AN EFFICIENCY TEST OF MODIFIED CYCLONE DESIGN AND CONSTRUCTION FOR FIBER GLASS DUST CONTROL IN CUTTING PROCESS OF DECORATED CAR ACCESSORY

MONGKOL CHIMNGAM

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Thesis

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AN EFFICIENCY TEST OF MODIFIED CYCLONE DESIGN AND CONSTRUCTION FOR FIBERGLASS DUST CONTROL IN CUTTING PROCESS OF DECORATED CAR ACCESSORY

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ABSTRACT

This study was modified cyclone efficiency test for dust control of a fiber glass reinforced plastic cutting process using a 101 mm portable grinding blade at 12,000 rounds per minute. The cyclone was a tangential vane axial inlet cyclone modified from two cyclone types 1) a tangential cyclone in which air inlet to cyclone body was by tangential direction and 2) a vane axial inlet cyclone in which air inlet was on the top side of the cyclone and air flow was created by vane moment. Design of the cyclone was based on dimension proportions of Strainmand. Modified cyclone had a 400 mm diameter 1016 mm cyclone length and 600 mm cone length.

The experiment required first an understanding of dust characteristics, dust size and dust distribution in order to help design the cyclone. The theory calculation for estimating in theory, cyclone efficiency could be tested at air inlet velocity of 0.61,0.91,1.52,3.05,4.57 and 6.10 m/sec. Based on possibilities, appropriate air inlet velocity for cyclone efficiency was tested at 1.52 m/sec. Dust size was separated to 5 levels 0.29-38.1 micron, 38.1-63.5 micron, 63.5-125 micron, 125-250 micron and above 250 micron. Cyclone collection efficiency was tested by weighing a filter located at the cyclone outlet, in order to find dust size and concentration.

Results showed that the average cyclone efficiency was 99.67% (standard deviation 0.3715%). Cyclone efficiency was 98.87%-99.89%. This study found a collection efficiency of more than 90%. This was significant when compared with theoretical cyclone efficiency calculation (p-value <0.001)

KEY WORDS: MODIFIED CYCLONE / FIBER GLASS DUST / DUST COLLECTOR / CUTTING PROCESS

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การทดสอบประสิทธิภาพของไซโคลนที่ออกแบบ และสร้างเพื่อควบคุมฝุ่นไฟเบอร์กลาส ในกระบวนการตัดชิ้นส่วนประดับยนต์ (AN EFFICIENCY TEST OF MODIFIED CYCLONE DESIGN AND CONSTRUCTION FOR FIBER GLASS DUST CONTROL IN CUTTING PROCESS OF DECORATE CAR ACCESSORY)

มงคล ฉิมงาม 4436046 PHIH/M

วท.ม. (สุขศาสตร์อุตสาหกรรมและความปลอดภัย)

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บทคัดย่อ

การศึกษานี้เป็นการทดสอบประสิทธิภาพของไซโคลนที่ออกแบบและสร้างเพื่อควบคุมฝุ่นไฟเบอร์กลาสในกระบวนการตัดชิ้นส่วนประดับยนต์ ด้วยเครื่องตัดเจียรขนาดใบเจียร 101 มม. ไซโคลนที่จัดสร้างขึ้นจะเป็นแบบ Tangential vane axial inlet cyclone type ซึ่งประยุกต์ไซโคลน 2 ลักษณะคือแบบ Tangential cyclone ที่ให้อากาศไหลเข้าในแนวสัมผัส

กับแบบ vane axial inlet cyclone type ที่ให้อากาศไหลเข้าทางตรงจากด้านบนและไหลวน

ในตัวไซโคลนด้วยใบโค้ง (vane) การคำนวณตามทฤษฎีของ Stairmand ได้ขนาดเส้นผ่าศูนย์กลาง 400 มม. ส่วนทรงกระบอกยาว 1016 มม. และส่วนกรวยยาว 600 มม.

การศึกษาข้อมูลของฝุ่นทดสอบ เพื่อใช้ในการออกแบบโดยการหาขนาดและการกระจายตัวของอนุภาค แล้วคำนวณความเร็วลมที่เข้าสู่ไซโคลนในแต่ละระดับคือ 0.61,0.91,1.52, 3.05, 4.57 และ 6.10 เมตรต่อวินาที โดยความเร็วลมที่เหมาะสมคือ 1.52 เมตรต่อวินาที ฝุ่นทดสอบมีขนาดต่าง ๆ 5 ขนาด คือ 0.29-38.1,38.1-63.5,63.5-125,125-250 และขนาดใหญ่กว่า 250 ไมครอน ค่าประสิทธิภาพของไซโคลนหาได้จากการชั่งน้ำหนักกระดาษกรองเพื่อหาความ เข้มข้นของฝุ่นแต่ละขนาดหลังผ่านไซโคลน

จากผลการทดสอบพบว่าค่าประสิทธิภาพมีค่าเฉลี่ย 99.67 % (ส่วนเบี่ยงเบนมาตรฐานเท่ากับ 0.3715 %) ซึ่งมีค่าอยู่ระหว่าง 98.87 % ถึง 99.89 % เมื่อเปรียบเทียบกับค่าประสิทธิภาพตามที่กำหนดพบว่ามีประสิทธิภาพสูงกว่า 90 % อย่างมีนัยสำคัญทางสถิติ (p-value <0.001)

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CHAPTER I
INTRODUCTION

1.1 Backgrounds and Rational

The raw materials for manufacturing the necessaries of life were made by natural materials such as wood, metal, glass etc. At present, the natural material use has decreased and been replaced by new types of materials. The improvement of materials technology for multipurpose applications is growing rapidly. Plastic and other new types of materials are used extensively, because plastic has better qualification than natural materials such as light weight crumbling resistance or rust. In addition, it is easy to design and decorate for application requirement.

From the best qualification of plastic materials, the plastic industry is well developed and has several types of products. In the plastic products which require high strength, reinforced materials are added into the products during the manufacturing process. The plastic which is developed by increasing the strength and toughness into plastic products called “Reinforced Plastic” [1]

In the automotive’s accessory industry, it requires product qualification, beauty, and strength. The reinforced plastic is made by mixing fiber glass into its products for improving product quality such as crumbling resistance, heat and chemical resistance, and electric insulation. The manufacturing process of reinforced plastics are begun by laying up the mat of fiber glass into a mold by mixing it with polyester resin, then taking it out of the mold and cutting the part of product over trim line before the top coat painting or decorating. The process of cutting generates particles of fiber glass and polyester resin into the working environment area. The particulate makes the operator working in this process exposed to fiber glass and polyester resin dust. It can cause skin and respiratory irritation. If an operator is exposed these particles for a long time they can cause occupational disease from working and the operator can develop more serious respiratory ailments.

Safety standard of fiber glass and polyester resin particle in Thailand and Occupational Safety and Health Administration (OSHA) of United States of America are not yet classified. However, The National Institute for Occupation safety and Health (NIOSH) and American Conference of Government Industrial Hygienist (ACGIH) of United States of America have recommended the time-weighted average - Threshold Limit Values of 1 fiber/cc by counting number of fiber. The TLV-TWA of total dust and respirable dust is 10 mg/m^3 and 3 mg/m^3, respectively.

Regarding air sampling for measuring dust concentration in cutting reinforced plastic process, total dust concentration was 115 mg/m^3 which was above the standard limit.(safety standard is 15 mg/m^3 for total dust and 4 mg/m^3 for respirable dust.), study characteristic of fiber glass dust see in appendix D

The general cyclone has limitations each type of cyclone will be used for collecting specify dust size and a normal cyclone often has approximately 90 % efficiency. To study the characteristics of fiber glass dust and effectiveness of dust control, the construction of modified high-efficiency single cyclone is needed.

To reduce the health risk from fiber glass and polyester resin dust exposure in operators who work in cutting reinforced plastic processes and to reduce hazardous sources in the workplace, the researcher would like to control dust in this process and construct an efficiency test of a modified high-effiiciency single cyclone for dust control in fiber glass reinforced plastic cutting process.

1.2 Objectives

1.2.1 To design and construct a modified high-effiiciency single cyclone for dust collection in fiber glass reinforced plastic cutting process using a portable grinder with 101 mm blade

1.2.2 To study efficiency of the constructed modified high-effiiciency single cyclone operating each inlet airflow rates.

1.3 Hypothesis

1.3.1 The collection efficiency of modified cyclone at appropriate air flow rate is more than 90%

1.3.2 The collection efficiency of the modified cyclone is more than 90 % each dust size

1.4 Variables

1.4.1 Independent variable

- Air flow rate
- Total dust concentration

1.4.2 Dependent variable

- Collection efficiency of modified high-effiiciency single cyclone

1.4.3 Control variable

- A portable grinder with 101 mm blade
- length of reinforced plastic use for cutting
- thickness of reinforced plastic
- modified cyclone
- dust concentration
- Temperature of air
- Ventilation system

1.5 Scope and Limitation of study

1.5.1 To construct and study efficiency of the modifed high-efficiency single cyclone for dust control generated from fiber glass reinforced plastic cutting processes.

1.5.2 To evaluate the concentration and charecteristics of fiber glass reinforced plastic dust

1.5.3 The fiber glass reinforced plastic dust released from the cutting process by a portable grinder with 101 mm blade and the thickness of product is not more than 50 mm

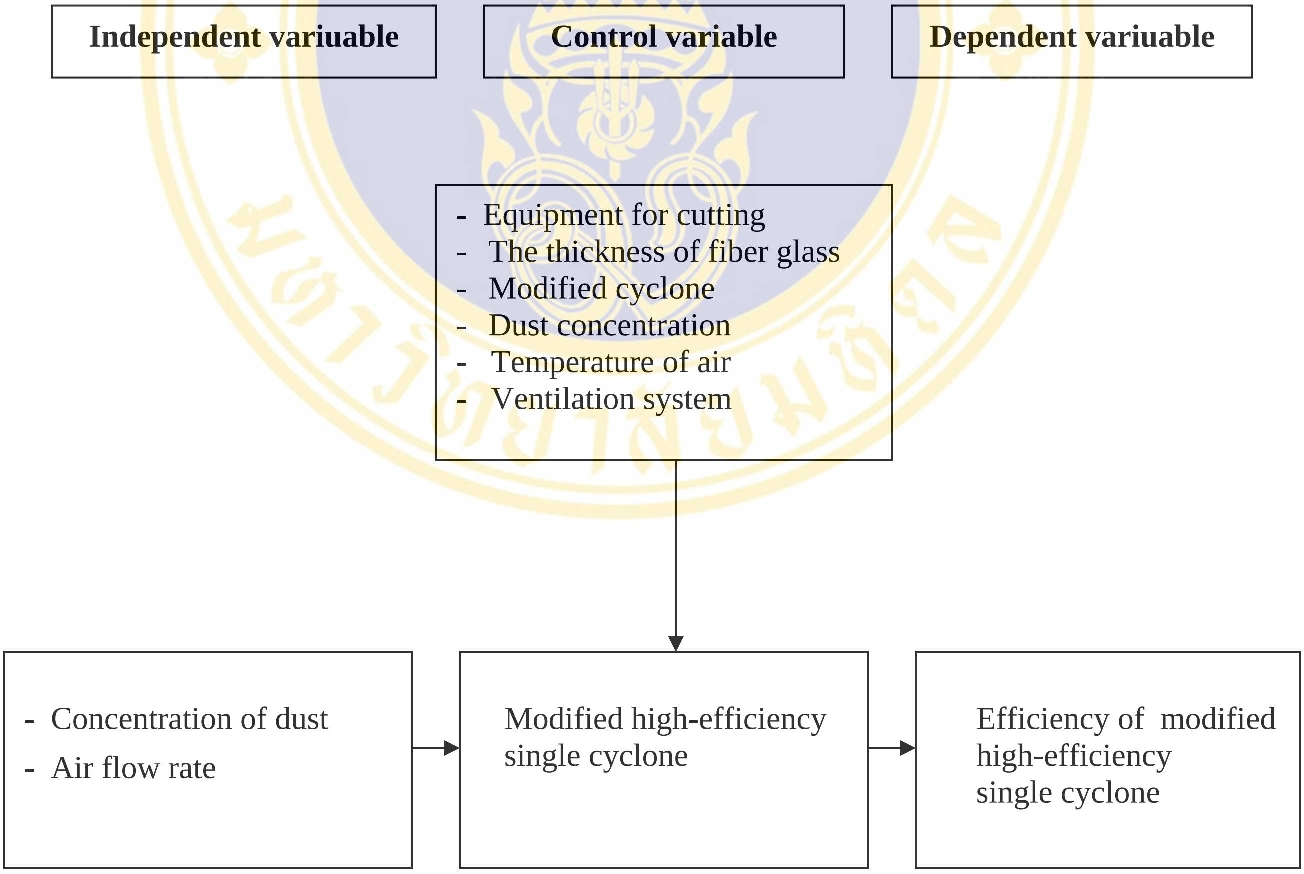
1.6 Out comes and Benefits

1.6.1 The modified high-effiiciency single cyclone can be operated to reduce the fiber glass dust

1.6.2 To know efficiency of the modified high-efficiency single cyclone for dust control based on the design pattern

1.6.3 To construct the prototype of a modifed high-efficiency single cyclone for dust control generated by a portable grinder with 101 mm blade

1.7 Conceptual framework



1.8 Glossary of terms and definitions

Reinforced plastic: The plastic product reinforced by strong and tough materials, mixed into plastic

Automotive's decorate car accessory: The equipment or plastic product used are installed into a car for modification or to increase beauty

Dust: A particle of reinforced plastic which is composed of polyester resin and fiberglass, generated by a portable grinder with 101 mm blade

Reinforced plastic cutting process: The cutting methods for cutting a part of a plastic product which is over limit of the trim line when released from the mold

Modified high-effiiciency single cyclone: A dust collector device that is used for controlling polyester resin and fiberglass dust. It can separate entrained particles from an air stream by the use of centrifugal force, inertial force and gravitational force. Cyclone's can combine the characteristics of vane axial inlet type and tangential type together. (Tangential vane axial inlet cyclone type)

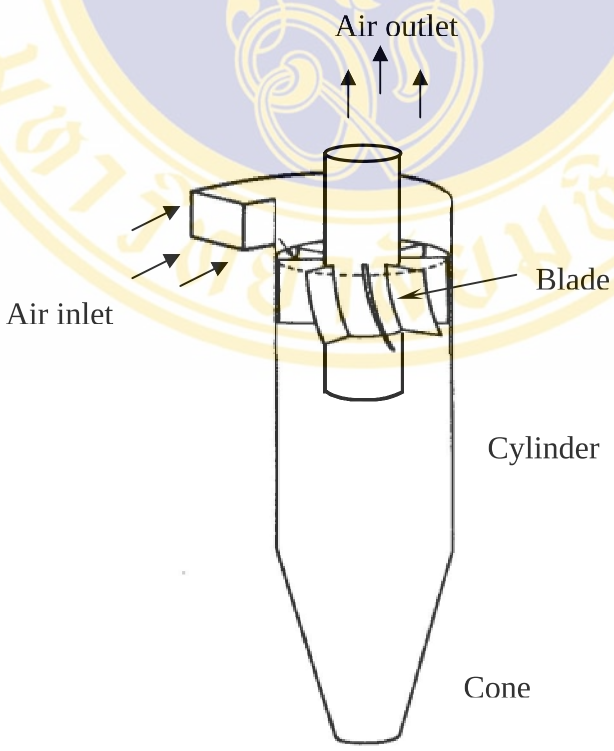


Figure 1-1 Modified Cyclone (Tangential vane axial inlet cyclone type)

CHAPTER II
LITERATURE REVIEW

2.1 Fiber glass reinforce plastic process (FRP)

Fiber glass products are used in many industries ,because fiber glass has the qualification of strength, lower cost than other raw materials such as metal, and techniques for molding fiber glass products are not complicated, low cost investment of machine or equipment suitable for beginners in small manufacturing processes.

The process of fiberglass product molding is as follows

1. Hand Lay-up (Continuous molding process)

This is the simplest process, low cost and mostly used in any manufacturing, suitable for every size of products. This method uses a mat type of fiber glass. The equipment of this method is a roller and a brush.(1)

2. Spray-up

The spray-up process is the second process, but the difference of this process from the first one is not using mat type fiber glass. This method uses a roll type of fiber glass and short fiber, mixed with polyester resin together and is sprayed out on the mold surface by a spray gun. The spray-up process can produce fiber glass products which have one smooth surface.

3. Matched molding

The matched molding process uses 2 parts of mold to join face to face and pressure force from a machine. The method has two types as follows

1. Hot matched molding: The hot matched molding process can produce fiber glass products which have high strength, the mold of this process made by steel.

2. Cold matched molding: The cold matched molding process can produce fiber glass products which have a smooth surface on two sides

4. Premix molding process

This process is similar to a matched molding process, but uses a short fiber glass and mixed with a polyester resin, then put into a mold and the mold is pressed with heat, rest for material set up and released from the mold. The premix molding process can produce fiber glass products which have smooth surface on two sides.

5. Pressure-bag molding

This process is similar to hand lay-up process and spray-up process by putting the mat type of fiber glass or spray-up a short fiber glass with mixed polyester resin into a surface of mold, when finished, put the rubber bag and press it firmly, push the air into the bag which makes it expand and press the fiber glass with polyester resin into the mold, wait for the material to set up and release the air from the rubber bag.

6. Vacuum-bag molding

The vacuum-bag molding process uses the external surface and vacuum air to expand a rubber bag, press fiber glass with polyester resin, putting them into the mold surface. This process is used to produce some products only.

7. Injection molding

The injection process uses a short roll type of fiber glass mixed with polyester resin, then injected via a pipe into a mold. This process inserts a piece of steel, wood or foam inside the product. This process is used to produce a large size of product such as a boat etc.

8. Centrifugal casting

This method is appropriate for making product that requires a smooth shape such as a pipe, a silo etc. The mold of centrifugal casting process is made from steel which is separated into two parts and put on roller moving around in a fixed speed. The process uses a mat type of fiber glass and injects polyester resin into a fiber glass when the mold moves around. The thickness of the product is controlled by a centrifugal force.

9. Filament winding

The filament winding process is used for making a product which requires a hole inside of the product such as a pipe or a buttom shape and used under pressure such as piping of a high presure liquid inside a smooth surface.

10. Continuous molding process

The process has two types as follows

1. Continuous pultrusion process: This process is used for making a product which requires length such as a rod for angling etc.

2. Continuos lamination: This process is used for making a product which requires a smooth surface plate such as a tile used for a roof.

2.2 Fiber glass reinforce plastic for automotive's decorated accessory manufacturing

Automotive's decorate accessory uses the hand lay-up process for molding product; the method begins by cutting a mat of fiber glass following a pattern or shape of mold and prepares a mold for lay-up by spraying gel-coat on a surface of the mold with a spray gun. The gel-coat composes of a gel-coat, a hardener, and a color etc. The mold is rest for gel-coat set up, then mix tulcom powder and a piece of fiber glass, painting the tulcom powder with a brush on surface of the mold and put fiber glass mat in the mold and painting it with a polyester resin. During polyester resin painting, we can increase the strength of product by adding many layers into the fiber glass mat, beware of polyester resin set up before finishing, and then release the product from the mold and clean up the equipment using acetone or thinner.

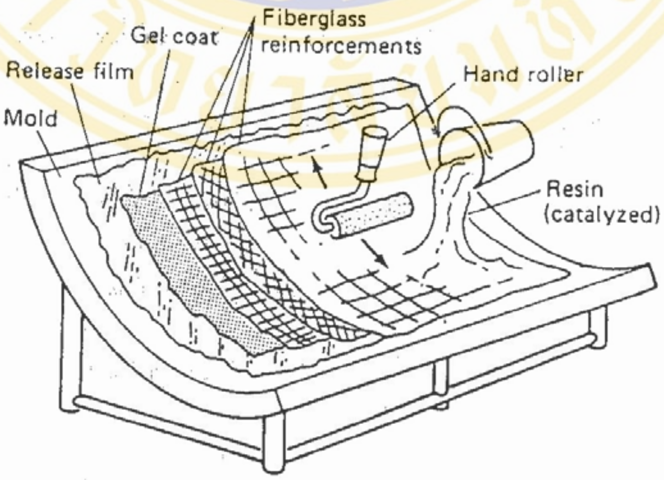


Figure 2-1 Hand lay-up process

The finished product will be sent to a cutting section for cutting the part which is over the boundary line during a hand lay-up process and then grinding by a portable grinder with a 101 mm blade, decorating with a hand file and installing clippers by a jig or checking fixer before preparing a surface for primer painting and top coat painting in the next section.

