DASHINDARAN THAVANTHRAM B. ENG. (HONS) MECHANICAL ENGINEERING JANUARY 2015

# DEVELOPMENT OF MICROWAVABLE DIESEL SOOT FILTER FOR DIESEL ENGINE EXHAUST SYSTEM

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**MECHANICAL ENGINEERING**

**UNIVERSITI TEKNOLOGI PETRONAS**

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# DEVELOPMENT OF MICROWAVABLE DIESEL SOOT FILTER FOR DIESEL ENGINE EXHAUST SYSTEM

By

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Dissertation submitted in partial fulfillment of
the requirements for the
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Universiti Teknologi Petronas

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# CERTIFICATION OF APPROVAL

**Development of Microwavable Diesel Soot Filters For Diesel Engine Exhaust System**

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Dashindaran A/L Thavanthram

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A project dissertation submitted to the
Mechanical Engineering Programme
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BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

______________________

(AP. Dr. Zainal Ambri Abdul Karim)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
JAN 2015

# 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.

___________________________________

**(DASHINDARAN THAVANTHRAM)**

# ABSTRACT

This paper offers the results from an experimental analysis for diesel soot oxidation alternative by using induction spring coils in microwaves. Soot particles are released from diesel exhaust systems because of the inadequate burning of hydrocarbons. The oxidation temperature of soot particles is extremely high, which ranges from $600^0$C – $700^0$C. Induction coil is used as the element to trap and combust soot because it is able to heat up through induced current method when it interacts with electromagnetic waves. When exposed to microwaves, the induction spring coils made of mild steel, which is a conductive material are able to experience steady and quick heating to very high temperatures. Therefore, the induction coils are anticipated to attain the necessary soot oxidation temperature. From previous research work, it is proven that a larger loop diameter and smaller wire diameter achieves the minimum temperature in the shortest time. The dimension of the spring coils used in this project 0.1cm as the wire diameter (d=0.1cm), 1.5cm as the loop diameter (d=1.5cm), 20 number of turns (N=20) and 4.2cm as the total length of the coil (L=4.2cm). The induction coils accumulated with soot particles released from the diesel engine combustion were then exposed to microwaves at 80% power levels for a period of 180 seconds. The weights of the induction coils were measured before and after the soot accumulation procedure in order to determine the weight of the soot collected. Then, the weights of the induction coils were measured before and after the soot oxidation procedure to determine the amount of soot oxidized. During the experiment, an infrared (IR) thermometer was used to measure the temperature of the induction coils every 30 seconds time interval for 180 seconds. From the results obtained, it is proven again that the smaller wire diameter and bigger coil diameter is able to achieves the minimum temperature in the shortest time.

# ACKNOWLEDGEMENT

First and foremost, thanks to GOD, the Almighty for the opportunity and blessing that He bestowed upon me throughout this project. Then, a special thanks to my dedicated and kind supervisor, AP. Dr. Zainal Ambri Abdul Karim for his guidance, support, time and vast knowledge in supervising and coordinating my final year project. Also, lab technicians, Mr. Khairul and Mr. Mahfuz who assisted me a lot during the experiment setup of my project. Furthermore, I would like to extend my gratitude to all my friends who have involved directly or indirectly in my project. Last but not least, I would like to take this opportunity to thank my family members especially my mother and sister, who constantly encouraged and supported me in my studies.

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# CHAPTER 1: INTRODUCTION

This project addresses the capability of the soot trap and the effectiveness of the heating elements in burning off the soot particles. This study also discusses about the utilization of microwaves in soot oxidation at extremely high temperatures. Also, the design and the performances of the heating elements are important to ensure a rapid and stable heating process.

## 1.1 BACKGROUND STUDY

Soot is a byproduct formed on account of incomplete burning of hydrocarbon and low effeciency of catalyst in combusting the three essential contaminations which are hydrocarbons, CO and $NO_x$ (Oger, 2012). In heavy-duty vehicles engine combustion, the exhaust gas contains soot particles which are controlled by stringent regulatory actions and air quality standards. Soot particles measure about 100 nanometers, which is extremely hard to trap and burn them off (Lamparter, 2000). One of the methods that have been practiced is by using diesel particulate filter, DPF. DPF is a device that traps diesel particulate matter or soot from diesel engine exhaust gas before it is released into the atmosphere (refer to Figure 1-1).

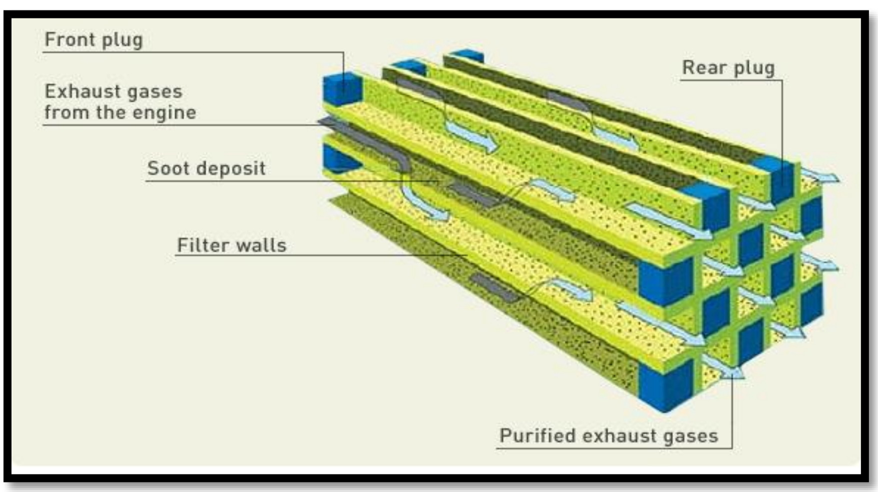


Figure 1-1: Diesel Particulate Filter, DPF

Recent particulate filters are able to trap from 30% until 95% of the dangerous soot. Using the most favorable diesel particulate filter (DPF), emission of soot can be further reduced to 0.001 g / km or less. However, these diesel soot trap filters are required to be removed and replaced regularly for optimum engine performance. The current work intends to create an in-situ soot trap utilizing spring coil components known as induction coils that can trap soot released, where the soot chamber containing the induction coils will be exposed to electromagnetic waves to oxidize the soot. The trap can be used continuously since regeneration of the trap is done during operation.

Through microwave heating, there is no direct heating process but there is energy transfer via electromagnetic means. When microwaves are emitted by a magnetron, the metal particles are excited and will collide with each other, eventually leading to heat generation through friction between the metal particles (Simonsen, 2008). This project focuses on the design of spring coils which have the ability to have high electric field density as well as to allow induced current for a steady heating procedure to oxidize the soot particles at its oxidation temperature.

