The present work was submitted to the Faculty of Engineering

Bachelor Thesis

Development of road dust filter to be attached on a public bus in Ulaanbaatar

By

Baljinnyam Guntevsuren

14405627854225

Supervisor 1/ Examiner 1 Prof. Dr. Sungchil Lee

Supervisor 2/ Examiner 2 Prof. Dr. Odbileg Norovryenchin

Ulaanbaatar/Nalaikh,

01-May-2019

Statutory Declaration

Guntevsuren, Baljinnyam

Last name, First name

14405627854225

Student ID Number

I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

Development of road dust filter to be attached on a public bus in Ulaanbaatar

Independently and without undue external help. I did not use any sources other those stated. In case that work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Ulaanbaatar, Mongolia

May 1, 2019

Place, Date

Signature

Abstract:

This thesis work focused on road dust reduction in Ulaanbaatar by filtering. It searched for ways to reduce the airborne with the filter attached on public bus operated in Ulaanbaatar city. The road dust contains the PM_{10} and $PM_{2.5}$ which are one of the dangerous materials in air pollution and can affect human health. The airflow around a public bus was simulated by ANSYS CFD software.

ANSYS Workbench 19.2 can simulate the with the pressure distribution around the bus, velocity streamlines and drag force. ANSYS has some fluid flow solvers which are fluent and CFX. In this study, CFX solver used to get an accurate result. The airflow around the public bus of the wind could predicted by ANSYS computer fluid dynamics.

Thesis main purpose of this study was collecting road dust from several locations within the filter. There are two methods used for collecting the dust sample. First ones were dust collected from the specific locations without the filtering and another one was road dust collected with the filter to be attached on public bus. Filter (activated carbon air filter) was attached back of public bus with the additional motor, because this location is more efficient way to collecting dust from the air.

The motor principle was just sucking the air into the air filter. This motor was working two weeks (186 hours). Each weeks had different way to sucking the air (inlet of the motor). First week 30g and next week 125g of $PM_{2.5}$ was collected.

Acknowledgement:

I wish to express my sincere thanks to GMIT Engineering Faculty and Tenuun-Ogoo LLC which helped me to apply knowledge to real world and support me to finish this thesis successfully and to learn from my supervisors. This research would not be possible without assistance of supervisors, professors and engineers of the company.

I would like to show my deep appreciation to my supervisors, Professor Sungchil Lee and Odbileg for their instruction, advice and helps for completion of this thesis. Both supervisors' suggestions are helpful for developing the research during research period. Also, I would like to appreciate the Mr.Darkhaa who is a mechanical engineer for helping in making design and prototype sharing his ideas with me. I am very thankful being supported and leanning from them.

I am also grateful for engineers and technicians who is working in the Tenuun-Ogoo LLC. These peoples gave me advice for making the design, helped installing the prototype filter on the bus and useful materials and informations. Also, Tenuun-Ogoo LLC gave me opportunities to work on their bus and I appreciate for that.

In the end, I would like to thank to my teachers and friends who are studying in same subjects for sharing knowledge related to this thesis and checking my mistakes during the time.

Table of content

Contents

List of figures and tables

List of Abbreviations

Ger	Mongolia traditional dwelling
PM_{10}	Particulate matter with 10 micrometers or less
$PM_{2.5}$	Particulate matter with 2.5 micrometers or less
MNS 4585:2016	Mongolian air quality standard
WHO	World Health Organization
CAD	Computer Aided Design
ANSYS	simulation software
CFD	computer fluid dynamics
ANSYS CFX	a computation fluid dynamics program
FVM	Finite volume methods
VOF	Type of Euler-Euler approach. Basically a surface tracking technique
SMM	Standard Method of Moments.
DOF	degrees of freedom.

Chapter 1 Introduction

1.1 Background

Air pollution has become one of the big challenging issues in Mongolia. In the winter time, air pollution in Ulaanbaatar reaches the highest in the world. There are 3 main sources of the air polluting factor in Ulaanbaatar:

- Ger district area for heating and cooking,
- Transportation with the traditional combustion engines cars
- Power plants heating systems.

