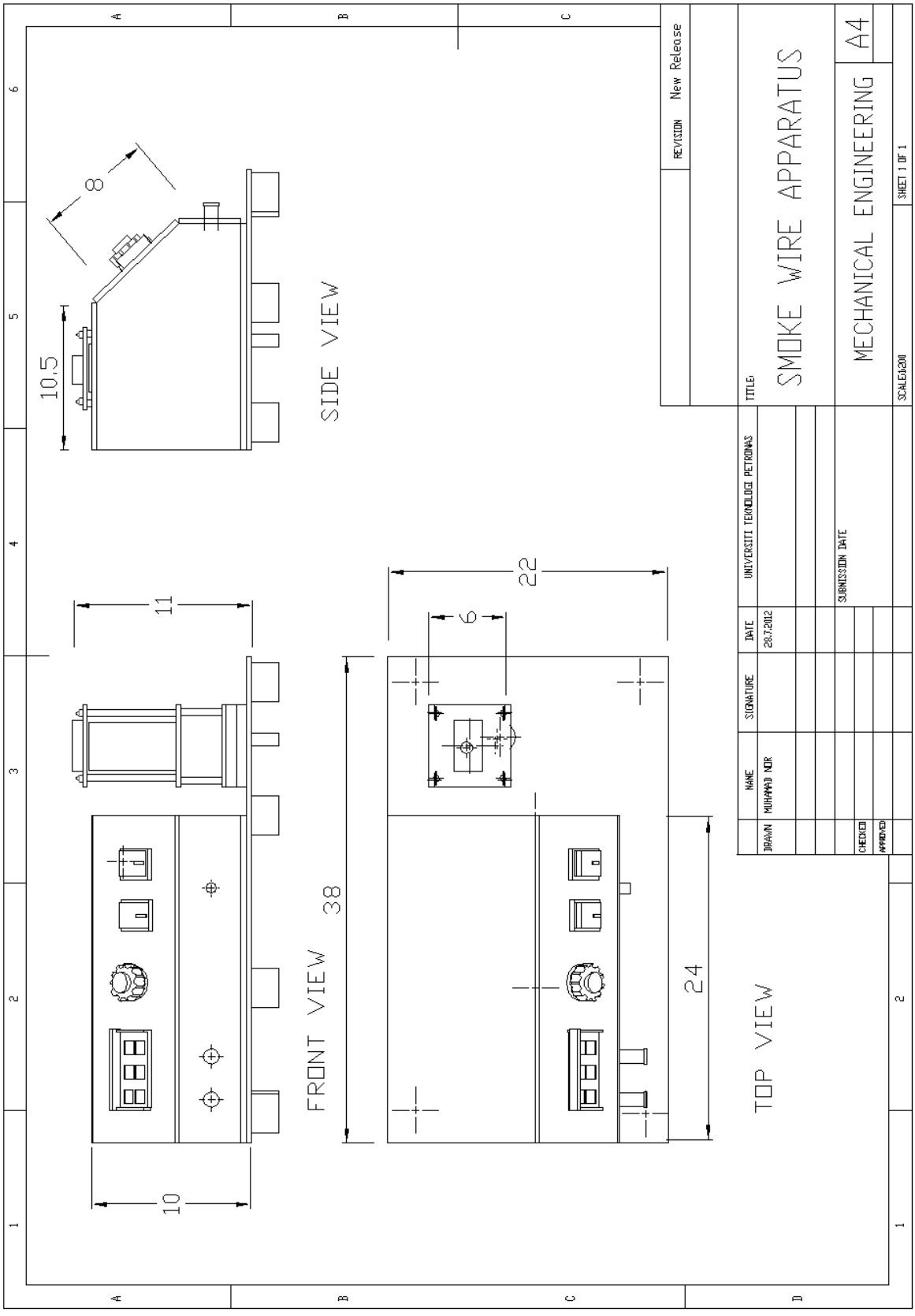


Figure 28: Technical drawing smoke wire apparatus with details specification

4.4 Construction of Prototype smoke wire apparatus

The design based on the proposed design in FYP 1.

Material been used for the construction of the casing is Perspex. There are several advantages using Perspex, it's economic, light and transparent. Furthermore, it not conducts any electricity.