## 1.2 PROBLEM STATEMENT

Soot particles are extremely minute, measuring up to 100nm and it is very complex to trap and gather them. When using induction coils, it is paramount to trap and oxidize the soot released from diesel engine exhaust systems before it escapes into the thin air. Current filter needs to be removed and replaced regularly for the regeneration process. High concentration of soot clogged in the DPF will affect the performance of the engine.

Also, the dimension of the spring coils need to be improved compared to previous design works to ensure rapid heating, together with better soot trapping and oxidizing ability. Therefore, this research discusses on enhancement in terms of soot trap and spring coil design for a greater efficiency.

## 1.3 OBJECTIVES OF STUDY

1. To study the capability of the current soot trap filter to trap and oxidize the soot particles by calculating the soot weight loss observed in the induction coils.

2. To design and fabricate a competent soot filter using induction spring coils.

## 1.4 SCOPE OF STUDY

The study of this research is split into two parts which are FYP 1 and FYP2. In FYP1, the focus is on conducting detailed literature review as well as determining the best dimension and design of the heating elements to burn off soot. Also, the design optimization of a more capable diesel soot trap channel together and the heating elements are carried out in AutoCAD 2007.

In FYP2, the fabrication of the heating elements and the diesel soot trap filter will be done according to the optimal design. The installation and testing of the diesel soot trap and heating elements took place where complete test-run was done for the new soot trap channel to investigate the filters efficiency and conduct necessary modification to the filter. The results obtained was plotted to investigate the efficiency of the heating elements in combusting the soot and validating the optimal dimensions of the heating element.

## 1.5 RELEVANCY OF THE PROJECT

Exhaust gas emissions are one of the primary contributors to air pollution and global warming. It causes severe environmental pollutions and in turn, endangering the lives in this planet. Also, soot particles emitted by diesel engines are the second cause of global warming (Kennedy, 1997).

This research focuses on the after-treatment of exhaust gas emitted by diesel engines utilizing diesel soot trap filters & means of microwave heating to oxidize the soot. Thus, the research addresses and yields the most suitable soot trap filter and the dimensions of the best performing heating elements.

## 1.6 FEASIBILITY OF THE PROJECT

The time provided to complete this project successfully is sufficient enough to ensure the result obtained corresponds to the project objective. With careful planning and time management between FYP1 and FYP2, the project was completed within the timeframe specified. Also, the cost for fabrication of the diesel soot trap filter and the induction coils are secured with the budget allocated to FYP students. Furthermore, facilities such as diesel engine, digital infrared thermometer, smoke meter, electrical equipments and microwave oven leak tester are readily available in the automotive laboratory.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 SOOT FORMATION

Soot is a minute particle released from diesel powered engines in mainly fuel-rich zones at high temperatures. Soot comprises generally of carbon and different components, for example, hydrogen and oxygen show in minute amount (Kennedy, 1997). Chemical equation of soot formation is shown below which yields the incompletely combusted carbon particles, $C_2$. In diesel ignition, soot is released along with carbon monoxide and hydrogen. The four reactant gases $O_2$, $CO_2$, $H_2O$ and $NO_2$ all oxidize and gasify soot with $NO_2$ the most reactive at low temperatures (Haynes, 1989). Soot has numerous dangerous ramifications as it can clog the exhaust system and produce dark and thick exhaust smoke (Stanmore, et al 2001). It is harmful when human beings breathe in air containing soot particles and develop airborne diseases such as asthma and suffocation. Soot is theorized to be the second largest cause of global warming (Lamparter, 2000).

$$\mathbf{C_mH_n + aO_2 \longrightarrow 2aCO + 0.5nH_2 + (m\text{-}2a)C_2}$$

Chemical Equation of Soot

The development from fluid or vapor stage hydrocarbons to strong soot particles includes six recognized procedures (Tree & Svensson, 2007). Among the processes are pyrolysis, nucleation, combination, surface development, agglomeration and oxidation. Figure 2-2 shows the schematic diagram of the soot development process. Soot is made up of agglomerates where its diameter is up to several hundred nanometers. Temperature at which soot can be oxidized is very high which is at $500^0C$ – $600^0C$ or more (Fraunhofer-Gesellschaft, 2011). The graphite like structure of soot presents higher resistance to oxidation (Oger, 2012). In any case, the regular temperature at the exhaust tail pipe extends from $200^0C$ - $400^0C$. This temperature is not adequate as the minimum soot oxidation temperature ranges from $600^0C$ and above.

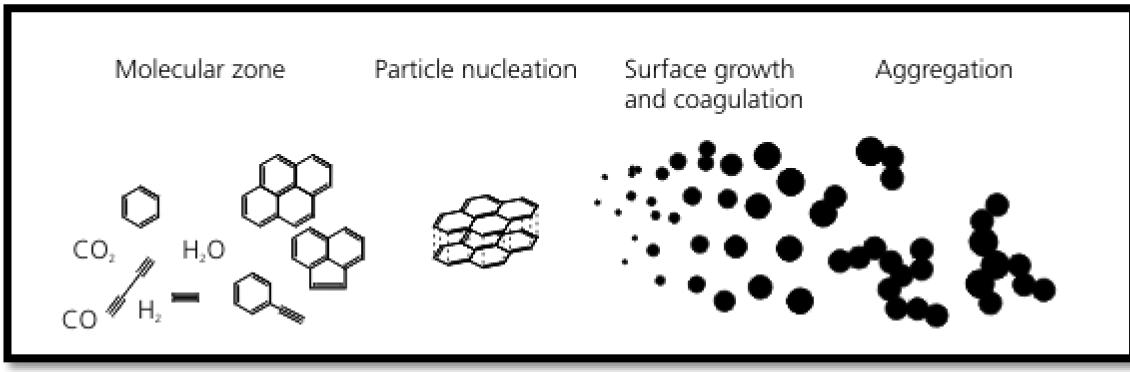


Figure 2-2: Schematic diagram of the soot particles development process

## 2.2 MEANS OF MICROWAVE HEATING AND PROPAGATION

Microwaves can be produced by a magnetron. Though, there are a few methods for producing microwaves, for example, gyrotrons and klystrons, magnetron is favored because of its ease and accessibility (Chandra, 2011). Magnetron is a device that produces high recurrence microwave power from high-voltage source. The average efficiency of a household oven is about 64% where additional power is required to operate the other equipments such as the lamps, magnetron cooling fan, the motors and the control circuits. However, the efficiency of magnetron is around 80% – 85%.

Microwave heating differs from conventional heating in light of the fact that the energy is strongly focused on the material itself, depending on the dielectric permittivity (Chandra, 2011). For coils made up of dielectric materials such as mild steel, the magnetic fields formed around the coil when it is hit by microwaves induce electrical charges that heats up the coils to the minimum soot oxidation temperature.

## 2.3 SOOT FILTER IN DIESEL ENGINE EXHAUST SYSTEMS

Particulate matter, (PM) filter systems will most likely be required for compliance of diesel-powered vehicles and equipment to future emission legislation. The major issue with such systems is that their reliable and cost-effective regeneration through oxidation of the collected soot particles. However, it is not currently possible under all engine operating conditions without additional external thermal energy.