The process of preparing a surface will begin by polishing and cleaning the product by a brush and a polishing cream or polishing a surface by the sand paper number 200 and polishing again before using the sand paper number 100 to recheck smoothness of surface and then send the product to a primer painting section

For the primer painting process, the operator sprays a primer color on a surface of the product and put it in an oven at 70°c, then return it to a preparing surface section again to check smoothness of surface and polishing by the sand paper again before final primer painting, and then send the product to a top coat painting section

Top coat process, an operator will spray the top coat color onto the product. The process is spraying a top coat and covering the surface by a lacqure and then putting it in an oven at 80°c, after that sending the product to be polished by a polishing cream and sending the product to a final quality section and an assembly section for installing the stop lamp, logo, and customer's sticker etc.

Final quality checking such as color, defect etc. is conducted by a quality control operator; then the product is sent to the finishing goods, to a packing section and after that the product is delivered to customers.

Process chart of fiber glass reinforced plastic for automotive's decorated accessory manufacturing. The process is separated into 8 sections as follows

1. Store & Inventory section
2. Forming section
3. Cutting section
4. Preparing surface section
5. Primer painting section
6. Top coat painting section
7. Quality control section
8. Finishing goods section

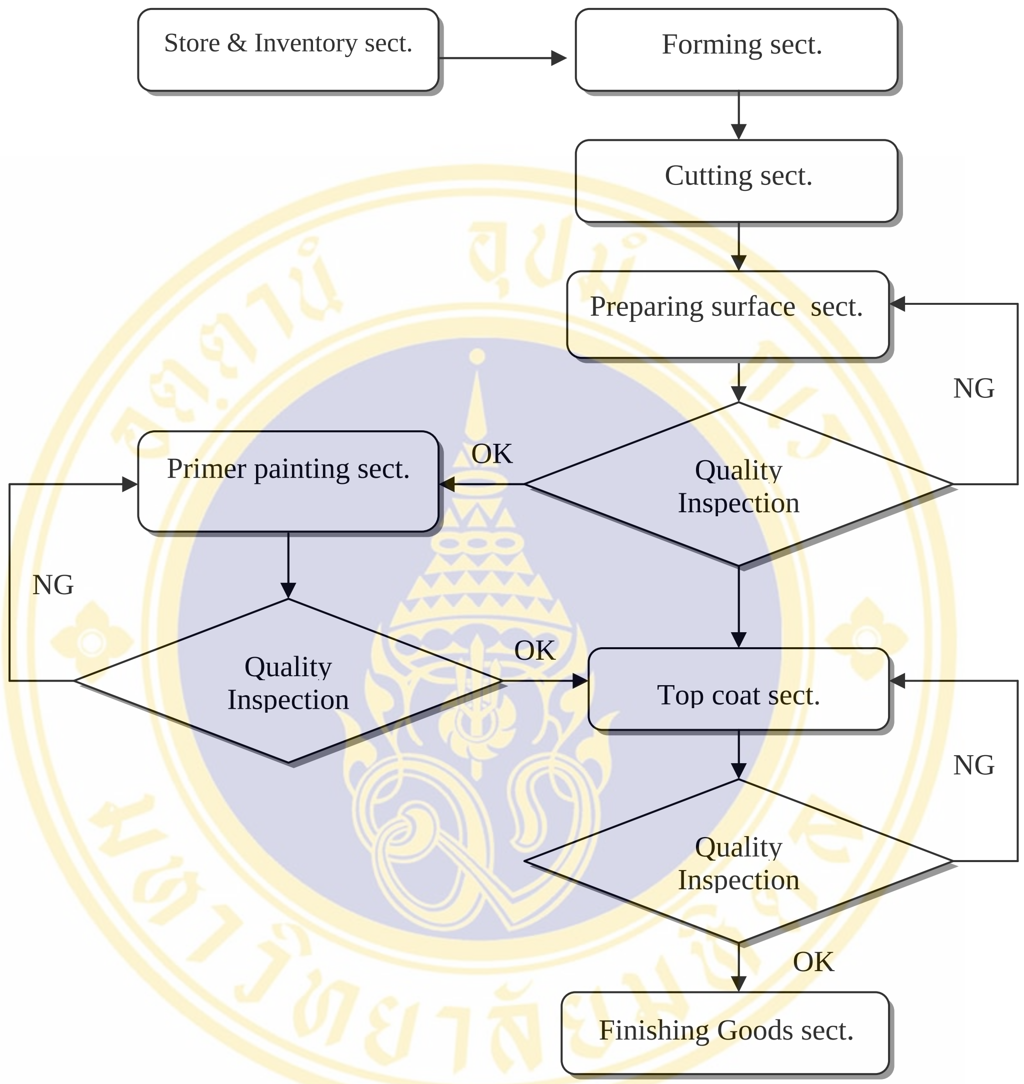


Figure 2-2 Fiber glass reinforce plastic for automotive's decorated accessory process

2.3 Cutting process of fiber glass reinforce plastic product

After molding of fiber glass it is reinforced by a hand lay-up process and is ready to release the product from a mold. The product is sent to a cutting process to cut the part of product which is over the border line. In this process, we will cut the product to the required shape by using a portable grinder with a 101 mm blade (Angle grinder model 9500 NB 100 mm 1,200 rpm figure 2-3)

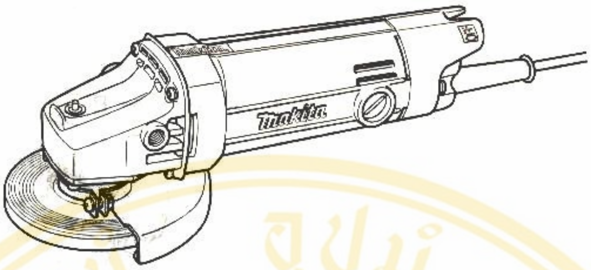


Figure 2-3 Angle grinder model 9500 NB 100 mm 1,200 rpm

In the cutting process, an operator will see the trim line on the surface of the product when the product is released from the mold. During the cutting, dust will be generated from fiber glass mixed with polyester resin into the working envorinment. The dust from product cutting uses a high speed fan to ventilate the dust to other area (Figure 2-4) Operators in nearby areas will be exposed to the hazardous dusts and this process will generate air pollution inside the working area.

Figure 2-4 Product cutting by portable grinder

2.4 Fiber glass

Fiber glass is a reinforced material adding a mechanical strength into a polyester resin. The fiber glass has various types such as roving, chopped strand, mat, fabrics etc. The fiber glass reinforced plastic manufacturing process uses specific types appropriate with size of product and product quality requirement. The fiber glass is coated by various chemical substances which has a quality for holding fiber glass and polyester resin together. The composition of fiber glass comprises 52-56% silicon dioxide, 16-25% calcium oxide, 12-16% aluminium oxide, 8-13% boron oxide, less than 1% sodium, 0-6% potassium oxide and magnesium oxide.

Fiber glass are made by melting natural minerals, mostly in the production process using polyester and epoxy resin to produce heat insulator, air filter etc. This composition and material can cause irritants or cancer. The International Agency for Research on Cancer (IARC) classified that fiber glass wood could cause cancer when inhaled in the lung. The classification of fiber glass as carcinogens comes from experiment by injecting the fiber glass into animals in the laboratory. However, mortality rate of workers in United States of America and Europe in fiber glass manufacturing process did not have evidence of human carcinogens, but IARC considered any materials which have information to identify cancer in animals. There are risks to carcinogens in human and IARC classified respirable fiber glass dusts in a group 2B (possible carcinogenic to human).

However, the epidemiologist is not yet identified, but OSHA recommended showing a warning label and hazard which may occur on a container of product. The warning label did not identify a risk level but OSHA recommended safety in the long term when operators exposed to fiber glass dust less than 1 fiber/cc Threshold Limit Value-Time-Weighted Averages (TLV-TWA). Normally, exposure to fiber glass dust in house, office etc. found less than 1 fiber/cc

The fiber glass dust can be exposed through the skin, inhalation, eye irritation and etc. The exposure can cause lung diseases, especially upper respiratory track and increased lung ailment when exposed to dust in long term. In addition, fiber glass dust can cause skin irritation, eye and upper respiratory track, and skin inflammation.

In 1987, epidemiology education in fiber glass industrial workers in U.S.A. reported that more than 16,000 workers had no increased a significant risk. In 1990, new information of risk reported a little significant increase in respiratory track cancer patient whose work was concerned with fiber glass when compared with normal population in the same community; this report found other confounding factors such as smoking and exposure to chemical substances and etc.(3)

Regarding an experiment in animals found that fiber glass dust can cause lung inflammation and chronic cough, toxicity of substance upon various chemical coated on fiber. However, a report found that tumor in respiratory tracks in experimental animals were caused by this substance and found that workers exposed to fiber glass in the long term developed the respiratory track obstruction and the nervous disease. Furthermore, the worker exposed to fiber glass found many fiber glasses in sputum at a clinic check-up. However, the result of health a check up could not conclude that the workers who worked with fiber glass dust can cause lung disease and the nervous disease, because the working environment and working condition information are not sufficient. The preventive method to avoid this hazard are monitoring the working environment and the result showed that concentration of dust was not over the limit of safety standards [(2)(3)]

Due to the standard of fiber glass dust, classified as nuisance dust (PEL= 5 mg/m^3 for respirable dust and 15.0 mg/m^3 for total dust), concentration measurement by weighting method but using a phase contrast optical microscopy method [(8)], the standard was set at 1 fiber/cc The recommended Threshold Limit Value-Time-Weighted Averages (TLV-TWA) of ACGIH and NIOSH is 1 fiber/cc and weighting method is 5.0 mg/m^3

2.5 Unsaturated polyester resin

Unsaturated polyester resin is a liquid plastic. It is mostly used for molding fiber glass product due to its low cost and is appropriate for molding. In raw material condition, unsaturated polyester resin is a liquid substance and has a smell, when it is mixed with some kind of chemical substances; it will change to active form and appear as a clear solid plastic. The unsaturated polyester resin has a composition of monostyrene. Generally, styrene is extracted from mixing substance of benzene and ethylene, monostyrene which is used as an active solvent for polymerization reaction. It can also be put in a polyester resin and jell coat in order to easily spray and paint; the ratio for mixing is 10-20%

Unsaturated polyester resin used in automotive's decorated accessory industry is iso-phthlic and neopentyl glycol type, which is appropriate for fiber glass reinforce plastic: FRP. According to the safety standard of polyester resin, both OSHA and ACGIH not yet declaration, but styrene monomer which composed in polyester resin are harmful to health, OSHA (PEL) and ACGIH (TLV) declared that 50 ppm was TLV-TWA for styrene and 100 ppm for Short Term Exposure Level (STEL).

Unsaturated polyester allocated in thermosetting type which comes from reaction of unsaturated polyester in the substance's such as styrene unsaturated polyester and polyvalent alcohols. This reaction is called estering. [26]

Prolonged exposure to unsaturated polyester resin can cause skin irritation and dermatitis; styrene substance absorbed through the skin becomes toxic.
In addition, eye contact may cause eye irritation of the mucous membranes, pain and redness. Individuals with chronic respiratory conditions (i.e., asthma, chronic bronchitis, emphysema, etc.) may be adversely affected by any fume or airborne particulate matter exposure [1][4][23]

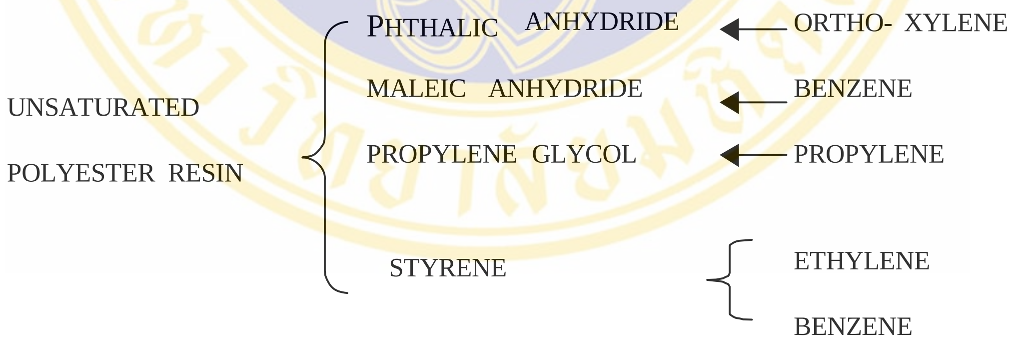


Figure 2-5 Substance in process of polyester resin producttion

ACGIH classiflied polyester resin dust as nuisance dust, Threshold Limit Value-Time-Weighted Averages (TLV-TWA) is 3 mg/m^3 for respirable dust and 10 mg/m^3 for total dust OSHA (PEL), NIOSH (REL) and Thailand standard has not established the standard for polyester resin dust.

2.6 Selection particles control equipment

Selection of dust control equipment and factors influencing equipment selection include the following

1. Efficiency required: acceptable quantity of pollution release into ambient
2. Gas stream characteristics: flow rate of gas stream, temperature, type or characteristics of gas stream etc.
3. Contaminant characteristics: contaminant concentration, size distribution and weight etc.
4. Cost of operation, maintenance, and construction etc.

First step of appropriate dust control equipment selection must consider several information as follows

1. Contaminant concentration
2. Size distribution
3. Air flow rate
4. Quantity of pollution

There is information on how to select the cleaning system. First, the cleaning system has to separate particles following required efficiency at a specific flow rate and then one needs to compare construction cost, operation cost of each system, then choose the most economic and highest efficiency system to operate the process. [6]

2.7 Particulets controls equipment types

Particulates collectors equipment has many types as follows

1. Setting Chambers

Setting chambers use principle of gravity force, when the particles in air flow through a chamber, contaminants or particulets in the air will fall down by gravity. Velocity of air when passed through the chamber should be low and does not make the dust on the floor of the chamber re-spread. Reduction the velocity of air inlet is carried out by expanding the size of the inlet duct to the chamber, and then velocity of inlet air will be reduced. In practice, this equipment is suitable for separating size of particles more than 50 micron, due to limitation of chamber length and collection efficiency. Advantages of setting chamber are easy construction, low cost, low energy to operate, low cost of maintenance and collecting dust without using water. Limitation of this equipment is it requires more space and has a low efficiency, especially low efficiency for collecting fine dust or small size particles.

2. Centrifugal Separators

Centrifugal separators use a principle of centrifugal force; centrifugal separators or cyclone uses air rotation to generate centrifugal force to separate particles from the air stream. The rotation of air stream can make dust move by inertial force to the separator's wall, then fall down to a dust hopper.

Cyclone has many types, classiflied by characteristics of air stream rotation as follows

2.1 Reverse-flow Cyclone , It has tangential air inlet and axil air inlet.

2.2 Straight-through-flow cyclone

2.3 Impeller collectors

Regarding the Reverse-flow Cyclone type, air stream inlet is sent to a cyclone by side route of upper part of cyclone; this type of air inlet makes rotation of air stream and particles move to the cyclone's wall by a centrifugal force and then fall down to a lower part of cyclone by a gravitational force.

For the straight-through-flow cyclone, air stream will pass through an impaller at the upper part of cyclone; it makes air move by a centrifugal force and the air outlet through the lower part of cyclone. This cyclone is a pre-cleaner device for separating big size paticles or ashes. Advantage of this equipment is a low presure drop and suitable for high flow rate.

For the impeller collectors cyclone, air stream inlet is perpendicular to direction of many impallers. The particles will be collected by the impallers and casted to hold around the device. Advantage of this equipment is compact equipment, but limitation is obstruction due to collection of particles inside equipment.

3. Scrubbers or Wet collectors

Scrubbers or Wet collectors use liquid to catch particles and increase particles size for easy collection; the liquid normally uses water. The method is to increase particles sizes and easily to separate particles from an air stream. The liquid or water will be sprayed to generate mist for increasing support catching between particles and water; for some big size particles, they will separated by gravitational force and for small size particles, they will separated by static electricity or force which is made by heat. The wet collector's equipment can separate fine solid or liquid particles size between 0.1 micron and 2.0 micron, higher efficiency than dry equipment due to agglomeration of fine particles to larger size, when contacting with water and little re-spread due to wet particles, and the particles being caught within a liquid layer. Advantage of wet collectors is many types available for selection appropriate with the problem's condition. The limitation of this equipment is high presure drop; then this equipment will require more energy for operation, and problem about liquid mixed with particles.

4. Fabric filters

Fabric filters are used in many industries. Most patterns are used in baghouse inside this equipment. There are many types of fabric bags. The particles in air stream will pass through fabric bags and particles will be catched by a fiber of fabric and a layer of filter. After that, particles which are collected by fabric filter will be removed by many methods such as shaking, air blowing and ring moving method. Considering for selected fabric filter is limited to the size of fiber, method of cleanning, cycle of equipment operation and accepted pressure drop for hight efficiency and low cost equipment. The limitation of this equipment is the cleaning process to avoid increased pressure drop.

5. Electrostatic precipitators

Electrostatic precipitators use static electricity for collecting particles at high flow rate of gas stream. Most electrostatic precipitators are used for separation of ashes from gas release from a power plant and are used for collection of particles, acid mist in chemical and steel industrials.

2.8 Dust collection by cyclone

Cyclone is equipment for dust separation from air stream by principle of centrifugal force which is an air stream moving around (vortex) particles, and then particles can be separated from the air stream. The vortex was generated by air stream flowing into cyclone's wall and spiral downwards. A cyclone collector is a structure without moving parts in which the velocity of an inlet gas stream is transformed into a confined vortex from which centrifugal forces tend to drive the suspended particles to the wall of the cyclone body. [7] [18]

Collection Mechanisms

Cyclone principle mechanisms have 2 type of forces as follows

A. Centrifugal force: The air stream will move around the inside of a cyclone which castes dust to the cyclone’s wall

B. Gravitational force: When particles move to the cyclone’s wall. The heavy particles move downward to the lower part of cloclone (hopper) by gravitational force.

The three forces acting on individual dust particles are gravitational, centrifugal, and frictional drag. The gravitational force is defined by Stokes law as applied to freely falling bodies. The frictional drag on a dust particle is caused by the relative motion of the particle and the gas and opposes the centrifugal forces acting on the particle. The major force causing separation of the dust particles from the gas stream is the centrifugal force induced by rotation of the dust-laden gas stream within the collector.[16] The gravitational, centrifugal, and frictional forces combine to determine the particle path and performance abilities.

Cyclone operating principles

Cyclone has a part of cylinder shape and a lower part is a cone shape illustrated in figure 2-6 The air inlet enters the body tangentially and spirals downwards in a lower part, generates vortex motion (main vortex) which is centrifugal force taking particles to the cyclone’s wall. This vortex motion will flow down to the lower part (cone) and air reverses flow in the core upper part (core vortex) and flow upwards to air outlet on the upper part of cyclone. In cyclone body, there is double vortex, particles cast to the cyclone’s wall and flow to lower part of the cyclone or hopper by gravitational force. Air stream without particles will flow upwards to upper part and released by the passing air outlet.

The dust laden gas is caused to spin in a downward spiral. The spinning action causes the suspended particles to migrate toward the inner wall of the cyclone.[14][20] The vertical force component of the downward spiral causes the particulate to be carried down through the cone section and into the hopper.