All those factors emit some gases: carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter PM. National Agency for Meteorology and Environment Monitoring consider the PM particle as more serious issue because of Mongolian air quality standard of PM. In January 2019, $PM_{2.5}$ average concentration of 195μg/m^{3,} were reported and this amount is 3 times higher than the air quality standard (MNS 4585:2016) for 24-hour mean content which is set at 50μg/m^3. PM_{10} and $PM_{2.5}$ can be damage human health and one of the causes of airborne diseases as well as death. PM 2.5 is more dangerous than other pollutants. So in winter time, a lot people in Ulaanbaatar are wearing the mask which can filter the PM $_{2.5}$.

Since the year 2000, the number of cars significantly increased and the cars produce some gases like NO_x and create the particulate matters because Ulaanbaatar's urban road quality is much lower than standards which leads to producing the airborne in the air and created the PM2.5. Almost 63% of public transports operating in Ulaanbaatar which has one of the cause to produce the heavy road dust. Currently, there are 82 companies serving on the Ulaanbaatar area with 1,662 bus routes running a total length of nearly 3,900km a day (1). Most of the public buses and private cars have been ran more than 10 years, which can affect the air pollutions. About 80% of peoples are using the public bus in capital city urban road. As a result of all people on streets are exposed to harmful air pollutants particles.

Furthermore, Gers and householders have immigrated to the capital city, and it causes expansion of the Gers districts. In winter time all householders and Gers need energy for produce the heating and cooking, therefore, Ger burns the conventional raw coal and it leads to result air pollutant. The national statistics of Mongolia estimated the usage of coal and wood per ger in a year. They also burn other materials for heating and it is more dangerous than conventional raw coal because it could release more harmful gases to environment.

1.2 Objectives

The purpose of this thesis is to design road dust filter prototype and analyzes the air quality of PM as well as find a way to reduce the air content of PM particles. Samples were collected two cases, first one PM2.5 filter is attached on a public bus and collect the road dust because the number of buses and working hour of public transportation is a benefit for compile the road heavy dusts.

Before installing the filter on a bus, airflow around the bus must be simulated on simulating software with the parameters to determine the most effective filter location. There are so many simulating programs relative to aerodynamics simulation. One of the widely used programs is ANSYS 19.2. This program solves the engineering problems using finite element analysis. It also can define the dimension of bus and object, after that, it can take the weight of bus, pressure temperature and other physical properties. Furthermore that software simulate and test the movements, fatigue, fluid flow, temperature distribution, electromagnetic efficiency and other effects. Fluid flow simulation is more considered for this thesis. Because airflow parameters, solving process and meshing analysis are the same as fluid flow.

The important thing of this study is filter type because PM2.5 should be collected by this filter. The activated carbon filter is used for that object because this working principle is not complicated just use the adsorptions process but its' efficiency is higher than other filters and this filter is wildly used.

Chapter 2 Literature Review

2.1 Air pollution in Ulaanbaatar

Mongolia is the one of the most polluted areas in the world, according to the World Health Organization (WHO) and estimates suggest that particulate air pollution causes one-tenth of the city's death because industrializations and urbanizations are increased which influences the air quality. Air pollution is related to reduce fetal growth, preterm birth, low birth weight, impaired cognitive development, and birth defect. Mongolian air pollution level reached the highest level especially in winter time, on January 30, 2018, at 05:00 am, air pollution levels of 3,320 μg/m^3 (at Baruun 4 zam) was reported, which is 133 times of the WHO guideline for the 24-hour mean concentration which is set at 25 μg/m^3 (2).

Mongolian capital city is located in the Valley Mountains to the north and south. About 60% of Mongolian population live in the Ulaanbaatar. This migration has led to main increases in the capital city's air pollution emissions. In 2018, the population of Ulaanbaatar's was 1, 44,669 (Figure 1) with 4 percentage growth rate. With that rate urban population is expected to reach 2 million in 2020. Immigration is influenced by two main factors. First one is higher incomes in city compared to countryside and another thing is job opportunities in the capital city. This rapid growth of the population leads to some lack of land classification in Ulaanbaatar. This shortage of infrastructure has brought many problems such as lack of clean sanitation, high level of air pollution.