Particulate filters capture solid soot particles by physically trapping the particles in their structure with efficiency up to 99%, but require frequent oxidation of the accumulated soot to prevent unacceptable levels of exhaust backpressure on the engine. Soot oxidation by the oxygen contained in the exhaust occurs at temperature levels that exceed 600°C. Such temperatures are seldom encountered under normal driving conditions. Figure 2-3 shows the current diesel soot filter design implemented in diesel exhaust systems.

All techniques however, still face problems and yet to achieve regeneration over the entire range of engine operating conditions with acceptable fuel penalty, system cost, and reliability. Catalyst-assisted regeneration of soot filters presents a number of advantages over direct thermal regeneration, including energy savings and higher trap material reliability, due to lower regeneration temperatures. However, a crucial factor affecting the efficiency of catalytic soot oxidation is the extent of the contact area between catalyst and soot. A low contact area results in low oxidation rates.

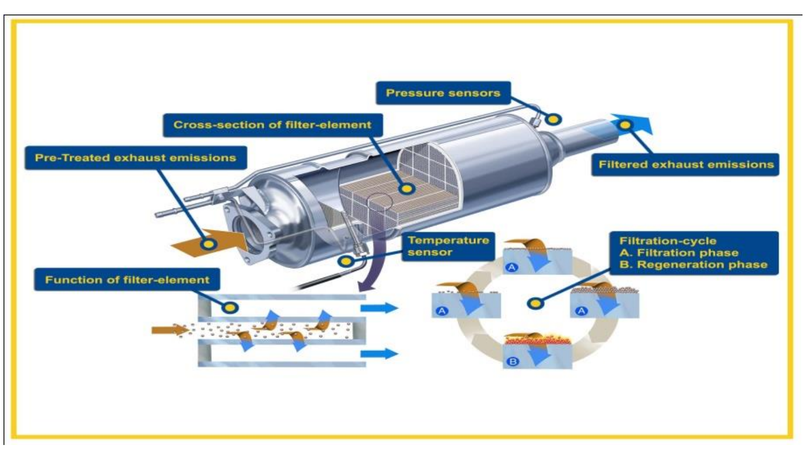


Figure 2-3: Current diesel soot filter design implemented in diesel exhaust systems

## 2.4 SOOT OXIDATION BY MEANS OF MICROWAVE PRINCIPLE

Soot oxidation is essential to prevent the soot particles from escaping into the thin air. In soot oxidation, microwave is favored as the most suitable means as it can achieve high temperatures within smaller time duration. Besides, by using microwave heating in a diesel soot trap channel, a Diesel Particulate Filter (DPF) does not have to be disengaged habitually to remove the trapped soot (Yoshikawa, N., Ishizuka, E. & Taniguchi, 2006).

Several researches conducted by Abdul Karim are the primary contributors in this project work. Soot oxidation has been a vital research for Abdul Karim et al (2012). An example of equipment which uses current induction is induction coils. The design of the heating elements, (induction coils) which is made up of conductive materials is taken from the current induction method. Current induction enables current flow between the spring coils and ensures a steady and swift heating process. According to Simonsen, S.B. (2008), electromagnetic waves are used to heat up the conductive materials through induction current method (refer to Figure 2-4).

In Abdul Karim's previous research study, spark formation was used to burn off the caught soot in the diesel soot trap filter. However, the spark formation undergoes an unsteady heating process. Induction coils have the ability to allow induced current and undergo a steady heating. Furthermore, the induction coils can withstand the oxidation temperature for a longer time period which is essential in soot burning.

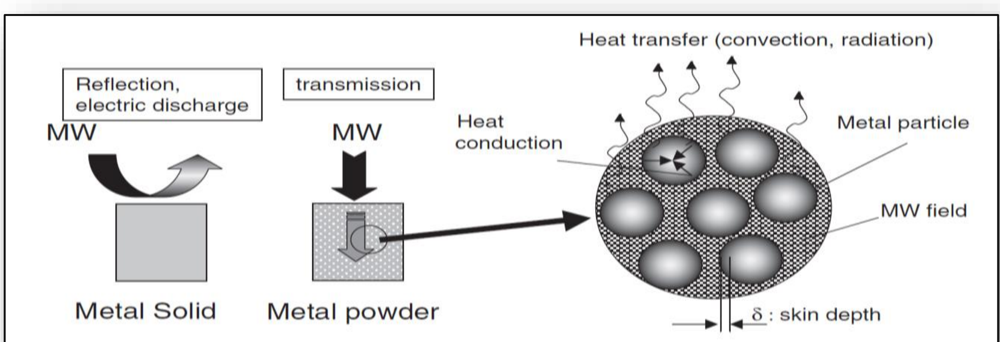


Figure 2-4: Illustration of Microwave Heating on Metal Particles (Simonsen et al, 2008)

# CHAPTER 3: METHODOLOGY

## 3.1 RESEARCH METHODOLOGY

Journal papers, research papers and educational articles are read to get a broader overview concerning this research. In this study, AutoCAD 2014 software is utilized to model a soot trap channel for diesel engines exhaust systems. Equipments such as microwave generator system, diesel engine, exhaust gas analyzer, smoke meter, induction coils of distinctive sizes as well as magnetron are already accessible for experimentation purposes in the automotive laboratory. There are several research activities that have been planned throughout the project work such as design and fabrication of induction coils, experimental set-up, soot collection and data gathering and analysis, result tabulation and conclusion and recommendation for future developments. Figure 3-1 shows the project flow diagram:-