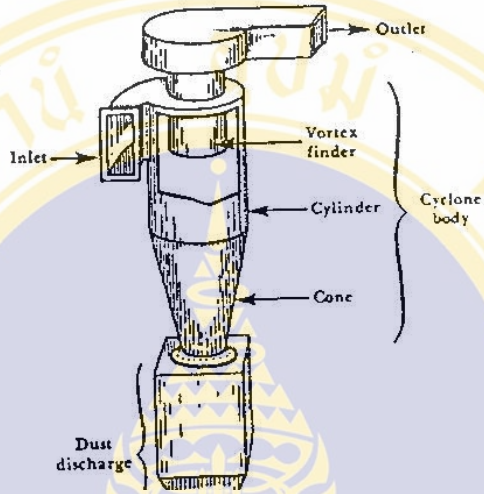


Figure 2-6 Cyclone structure

The dirty gas enters at the top of the cyclone and is given a spinning motion because of its tangential entry. Particles are forced to the wall by centrifugal force and they fall down the wall due to gravity. At the bottom of the cyclone[19], the gas flow reverses to form an inner core which leaves at the top of the unit.

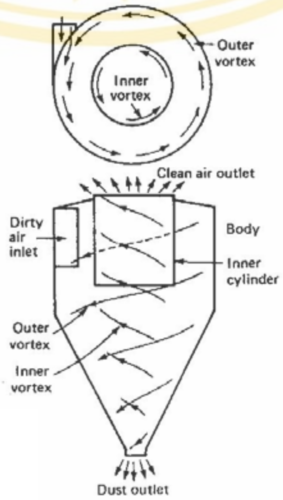


Figure 2-7 Principle of operation of the reverse flow cyclone separator

Cyclone consists of a vertical cylindrical body, with a dust outlet at the conical bottom. The gas enters through a rectangular inlet, normally twice as high as it is wide, arranged tangentially to the circular body of the cyclone, so that the entering gas flows around the circumference of the cylindrical body, not radially inward. The gas spirals around the outer part of the cylindrical body with a downward component, then truns and spirals upward, leaving through the outlet at the top of the device. During the outerspiral of the gas, the particles are driven to the wall by centrifugal force[24], where they collect, attach to each other, and form larger agglomerates that slide down the wall by gravity and collect in the dust hopper in the bottom.

Forces effecting particles

By disregarding gravitational forces, each dust particle is subjected to three different forces

1. **Inertial** This is the tendency to move in a straight line and is a function of particle mass and velocity.

2. **Centrifugal force** This force is created as a result of the shape of the cyclone. It is a function of the particle's velocity, radius of curvature within the cyclone walls, and mass.

3. **Viscous drag** This force is created as a result of the resistance to flow within the gas medium. [20] (illustrated in figure 2-8) viscous drag is a function of particle size and shape and the viscosity of the gas.

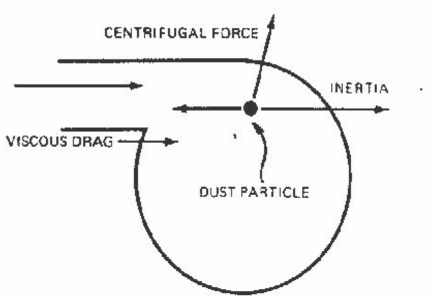
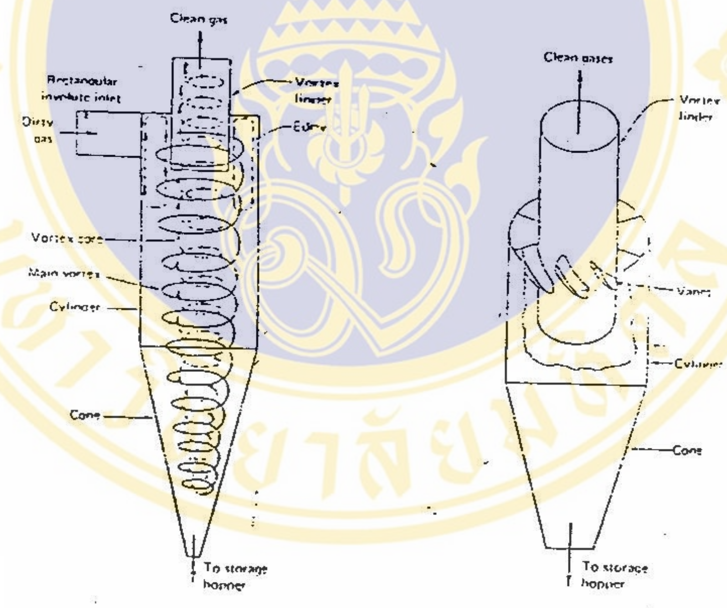


Figure 2-8 Efficiency cyclone design effects a balance between the inertia, centrifugal force, and viscous drag forces which interact on the particle

Cyclone type

In the original cyclone design, air enters the body tangentially, and inside the cyclone, assumes two forms, one circulating adjacent to the outer wall, subjecting dust particles to centrifugal force and causing the larger of them to migrate radially toward the wall, and a concentric inner gas spiral finer particles, moving up the exit duct passage at the top.[5][21] Dust concentrated into the dust collection hopper below the cyclone.

Cyclone was classified in two types, depending on how the gas stream enters for vortex motion in body and leaves as follows , illustrated in figure 2-9



A : Tangential entry cyclone B : Axial entry cyclone type

Figure 2-9 Cyclone type

The necessary elements of a cyclone consist of a gas inlet which produces the vortex; an axial outlet for cleaned gas; and a dust discharge opening. The various arrangements of these elements lead to a classification system of types figure 2-10

Cyclone is used in two basic forms, the tangential inlet and the axial. In actual industrial practice, the tangential inlet type is usually a large (1-5 m in diameter) single cyclone[(1)(18)(23)], while the axil inlet cyclone is relatively small (about 20 cm in diameter and arranged in parallel unit for the desired capacity).

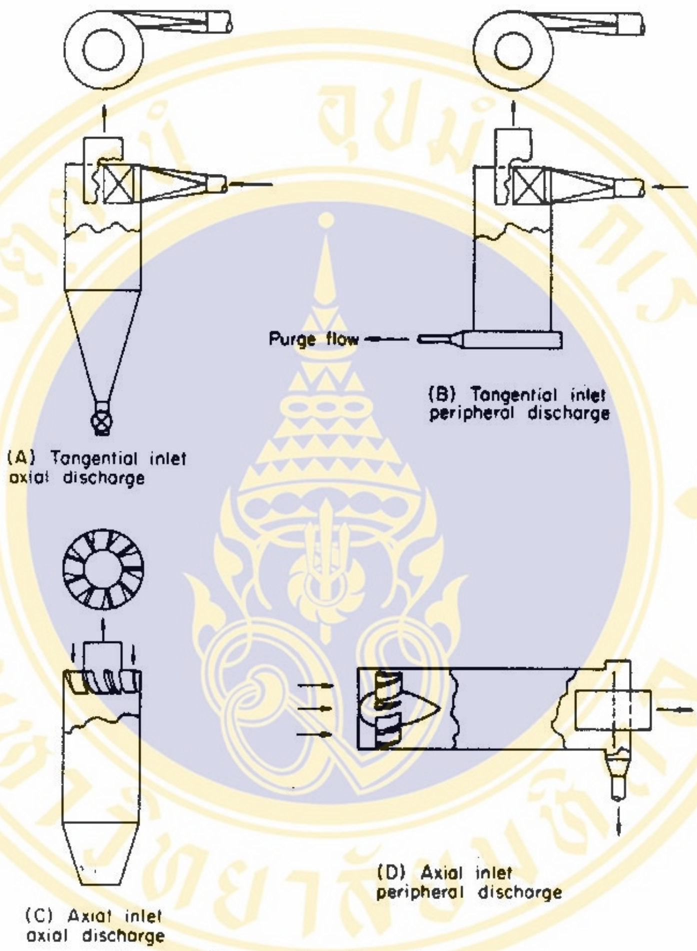


Figure 2-10 Types of cyclone in common use

A. The common cyclone, tangential inlet with axial dust discharge
B. Tangential inlet with peripheral dust dischage
C. Axial inlet through swirl vanes, with axial dust discharge
D. Axial inlet through swirl vanes, with peripheral dust discharge

Air stream tangential entry flow to cyclone body in vortex motion. The duct of a air inlet most have guadrilateral shape which has curved walls inside and touch with cylinder cyclone body. Axil entry cyclone type, the air and particles will flow to the cyclone followed by cyclone axil vanes (figure 2-10), this type is mostly used in multi-cyclone.[5] Normally, cyclone work depends on inertia force of particles which have linear motion, when the air flow changed direction, the centrifugal force was generated.

Most of cyclone is made by carbon steel or ceramic materials, if used in high temperature or corrosive condition, inside of the body must be smooth. Due to cyclone having no moving parts inside, it is easy to operate and maintain.

2.8.4 Cyclone configuration and Relative dimension

Figure 2.11 is tangential entry cyclone type, shown in 8 dimensions. The ratio of dimensions are:

$$D_c / D_c , a / D_c , b / D_c , D_e / D_c , S / D_c , H / D_c , B / D_c$$

The ratio will show configuration of cyclone, which has 1 dimension. D_c means cyclone diameter. [15]

Table 2-1 Ratio of cyclone

Dimension	Ratio
Body diameter (Dc/Dc)	1.0
Height of inlet (a/Dc)	0.5
Width of inlet (b/Dc)	0.2
Diameter of gas exit (De/Dc)	0.5
Length of vortex finder (S/Dc)	0.5
Length of body (H/Dc)	1.5
Length of cone (h/Dc)	2.5
Diameter of dust outlet (B/Dc)	0.375

If designing cyclone by other configurations should consider the following:

1) $a \leq S$: to avoid particles inlet flow through outlet immediately
2) $b \leq (D_C - D_e) / 2$: to avoid more pressure drop
3) $H + h \geq 3D_C$: to vortex motion stay inside cyclone body
4) Corner of cone about 7- 8° : easy to drain particles
5) $D_e / D_C \sim 0.4 - 0.5$, $H + h / D_e \sim 8 - 10$ and $S / D_e \sim 1$: to most collection efficiency

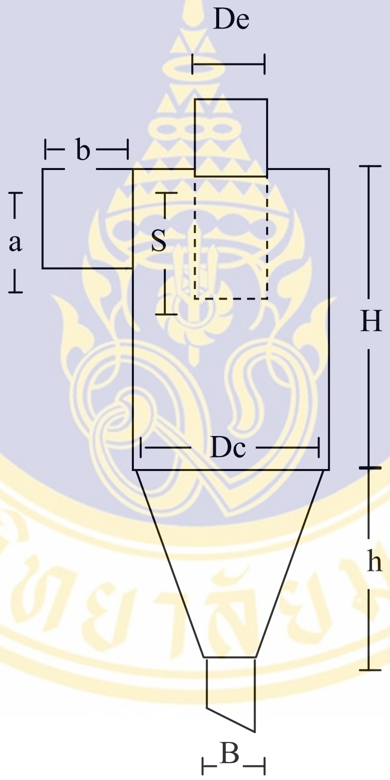


Figure 2-11 Configuration and dimension of cyclone

2.8.5 Cyclone efficiency calculation

1. Calculation of overall collection efficiency

$$\eta_T = \Sigma \, mi \, .ni$$

2. For saltation velocity (Vs),

$$Vs = 2.055 \, \omega \left[\frac{(b/Dc)^{0.4}}{(1-b/Dc)^{1/3}} \right] Dc^{0.067} \cdot Vi^{2/3}$$

$$\omega = [\, 4g.\mu \, (\rho_p - \rho_f) / 3 \, \rho_f^2 \,]^{1/3}$$

If Vi / Vs = 1.25 , Cyclone will have maximum collection efficiency.

If Vi / Vs $\geq$ 1.36 , Cyclone will cause the re-entrainment.

3. Volumetic flow rate (Q) calculation,

$$Q = abVi$$

4. Natural length (l) calculation,

$$l = 2.3 \, De \, (Dc^2 / ab)^{1/3}$$

5. Vortex exponent (n) , Cyclone configuration factor (G) and Relaxation time (τ)

$$n = 1-[1-(12Dc/2.5)^{0.14}] \, [\, (T+460)/530]^{0.3}$$

The equation for cyclone configuration factor (G) is as follows

$$G = 8Kc/Ka^2. \, Kb$$

$$Ka = a/Dc$$

$$Kb = b/Dc$$

$$Kc = (2Vs+Vnl\ ,\ H)/2Dc^3$$

$$Vs = [\pi(a/2)(Dc^2 - De^2)]/4$$

If l > (H-S) will use V_H value for equation (2.13.3)

$$V_H = \frac{\pi\ Dc^2}{4}(h\text{-}s) + \left(\frac{\pi\ Dc^2}{4}\right)\left(\frac{H\text{-}h}{3}\right)\left(1+\frac{B}{Dc} - \frac{B^2}{Dc^2}\right) - \frac{\pi\ De^2}{4}(H\text{-}s)$$

If l < (H-S) will use Vnl value for equation (2.13.3)

$$V_{nl} = \frac{\pi\ Dc^2}{4}(h\text{-}s) + \left(\frac{\pi\ Dc^2}{4}\right)\left(\frac{l+s\text{-}h}{3}\right)\left(1+\frac{d}{Dc} - \frac{d^2}{Dc^2}\right) - \frac{\pi\ De^2}{4} \cdot l$$

$$d = Dc - (Dc\text{-}B)\ [(s+l\text{-}h) / (H\text{-}h)]$$

6. Grade efficiency or fractional calculation

$$\eta i = 1 - \exp\left\{-2\left[\frac{G\tau iQ}{Dc^3}(n+1)\right]^{0.5/(n+1)}\right\}$$

7. Pressure drop (Δp) calculation

$$\Delta p = 0.003\ \rho f\ .\ Vi^2\ .\ N_H$$

$$N_H = K(ab / De)$$

K = Constant value

= 7.5 , If cyclone has neutral inlet vane

= 16 , If cyclone does not have neutral inlet vane

De = Cyclone gas-outlet diameter, ft

8. Adjusted cyclone ratio

To most efficiency must consider the criteria as follows

1. $a < S$ (To avoid short-circuiting)
2. $b < ½ (Dc\text{-}De)$ (To avoid immediate contraction)
3. $S + l \leq H$ (To maintain air turning inside cyclone)

4. S < h
5. h < H
6. $\Delta p < 10'' H_2O$
7. $Vi / Vs \leq 1.35$ (To avoid short-circuiting of air turning)
8. $Vi / Vs = 1.25$ (To optimun cyclone efficiency)

2.9 Cut size or Cut diameter

Cut size or cut diameter is particle size collected by 50% collection efficiency. The particles size larger than cut size were collected by cyclone efficiency more than 50%, cut size depends on characteristic of carrier gas and cyclone performance and operating conditions.[(7)(9)(22)]

The equation for finding cut size as follows

$$(d_p)_{cut} = \sqrt{\frac{9 \mu w}{2 \P N_e V_g (\rho p - \rho g)}}$$

when μ = viscosity , Pa.s

Ne = effective number of turns

Vg = velocity of air inlet , m/s

ρp = density of particles , kg/m^3

ρg = density of air , kg/m^3

w = air inlet width , m

2.10 Cyclone efficiency

In general, cyclone collection efficiency varies directly with the dust particle density and particle size, dust loading, the square of the cyclone inlet velocity, cyclone body length, number of gas stream revolutions, and ratio of cyclone body diameter to outlet diameter. The collection efficiency varies inversely as the gas density, gas viscosity, cyclone diameter, gas outlet diameter, gas inlet duct width, and inlet area. The collection efficiency of the cyclone depends on various factors. The cyclone efficiency will increase when various factors increased[5] [16] [17] [18] [22]

1. size of paticles
2. density of particles
3. velocity of air inlet
4. length of cyclone body
5. number of turns
6. smoothness of cyclone's wall

The cyclone efficiency will decrease when some factors increase :

1. viscosity of air
2. cyclone diameter
3. air outlet diameter
4. area of air inlet

There are many equations to calculate cyclone efficiency in grade pattern of fractional efficiency, for same particles size, fractional efficiency means fraction of particles size which is collected by the cyclone when compared with same inlet particles size. The design of a cyclone separator represents a compromise among collection efficiency, pressure drop, and size. Higher efficiencies require higher pressure drop (i.e., inlet gas velocities) and larger size (i.e.,body length).

Predicting efficiency of cyclone

Many investigations attempt to correlate cyclone performance with various parameters. Lapple(1951 and 1963) treats the subject at length in several publications, introducing the concept of cut size (D_{pc}) which is defined as the diameter of those particles collected with 50 percent efficiency. Collection efficiency for particles larger than the cut size will be greater than 50 percent while that for smaller particles will be less. Another term used is the average partcle size (D_p), which is simply the average of the size range. For example, if the size range is 10 to 15 micron, $D_p = 12.5$ microm. Additional expermental data have been used to check lapple's ratios of D_p/D_{pc}. All have been compared favorably with the original curve of Lapple.

Lapple's method was using principle of centrifugal force balance and drag force which is active in cyclone body, to calculate cut size of particles $(d_p)_{cut}$ by the above equation. Lapple had used the result of the same cyclone experiment and concluded in graph pattern for calculation of cyclone efficiency. There is ploting between cyclone efficiency (η_t) and ration of particls with cut size $(d_p / (d_p)_{cut})$ which is predicting efficiency in the same cyclone pattern.

Improving cyclone performance

Mechanical Collectors

One of the earliest types of dust collectors used in industry is the mechanical cyclone collector. More cyclone collectors are used in commercial applications today than any type other of collector. [20]

Basically there are two types of mechanical collectors in commercial applications, tangential inlet cyclone, and axial inlet collectors as shown in figure 2-12 (a) and (b).

Axial inlet cyclones are frequently referred to as multicyclones. General small diameter (from 3 to 24 in.), they are grouped together in a common housing with a common inlet and a series of gas outlet tubes that discharge at a common plenum. Because of their small diameter, they are usually of higher efficiency than the large diameter tangential cyclone. However, the smaller size of the axial cyclone usually results in axial inlet which is proportionately small and prone to plugging. This is especially true where there is moisture and/or a high inlet dust loading designed for large-scale operations. Multitube type cyclones can handle magtitudes of gas volume at about 50 percent of the cost of the large-diameter tangential cyclone.

In principle, however, both types of collectors are alike. Whether the dust laden gas enters tangentially through a duct or is directed by "turning" vanes, it is caused to spin in a downward spiral.

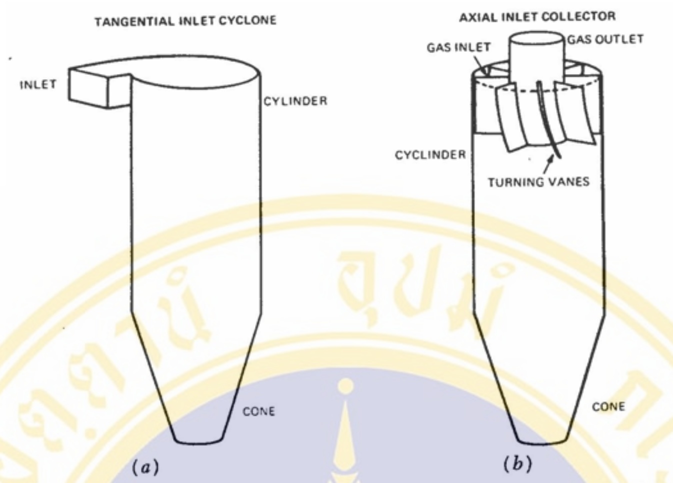


Figure 2-12 Both tangential and axial inlet mechanical collectors utilize centrifugal force for particle collection

In both types of collectors, the dust laden gas is caused to spin in a downward spiral. The spinning action causes the suspended particles to migrate toward the inner wall of the cyclone. The vertical force component of the downward spiral causes the particulate to be carried down through the cone section and into the hopper. As the gases moves downward, the cyclonic phenomenon takes place. An ascending vortex is developed by gas migrating along the entire length of the cyclone. This vortex has its terminal vertex at the apex of the cone. Because of centrifugal and inertial force of the migrating gas it is generally particulate free. The ascending vortex rises through the center of the cyclone and is finally exhausted through the gas outlet tip and/or vortex finder.