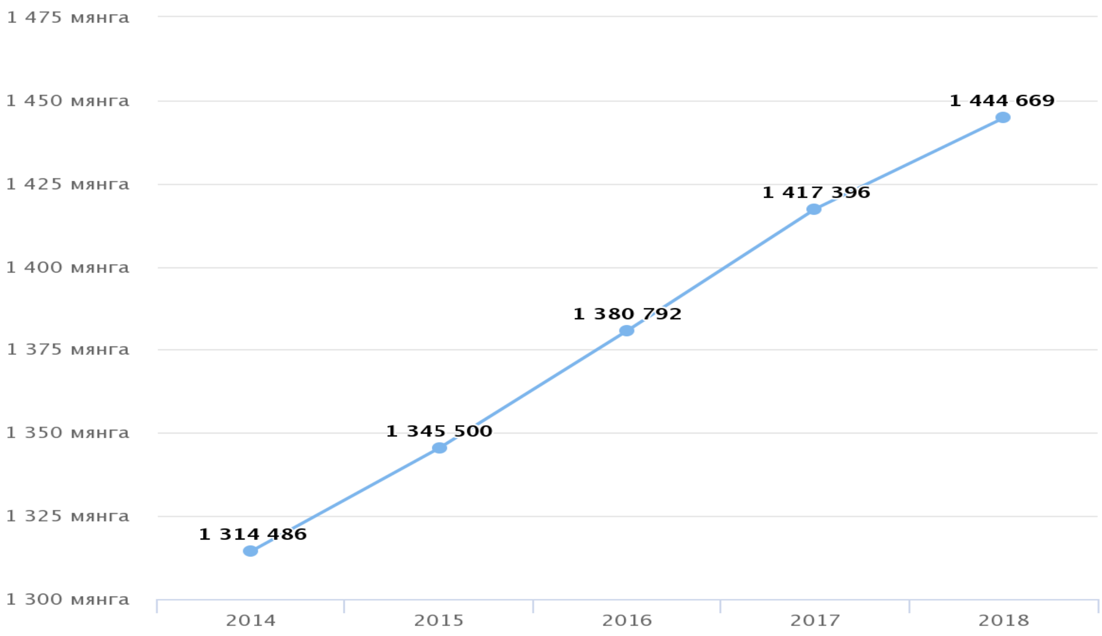


Figure 1: Population growth in Ulaanbaatar

Source*: Ulaanbaatar Statistical Year Book, 2019*

The main polluting sources are Ger districts, old trucks, industrial boilers and road dust. Mongolia is one of the coldest country in the world, with the average annual temperature -1.3^{O}C. Most pollutants have particulate matter PM, sulfur dioxide (SO_2), volatile organic compounds (VOCs), lead (Pb), carbon monoxide (CO), nitrogen oxides (NO_x), and ozone (O_3) (secondary pollutant formed due to the chemical interaction of the various pollutants). This all pollutants are studied and have established air quality standard under WHO to safeguard public health. Particulate matter (PM) is the most dangerous pollutants which can harm human health.

2.2 Air pollution sources In Ulaanbaatar

Air pollutants are divided into two main sections, primary and secondary (3). Primary pollutants are emitted by a process, for example, burning coals in power plant or emission gasses from the vehicles' combustion t but secondary pollutants are not radiated from the sources. Instead, the form as a result of the pollutants emitted from these sources reacting with molecules in the atmosphere. Example of secondary pollutant combined NO_2, which is formed as NO combines with the oxygen in the air and acid rain another one is photochemical smog. Also some pollutants can be both sources which means primary and secondary pollutants are emitted directly and formed from other primary pollutants respectfully. Ulaanbaatar's air pollution main sources are coal combustion heat system, power plant, approximately 400 heat-only boilers and wind blow dust (4). The air pollution sources in Ulaanbaatar are:

1. Cook stove in Gers
2. Livestock
3. Power plants
4. Heat only boilers
5. Vehicular traffic
6. Flying dust
7. Construction industry
8. Garbage burning
9. Hospital waste burning
10. Cook stove in kiosks and Food shops (3)

2.2.1 Cook Stove in Gers

In 2005, Number of Ger and households were estimated as 120,000 but after five years (2010) this number was doubled to 297,000. All Gers and households need energy for cooking, heating and for running vehicles. In Ulaanbaatar, fossil fuel and coal are the primary sources of energy for the boiling system, and motor cars. In winter time heating system required for Ger districts and households for those reasons, they use the poor quality coal. Most of the Mongolian coal mining mainly produce the lignite with heating values ranging from 2,700 to 4,000 kcal/kg, 18-35% moisture and 12-25% ash. All coals mined in Mongolia have low sulfur contains (less than one percent).