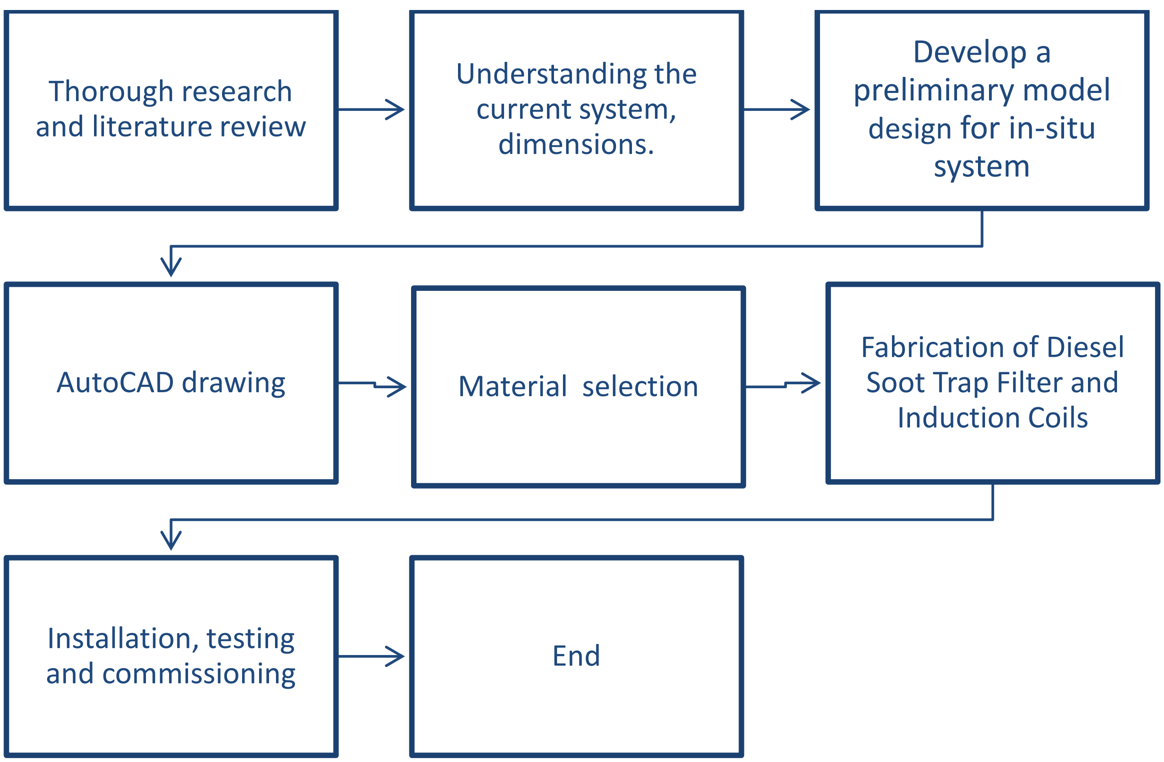


Figure 3-1: Project Flow Diagram

## 3.2 PROJECT ACTIVITIES

### 3.2.1 TOOLS AND EQUIPMENTS

- Designing software e.g. AutoCAD 2014.
- Microwave leak detector
- Smoke meter
- Exhaust emission analyzer
- Fabrication tools e.g. welder, cutter, rivet and etc.
- Electrical equipment e.g. voltmeter, test pen.
- Working engine diesel application.
- Induction coils

### 3.2.2 PROJECT KEY MILESTONES

| No. | Project Key Milestones | Estimated Date of Task Completion |
| --- | --- | --- |
| 1 | Detailed Literature Reviews | **FYP1** Week 7 |
| 2 | Development of a preliminary model design for an in-situ system | **FYP1** Week 7 & 8 |
| 3 | AutoCAD drawing of engineering design | **FYP1** Week 12 & 13 |
| 4 | Fabrication drawing | **FYP1** Week 12 - 14 |
| 5 | Completion of prototype fabrication | **FYP2** Week 12 |
| 6 | Completion of prototype testing and necessary modifications | **FYP2** Week 13 |
| 7 | Experimental setup and complete test run of the fabricated material. | **FYP2** Week 13 |
| 8 | Experimental data collection and data analysis. | **FYP2** Week 13 |
| 9 | Submission of Dissertation (soft bound) & Technical Paper | **FYP2** Week 14 |
| 10 | Submission of Dissertation (hard bound) and Viva presentation | **FYP2** Week 15 |

Figure 3-2: Key Milestones

## 3.3 GANTT CHART

### 3.3.1 FYP1 GANTT CHART

| No | PROJECT RELATED ACTIVITIES | Weeks | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1 | FYP Project Title Selection and meeting with FYP coordinator and supervisor. | ■ | ■ | | | | | | | | | | | | |
| 2 | Groundwork Research Study and Preliminary study work | | ■ | ■ | ■ | | | | | | | | | | |
| 3 | Detailed literature review study with data collection and analysis | | ■ | ■ | ■ | | | | | | | | | | |
| 3 | Preparing Extended Proposal | | | | ■ | ■ | ■ | | | | | | | | |
| 4 | Submission of Extended Proposal | | | | | | ■ | | | | | | | | |
| 5 | Proposal Defense | | | | | | | | ■ | ■ | | | | | |
| 6 | Developing a preliminary model design for an in-situ system | | | | | | | ■ | ■ | | | | | | |
| 7 | AutoCAD drawing, Engineering Design of the heating elements | | | | | | | | | | ■ | ■ | ■ | | |
| 8 | Fabrication Drawing of heating elements | | | | | | | | | | | | ■ | ■ | ■ |
| 9 | Preparation of Interim Report | | | | | | | | | | ■ | ■ | ■ | ■ | |
| 10 | Submission of Interim Draft Report | | | | | | | | | | | | ■ | ■ | |
| 11 | Submission of Final Interim Report to supervisor and course coordinator | | | | | | | | | | | | | | ■ |

Table 3-3: FYP1 Gantt Chart

### 3.3.2 FYP2 GANTT CHART

| No | PROJECT RELATED ACTIVITIES | Weeks | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 1 | Selection of the optimal design for the heating elements and diesel soot trap filter | ■ | | | | | | | | | | | | | | |
| 2 | Fabrication of the heating elements | | | | | | | | | ■ | ■ | ■ | ■ | ■ | | |
| 3 | Soot collection of heating elements | | | | | | | | | | | | | | ■ | ■ |
| 3 | Establishment of Experimental Set Up and Procedures | | | | | | | | | | | | | | ■ | ■ |
| 4 | Conduct Experiment and Data Gathering | | | | | | | | | | | | | | ■ | ■ |
| 5 | Result Analysis | | | | | | | | | | | | | | ■ | ■ |
| 6 | Submission of Progress Report | | | | | | | | | | ■ | | | | | |
| 7 | Submission of Draft Report | | | | | | | | | | | | | | ■ | |
| 8 | Submission of Dissertation (Soft Bound) | | | | | | | | | | | | | | ■ | |
| 9 | Submission of Technical Paper | | | | | | | | | | | | | | ■ | |
| 10 | Oral Presentation | | | | | | | | | | | | | | ■ | ■ |
| 11 | Submission of Project Dissertation (Hard Bound) | | | | | | | | | | | | | | ■ | ■ |

Table 3-4: FYP2 Gantt Chart

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Design of Soot Filter and Induction Coils

### 4.1.1 Soot Trap Filter Chamber Design

The diesel soot trap filter is made of mild steel and it is capable of withstanding temperatures above $700^0$C for a tolerable period. Figure 4-1 and figure 4-2 shows the final design of the diesel soot trap filter. Figure 4-3 shows the components of the diesel soot trap filter chamber. The dimensions of the soot trap filter chamber design is based on previous work results (Abdul Karim et al. 2013). The exhaust inlet and outlet chamber were based on the dimensions of the flow pipe connected to the diesel engine available in the automotive laboratory. Nevertheless, the microwave chamber connector is based on the latest design being developed currently.