Development of cyclone efficiency

Cyclone Collection efficiency is determined by the pressure drop. The pressure drop can be increased or decreased by varying the diameter of the cyclone body or by varying the volumetric flow rate per tube. These features must be designed into the system.[14] If the cyclone is operated at a lower volumetric flow rate, dampers should be used so that the gas velocity will be increased. Since the cyclone has no moving parts, fine-tuning them is very difficult. Spiral vanes are used in axial-entry cyclone, allowing some control of volumetric flow rate by moving a vane in and out of a constricted opening in the collector element. When full maximum rotation is induced, resulting in greater centrifugal action. Dampers at the inlet are used to control turn-down of gas flow. This can be accomplished if the collector is sectionalized and allowed for the designed pressure drop to be maintained. The excess tubes can be capped off if the turn-down is permanent.

Efficiency can be improved by arranging cyclones in series or parallel. These gains can be offset by increased maintenance problems. However, Multicyclone arrangement plug more easily and, when common hoppers are used, uneven flow distribution can lead to re-entrainment problems.

A typical series arrangement is illustrated in figure 2-13 Large particles can be collected in the first cyclone, with a smaller, more efficient cyclone to collect the smaller particles. This reduces dust loading in the second cyclone, which helps avoid abrasion and plugging. Also, if the first cyclone becomes plugged, the second one will still do some collection. The pressure drop in the second cyclone adds to the overall pressure drop of the system, which could be a disadvantage.

Cyclone has been designed in many types of parallel arrangements. Figure 2-15 shows a parallel arrangement using tangential entry cyclone. With an arrangement such as this, higher volumes of gas can be treated at reasonable pressure drops. Channeling of gas through one or several cyclones can occur if a common hopper is used, so it is important that the cyclone has the same pressure drop.

A battery of axial-entry cyclones is illustrated in figure 2-14 High collection efficiency can be obtained with this arrangement, with reductions in pressure drop, space, and cost. Pressure drop of 7.44 to 11.16 mm Hg are commonly obtained.

Axial entry minimizes the eddy formation that is common in tangential-entry cyclones. The vortex is created by inlet guide vanes.

The inlet plenum for the multicyclone should be designed so that the gas flow is evenly distributed to each cyclone. Since the vanes and smaller outlet tubes are prone to plugging, sticky materials should not be collected.

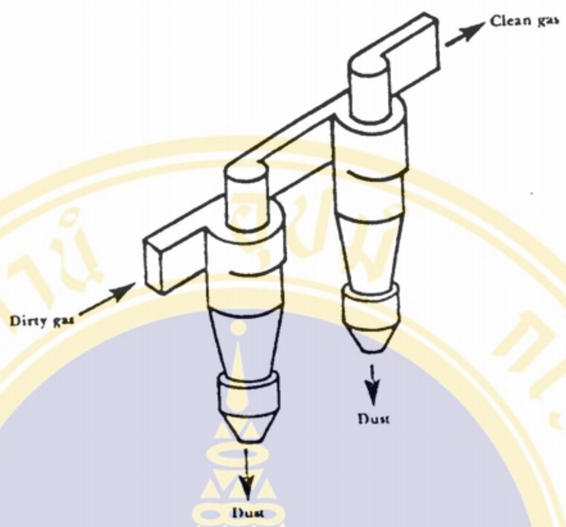


Figure 2-13 Cyclone in series

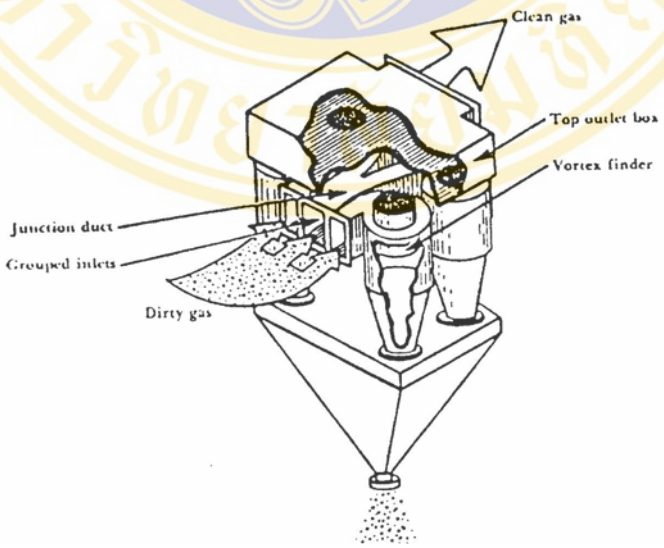


Figure 2-14 Battery of four involute cyclones in parallel

Multiple-Cyclone Separators

When high efficiency (which requires small a cyclone diameter) and large through put are both desired, a number of cyclones can be operated in parallel. In multiple-cyclone separator, the housing contains a large number of tubes that have a common gas inlet and outlet in the chamber.(15) The gas enters the tubes through axial inlet vanes that impart a circular motion , illustrated in figure 2-15

A multiple-cyclone separator consists of a number of small-diameter cyclone's operating in parallel, having a common gas inlet and outlet, as in figure 2-16. The flow pattern differs from that in a conventional cyclone in that the gas, instead of entering at the side to initiate the swirling action, enters at the top of the collecting tube and has a swirling action imparted to it by a stationary vane positioned in its path. The diameters of the collecting tubes usually range from 0.30 m to as small as 5.08 cm. Properly designed unit can be constructed that have collection efficiency as high as 90 percent for particulates in the 5 to 10 micron range. (22)

Figure 2-15 Vane Axial Entry Cyclone

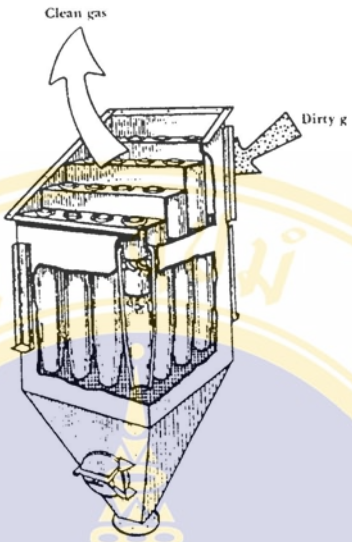


Figure 2-16 Battery of vane- axial cyclone

Aerodynamic diameter

The particles separation characteristic of inertial gravitational collectors depend on particle "aerodynamic diameter". The particle collection mechanism pit the particle's aerodymanic resistance againts its inertia or an external force [27]

Aerodynamic diameter is defined as the diameter of a smooth , unit density ($\rho_0 = 1$ g / cm^3) sphere that has the same setting velocity as the particle. It is dependent on the particle density and particle shape, as well as the particle size. The general expression for theparticle aerodynamic diameter , d_a , is

$$d_a = \left[\frac{\rho\, C}{\rho_0\, Ca} \right]^{1/2} d_p$$

When : ρ = particle density

ρ_0 = 1 g / cm^3

C = slip factor evaluated for the particle diameter d_p

Ca = slip factor evaluated for the particle diameter d_a

d_p = physical diameter for spherical particles and the stokes diameter for nonspherical particle

Slip factor (*C*)

Slip factor (*C*) is an empirical factor that accounts for reduction in the drag force on particles due to the "slip" of the gas molecules at the particle surface. It is important for small particles, less than 1 µm in diameter . The slip factor is a function of the ratio between perticle diameter and mean free path of the suspending gas.

For large particles > 5 µm $C = 1$; for smaller particles $C > 1$

Particle stoke diameter (d_p)

The particle stoke diameter (d_p) is defined as the diameter of a sphere having the same density and settling velocity as the particle. For a smooth, spherically shaped particle, d_p exactly equals the physical diameter of the particle. For irregularly shaped particles, d_p is the diameter that characterizers the aerodynamic drag force on the particle.

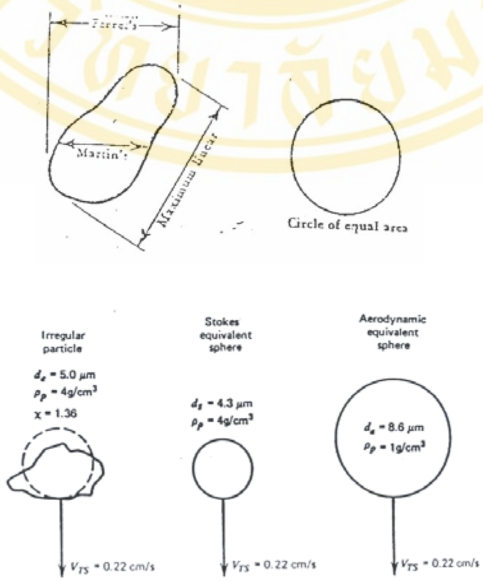


Figure 2-17 An irregularly shaped particle and its equivalent stokes and aerodynamic spheres (equivalent settling velocity)

2.11 Related literatures

Cyclone dust collectors have been studied and designed in particles characteristics to find appropriated cyclone types suitable with each particles types or process of particles generated such as wood particle and particles from aluminum process and particles mixed asbestos from cutting tile process and particles from cast cutting and including fiber glass dust from sanding surfboard process. The cyclone designed for moveable and used wood particle for efficiency test by Vichai Pruktharathikul[11] had designed high efficiency cyclone type, dimension proportion of cyclone 20.32 cm diameter and 81.28 cm. The results of the study had found that the size of particles effect cyclone efficiency. The particles size 45 micron cyclone efficiency about 95.0 % and particles size above 106 micron cyclone efficiency about 99.7 %. Particles from aluminum process were studied by Woraluk Kunthimapun.[13] The cyclone was designed in conventional cyclone type. The dimention proportion of cyclone 43.18 cm diameter. The results of study found that concentration of dust effect to cyclone efficiency. When high dust concentration inlet to cyclone, efficiency will increase until dust concentration is above 100 mg/m^3 cyclone performance trend decreases

Particles from cutting and sanding processes were studied and designed for control particles. Tongchai Jithan and Wanpan Songkham had studied and designed cyclones in multi-cyclone type. Tongchai Jithan[10] studied efficiency of dust control system's for cutting tile mixed with asbestos and efficiency of cyclone depended on concentration of particles and method of dust generated process. Wanpan Songkham [12] had designed and constructed multi-cyclone to control fiber glass dust in sanding surfboard processes. An air flow rate for efficiency test is set at 3 ranges. The results of the study found that varied air flow changed the efficiency. An appropriate air flow rate equal 426.72-441.96 m^3/min, cyclone efficiency was 85.57 %. Janchai Sriboon[22] had studied and designed moveable dust control systems to control dust from cast cutting processes. The dust control system designed high efficiency cyclone which base on Stairmand theory and Lapple theory. The results of the study had found that cyclone efficiency about 99 % and operators who working in cast cutting process exposure to dust decreases about 0.39 mg/m^3.

CHAPTER III
MATERIALS AND METHODS

3.1 Study Design

This study was an experimental study of modified cyclone efficiency tests for dust control which was generated from the fiber glass reinforced plastic cutting process. The dust was released from the cutting process by using a portable grinder with a 101 mm blade at 12,000 rounds per minute. This study separated dust size for 5 level 0.29 to 38.1 micron , 38.1 to 63.5 micron , 63.5 to 125 micron , 125 to 250 micron and above 250 micron. Cyclone collection efficiency method was weighting filter for find each dust size concentration at cyclone outlet. The calculation of efficiency was presented in percent of efficiency.

3.2 Methods

3.2.1 Study physical characteristics of dust

1. Dust size distribution

Size distribution of dust was analyzed by using the particle size analyzer, Mastersizer S. The result of analysis was presented by percentage of dust size range per amount of total dust and finding dust size and dust distribution of particles between 0.05-900 micron with an error not over +/- 5% and possible calculation of dust surface when density of particles is known.

Analysis Instrument: Particle size Analyzer Laser, Model Mastersizer S Ver.2.19, Malvem Instruments Limited.,UK Serial Number : 33544 / 756

Process Principle of Instrument: when the light throw passed particles in fluid media, it made a phenomenon of light dispersion. The pattern of light concentration was dispersed from particles. It had specific pattern of each dispersed angle, high concentration of light at some angle depended on diameter of particles and frequency of light waves. The qualification of light dispersed by particles is used for calculation of particle size in case that light dispersed has not lost power (Reyleign scattering).

The Mastersizer used helium-neon laser, beam range of 632.8 nanometer. Laser beam expanded by beam expander and threw to particles in fluid media. Laser beam was dispersed by particles passing to condenser lens, generated pattern of “Far field diffraction pattern” at Photocell detector which was certained with direction of laser beam at focus point. Far field diffraction pattern showed light concentration related to particle size distribution. Collected light lens were designed for specific qualification, dispersed light in any position in laser beam, the pattern of Far field diffraction pattern did not move and the center of focus point always on the core optic lens. The moving of particles was not affected to Far field diffraction pattern except in case of particles had more high speed moving.

Analysis condition : 1.Range Lens : 300 RF mm
He-Ne laser source ,λ : 633 nm,
Beam Length : 2.40 mm
Particle size range analysis : 0.05-900 μm
Small sample dispersion Unit (MS1) in 600 ml Beaker
Dispering medium : deionized water
Laser Power : 81.5

2 Density of dust

Particulate density calculation as follows. Please see detail in appendix C

Sampler : Particulate sampler 10 g

Method :

1. weigh the bottle (W_1)
2. weigh the bottle + water (W_2)
3. weigh the bottle + particulate (2-3 g) (W_3)
4. contain water into bottle and boil 30 minute, rest the bottle to room temperature, and then contain water to bottle
5. weigh the bottle + particle + water (W_4)
6. temperature record

7. calculation

- weigh the water which have equal volume with bottle volume which without particle volume (W_5) = W_1-W_2
- weigh the particulate (Ws) = W_3-W_1
- weigh the water which have equal volume with bottle volume which without particulate volume (W_6) = W_4-W_3
- weigh the water which have equal particulate volume (W7) = W_5-W_6
- water volume which have equal particulate volume (Vs) = W_7-ρ_0
- particulate density = Ws / Vs

3.2.2 Dust collector design and calculation

3.2.2.1 Cyclone design

Basically there are two types of cyclone mechanical, tangential inlet cyclone type and axial inlet cyclone type. An advantage of tangential inlet cyclone type is air stream inlet through cyclone by side duct of cyclone body, air stream tangential flow to inner cyclone wall for separate particulate from air stream. An axial inlet cyclone type, air stream inlet to cyclone from above cyclone body and flow pass turning vanes for control air stream to spin in a downward spiral and flow inner cyclone wall for separate particulate from air stream.

Modified cyclone was designed by applied advantage characteristics of tangential inlet cyclone type and axial inlet cyclone type together, air inlet at side duct of cyclone body and control air stream passed through blade (turning vanes), it caused to spin in a downward spiral and flow inner cyclone wall which increased cyclone efficiency. Modified cyclone was illustrated in figure 3-1 (a) and (b).

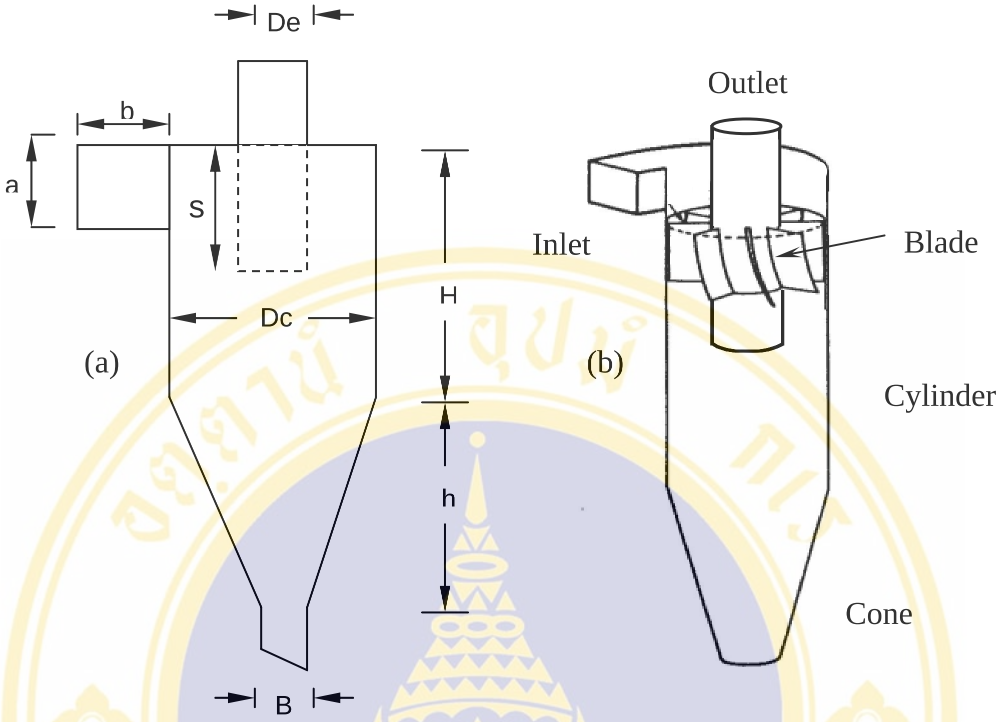


Figure 3-1 (a) Symbol of cyclone proportion
(b) Modified cyclone (Tangential vane axial inlet cyclone type)

Table 3-1 Modified cyclone design configuration

Description	Stairmand	Design cyclone (mm)
Body diameter (Dc/Dc)	1.0	400
Height of inlet (a/Dc)	0.5	200
Width of inlet (b/Dc)	0.2	80
Diameter of gas exit (De/Dc)	$\geq$ 0.5	203
Length of vortex finder (S/Dc)	> 0.5	254
Length of body (H/Dc)	> 1.5	1016
Length of cone (h/Dc)	< 2.5	600
Diameter of dust outlet (B/Dc)	$\geq$ 0.375	152

3.2.2.2 Cut size or Cut diameter calculation

The calculation of cut size or cut diameter for finding size of particles was collected by 50 % cyclone efficiency. The particles size larger than cut size were collected by cyclone efficiency more than 50%. Calculating the cut size using equation is as follows

$$dp_{cut} = \left[\frac{9\,\mu\,W}{2\,\pi\,N_e\rho_p V_g}\right]^{1/2}$$

when μ = Viscosity , Pa.s

N_e = Effective number of turns

V_g = Velocity of air inlet

ρ_p = Density of particles

W = Width of air inlet

3.2.2.3 Local exhaust ventilation unit design and calculation and Hood design

Local exhaust ventilation unit design was based on recommen- -dation of ACGIH (Industrial Ventilation Manual recommendation) and hood design was applied by recommendation of ACGIH (Hand grinding bench VS-80-18), method of local exhaust ventilation system design and calculation is as follows

1. Hood design

   Applied the recommendation of ACGIH (Hand grinding bench VS-80-18) see in appendix E
2. Duct size calculation

   We can calculate duct size by using equation $Q = AV$
3. Losses calculation

   3.1 Acceleration loss

We can calculate acceleration loss by using equation below

$$V = 4005 \sqrt{VP}$$

when $SP = -VP$

3.2 Hood entry loss

3.3 We can calculate by hood entry loss using equation below

when $he = 0.25\ VPd$

3.4 Straight duct loss

3.5 We can calculate straight duct loss by using equation below

Length of duct x Friction loss of duct

3.6 Elbow loss

3.7 Total loss before fan inlet (SPi)

4. Total loss after fan outlet (SPo) calculation
5. Cyclone losses calculation
6. Overall losses calculation

   We can calculate overall losses by using equation below

   $$\text{Overall losses} = SPo - SPi - VPi$$

7. Horsepower calculation

   We can calculate horsepower by using equation below :

   $$HP = (Q \times SPf) / 6356\ ME$$

3.2.3 Calculation air inlet velocity

Due to air inlet velocity related to cyclone collection efficiency when adjust air flow rate. To appropriate cyclone efficiency, air inlet velocity calculating in each air inlet velocity at 0.61,0.91,1.52,3.05,4.57 and 6.10 m/sec.