The number of 130,000 Gers and household are using 0.6million tons of coal per year (5) also average Ger areas burn 3.0m^3 of fuel wood in each year. Most of the raw coals are supplied from the local coal mines with the high ash content also coals are used in the winter time. Annually coals are demanded mainly between Novembers to February.

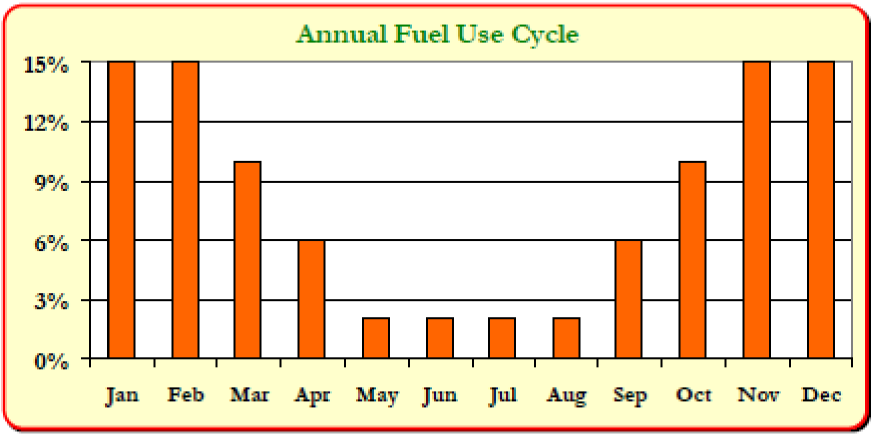


Figure 2: Annual Coal Use Cycle (2)

In the Gers and householders are abroad use of conventional and not suitable for burning materials which is lead to the risky pollutant levels from usage. The not suitable for burning materials such as rubber tubs and bricks dipped in coal tar. This all sources also create energy for intermittent cooking and heating needs but it is harmful to the environment.

2.2.2 Heavy traffics and Road dust

In Ulaanbaatar, estimated 402,000 total number of vehicles are registered in 2018. Recent year, the number of automobiles is significantly increased in. With that fast growth in the number of cars has overpowered capitals infrastructure. Which is becoming a progressive traffic jam problem for the districts. Because of narrow roads and secondary street capacity. Also, this growth produces some problems for an example worse traffic ingestion and produce gas related to pollution. In last five year, the number of vehicles (bus, car ownership, tracks) is increased from the 297,008 to 401,725 also