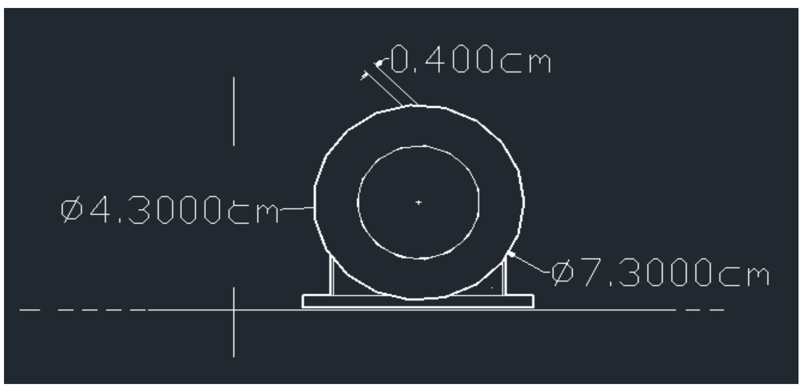


Figure 4-1: Final Design of Diesel Soot Trap Filter (Front View)

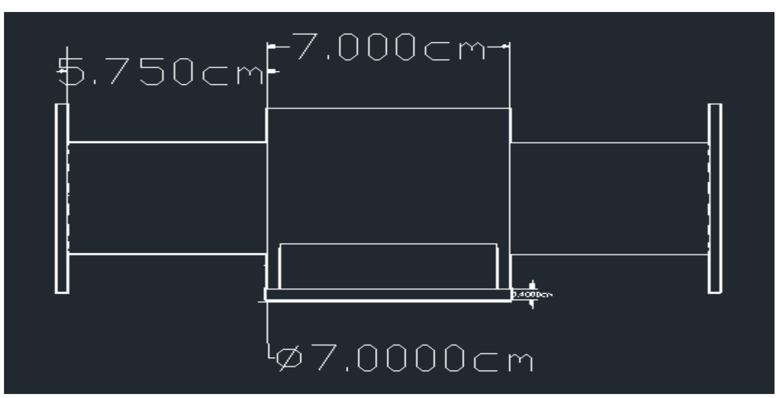


Figure 4-2: Final Design of Diesel Soot Trap Filter (Right View)

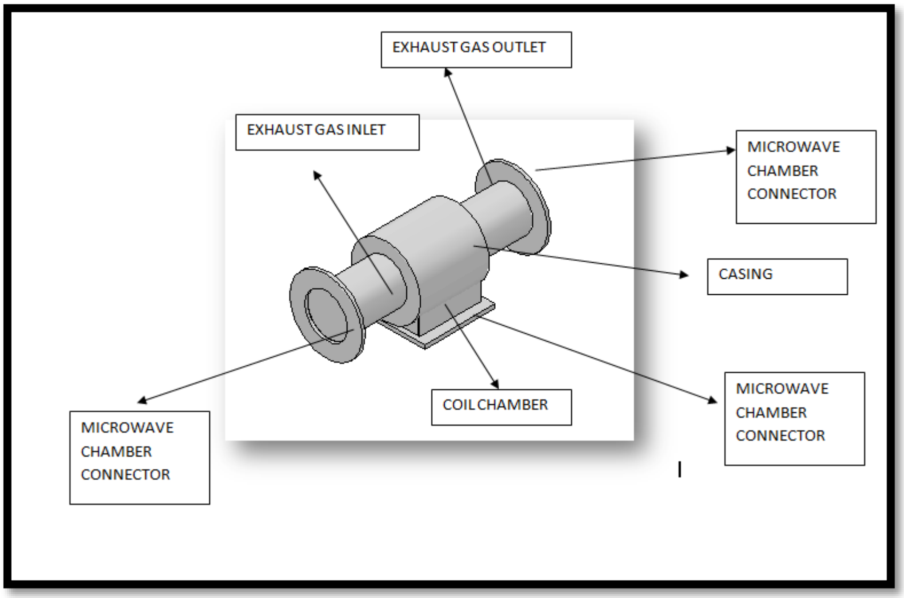


Figure 4-3: Components of the diesel soot trap filter chamber

### 4.1.2 Spring Coil Design

The coils are designed based on three parameters such as the diameter of the wire, diameter of the loop and the number of turns of the spring. There are a total of 8 different dimensions of coil which are tested during the experimental set-up to find the best dimension among them.

Table 4-1: Proposed Dimension of Induction Coil

| Coil | Diameter of wire, d (cm) | Diameter of loop, D (cm) | No of turns N |
|---|---|---|---|
| A1 | 0.1 | 1 | 10 |
| A2 | 0.1 | 1 | 20 |
| A3 | 0.1 | 1.5 | 10 |
| A4 | 0.1 | 1.5 | 20 |
| B1 | 0.2 | 1 | 10 |
| B2 | 0.2 | 1 | 20 |
| B3 | 0.2 | 1.5 | 10 |
| B4 | 0.2 | 1.5 | 20 |

Table 4-2 shows the properties of the chosen material, which is mild steel. From previous work results, mild steel was selected as the material for induction coils. Thus, taking this into consideration, mild steel was used as the material for the induction coils in this research as well.

Table 4-2: Physical properties of Mild Steel

| Materials | Electrical Conductivity (S/m) | Thermal Conductivity (W.m/K) | Melting Point ($^0$C) |
|---|---|---|---|
| Mild steel | 5.96 X $10^6$ | 90 | 1425 |

Table 4-3 shows the chosen final dimension for the induction coils. Coil A4 has a total length of 4.2cm, 20 turns, 1.5cm as the diameter of the loop and 0.1cm as the diameter of the wire. A total of eight coil A4 will be arranged in the diesel soot trap filter to trap the soot released from the diesel engine. Coil A4 is chosen as the best dimension for the induction coil. This is because induction coil A4 has the ability to allow more induced current and undergo a steady heating in less time. It will develop a higher electric field density which will increase the temperature induction coils to the soot oxidation temperature. Figure 4-3, Figure 4-4 and Figure 4-5 shows the final design of the induction coils for coil A4. These figures show the length of the coil, loop diameter, and the wire diameter respectively.