3.2.4 Materials and Instrument

3.2.4.1 Fiber glass reinforce plastic sampler

Fiber glass reinforced plastic sampler for generating dust to cylone efficiency test and control thickness of sampler not over than 5 mm

3.2.4.2 Portable grinder

Portable grinder with a 101 mm blade model 9500 NB 100 mm 1,200 rpm Serial number : 884330 A 5

3.2.4.3 Instrument for measuring air velocity

Instrument for measuring air velocity and temperature and humidity was Air Velocity Meter, Velocity Plus, Model 8386A –M-GB, Serial number : 03120366

3.2.4.4 Air sampling pump

Air sampling pump (SKC) Eighty Folr PA.15330 , Model : 224-PCXR 8 Serial number : 531466

Calibrate air sampling pump at 2 L/min by Soap-bubble meter

3.2.4.5 Sieve for separate each dust size

A sieve for separate fiberglass dust sampler to each dust size range, sieve net number 18,60,120 and 230 for saparate dust size 0.29 -38.1, 38.1-63.5, 63.5 -125, 125-250 and 250 micron above.

3.2.4.6 Balance machine

Balance machine AX 205 Delta Range, Mettler-Toledo, Ver.3.11 Serial number : 4728-46

3.2.4.7 Tangential vane axial inlet cyclone

A cyclone was used for controlling polyester resin and fiberglass dust. It can separate entrained from an air stream by the used centrifugal force, inertial force and gravitational force. Cyclone was designed by applied advantage characteristics of vane axial inlet type and tangential type together, dimension proportion of cyclone 400 mm diameter , 1016 mm long of body , 600 mm long of cone.

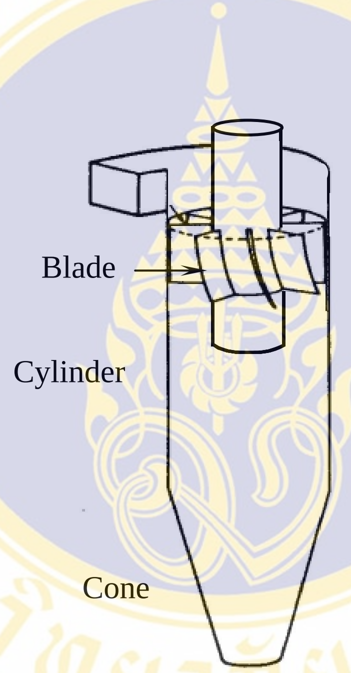


Figure 3-2 Tangential vane axial inlet cyclone

3.2.4.8 Local exhaust ventilation complete set (hooh,duct,modified cyclone and fan)

A local exhaust ventilation unit was composed of a hood which is recommended by ACGIH (VS print 80-18 Hand grinding bench) connected with the tangential vane axial inlet cyclone by an 20.32 cm duct diameter and 3 horse-power fan.

3.3 Experimental design

3.3.1 Dust concentration in working environment

Air sampling at the working environment (area sampling) during fiber glass reinforce plastic cutting process for finding dust concentration in working area.

Methods

1. Calibrate air sampling pump by soap bubble meter, equivalent 2 L/min air flow rate.
2. Prepare glass fiber filter diameter 3.7 cm for air sampling
3. Weight each glass fiber filter and record.
4. Contain each glass fiber filter into filter holder diameter 3.7 cm and keep In desiccator cabinet.
5. To prepare local exhaust ventilation complete set to operate.
6. Control length of cutting on fiber glass sample by measuring equivalent each sample.
7. Install air sampling pump complete set at working area in cutting process. (sampling point at 130 cm from ground, nearly operator sitting)

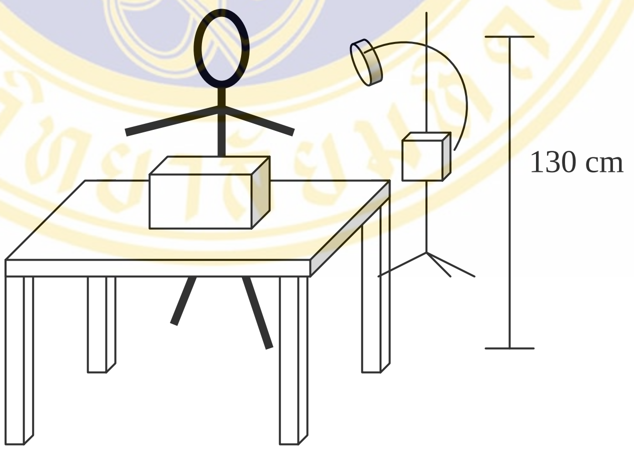


Figure 3-3 Air sampling in fiber glass cutting process

8. To proceed the local exhaust ventilation by switching on and then wait 5 minutes for ventilation unit.
9. Measure air inlet velocity, temperature and humidity by air velocity meter.
10. To proceed turn the air sampling pump by switching on.

11. Cutting the fiber glass sample by portable grinder within length of cutting.

12. After cutting fiber glass sample, wait 5 minute for the ventilation unit to collect the dust completely.

13. Switch off air sampling pump and change new filter holder.

14. Data record and proceed step 8 to12 each sample.

15. Data collection for 10 sample

Soap bubble meter calibration :

1. Connect the buret 1000 ml size to air sampling pump by tube.
2. Prepare soap solution in beaker 250 ml size.
3. Switch on air sampling pump.
4. Put the buret to surface of soap solution in beaker for make the soap film.
5. Measure the time when soap film move.
6. Adjust the air flow rate of air sampling pump to 2 L/min as follows

$$\text{air flow rate} = \frac{1{,}000\text{ ml}}{30\text{ sec}} \times \frac{60\text{ sec}}{1\text{ min}} = 2{,}000\text{ ml/min or } 2\text{ L/min}$$

3.3.2 Cyclone collection efficiency test

Cyclone collection efficiency test was measured by calculating dust inlet concentration with dust outlet concentration of each dust size.

Methods

1 Preparation dust sample methods

1.1 This study use sieve number 18 , 60 , 120 and 230 for separating dust to 5 levels.

1.2 Dust sample have 0.29 to 38.1 micron , 38.1 to 63.5 micron , 63.5 to 125 micron , 125 to 250 micron and 250 micron above.

1.3 Sieve dust sample for 3 sample each size, total 15 samples.

1.4 Contain dust sample in vial.

1.5 Weight each dust size and record

1.6 Keep dust sample in desiccator cabinet.

2. Preparation filter holder and glass fiber filter

2.1 construct filter holder which is suitable for outlet of cyclone made from acrelic plastic sheet.

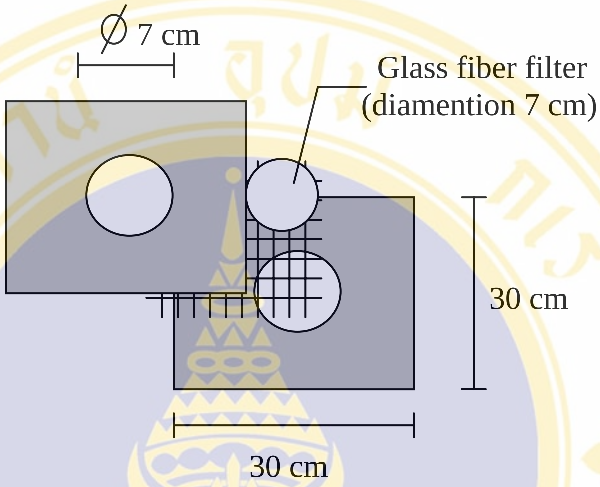


Figure 3-4 Filter holder

2.2 Prepare glass fiber filter (diameter 7 cm) for dust sampling collection, prepare 3 filter each dust size and 3 filter for blank, total 18 filter

2.3 Weight each glass fiber filter and record,

2.4 Keep glass fiber filter in desiccator cabinet.

3.4 Data collection

3.4.1 Stage of cyclone efficiency test

3.4.1.1 Dust sample

Weight dust sample, 3 sample each dust size and contain in vial as follow

1. Pre-weight vial (size 10 ml) 3 vial each dust size, total 15 vial and record.
2. Contain dust sample into vial.
3. Post-weight each vial (particulate and vial) and record.
4. Finding dust weight by post weight subtract with pre weight.
5. Record dust weight.
6. Label at each vial and separate each dust size.

7. Keep dust sample in desiccator cabinet.

Sample dust weight showed in Table 3-2 as follow.

Table 3-2 Dust weight each sample for release to cyclone

Sample	Dust size(micron)	Dust weight (g)
1	250 - 409.45	5.24
2	250 - 409.45	4.93
3	250 - 409.45	5.07
4	125 - 250	6.59
5	125 - 250	5.60
6	125 - 250	4.22
7	63.5 - 125	4.87
8	63.5 - 125	5.87
9	63.5 - 125	6.23
10	38.1 – 63.5	5.82
11	38.1 – 63.5	5.80
12	38.1 – 63.5	5.98
13	0.29 – 38.1	0.37
14	0.29 – 38.1	0.34
15	0.29 – 38.1	0.32

3.4.1.2 Cyclone efficiency test stage

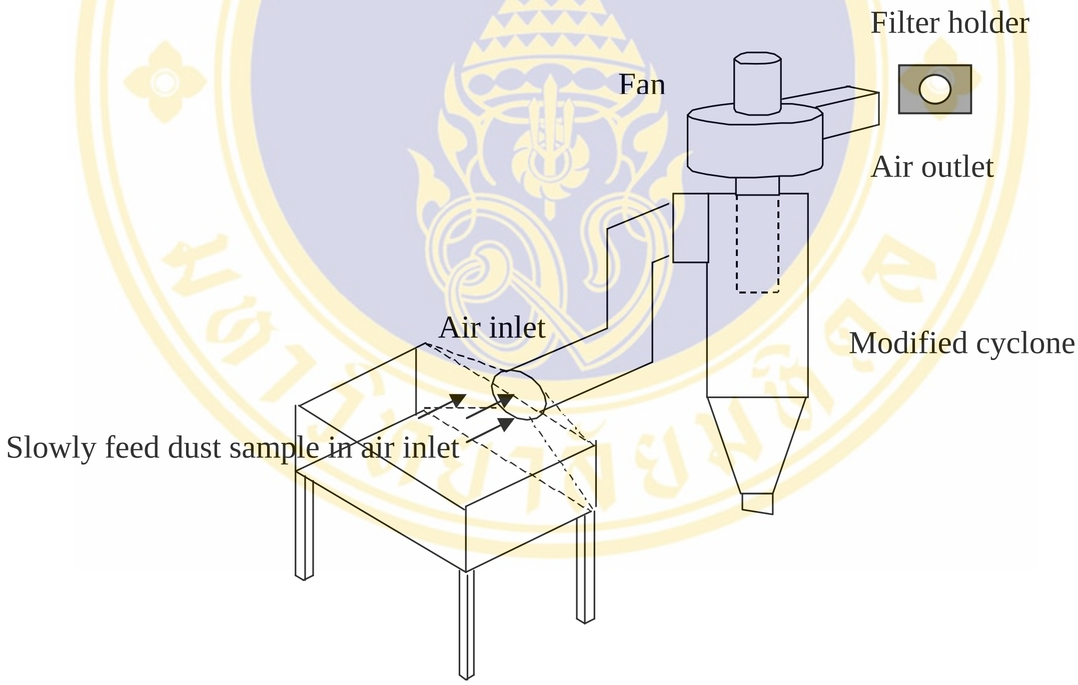
1. Install of the filter holder with glass fiber filter (dimention 7 cm) to outlet of cyclone.

2. Start up the fan by switching on and wait 5 minutes for ventilation unit to complete operation.

3. Measure the air inlet velocity, temperature and humidity at hood inlet by Air Velocity Meter.

4. Record air inlet velocity, temperature and humidity

5. Prepare dust sample each vial (dust sample in table 3-2)
6. Initial release dust sample from the vial and put dust sample down on plate
7. Slowly feed few dust sample into air inlet and waiting for 5 minutes to make sure that dust sample spin flow within cyclone wall.
8. Shut down the fan by switching off and waiting for the fan to stop.
9. Uninstall the filter holder and change the new glass fiber filter.
10. Repeat the steps of 1 to 8 each dust sample (dust sample in table 3-2)
11. Keep the filter in desiccator cabinet and weight by balance machine for calculation dust sample concentration.



- Initial release dust sample from the vial and put dust sample down on plate
- Slowly feed few dust sample into air inlet and waiting for 5 minutes to make sure that dust sample spin flow within cyclone wall.
- Release each dust sample 1- 15 (table 3-2)

Figure 3-5 Release dust sample to cyclone

3.4.2 Dust concentration measurement and modified cyclone efficiency measurement

3.4.2.1 Dust concentration measurement

Total dust concentration calculation, C (mg/m^3) per air volume, V(L)

$$C = \frac{(W2-W1) - (B2-B1) \times 10^3}{V} \quad mg/m^3$$

When ; C = concentration (mg/m)^3

W1 = filter weight before air sampling (mg)

W2 = filter weight after air sampling (mg)

B1 = average blank filter weight before air sampling (mg)

B2 = average blank filter weight after air sampling (mg)

3.4.2.2 Modified cyclone efficiency measurement

Modified cyclone efficiency was calculated by dust concentration before pass through the cyclone (C1) subtracted by dust concentration after dust collected by cyclone (C2) and divide by dust concentration before pass through the cyclone (C1) and multiply by 100. The modified cyclone collection efficiency was present in percent of efficiency.

$$\text{Dust collection efficiency} = \frac{(C1 - C2)}{C1} \times 100$$

When ;

C1 = dust concentration before passing through the cyclone

C2 = dust concentration after passing through the cyclone

3.5 Data analysis

The data of experiment were analyzed using t-test

1. Calculation data from experiments for finding average dust quantity and dust size from data analysis by particulets size distribution analyzer (Mastersizer S)
2. Calculation data from experiments for finding total dust concentration in working environment during local exhaust ventilation complete set operate
3. Calculation data from experiments for finding collection efficiency of tangential vane axial inlet cyclone
4. Statistic by t-test (p-value < 0.05). Collection efficiency more than 90%

CHAPTER IV
RESULTS

The modified cyclone was constructed and designed by applying the advantage characteristics of tangential cyclone type and vane axial inlet cyclone type combined together (Tangential vane axial inlet cyclone type)

The modified cyclone was appropriated with dust characteristics and dust analysis such as dust concentration, dust size distribution and other physical characteristics. From result of repeated recalculation and redesign, we can construct a suitable cyclone separator for fiber glass dust collection in cutting processes of car's decorate accessorys which are made by fiber glass reinforced plastic using a portable grinder with 101 mm diameter which was mostly used in the cutting process of fiber glass product manufacturing.

Modified cyclone calculation was a constructed cyclone with 400 mm diameter, 1016 mm cylinder high, 600 mm cone high and connected with local exhaust ventilation system and hood by using ACGIH Industrial Ventilation Manual recommendation. Process of data collection was conducted by separated dust size for 5 level 0.29-38.1 micron , 38.1-63.5 micron , 63.5-125 micron , 125-250 micron and above 250 micron. Cyclone collection efficiency method was weight filter for find each dust size concentration at cyclone outlet.

Modified cyclone collection efficiency was calculated in percent of efficiency and t-test. The results of this study was presented in sequence as follows

4.1 Physical characteristics of dust

4.1.1 Results of dust size and dust distribution

1.Dust size distribution by used Mastersizer S

Fiber glass dust was analysed by Mastersizer S. This instrument can analyse dust size and dust distribution ranging 0.05-900 micron. The results was presented in percent of each dust size range per total sample particulate. The analysis results were presented in table 4-1

Table 4-1 Dust size distribution by Mastersizer S

Dust size (μ m)	Dust size average (μ m)	Weight by volume (%)	Cum.weight (%)
0.23 – 0.91	0.57	3.12	3.12
0.92 – 2.65	1.79	10.18	13.30
2.66 – 5.69	4.18	11.83	25.13
5.70 – 12.21	8.96	17.48	42.61
12.22 – 41.43	26.83	34.85	77.46
41.44 – 65.51	53.48	10.60	88.06
65.52 – 88.91	77.22	4.78	92.84
88.92 – 140.58	114.75	4.26	97.10
140.59 – 409.45	275.02	2.90	100.00

The results of dust size distribution and dust concentration of fiber glass reinforced plastic from cutting process by a portable grinder with 101 mm blade had showed that the range of dust size distribution was 0.23 – 409.45 micron. Most of dust size between 12.22 – 41.43 micron (average of 26.83 micron). The distribution of dust size had 0.92 – 2.65 micron (average of 1.79 micron) = 10.18 % , dust size between 2.66 – 5.69 micron (average 4.18 micron) = 11.83 % , dust size between 5.70 – 21.21 micron (average of 8.96 micron) = 17.48 %, dust size betwen 41.44 – 65.61 micron (average 53.48 micron) = 10.60 %. The results of dust size distribution and dust concentration was presented in figure 4-1

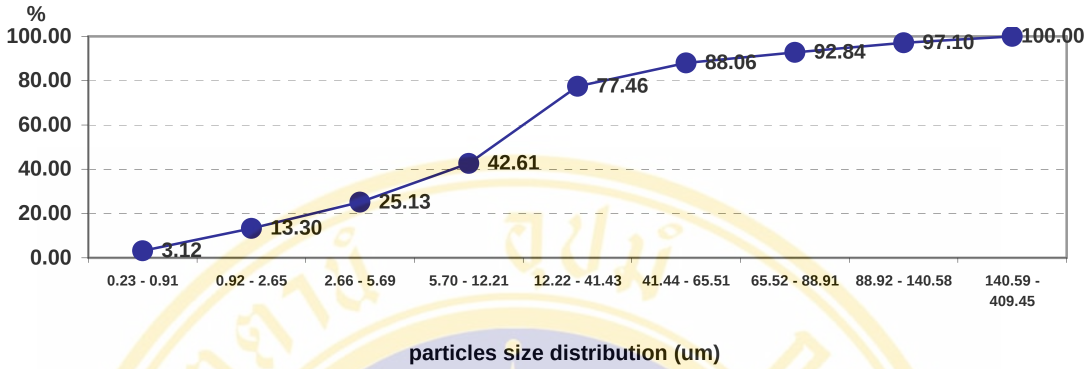


Figure 4-1 Dust size distribution (micron) in percent (%)

4.1.2 Dust density analysis

The results of dust density of decorated car's accessory product which was made from fiber glass reinforced plastic dust had 1.50 gm/cc Method of density calculation is presented in appendix C

4.2 Dust control unit calculation

4.2.1 Modified cyclone calculation and design

1. Modified cyclone design was applied dimensional proportions of Stairmand.

The results of calculation is presented as follows

Table 4-2 Modified cyclone design configuration

Description	Stairmand	Design cyclone (mm)
Body diameter (Dc/Dc)	1.0	400
Height of inlet (a/Dc)	0.5	200
Width of inlet (b/Dc)	0.2	80
Diameter of gas exit (De/Dc)	≥ 0.5	203
Length of vortex finder (S/Dc)	> 0.5	254
Length of body (H/Dc)	> 1.5	1016
Length of cone (h/Dc)	< 2.5	600
Diameter of dust outlet (B/Dc)	≥ 0.375	152

Adjusted length of value finder (S) for compliance with cyclone proportion criteria, showed in detail in table 4-3

2. Modified cyclone proportion criteria for optimum performance

Table 4-3 Cyclone criteria

Criteria	Result of design (mm)
$a < S$	$200 < 254$
$b < ½ (Dc-De)$	$80 < ½ (400-203)$
$S + 1 \leq H$	$254 + 82 \leq 1016$
$S < h$	$254 < 60$
$h < H$	$600 < 1016$
$\triangle P < 18.6$ mm Hg	$3.3274 < 18.6$ mm Hg
$vi / vs \leq 1.35$	$0.3278 \leq 34.29$