Figure 3: Not suitable for burning sources

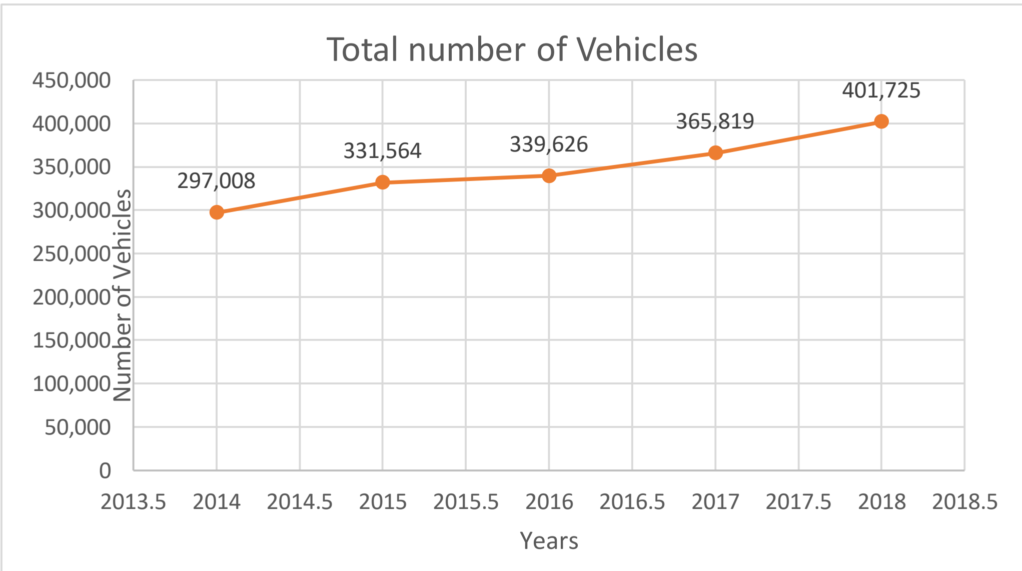


Figure 4: Total number of vehicles

last decade, the percentage of vehicle passenger vehicles has increased from 25% to 65% in 2005 (3).

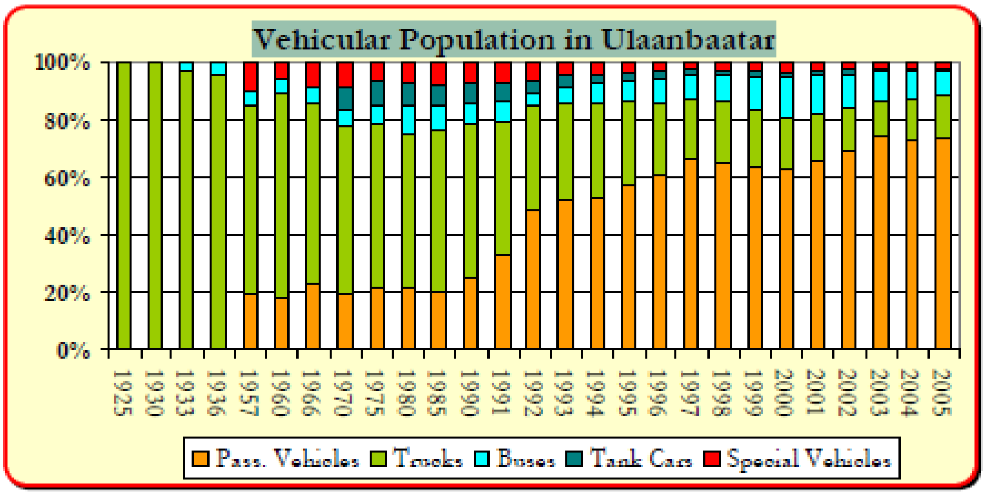


Figure 5: Vehicular Population in Ulaanbaatar (2)

Sources: *Ulaanbaatar Statistical Year Book, 2018,*

Almost 50% of public transportation are working urban traffic in Ulaanbaatar. Large bus and microbus are used public transportation from the 2000s also demand is significantly increased. In 2011, the estimated all transporting demand in the capital city was 2.9 million trips a day including walking trips(1).Also total transportation demand in the city consists walking (31.0%), car (23,4%), taxi (9.45), bus (33.7%) others (2.5%) . This achievement of public transport has been blocked by the increasing issues of traffic jam and effect the traffic networks systems. These reasons led to economic inefficiency due to rise travel time and health problems as poor air quality. The Ulaanbaatar's infrastructure has inefficient traffic management, poor safety conditions, and weak public transportation systems. In the specific location of Ulaanbaatar has more traffic jams (220 seconds/vehicle), as a resulting average speed of 5-8 km/hour in the central section of Ulaanbaatar during the rush hours (1). Also, traffic accidents are common due to bad infrastructure management and undisciplined interaction of pedestrians and vehicles.

Type of Vehicle	Average Vehicle KM Traveled
Car	40
Bus (Regular)	200
Bus (micro)	275
Taxi	140
Truck	150

Table 1: Average vehicles kilometer traveled in Ulaanbaatar

Thus pollution, traffic jam and health problems caused by increasing private car will have detrimental social and economic damage in the quality of life in Ulaanbaatar.