Table 4-3: Final Dimension of Induction Coil

| Coil | Diameter of wire, d (cm) | Diameter of loop, D (cm) | No. of turns, N |
|---|---|---|---|
| A4 | 0.1 | 1.5 | 20 |

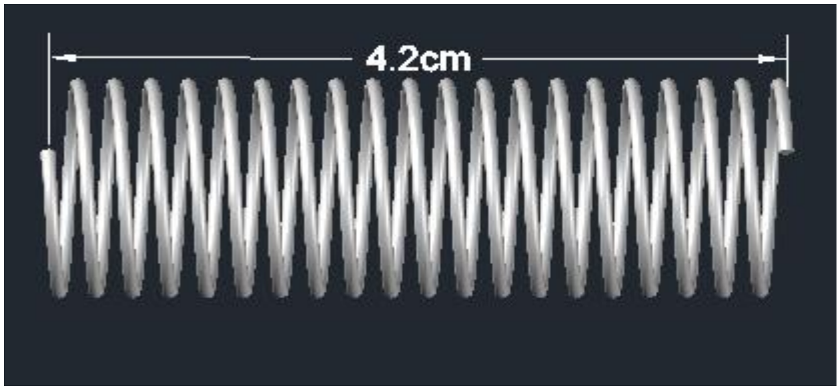


Figure 4-4: Final Design of Induction Coils A4 (Right View)

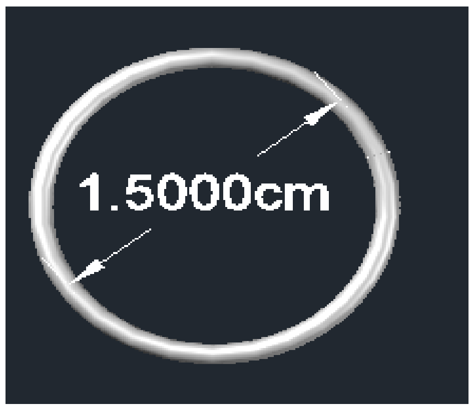


Figure 4-5: Final Design of Induction Coils A4 (Front View)

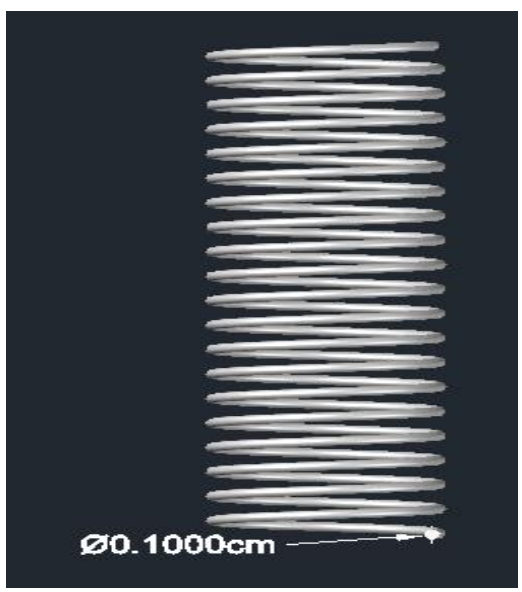


Figure 4-6: Final Design of Induction Coils A4 (Top View)

### 4.1.3 Spring Holder Design

A total of eight A4 coils will be used in the diesel soot trap filter to trap the soot released by the diesel engine. Figure 4-6 and figure 4-7 shows the design of the spring coil holder in front view and south-east view respectively. The material used for the spring coil holder is Polytetrafluoroethylene, which is also known as Teflon. This material is proposed from previous work results Abdul Karim et al. (2013). It is a thermoplastic polymer and it is able to withstand the soot oxidation temperature for reasonable time duration. Based on the length/diameter ratio of the spring coil holder, it is found that eight springs with a diameter of 1.5 cm would be sufficient to place and arrange them in the spring coil holder as shown in the figure below.

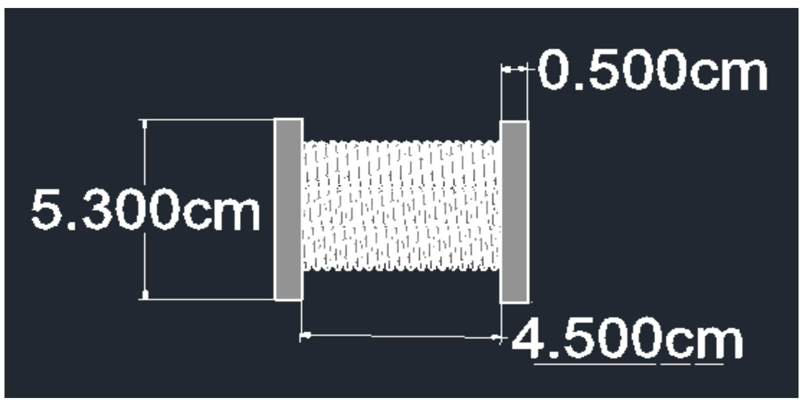


Figure 4-7: Final Design of Spring Coil Holder (Front View)

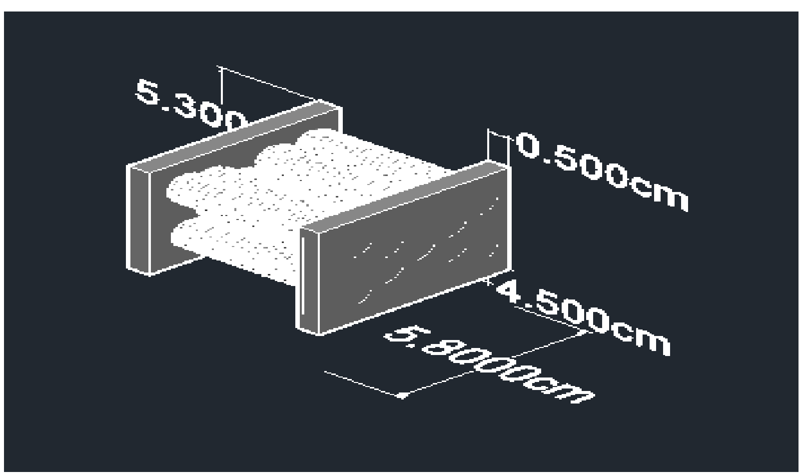


Figure 4-8: Final Design of Spring Coil Holder (South-East View)

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSION

As conclusion, soot can be oxidized at temperature above $600^0$C Abdul Karim et al (2013). Due to low exhaust temperature, self generation for soot oxidation purposes is not applicable. Therefore, another method is required to be developed to ensure that soot can be trapped and burned before leaving the diesel exhaust system. From the literature review, it is possible to use microwave heating technique in soot oxidation strategy. The surrounding temperature of microwave cavity can be increased by inserting metal into it. When electromagnetic wave is incident perpendicularly on metal, the metal will start to produce arc which will help increase the surrounding temperature of cavity.

The design of the heating elements is spring coil. Spring coil is chosen as the design for the heating elements because of current induction possibility. Current induction will allow current flow and ensure stable heating throughout the coil. The material used for the induction coils is mild steel. Other materials that have a higher thermal conductivity such as aluminium and brass are able to achieve high spark temperature at low power levels but tend to melt at temperatures above $600^0$C due to its low melting point. Mild steel has a tolerable thermal conductivity since it is able to produce spark temperature at $600^0$C with 70-80% microwave power levels.

From previous research work, it is proven that larger diameter of mild steel is much more preferable as it does not melt easily when exposed to microwaves for several times compared to small diameter. However, small diameter mild steel is able to achieve higher temperature compared to bigger mild steel diameter. Therefore, three sets of identical spring coils with a small diameter were fabricated to acquire accurate results from the experiment for a better result analysis and interpretation.