3. Dust size distribution analysis

Results of fiber glass reinforced plastic dust size distribution analysis from cutting process by a portable grinder with 101 mm blade had conducted using particle size analyzer (Mastersizer S) showed in table 4-1 and value which can be used in a cyclone calculation:

Inlet velocity , Vi = 2.87 m/sec

Fluid viscosity , μ = 5.79×10^{-6} kg / m.s

Fluid density , ρ_f = 0.0104 kg / m^3

Particles density , ρ_p = 12.94 kg / m^3

4. Method of cyclone calculation

Cyclone was constructed based on dimension proportion of stairmand and calculation procedure as follows

4.1 Overall efficiency calculation

Table 4-4 Setting efficiency of each particles size in percentage (%)

Overall efficiency

Item	Particulet size (micron)			% weight	% weight	ni %	avg. ni %
	sieve No.	sieve	Mastersizer				
1	No.18	0.23-38.1	0.23 - 0.91	3.12	77.46	80-90	85
			0.91 - 2.65	10.18			
			2.66 - 5.69	11.83			
			5.7 - 12.21	17.48			
			12.22 - 41.43	34.85			
2	No.60	38.1-63.5	41.44 - 65.51	10.6	10.6	90-95	92.5
3	No.120	63.5-125	65.52 - 88.91	4.78	4.78	90-95	92.5
4	No.230	125-250	88.92 - 140.58	4.26	4.26	95-100	97.5
5		250-409.5	140.59 - 409.45	2.9	2.9	95-100	97.5

$$\eta_T = \sum m_i \eta_i \ldots..$$

$$= \sum m_1 \eta_1 + m_2 \eta_2 + \ldots. + m_9 \eta_9$$

$$= (77.46 \times 0.85)+(10.6 \times 0.85)+(4.78 \times 0.925)+(4.26 \times 0.925)$$

$$+(2.9 \times 0.975)$$

$$= 86.04\ \%$$

4.2 Saltation Velocity (Vs) calculation

$$Vs = 2.055\,\omega \left[\frac{(b / Dc)^{0.4}}{(1-b / Dc)^{1/3}} \right] Dc^{0.067} . Vi^{2/3}$$

When :

$$\omega = [\,4\, g \,.\, \mu \,(\rho_p - \rho_f) / 3\rho f^{2}]^{1/3}$$

$$\omega = [\,4 \times 32.2 \times (1.2766 \times 10^{-6}) \times (93.62 - 0.075) / 3(0.075)^{2}]^{1/3}$$

$$= [\,0.1538 / 0.0168]^{0.33}$$

$$= 0.6330 \text{ m/sec}$$

From cyclone dimension proportion Dc = 400 mm , b = 0.2 Dc = 80 mm

$$Vs = 2.055 \times 2.0765 \left[\frac{(3.15 / 15.75)^{0.4}}{1-(3.15 / 15.75)^{0.33}} \right] 15.75^{0.067} . 9.43^{0.66}$$

$$Vs = 8.7679 \text{ m/sec}$$

$$Vi / Vs = 2.87 / 8.7679 = 0.32$$

4.3 Volumetric flow rate calculation

$$Q = abvi$$

$$= 0.65 \times 0.25 \times 2.87$$

$$= 0.4857 \text{ m}^3/\text{sec}$$

4.4 Natural length (l) calculation

$$l = 2.3\, De \left(\frac{Dc^{2}}{ab} \right)^{1/3}$$

$$= 2.3 (0.66) \left(\frac{1.3125^{2}}{0.6562 \times 0.2625} \right)^{1/3}$$

$$= 0.9892 \text{ m}$$

4.5 Vortex exponent (n) calculation

$$n = 1 - \left[1 - \frac{(12\,Dc)^{0.14}}{2.5}\right]\left[\frac{T + 460}{530}\right]^{0.3}$$

$$= 1 - \left[1 - \frac{(12 \times 1)^{0.14}}{2.5}\right]\left[\frac{100.4 + 460}{530}\right]^{0.3}$$

$$= 1 - \left[1 - \frac{1.4710}{2.5}\right][1.0168]$$

$$= 1 - [0.5884][1.0168]$$

$$= 0.4017$$

4.6 Cyclone configuration factor (G) calculation

$$G = 8Kc / ka^2 . kb^2$$

When :

$Ka = a / Dc = 7.875 / 15.75 = 0.5$

$Kb = b / Dc = 3.150 / 15.75 = 0.2$

$Kc = (2Vs+Vnl,H) / 2Dc^3$

$Vs = [\pi (S-a/2) (Dc^2 - De^2)] / 4$

From cyclone dimension proportion

S = 0.5 Dc = 0.5 (400 mm) = 200 mm ,adjust to 254 mm

De = 0.5 Dc = 0.5 (400 mm) = 200 mm

$$Vs = [\pi \{(10/2)-(7.875/12)/2\}(15.75)^2 - (8/12)^2] / 4$$

$$= 0.0910 \text{ m/sec}$$

From value of l calculation = 0.9892 m/s = 989.29 mm

H = 1016 mm

S = 254 mm

l > (H-S) = 989.29 > (1016 – 254)

If l > (H-S) must used V_H for calculate Kc value

$$VH = \frac{\pi Dc^2}{4}(h-s) + \left(\frac{\pi Dc^2}{4}\right)\frac{(H-h)}{3}\left(1+\frac{B}{Dc}+\frac{B^2}{Dc^2}\right) - \frac{\pi De^2}{4}(H-S)$$

When Dc = 400 mm , De = 203 mm , S = 254 mm , H = 1016 mm

b = 80 mm , h = 600 mm , l = 989.29 mm , B = 152 mm

$$VH = \frac{\pi Dc^2}{4}(h-s) + \left(\frac{\pi Dc^2}{4}\right)\frac{(H-h)}{3}\left(1+\frac{B}{Dc}+\frac{B^2}{Dc^2}\right) - \frac{\pi De^2}{4}(H-S)$$

= 1.35 x (2.45) + 1.35 x 0.43 x (1+0.50+0.25) - 0.34 x 2.45

= 1.0637 m

$Kc = (2Vs+Vnl,H) / 2Dc^3$

$= (2(0.2988) + 3.49) / 2(1.3125)^3$

$= 0.9039$

used Kc value in equation of G

$G = 8Kc / ka^2 . kb^2$

$= 8(0.9039) / 0.5^2 \times 0.2^2$

$= 723.12$

4.7 Relaxation time (τ) calculation

$\tau = \rho_p (dpi)^2 / (18\ \mu)$

When $\rho_p = 93.62$

$\mu = 1.2766 \times 10^{-5}$

Using particle size value of each size in the equation of τ, we can find Relaxation Time of each size dust as follows

Table 4-5 Relaxation Time of Particle , τi

Relaxation Time of Particle

Particle size (Micron)		Average particle size ($X 10^{-6}$ meter)	Average particle size ($X 10^{-4}$ ft)	τi (sec)
0.23	41.43	20.72	0.6799	1.88×10^{-3}
41.44	65.51	32.76	1.0750	4.70×10^{-3}
65.52	88.91	44.46	1.4590	8.67×10^{-2}
88.92	140.58	70.29	2.3069	2.16×10^{-1}
140.59	409.50	204.75	6.7199	1.83×10^{-1}

4.8 Grade Efficiency or Fractional (ηi) of each size calculation

$$\eta i = 1- \exp \left\{-2 \left[\frac{G \tau i \; Q}{Dc^3} (n+1)\right]^{0.5/(n+1)}\right\}$$

When : $Q = 29.1450 \; m^3/min$

$Dc = 400$ mm

$n = 0.4017$

$G = 723.12$

Table 4-6 Grade Efficiency or Fractional (ηi) of each dust size

Average dust size (micron)	ti (second)	ni (%)
20.83	1.88×10^{-3}	0.890
53.5	4.70×10^{-3}	0.954
77.21	8.67×10^{-2}	0.999
114.75	2.16×10^{-1}	1.000
275.08	1.83×10^{-1}	1.000

4.9 Overall efficiency calculation

$$\eta_T = \sum m_i \eta_i \ldots\ldots$$

$$= \sum m_1 \eta_1 + m_2 \eta_2 + \ldots. + m_9 \eta_9$$

$$= (77.46 \text{ X } 0.89)+(10.6 \text{ X } 0.95)+(4.78 \text{ X } 0.99)+ (4.26 \text{ X } 1.00)+(2.9 \text{ X } 1.00)$$

$$= 90.90 \%$$

4.10 Pressure drop (Δp) calculation

$$\Delta p = 0.003 \ \rho_f .V^2 .NH$$

$$NH = K (ab) / De^2$$

When : $K = 16$, $a = 200$ mm , $b = 80$ mm , $De = 203$ mm

$$NH = 16 (200 \times 80) / 203^2$$

$$= 0.0306$$

$$\Delta p = 0.003 \times (0.075) \times (9.43)^2 \times 0.0306$$

$$= 3.3274 \text{ mm}$$

Pressure drop of cyclone = 3.3274 mm

4.2.2 Cut size or cut diameter calculation

Cut size or cut diameter is particle size collected by 50% collection efficiency. The particles size was larger than the cut size when collected by cyclone efficiency more than 50% , cut size depends on characteristic of carrier gas and cyclone performance and operating conditions.[7][9][22]

From calculation and design, cyclone had 0.0822 m width of air inlet. We can calculate the cut size or cut diameter by the equation below

$$dp_{cut} = \left[\frac{9\,\mu\,W}{2\,\pi\,N_e \rho_p V_g} \right]^{1/2}$$

when μ = 1.2766×10^{-5}

N_e = 10

V_g = 17.98 m/s

ρ_p = 42.46 kg/ft^3

W = 0.0822 m

$$dp_{cut} = \left[\frac{(9)\ 1.2766X10^{-5}\ (0.27)}{2\pi\ (10)(93.62)\ (59)} \right]^{1/2}$$

$$= 2.882 \times 10^{-6}\ \text{m}$$

$$= 30.5\ \text{micron}$$

4.2.3 Local exhaust ventilation system and Hood design calculation

1. **Hood adjusted for practical operation in a workplace, based on ACGIH recommendation (VS Print 80-18 "Hand grinding bench")**

V = 1371.6 m/min setting = minimun duct velocity = 1066.8 m/min

Q = 457.2 m^3/min setting Q = 45.72 to 76.2 m^3/min of bench area (0.91 m X 0.60 m)

he = 0.25 VPd

2. Duct

Selection of duct diameter

Q = AV

A = 457.2 / 1371.6

= 0.33 m^2

Duct area = $\pi d^2 / 4$

Selection of duct diameter close to a value from calculation of 20.32 cm (0.1064 m^2)

Q = 0.1064 X 1371.6

= 145.93 m^3/ min

3. Losses

3.1 Acceleration loss

V = 4005 $\sqrt{VP}$

VP = $(1371.6 / 4005)^2$

= 0.22 mm Hg

When SP = - VP

= - 0.22 mm Hg

3.2 Hood entry loss

When he = 0.25 VPd

= 0.25 x (- 0.22 mm Hg)

= -0.055 mm Hg

3.3 Straight duct loss

When duct length = 4.26 m

Friction loss of 20.32 cm duct diameter = 0.0478 mm Hg

= 14 x (-0.0478 mm Hg)

= -0.6692 mm Hg

3.4 Elbow loss (90° 4 point)

1 - 90° elbow = 8 equivalent feet

= 8 (4) (-0.0478 mm Hg)

= - 1.53 mm Hg

3.5 Total loss before fan inlet (SPi)

= (-0.22)+(-0.055)+(-0.6692)+(-1.53)

= -2.47 mm Hg

4. Total loss after fan outlet (SPo)

= 1.52 m X (0.0478 mm Hg)

= 0.0726 mm Hg)

5. Cyclone losses

= - 0.48 mm Hg

6. Overall losses (SPf)

= SPo – SPi – VPi

= (0.22) -(-2.47) -(-0.48) -(0.0726)

= 3.10 mm Hg

7. Calculating horsepower

HP = (Q x SPf) / 6356 ME

When Q = 457.2 m^3/min , SPf = 7.7130 mm Hg , ME = 0.6

$$HP = (452.7 \times 7.7130) / 6356 \times 0.6$$
$$= 0.33 \text{ HP}$$ (HP fan should be 3 HP due to require fan speed for appropriate air velocity)

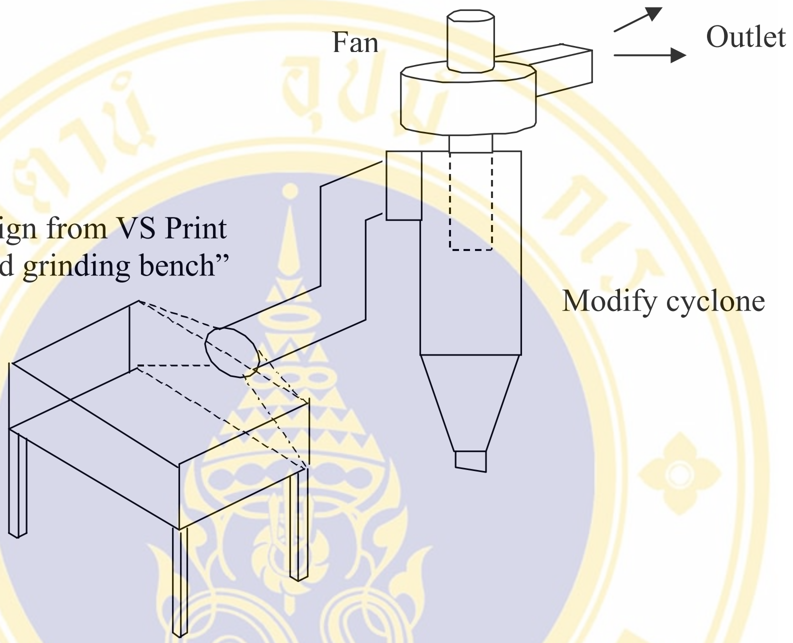


Figure 4-2 Local exhaust ventilation unit, Hood and Modified cyclone complete set

4.3 Finding optimum air inlet velocity

Calculating air inlet velocity for estimating cyclone efficiency in each air inlet velocity at 0.61, 0.91, 1.52, 3.05, 4.57 and 6.10 m/sec Due to cyclone collection efficiency it begins decreasing at a very high air inlet velocity, then choose optimum air inlet velocity for cyclone efficiency test

The result of calculation is presented in table 4-7 to 4-12 as follows

4.3.1 Grade Efficiency or Fractional (ηi) of each size calculation

Adjusted air flow rate, Vi = 0.61 m/sec , Q= 6.18 m^3/min

$$\eta i = 1 - \exp\left\{-2\left[\frac{G\,\tau i\,Q\,(n+1)}{Dc^3}\right]^{0.5/(n+1)}\right\}$$

When : $Q = 6.18\ m^3/min$, $V_i = 0.61$ m/sec

$Dc = 400$ mm

$n = 0.4017$

$G = 723.12$

Table 4-7 Grade Efficiency or Fractional (ηi) of each dust size (Vi = 0.61 m/sec)

ηi value of each dust size

Average dust size (micron)	τi (Second)	ηi (%)
20.38	1.88×10^{-3}	0.9090
53.5	4.70×10^{-3}	0.9650
77.21	8.67×10^{-2}	0.9990
114.75	2.16×10^{-1}	1.0000
275.08	1.83×10^{-1}	1.0000

Overall efficiency calculation

$$\eta_T = \sum m_i \eta_i \ldots..$$

$$= \sum m_1 \eta_1 + m_2 \eta_2 + \ldots. + m_9 \eta_9$$

$$= (77.46 \times 0.90)+(10.6 \times 0.96)+(4.78 \times 0.99)+$$

$$(4.26 \times 1.00)+(2.9 \times 1.00)$$

$$= 91.78\ \%$$

4.3.2 Grade Efficiency or Fractional (ηi) of each size calculation

Adjusted air flow rate Vi = 0.91 m/sec , Q = 9.27 m^3/min

$$\eta i = 1 - \exp\left\{-2\left[\frac{G\,\tau i\,Q}{Dc^3}(n+1)\right]^{0.5/(n+1)}\right\}$$

When : Q = 9.27 m^3/min , Vi = 0.91 m/sec

Dc = 400 mm

n = 0.4017

G = 723.12

Table 4-8 Grade Efficiency or Fractional (ηi) of each dust size (Vi = 0.91 m/sec)

ηi value of each dust size

Average dust size (micron)	τi (Second)	ηi (%)
20.83	1.88×10^{-3}	0.9380
53.5	4.70×10^{-3}	0.9790
77.21	8.67×10^{-2}	0.9990
114.75	2.16×10^{-1}	1.0000
275.08	1.83×10^{-1}	1.0000

Overall efficiency calculation

$$\eta_T = \sum m_i \eta_i \ldots..$$

$$= \sum m_1 \eta_1 + m_2 \eta_2 + \ldots. + m_9 \eta_9$$

$$= (77.46 \times 0.93)+(10.6 \times 0.97)+(4.78 \times 0.99)+(4.26 \times 1.0000)+(2.9 \times 1.0000)$$

$$= 89.98\ \%$$

4.3.3 Grade Efficiency or Fractional (ηi) of each size calculation

Adjusted air flow rate Vi = 1.52 m/sec , Q = 17.34 m^3/min

$$\eta i = 1 - \exp \{-2 [\frac{G \tau i Q}{Dc^3} (n+1)]^{0.5/(n+1)}\}$$

When : Q = 17.34 m^3/min , Vi = 1.52 m/sec

Dc = 400 m

n = 0.4017

G = 723.12

Table 4-9 Grade Efficiency or Fractional (ηi) of each dust size (Vi = 1.52 m/sec)

ηi value of each dust size

Average dust size (micron)	τi (Second)	ηi (%)
20.83	1.88×10^{-3}	0.9690
53.5	4.70×10^{-3}	0.9920
77.21	8.67×10^{-2}	0.9990
114.75	2.16×10^{-1}	1.0000
275.08	1.83×10^{-1}	1.0000

Overall efficiency calculation

$\eta_T = \sum m_i \eta_i$ …..

$= \sum m_1 \eta_1 + m_2 \eta_2 + \ldots + m_9 \eta_9$

= (77.46 X 0.96)+(10.6 X 0.99)+(4.78 X 0.99)+ (4.26 X 1.00)+(2.9 X 1.00)

= 96.74 %

4.3.4 Grade Efficiency or Fractional (ηi) of each size calculation

Adjusted air flow rate Vi = 3.05 m/sec , Q = 29.13 m^3/min

$$\eta i = 1- \exp \{-2 [\frac{G \tau i\ Q}{Dc^3} (n+1)]^{0.5/(n+1)}\}$$

When : Q = 29.13 m^3/min , Vi = 3.05 m/sec

Dc = 400 mm

n = 0.4017

G = 723.12

Table 4-10 Grade Efficiency or Fractional (ηi) of each dust size (Vi = 3.05 m/sec)

ηi value of each dust size

Average dust size (micron)	τi (Second)	ηi (%)
20.83	1.88×10^{-3}	0.9850
53.5	4.70×10^{-3}	0.9970
77.21	8.67×10^{-2}	0.9990
114.75	2.16×10^{-1}	1.0000
275.08	1.83×10^{-1}	1.0000

Overall efficiency calculation

$\eta_T = \sum m_i \eta_i$ …..