In 2018, Mongolia has 940,372 public transportation of which 847,414 are automobiles. Out of all automobiles, 401,725 (50%) vehicles are registered in Ulaanbaatar (Figure 5). 757,157 (80%) of all cars were used for more than 10 years also 14,824 (16%) cars have traditional combustion engines, 19,094 cars working with a gas engine and only 108 (0.01%) cars have electrical motors.

There is a correlation between the increased number of vehicles and the increased number of patient's respiratory diseases in Ulaanbaatar. This all vehicles emissions can harm for health of the population residing in the apartment area. Car emissions contain some gases which are nitrogen oxide, carbon mono oxide and also produce the particulate matters PM.

Airborne specks of dust can penetrate human lunge without any filtering. One of the most important sources of airborne at traffic jam areas is re-suspension of already collected dust on due to traffic. Also there some sources include unpaved roads, an agricultural area, and construction sites.

In Ulaanbaatar, most of Ger areas are unpaved and dry spring and autumn. The problem of airborne is very persistent and very common (sight Figure 6). Dust emission from the paved road is also one of the problems in Ulaanbaatar city because of all vehicles traveling on the paved road around the Ulaanbaatar's area as well as high present on the road surface. Airborne is included in large amount of PM and committed in dry and arid conditions. Although generally airborne can cause health problems, alone or combined with other air pollutants.

Also, airborne can created from the factors and construction of buildings, for examples land cleaning, drilling, blasting and ground exaction also fill operations. Emission factors are predicted on the type of structure and duration of factories. For example, one householder construction duration is in 6 months, for apartments building is 12 months. Within this construction can create approximately 0.011 tons PM_{10} / arcmoth to 0.11 tons PM_{10}/arc –month. This all dust came from the construction vehicles run over temporary roads at construction sites.

Figure 6: Examples of airborne in Ulaanbaatar

2.3 Particulate matter and Public health

Before 2016, New Delhi and Beijing were the highest level of air pollution in the world, after the 2016 Ulaanbaatar is surpassed these two capitals. Most dangerous for health air contains of pollutants is particle matters ($PM_{2.5}$) because these particles diameters is less than 2.5 microns meters which is can be penetrated to the human lung without the filtering. It is a major cause of diseases such as stroke, heart disease, and lung cancer, acute also chronic respiratory diseases. In 2012, one out of nine deaths in Mongolia was the result of air pollution-related diseases. More than half of child deaths from pneumonia in Mongolia are due to indoor air pollution (2). In Mongolia, indoor and outdoor air pollution accounts for 132 deaths per 100 000 people per year, whereas the global average is 92 deaths per 100 000 people (6).

Data from Mongolian National Agency for Meteorology and Environments Monitoring measure air quality in Ulaanbaatar specific areas from 2016 to 2018. The current WHO guideline for $PM_{2.5}$ is set at 5-10µg/m^3 for the annual mean concentration. In Ulaanbaatar, the average concentration of $PM_{2.5}$ from 2016 to 2018 was 106µg/m^3 (Figure 7), more than 10 times the WHO guideline for the annual mean concentration in a specific region. Also, this number can be affected by the difference between natures and specific areas. In winter times these numbers will significantly increase mentioned