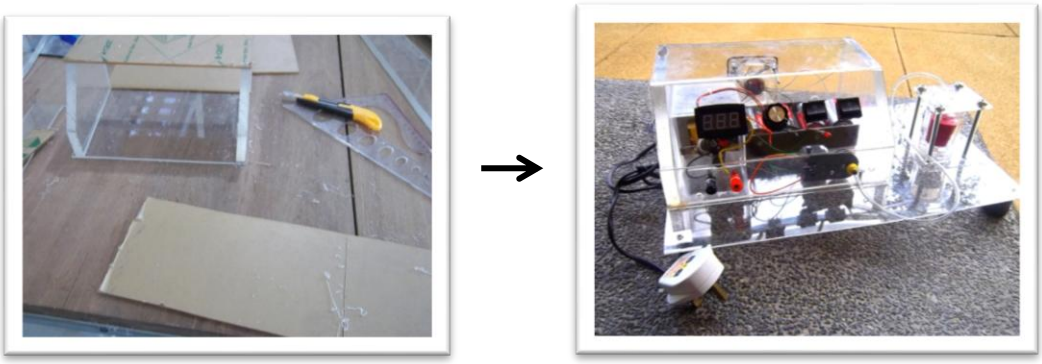


Figure 29: Construction of the prototype

4.4.1 Circuit assembly and testing

To ensure the smoke wire apparatus capable to regulated voltage, the circuit of the board has been assembling based on the diagram below.

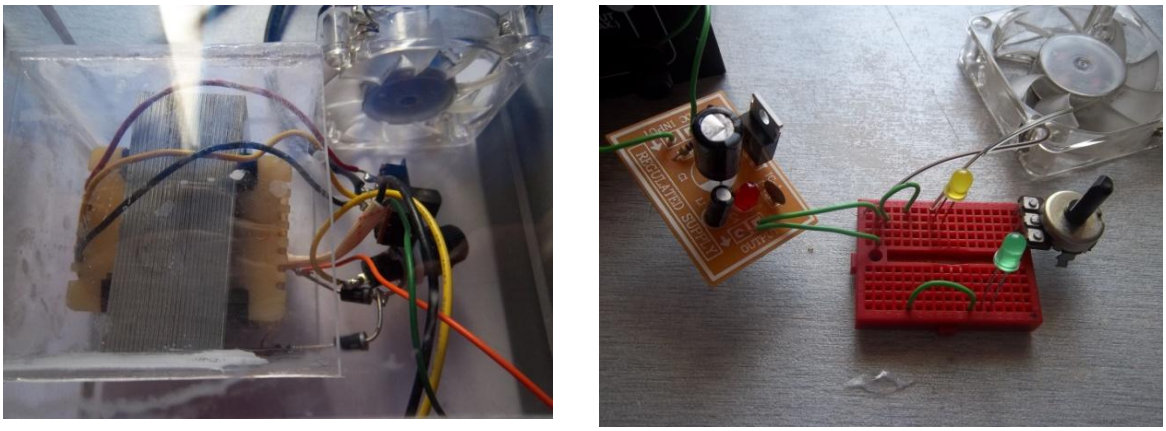


Figure 30: Regulated power supply of the DC current

To test the circuit, the assembled hardware was connected to a DC power supply and a multimeter. The DC power supply was set to 12 volts, a general operating voltage for numerous electronic components. The multimeter serves to measure the output voltage from the Op-Amp.