In order to have reliable oxidation unit, soot oxidation inceptor must be designed. The induction coil is placed inside the inceptor case to act as a soot trap. The soot particles will collect at the induction coils and get oxidized when hit by microwaves before it is released into the thin air.

## 5.2 RECOMMENDATION

As a recommendation, the experiment need to be carried out using microwave oven which has a stirrer or fan. The stirrer is used to avoid irregular heating inside the microwave oven without the need to rotate the specimen using rotating plate. Besides that, it is recommended to use other type of temperature measurement tool which has range more than $1000^0$C like optic fiber thermometer. Last but not least, the design needs to be tested to check the validity of the design. Thus, a prototype needs to be produced.

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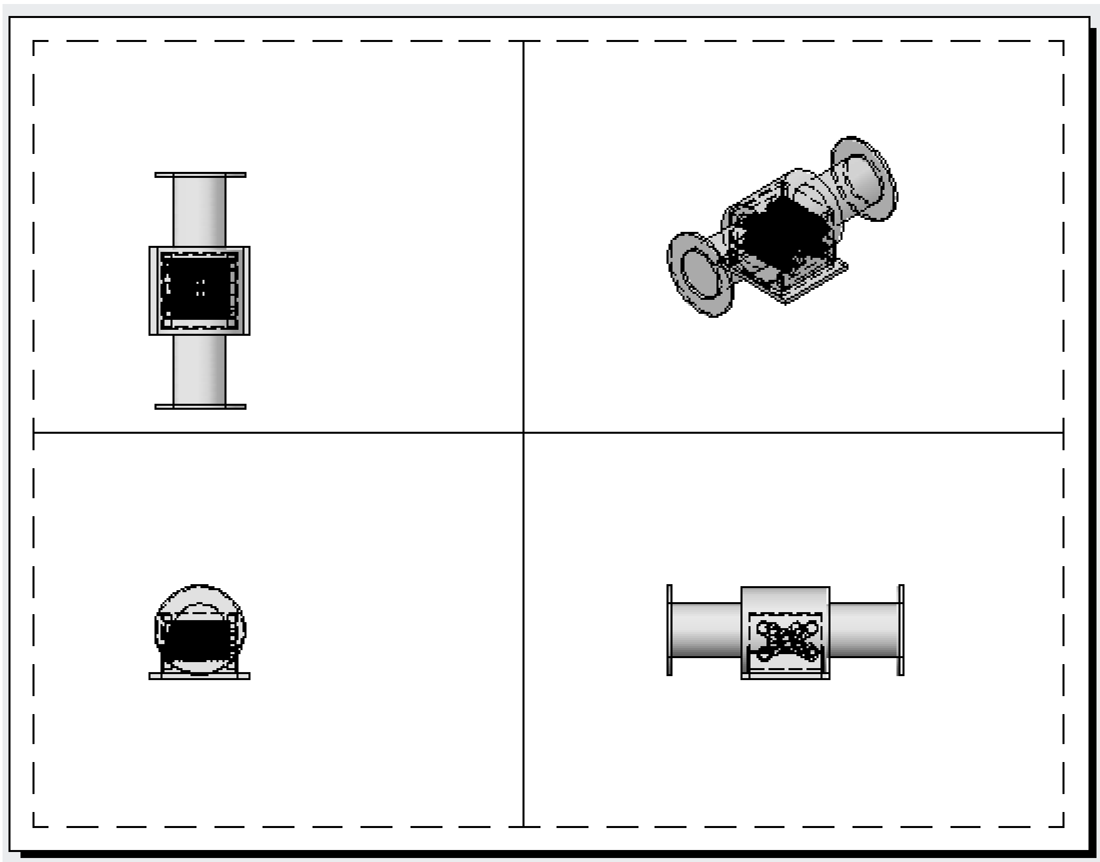
# APPENDICES