$= \sum m_1 \eta_1 + m_2 \eta_2 + \ldots + m_9 \eta_9$

$= (77.46 \times 0.98)+(10.6 \times 0.99)+(4.78 \times 0.99)+ (4.26 \times 1.00)+(2.9 \times 1.00)$

$= 98.29$ %

4.3.5 Grade Efficiency or Fractional (ηi) of each size calculation

Adjusted air flow rate Vi = 4.57 m/sec ,Q = 46.36 m^3/min

$$\eta i = 1 - \exp\left\{-2\left[\frac{G\,\tau i\,Q\,(n+1)}{Dc^3}\right]^{0.5/(n+1)}\right\}$$

When : Q = 46.36 m^3/min ,Vi = 4.57 m/sec

Dc = 400 mm

n = 0.4017

G = 723.12

Table 4-11 Grade Efficiency or Fractional (ηi) of each dust size (Vi = 4.57 m/sec)

ηi value of each dust size

Average dust size (micron)	τi (Second)	ηi (%)
20.83	1.88×10^{-3}	0.9930
53.5	4.70×10^{-3}	0.9990
77.21	8.67×10^{-2}	1.0000
114.75	2.16×10^{-1}	1.0000
275.08	1.83×10^{-1}	1.0000

Overall efficiency calculation

$\eta_T = \sum m_i \eta_i \ldots..$

$= \sum m_1 \eta_1 + m_2 \eta_2 + \ldots. + m_9 \eta_9$

$= (77.46 \times 0.99)+(10.6 \times 0.99)+(4.78 \times 1.00)+$
$(4.26 \times 1.00)+(2.9 \times 1.0)$

$= 99.11$ %

4.3.6 Grade Efficiency or Fractional (ηi) of each size calculation

Adjusted air flow rate Vi = 6.10 m/sec , Q = 61.81 m^3/min

$$\eta i = 1 - \exp\left\{-2\left[\frac{G\,\tau i\,Q}{Dc^3}(n+1)\right]^{0.5/(n+1)}\right\}$$

When : Q = 61.81 m^3/min , Vi = 6.10 m/sec

Dc = 400 mm

n = 0.4017

G = 723.12

Table 4-12 Grade Efficiency or Fractional (ηi) of each dust size (Vi = 6.10 m/sec)

ηi value of each dust size

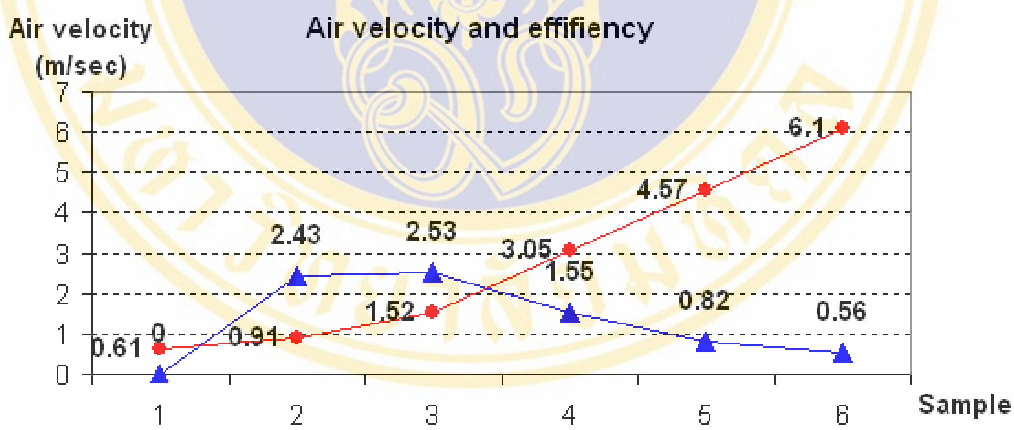
Average dust size (micron)	τi (Second)	ηi (%)
20.83	1.88×10^{-3}	0.9960
53.5	4.70×10^{-3}	0.9990
77.21	8.67×10^{-2}	1.0000
114.75	2.16×10^{-1}	1.0000
275.08	1.83×10^{-1}	1.0000

Overall efficiency calculation

$$\eta_T = \sum m_i \eta_i \ldots..$$
$$= \sum m_1 \eta_1 + m_2 \eta_2 + \ldots. + m_9 \eta_9$$
$$= (77.46 \times 0.99)+(10.6 \times 0.99)+(4.78 \times 1.00)+ (4.26 \times 1.00)+(2.9 \times 1.00)$$
$$= 99.67\ \%$$

Table 4-13 Calculation result of modified cyclone efficiency when adjusted air flow rate and quantity of air inlet to the cyclone, comparison of each air flow rate and added percent when adjusted the air flow rate.

Sample	Vi (m/Sec)	Increase Vi	Q (m3/min)	Eff (%)	interval (%)
1	0.61		6.18	91.78	
2	0.91	0.3	9.27	94.21	2.43
3	1.52	0.61	17.34	96.74	2.53
4	3.05	1.53	29.13	98.29	1.55
5	4.57	1.52	46.36	99.11	0.82
6	6.10	1.53	61.81	99.67	0.56



● = number of sample when increase air velocity

▲ = interval of increase cyclone efficiency (%)

Figure 4-3 Air velocity and cyclone efficiency

4.4 Dust concentration in working environment

Air sampling in the working environment (area sampling) during fiber glass reinforced plastic cutting precess for finding dust concentration in working area.

Installation air sampling pump at working area in cutting process by sampling point at nearly breathing zone of operators seat. (Figure 3-3 Air sampling in fiber glass cutting process)

Air sampling by personal pump and collecting dust using a glass fiber filter, then weight the glass fiber filter to find dust concentration in the working environment. Total dust concentration calculation, C (mg/m^3) per air volume, V(L) was carried out as follows

$$C = \frac{(W2-W1) - \times 10^3}{V} \quad mg/m^3$$

When ; C = concentration $(mg/m)^3$

W1 = weight of filter before air sampling (mg)

W2 = weight of filter after air sampling (mg)

The condition of cutting process was 5 mm thick of sample product and 100 cm cutting length, using a portable grinder with 101 mm blade diameter and 2 mm blade thick, 12,000 rpm and cutting duration of 3 minute. Air sampling flow rate was of 2 liter per minute, and doing the experiment for ten replications.

The results are presented in table 4-14

Table 4-14 Dust concentration in working environment

Sample No.	Total dust concentration in the working environment			
	Pre-weight (mg)	Post-weight (mg)	Post w - Pre w (mg)	Concentration (mg/m^3)
1	73.88	74.00	0.12	20.00
2	74.99	75.30	0.31	51.66
3	73.78	72.61	0.23	38.33
4	74.68	74.90	0.22	36.66
5	73.74	74.04	0.30	50.00
6	75.12	75.37	0.25	41.67
7	74.01	74.21	0.20	33.33
8	75.58	75.83	0.25	41.57
9	75.04	75.23	0.19	31.66
10	74.50	74.62	0.12	20.00
Total	745.32	747.51	2.19	365.00
Mean	74.53	74.61	0.22	36.49
SD	0.652	0.935	0.065	10.779

Table 4-14 shows total dust concentrations in the working environment by personal air sampling pump, sampling time 5 minute each sample.

Average weight of glass fiber filter before air sampling was 74.53 mg with a standard deviation of 0.652 mg the and average weight of the glass fiber filter after air sampling was 74.61 mg with a standard deviation of 0.935 mg and average weight of dust was 0.22 mg with a standard deviation of 0.065 mg. The results of averge total dust concentration had 36.49 mg/m^3 with a standard deviation of 10.779 mg/m^3.

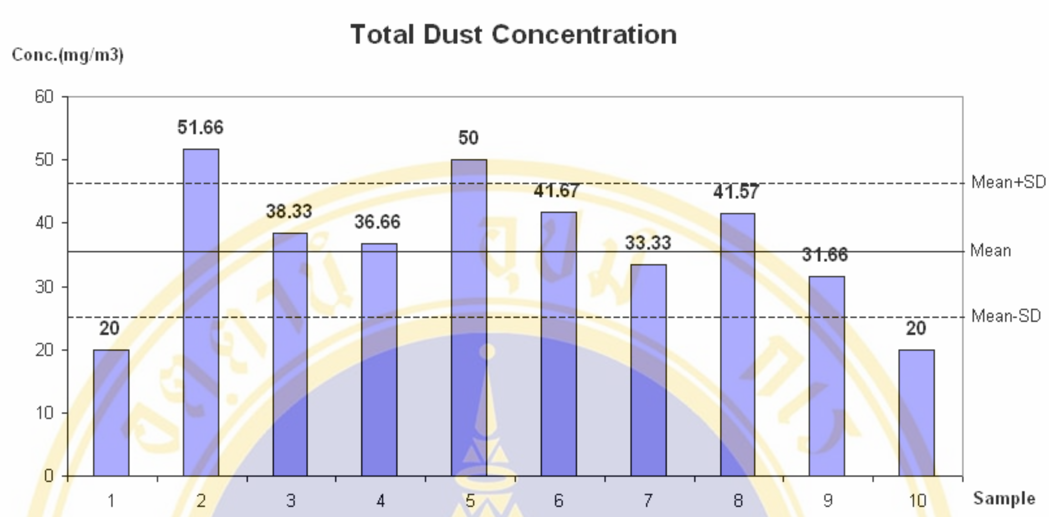


Figure 4-4 Total dust concentration in the working environment

4.5 Modified cyclone collection efficiency

Modified cyclone collection efficiency was measured by calculation of the dust inlet concentration and dust outlet concentration for each dust size. This study had separated dust size range for 5 level and 3 sample each level, 0.29 to 38.1 micron 38.1 to 63.5 micron, 63.5 to 125 micron, 125 to 250 micron and 250 micron above. Dust separation by sieve number 18, 60,120 and number 230. Dust collection efficiency calculation as follows

$$\text{Dust collection efficiency} = \frac{(\text{Inlet dust concentration - Outlet dust concentration})}{\text{Inlet dust concentration}} \times 100$$

Table 4-15 Modified cyclone collection efficiency

size (micron)	Sample No.	Pre weight (g)	Post weight (g)	Post w- Pre w	Inlet Conc. (mg/m3)	Out Conc. (mg/m3)	Efficiency (%)	Avg. Eff. (%)
250 ++	1	0.3663	0.3723	0.0060	1056.25	1.2500	99.8817	99.86
	2	0.3649	0.3728	0.0079	1027.08	1.6458	99.8398	
	3	0.3663	0.3739	0.0076	1091.67	1.5833	99.8550	
125 - 250	4	0.3661	0.3738	0.0077	879.17	1.6042	99.8175	99.86
	5	0.3651	0.3720	0.0068	1166.67	1.4167	99.8786	
	6	0.3644	0.3714	0.0070	1372.92	1.4583	99.8938	
63.5 - 125	7	0.3613	0.3697	0.0084	1297.92	1.7500	99.8652	99.86
	8	0.3644	0.3724	0.0080	1222.92	1.6667	99.8637	
	9	0.3644	0.3716	0.0072	1014.58	1.5000	99.8522	
38.1 - 63.5	10	0.3637	0.3734	0.0097	1245.83	2.0208	99.8378	99.82
	11	0.3628	0.3741	0.0113	1208.33	2.3542	99.8052	
	12	0.3628	0.3741	0.0112	1212.50	2.3333	99.8076	
0 - 38.1	13	0.3654	0.3690	0.0036	66.67	0.7500	98.8750	98.96
	14	0.3646	0.3681	0.0035	70.83	0.7292	98.9706	
	15	0.3636	0.3672	0.0036	77.08	0.7500	99.0270	
Mean							99.6714	
SD							0.3715	

t-test = 1039.139 df = 14 p-value < 0.001

95 % Confidence Interval of the difference = 99.4657 – 99.881

Table 4-15 Shows results of modified cyclone collection efficiency. The percentage of average efficiency of dust size range 250 micron above equal 99.86 % The percentage of average efficiency of dust size range 125-250 micron equal 99.86 %. The percentage of average efficiency of dust size range 63.5-125 micron equal 99.86 %. The percentage of average efficiency of dust size range 38.1-63.5 micron equal 99.82 %.and the percentage of average efficiency of dust size range 0-38.1 micron equal 98.96 %.

The percentage of collection efficiency between 98.87 % to 99.89 % with a standard deviation 0.3715 % and percentage of mean efficiency of cyclone equal 99.67 %

Cyclone collection efficiency of each dust size range was more than 90 % compliance with hypothesis (t-test = 1039.139 df = 14 p-value < 0.001)

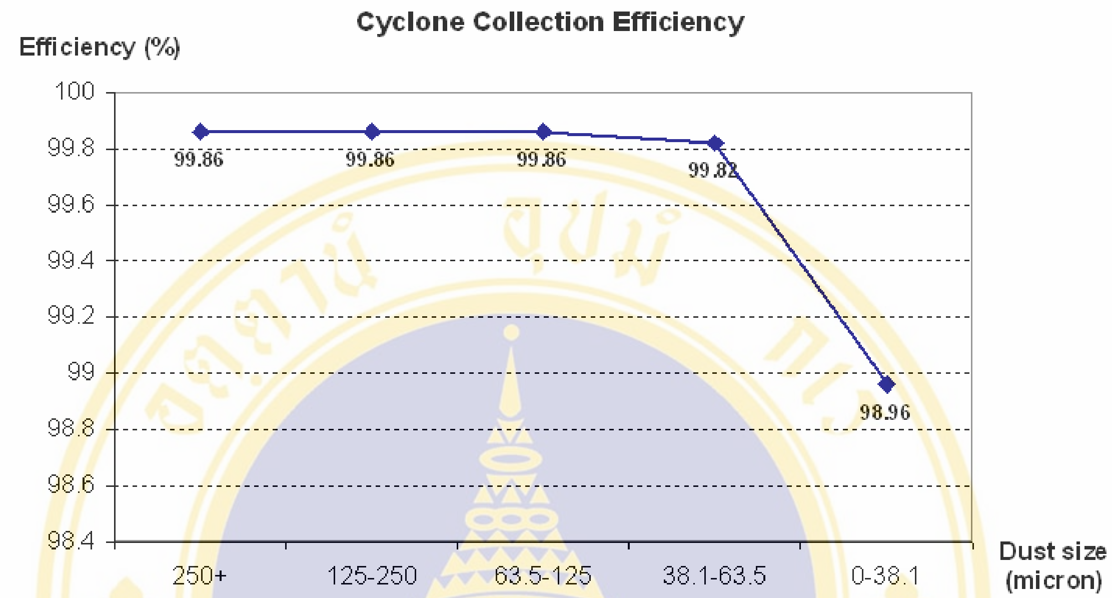


Figure 4-5 Cyclone collection efficiency each particulet size

Figure 4-5 Shows results of cyclone collection efficiency each dust size range. Cyclone have high efficiency for large size and trend of efficiency to decrease for small size

CHAPTER V
DISCUSSION

Modified cyclone was designed by applying advantage characteristics of vane axial inlet type and tangential type. Cyclone efficiency test method was compared dust concentration by weight filter for find concentration each dust size at cyclone outlet.

5.1 Design and construction of modified cyclone

Results of this study was found that factors to increase cyclone efficiency due to modified air inlet pattern for fix direction of air stream inlet before air stream flow spin inner cyclone wall, for increase cyclone efficiency for separate dust from air stream

Design of the modified cyclone was a tangential vane axial inlet cyclone type. Dimensional proportions of this cyclone apply from Stairmand theory, because of this cyclone pattern. It is appropriate to apply to high efficiency and is simple to modify to solve the dust problem in working conditions and easy to maintenance.

Study results was found that modified cyclone appropriate to collected large size such as dust which generated from cutting process

Due to air inlet velocity effect to efficiency of cyclone, this studied require appropriate air inlet velocity, 3 horse-power fan chosen to used in this studied.

5.2 Experimental results

5.2.1 Dust size and dust distribution

Dust analysis using Particle size analyzer (Mastersizer S). Dust size of fiber glass range 0.23 - 409.45 micron. Most of dust size had large size (total dust) around 60% which cyclone suitable for collected dust large size.

Results of dust distribution studied found that most of dust size range 12.22 – 41.43 micron (average 26.83 micron) have 34.85 % and small dust size (respirable dust) have around 40 %

5.2.2 Results of modified cyclone efficiency test

The appropriate air inlet velocity at 1.52 m/sec was chosen for construction and test of cyclone efficiency because of at 1.52 m/sec cyclone have most efficiency when compared with fan horse-power.

Regarding modified cyclone efficiency range from 98.87 % to 99.89 % and mean of percentage efficiency was 99.67 %.

Collection efficiency of the cyclone was more than 90 %. This was significant when compared with cyclone efficiency in calculation ($p < 0.001$)

5.2.3 Air velocity

Data from calculation was conducted for cyclone efficiency test at each air inlet velocity of 0.61, 0.91, 1.52, 3.05, 4.57 and 6.10 m/sec. Cyclone efficiency increased when air inlet velocity to the cyclone increased, but the trend of cyclone efficiency decreased at 3.05, 4.57 and 6.10 m/sec (1.55%, 0.82%, 0.56%)respectively, while increasing air inlet velocity at 50%, as presented in table 4-13

5.2.4 Efficiency calculation of modified cyclone

Efficiency calculation of normal cyclone has around 90 %. Design of this cyclone was tangential vane axial inlet cyclone type. It was modified from two cyclone types of 1)Tangential cyclone type which air inlet to cyclone body by tangential direction and 2)Vane axial inlet cyclone type which air inlet from top side to cyclone body and turn in cyclone cylinder by vane. Control direction of air inlet to cyclone body will increase efficiency of cyclone more than the normal cyclone.

5.2.5 Experimental results of modified cyclone

To increase collection efficiency of cyclone, other factors when increase cyclone efficiency will increase. Therefore cyclone design should considerate some factors such as air inlet velocity, diameter of cyclone body, smoothness of inside cyclone wall. Results of this study was found that major factors to increase cyclone efficiency by modified inlet of air stream (inlet area 16,000 mm^3) and fix air stream direction input to cyclone at side of cyclone body and flow pass through blade before air stream spin flow inside cyclone wall which constructed from smooth metal sheet for smoothness of inside cyclone wall and increase number of air stream spin flow by design height of cyclone cylinder 1016 mm

The results of efficiency study of dust size range 38.1 micron above estimate 99% and less than 38.1 micron estimate 98%, and trend of efficiency of modified cyclone will decrease for small dust sample.

Dust sample size 0.29 – 38.1 micron have percent of efficiency decrease as presented in figure 4-5

Most size range of fiber glass dust have larger than 10 micron (estimated 60 %) and dust size range less than 10 micron (and estimated 40 %)

Dust size range in fiber glass cutting process larger than 10 micron (60%) classify in total dust and dust size range less than 10 micron (40%) classify in respirable dust. Results of the cyclone efficiency test was found that modified cyclone can collect both dust size (99.67%)

CHAPTER VI
CONCLUSION AND RECOMMENDATION

This study was an experimental study of efficiency test of modified cyclone for controling dust generated by the cutting process of decorated car accessory products of fiber glass reinforced plastic. Design of the cyclone was modified from dimension proportion of Strainmand. The results of calculation was tangential vane axial inlet cyclone type, 400 mm diameter, 1016 mm high cylinder, 600 mm high cone, and then assembled with 20.32 cm duct diameter of local exhaust ventilation unit and hood design suitable for working processes which followed recommendation of American Conference of Governmental Industrial Hygienists, VS 80-18 "Hand grind bench" and 3 horse-power fan, three phase types.

This experiment setting was 1.52 m/sec air inlet velocity, average modified cyclone efficiency of 99.67 %, collection efficiency range between 98.87 %-99.87 % with a standard diviation of 0.3715 %. Collection efficiency of cyclone more than 90 %. That was significant when compared with cyclone efficiency in calculation ($p < 0.001$)

6.1 Conclusion

6.1.1 The dust characteristic by particle size analyzer (Mastersizer S) found most particulates size range between 10 to 65 micron, all particulate size range between 0.23 to 409.45 micron.

6.1.2 Factors of cyclone design for increase cyclone dust collection efficiency must increase some factors such as direction of suitable air stream inlet to cyclone body, increase air inlet velocity, increase time for air stream spin flow inside cyclone wall and make air stream spin flow easily inside cyclone wall by using smooth material surface.

This study was designed pattern air inlet for fix direction of air stream inlet by designed for air strem input to cyclone at side of cyclone body and used blade for increase spin flow of air inlet and this study used air inlet velocity 1.52 m/sec and increase other factors to increase cyclone efficiency such as area of air inlet and diameter of cyclone body by design area of air inlet (inlet area 16,000 mm^3)and design to increase cyclone diameter (400 mm) and increase length of cyclone to 1016 mm for increase air stream spin flow inside cyclone wall.