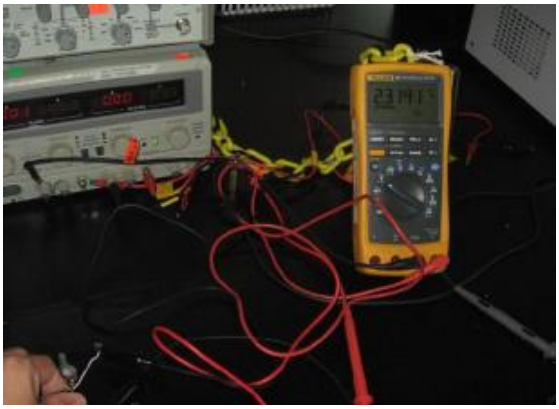


Figure 31: Testing the circuit at electronic lab at block 23

4.4.2 Prototype Assembly

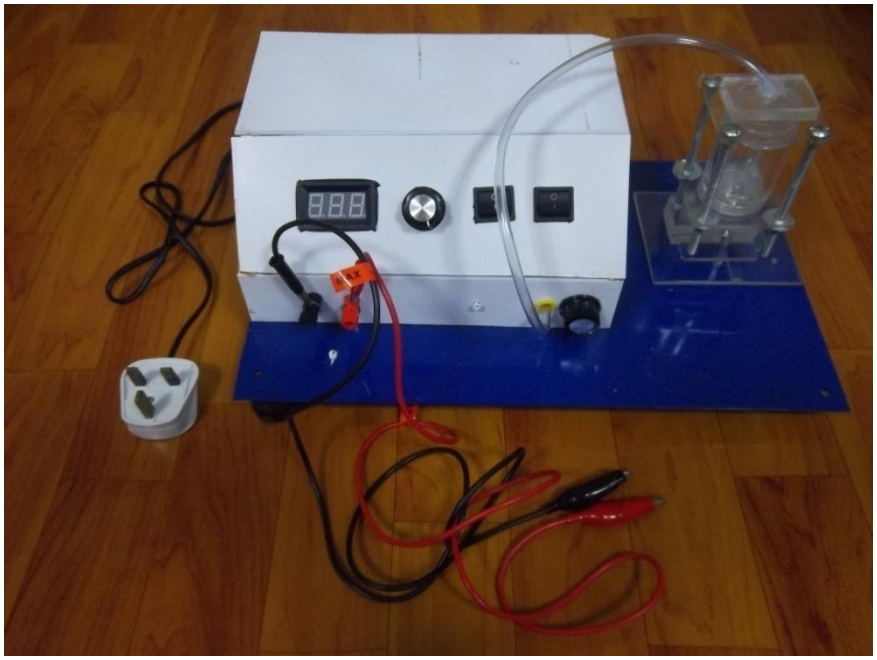


Figure 32: Prototype of smoke wire apparatus

CHAPTER 5
CONCLUSION AND RECOMENDATION

As a conclusion for this final year project, this dissertation includes the design and parameter for the smoke wire apparatus to be operated. The experiment and analysis been done through this project has chosen type B1(Ø0.32mm), two coiled nicrome wire as the heating wire, since it gives good smoke flow visualization with the continuous oil delivery system. The smoke can be generated at good visibility when the been operated at wind tunnel range speed between 0.5m/s to 1.5m/s. The current need to be supply to heat the wire is between 8v to 11v and current at 1.2 to 2.2 ampere, based on the temperature of surrounding and liquid. As the smoke flow visualization technique been used to analyze the flow profile, from the result figure 24, the flow separation point, wake region and recirculation clearly can be seen.

All vegetable that been tested in the experiment, can produce good amount of smoke when be compared to commercial smoke liquid, (Fog liquid Antari HLZ-1). The sunflower seed oil and coconut oil are the best alternative to be used as the replacement of the commercial liquid since it can produce good smoke visibility, easily available and cheaper.

The portable smoke wire apparatus that been constructed can be used in the wind tunnel UTP for student in understanding the flow profile of air.

5.1 Recommendation

For the future, to improve smoke wire apparatus,

1. Use sensor to detect smoke been released to alert the user to capture the flow profile.
2. Research better smoke liquid that can give good quality of smoke.

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APPENDIX

Appendix 1: Experiment Procedure

Appendix 1.1 : To find wire diameter and speed of the wind tunnel

1. Nichrome wire and copper wire been prepared for the experiment. There are 2 set of the nicrome wire with different diameter
2. Coiled the nicrome wire and copper wire to get different diameter of the product. Label for each type.
3. Wire type A, been select and attached to the wind tunnel test section using crocodile clip at end of each wire. (There are hole inside the wind tunnel test section to be used for installing the wire)
4. The crocodile clip been attached to the power supply that can regulated the voltage from 0 – 30V.
5. Ensure the wire type A, in test section in straight line, and not touching the test section.(short circuit will happen if the wire touched the test section when power supply been on)
6. Set up the camera at angle 30^{o} from the test section. Set the camera to capture 6 pictures continuous in 10 seconds. Set the stopwatch to zero.
7. Heated the wire type A, at 3 Voltage, and wait for around 10 seconds.
8. Using brush to wipe the wire with commercial smoke liquid (HLZ-Antari).
9. Remove any residue or remaining oil that not attached to the wire.
10. Wind tunnel been switch on and set at speed 0.5m/s.
11. Voltage of the power supply been set at maximum, and control the current by increasing the value until the smoke appear.
12. Start the stopwatch and the camera to capture the picture.
13. Record the value of the voltage and current been used. Observed the properties smoke been generated. Stopwatch been stopped as no smoke been generated.
14. Step 3 till step 15 been repeated using other type of wire.
15. When all wire been tested at wind tunnel speed 0.5m/s, step 3 till step 15 been repeated using wind tunnel speed at 1m/s, 1.5m/s and 2.0m/s