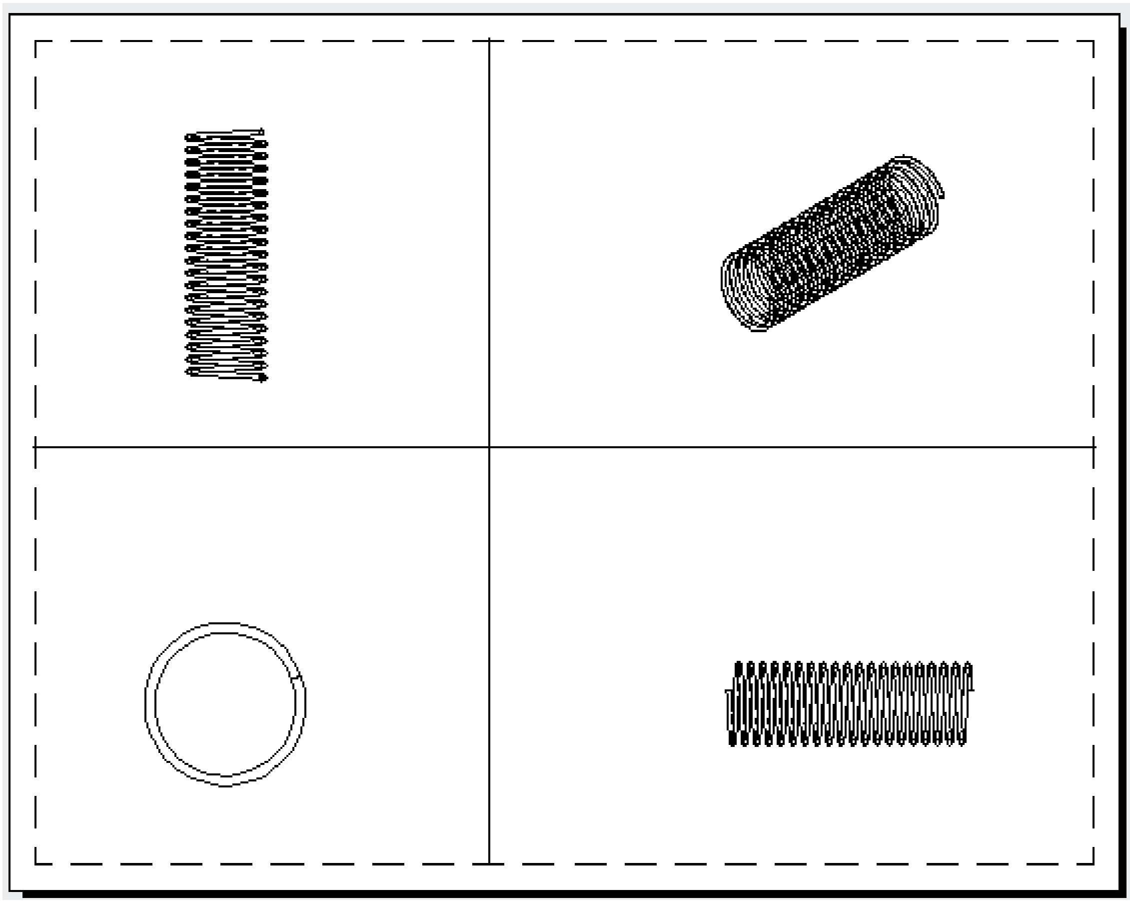
## APPENDIX A

Soot Trap Filter Design

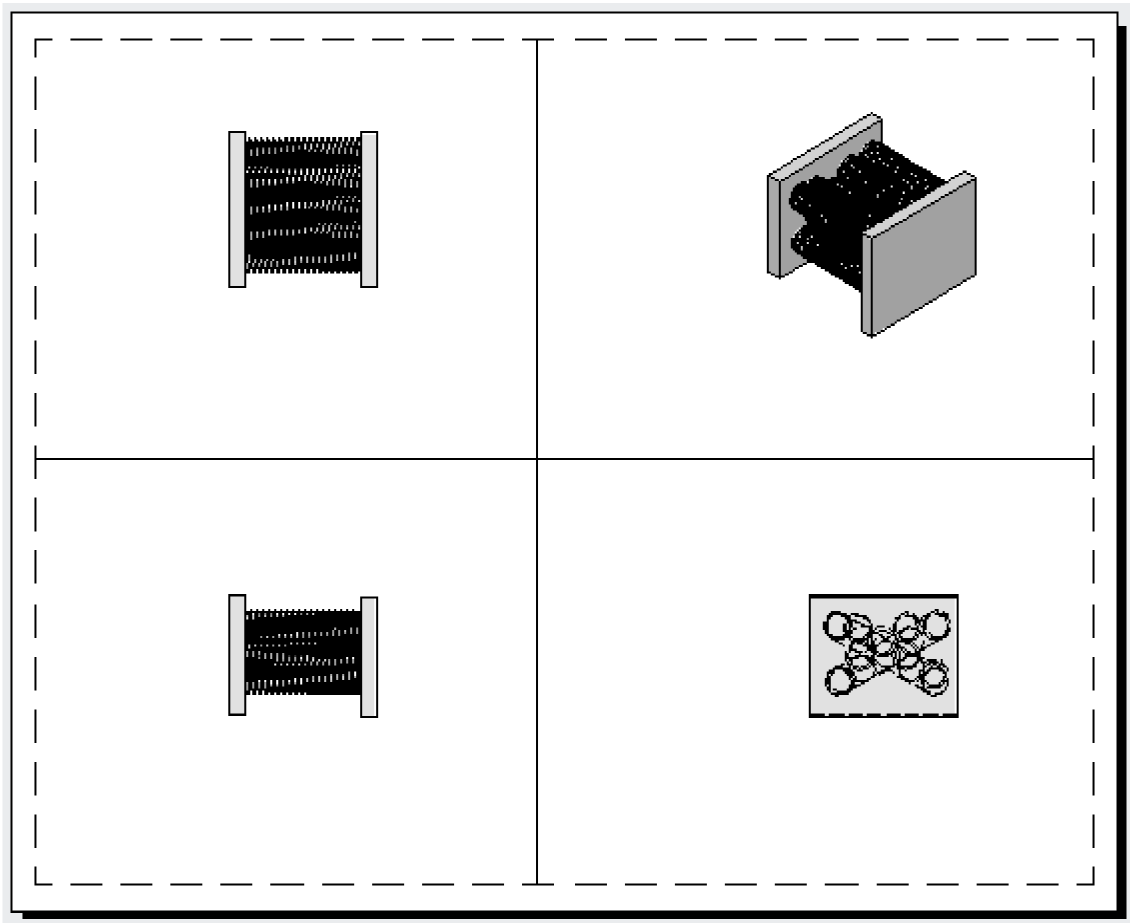


**APPENDIX B**

Spring Coil Design

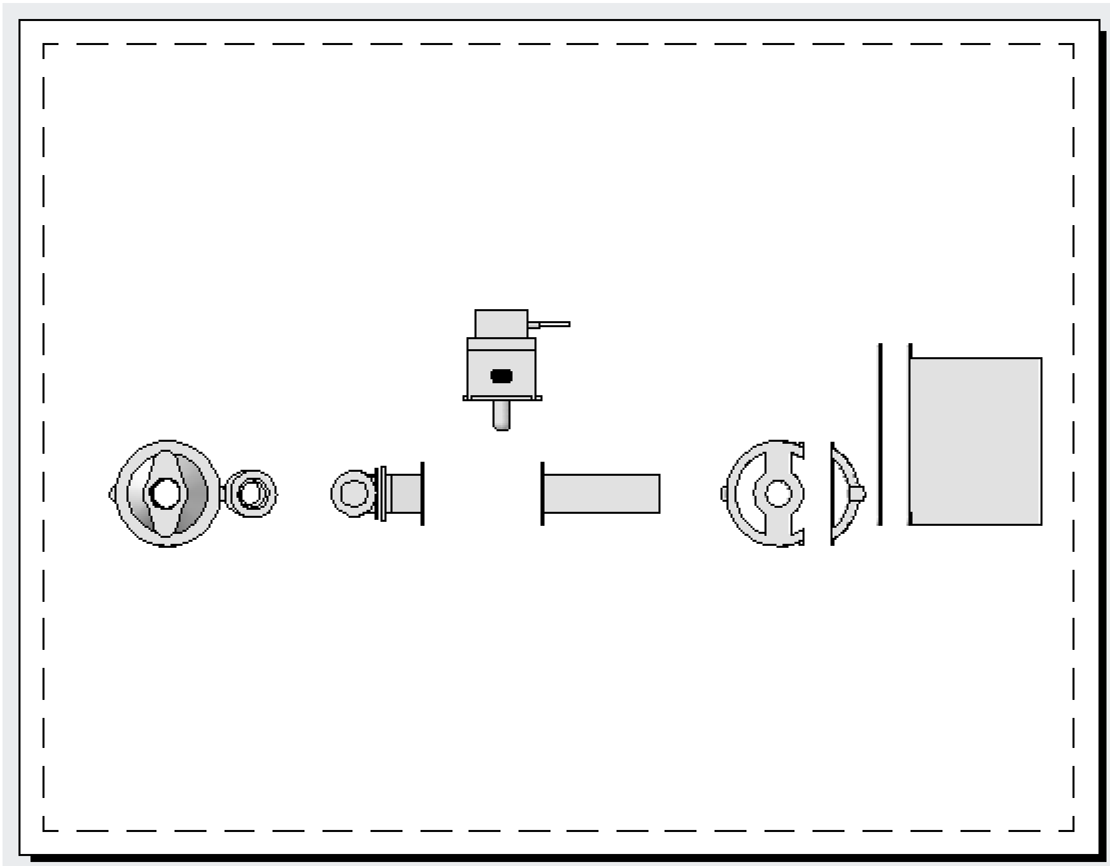


**APPENDIX C**
Spring Coil Holder Design



**APPENDIX D**

Soot Chamber Exploded Design



**APPENDIX E**

Soot Chamber Design