6.1.3 Preparation of dust for cyclone efficiency test

This study was separated 5 range of dust size (0.29 to 38.1 micron , 38.1 to 63.5 micron , 63.5 to 125 micron , 125 to 250 micron and 250 micron above) by seive No.18 , No.60 , No.120 , No.230. During prepared each dust size range for cyclone efficiency test by sieve , small dust size range may be lose from sieve container.

6.1.4 Dust from cutting process by used portable grinder

While cutting by used portable grinder some factors effecting to modified cyclone collection efficiency (study dust concentration in working environment), the dust was casted following spinning force of the blade, the dust fall down to the ground of the hood especially large size dusts. Therefore, chance of large size dusts going into the inlet to the cyclone was less than small size dusts which suspend inside the hood chamber.

6.2 Recommendation

This study was found that some factors which effect to cyclone collection efficiency such as quantity or concentration of dust, air inlet velocity to cyclone, proportion of cyclone such as area of air inlet, diameter of cyclone. Results from study was found efficiency of modified cyclone decrease following small dust size.

To increase dust collection efficiency of cyclone should considerate other factors such as air inlet velocity or proportion of cyclone. Recommendation of future efficiency cyclone study as follow.

- **Dust size** Dust physical characteristic study for data to design appropriate cyclone with suitable for each dust size range due to ordinary cyclone suitable for collect large dust size.

- **Air inlet velocity** When increase air inlet velocity to cyclone make increase efficiency of cyclone. Results from this study was found air inlet velocity relate to cyclone efficiency. In addition very high air inlet velocity make cyclone efficiency to begin consistent. Recommendation of future study should considerate appropriate air inlet velocity with dust type.

- **Cyclone proportion** This factor is important to cyclone efficiency, increasing area of air inlet and cyclone diameter will increase cyclone efficiency. Recommendation of future study should considerate cyclone design suitable for dust type, air inlet velocity and dust physical characteristic such as quantity or concentration, dust size range etc.

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APPENDIX

APPENDIX A

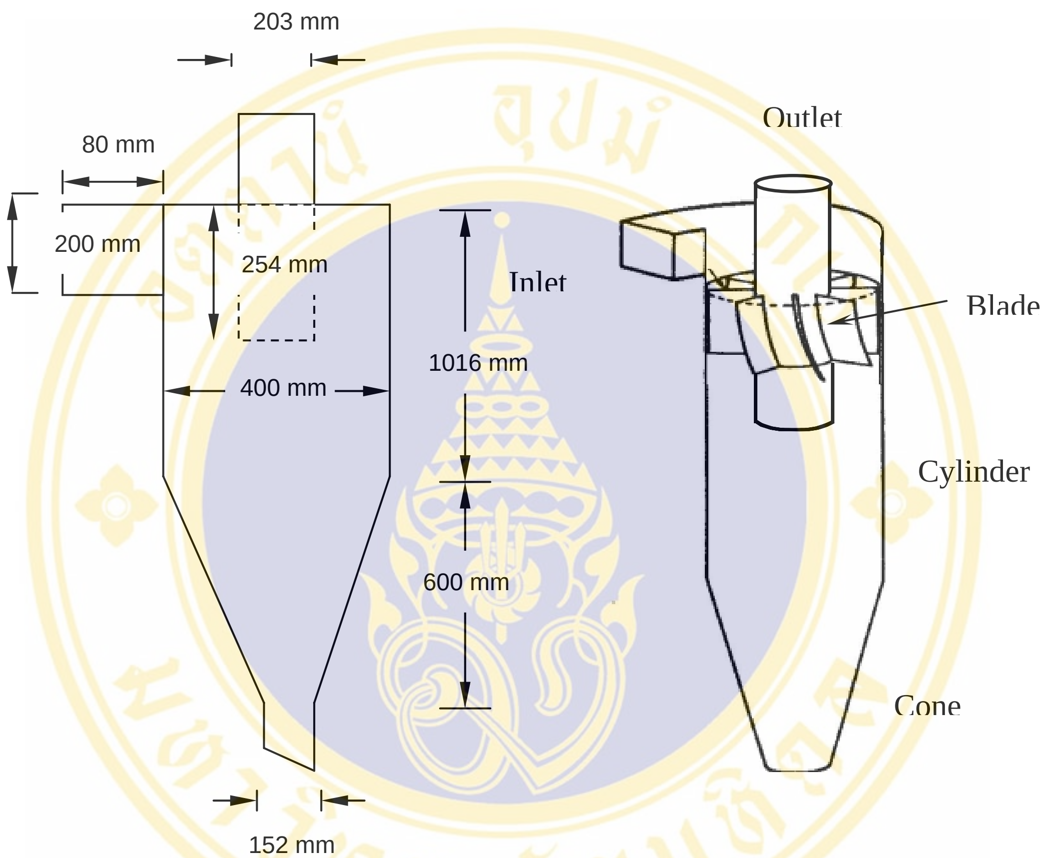
Picture of modify cyclone

Cyclone and Local Exhaust Ventilation

Tangential vane axil inlet cyclone

APPENDIX B

Dimension of modified cyclone



APPENDIX C

Particulate density calculation by used pycnometer bottle

Material : Particle sample 10 g

Method :

1. Balance bottle (W_1)
2. Balance bottle + water (W_2)
3. Balance bottle + particle (2-3 g) (W_3)
4. contain water into bottle and boil 30 minute, rest the bottle to room temperature, and then contain water to bottle
5. Balance bottle + particle + water (W_4)
6. temperature record
7. calculation
   - Balance water which have equal volume with bottle volume which without particle volume (W_5) $= W_1 - W_2$
   - Balance particle (Ws) $= W_3 - W_1$
   - Balance water which have equal volume with bottle volume which without particle volume (W_6) $= W_4 - W_3$
   - Balance water which have equal particle volume (W7) $= W_5 - W_6$
   - water volume which have equal particle volume (Vs) $= W_7 - \rho_0$
   - particle density = Ws / Vs

Result :

1) W_1	=	46.7280 gm	W_5	$= W_2 - W_1$	= 146.8079 - 46.7280	= 100.0799 gm
W_2	=	146.8079 gm	Ws	$= W_3 - W_1$	= 49.7138 - 46.7280	= 2.9858 gm
W_3	=	49.7238 gm	W_6	$= W_4 - W_3$	= 147.7911 - 49.7138	= 98.0773 gm
W_4	=	147.7911 gm	W_7	$= W_5 - W_6$	= 100.0719 - 98.0773	= 2.0026 gm
T	=	30 °C	Vs	$= W_7 - \rho_0$	= 2.0026 / 0.9956	= 2.0114 gm
ρ	=	0.9956 gm/cc	D	= Ws / Vs	= 2.9858 / 2.0114	= 1.48 gm/cc

2) W_1 = 46.7441 gm	W_5 = W_2-W_1 = 146.8032 - 46.7441	= 100.0591 gm
W_2 = 146.8032 gm	Ws = W_3-W_1 = 49.7255 - 46.7411	= 2.9814 gm
W_3 = 49.7255 gm	W_6 = W_4-W_3 = 147.8078 - 49.7255	= 98.0823 gm
W_4 = 147.8078 gm	W_7 = W_5-W_6 = 100.0591 - 98.0823	= 1.9768 gm
T = 30 °C	Vs = W_7-ρ_0 = 1.9768 / 0.9956	= 1.9855 gm
ρ = 0.9956 gm/cc	D = Ws / Vs = 2.9814 / 1.9855	= 1.50 gm/cc

3) W_1 = 46.7478 gm	W_5 = W_2-W_1 = 146.7893 - 46.7478	= 100.0415 gm
W_2 = 146.7893 gm	Ws = W_3-W_1 = 49.6718 - 46.7478	= 2.9240 gm
W_3 = 49.6718 gm	W_6 = W_4-W_3 = 147.7977 - 49.6718	= 98.1259 gm
W_4 = 147.7977 gm	W_7 = W_5-W_6 = 100.0415 - 98.1259	= 1.9156 gm
T = 30 °C	Vs = W_7-ρ_0 = 1.9156 / 0.9956	= 1.9241 gm
ρ = 0.9956 gm/cc	D = Ws / Vs = 2.9240 / 1.9241	= 1.52 g/cc

Average particle density = 1.48 + 1.50 + 1.52 / 3 = 4.50 / 3 = 1.50 gm/cc

APPENDIX D

Physical characteristics of dust studied

Result of dust concentration, dust size and dust distribution

1. Total dust concentration

Cutting sample product in a sealed chamber and air sampling using a personal air sampling pump and dust collected by a filter. Find dust concentration by calculation from data of balance the filter (before and after air sampling). Total dust and respirable dust concentration, C (mg/m^3) per air volume, V(L) was calculated as follows

$$C = \frac{(W2-W1) - (B2-B1)\ X10^3}{V}\ , mg/m^3$$

When ;	C	=	concentration ($mg/m)^3$
	W1	=	weight of filter before air sampling (mg)
	W2	=	weight of filter after air sampling (mg)
	B1	=	average weight of blank filter before air sampling (mg)
	B2	=	average weight of blank filter after air sampling (mg)

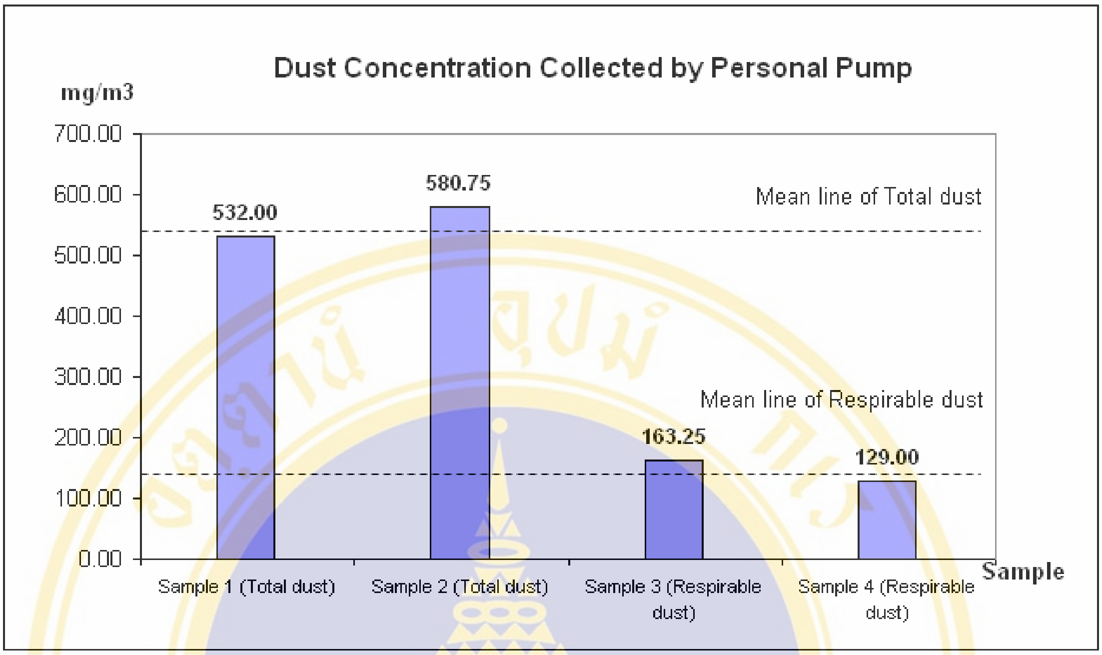
The condition of cutting process was 3 mm thick of sample product and 200 cm. cutting long, using a portable grinder with 101 mm blade and 2 mm. blade thick, 12,000 rpm and cutting duration of 20 minute. The results of total and respirable dust concentrations shows in table

Results of total dust concentration and respirable dust concentration

No.	Pre-weight (g)	Post – weight (g)	(Post-weight –Pre-weight) (g)	Concentration (mg/m3)	Remark
1	0.07445	0.09573	0.02128	532.00	fiber glass filter
2	0.01242	0.03565	0.02323	580.75	PVC filter
Total	0.08687	0.13138	0.04451	1112.75	
Mean	0.04344	0.06569	0.02226	556.38	
SD				34.4715	

No.	Pre-weight (g)	Post – weight (g)	(Post-weight –Pre-weight) (g)	Concentration (mg/m3)	Remark
3	0.07577	0.08230	0.00653	163.25	Cyclone collector / Fiber glass filter
4	0.01221	0.01737	0.00516	129.00	Cyclone Collector / PVC filter
Total	0.08798	0.09967	0.01169	292.25	
Mean	0.04399	0.04984	0.00585	146.13	
SD				24.2185	
5	0.07506	0.07511	0.00005		(Blank)
6	0.01210	0.01218	0.00008		(Blank)

Shows both total dust and respirable dust concentration. The average total dust concentration was 556.38 mg/m^3 with standard deviation of 34.4715 mg/m^3 and average respirable dust concentration was 146.13 mg/m^3 with standard deviation of 24.2185 mg/m^3.



Fiber glass dust concentration from sample product cutting test in a sealed chamber, total dust air sampling (sample 1,2) and respirable dust air sampling (sample 3,4)

2. Respirable dust concentration

Sample product cutting test was conducted in a sealed chamber and air sampling using Anderson sample.

The condition of cutting process was 3 mm thick of sample product and 50 cm cutting long, using a portable grinder with 101 mm blade diameter and 2 mm blade thick, 12,000 rpm and cutting duration of 5 minute. Air sampling flow rate was at 24 liter per minute,total air volume of 120 liter and carring the experiment for three replications. The results are presented in the table

Result of respirable dust sampling by Anderson samplers

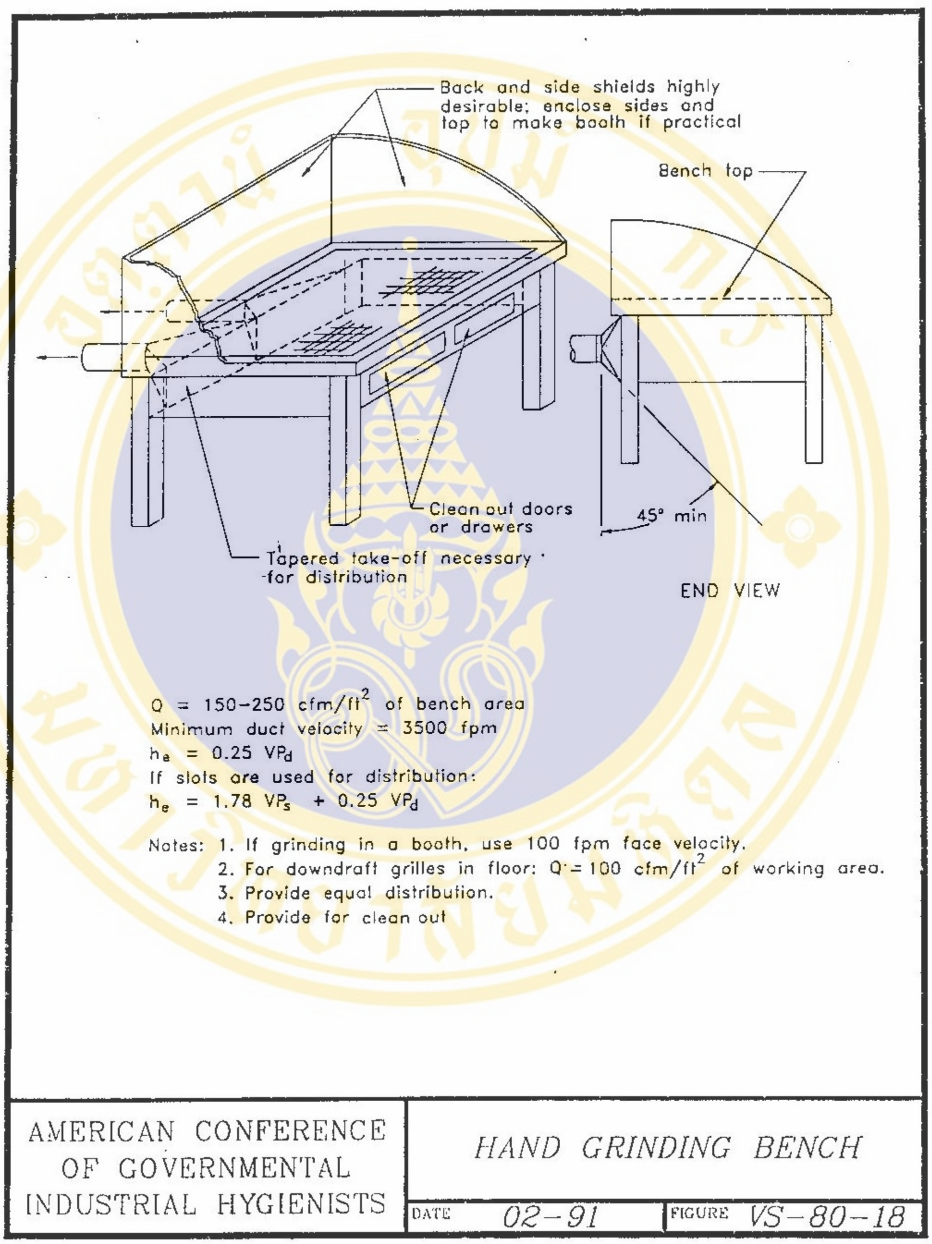
Stage	Size range (µm)	Weight (mg)	Size ragne %	Cumulative %
1	5.8 – 9.0	16.17667	36.73	36.73
2	4.7 – 5.8	7.25867	16.48	53.21
3	3.3 – 4.7	7.94000	18.03	71.23
4	2.1 – 3.3	6.79000	15.42	86.65
5	1.1 – 2.1	3.73333	8.48	95.13
6	0.7 – 1.1	1.37667	3.13	98.25
7	0.4 – 0.7	0.21333	0.48	98.74
Back up filter	0 – 0.4	0.55667	1.26	100.00
Total		44.04333	100.00	100.00

Shows percent of respirable dust concentration. The respirable dust weight was 44 mg in an air volume of 120 liter. Most dust size was more than 5.8 micron range or 36.78 %; weight equals to 16.17 mg

	(W1) PRE-WEIGHT (g)					(W2) POST-WEIGHT (g)					(W2-W1)	Size	Cumulative	Size range of
	1	2	3	Total	Average	1	2	3	Total	Average	(mg)	Range %	%	Anderson Samplers
0														9.0-10.0 & 10.0 above
1	15.58891	15.58801	15.5885	46.76548	15.58849	15.60325	15.60236	15.60840	46.81401	15.60467	16.17667	36.73	36.73	5.8-9.0
2	15.76421	15.76346	15.7639	47.21958	15.76386	15.77020	15.76959	15.77356	47.31335	15.77112	7.25667	16.48	53.21	4.7-5.8
3	15.70640	15.70581	15.7091	47.12139	15.70713	15.71426	15.71374	15.71721	47.14521	15.71507	7.94000	18.03	71.23	3.3-4.7
4	15.31263	15.31190	15.3124	45.93700	15.31233	15.31900	15.31819	15.32018	45.95737	15.31912	6.79000	15.42	86.65	2.1-3.3
5	15.56789	15.56740	15.5679	46.70325	15.56775	15.57135	15.57120	15.57190	46.71445	15.57148	3.73333	8.48	95.13	1.1-2.1
6	15.25345	15.25284	15.2534	45.75973	15.25324	15.25520	15.25427	15.25439	45.76366	15.25462	1.37667	3.13	98.25	0.7-1.1
7	15.77133	15.77049	15.7713	47.31321	15.77107	15.77193	15.77095	15.77097	47.31385	15.77128	0.21333	0.48	98.74	0.4-0.7
Backup filter	0.36027	0.36164	0.36234	1.08425	0.36142	0.36081	0.36221	0.36290	1.08529	0.36197	0.55667	1.25	100.00	0-0.4
Total	109.3250	109.3215	109.329	327.9758	109.3253	109.3660	109.3551	109.3795	328.1080	109.3693	44.04333	100.00	100.00	

Size distribution by Anderson samplers

APPENDIX E



VS-80-18 “Hand grinding bench”

BIOGRAPHY

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