Appendix 1.2 To find the best smoke liquid that has same potential as commercial smoke liquid

1. Attach 2 coiled nicrome wire diameter 0.32mm to the wind tunnel test section using crocodile clip.
2. The crocodile clip been attached to the power supply that can regulated the voltage from 0 – 30V.
3. Ensure the wire type A, in test section in straight line, and not touching the test section.(short circuit will happen if the wire touched the test section when power supply been on)
4. Set up the camera at angle 30 from the test section. Set the camera to capture 6 pictures continuous in 10 seconds.
5. Set the stopwatch to zero.
6. Heated the wire type A, at 3 Voltage, and wait for around 10 seconds.
7. Using brush to wipe the wire with sun flower seed oil Ensure same thickness around the wire
8. Remove any residue or remaining oil that not attached to the wire.
9. Wind tunnel been switch on and set at speed 0.5m/s.
10. Voltage of the power supply been set at maximum, and control the current by increasing the value until the smoke appear.
11. Start the stopwatch and the camera to capture the picture.
12. Record the value of the voltage and current been used. Observed the properties smoke been generated.
13. Stopwatch been stopped as no smoke been generated.
14. Step 3 till step 15 been repeated using other types of vegetable oil , coconut oil, olive oil and soy bean oil.

Appendix 1.3 : To determine oil flow rate of the oil for continuous operation

1. The weight of the empty beaker been measured using Mettler Toledo (digital weight measurement) then recorded.
2. 5ml of the commercial smoke liquid (Antari HLZ-1) is dripped into the beaker using syringe.
3. The weight of the liquid been measured using Mettler Toledo. (Density of the liquid, volume of the liquid been calculated)
4. 45ml of liquid been added to the beaker till it reach around 50ml. Then the liquid been filled into the oil reservoir system.
5. Install the oil reservoir system to the test section of the wind tunnel. The nicrome wire been connected to the power supply. Then been heated at 3v for about 10 seconds.
6. Switch on the wind tunnel, and set speed at 0.5m/s. switch on the pump ensure the oil is flowing.
7. As the oil start flowing, the air pump is switch off. Start the stopwatch
8. Increase the voltage and current of the power supply until it the smoke been generated is gratified. The flow rate of oil is measured by counting the rate of droplet liquid to the heating wire.
9. Stop the stopwatch after the flow rate has been determined.

Appendix 1.4 : Smoke flow visualization across Aerofoil blade

1. Aerofoil blade been installed to the wind tunnel test section
2. Adjust the angle of the blade at 30^{o}
3. 2 coiled Nicrome wire (0.32mm) and power supply been installed to the test section. The wire been heated at 3V for around 10 seconds.
4. The wire been coated with smoke liquid using brush
5. Set up the camera in front of the Aerofoil blade, Set the camera to capture 6 pictures continuous in 10 seconds.
6. The wind tunnel is switch on and set to 0.5m/s.
7. Increase the voltage and current to the wire till smoke generated
8. Capture the flow profile of smoke passing the Aerofoil blade.
9. Repeat step 2 till 8 using wind tunnel speed at 1m/s, 1.5m/s and 2m/s
10. After all experiment been done, the wind tunnel been switch off and other equipment is turned off

Appendix 2 : Gantt chart

Gantt Chart (FYP 1 MBB 4012)

No.	Activities /Weeks	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of project topic															
2	Meeting with supervisor															
3.	Preliminary Research Work															
4	Research regarding smoke wire															
5	Submission of Extended Proposal Defence															
6	Prepare and purchase equipment and material															

Mid-Semester break

7	Proposal Defence																
8	Determine parameter smoke wire																
9	Design smoke wire apparatus																
10	Submission of Interim Draft Report																
10	Submission of Interim Report																

▲ -Milestone

Gantt Chart (FYP 2 MBB 4024)

No.	Activities /Weeks	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Prepare for experimental testing																
2	Testing the wire and liquid and wind tunnel																
3.	Run testing and take experimental data																
4	Submission of Progress Report																
5	Analyzing data and result documentation. Pre-EDX																
6	Submission of Draft Report																
7	Submission of Dissertation (soft bound)																
8	Submission of Technical Paper																
9	Oral Presentation																
10	Submission of Project Dissertation (hard bound)																

Mid-Semester break