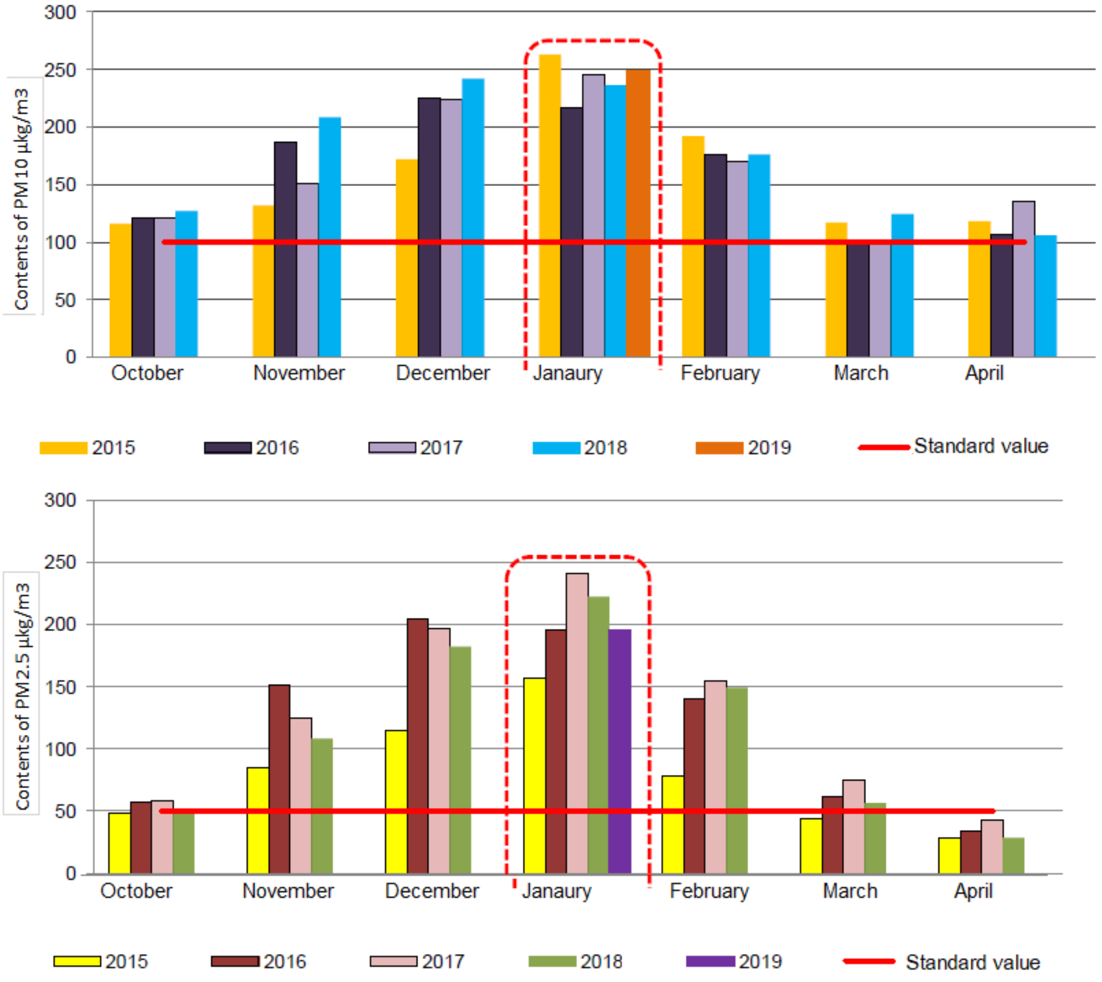


Figure 7: Average content of PM10 and PM2.5

in section 2.2.1.

About 10% of Mongolian air pollution is public and private transportation. Transportation is one of the expanding sectors in Ulaanbaatar with an estimated 15 percent annual growth rate from 2004 to 2018, not include in a private vehicle. Mongolian has 940,327 vehicles and about the 800,000 are the automobiles. Almost 59% of vehicles are registered in Ulaanbaatar. 80% of cars have the same as combined engines but these cars running over the ten years that is why cars are the source of air polluting. These vehicles can create greenhouse gas to the environment as well as produce the particle matters ($PM_{2.5}$).

Category	PM_{10}	$PM_{2.5}$	SO_2	NO_x
Household stoves in Gers	34,664	20,798	6,668	11,124
Kiosks and Food shops	3,683	2,210	614	924
Power plants	52,650	21,060	28,800	62,109
Heat only boilers	31,693	12,677	7,134	10,739
Vehicles	4,931	2,466	2,894	21,450
Fugitive dust – paved roads	4,508	1,127		
Fugitive dust – unpaved roads	14,878	2,976		
Brick industry	8,558	3,423	658	991
Waste – open burning	8,064	6,048		
Waste – hospitals	647	323		
Unknown	12,000	5,000		
Total	**176,276**	**78,108**	**46,769**	**107,337**

Figure 8: Estimation of inventory for Ulaanbaatar in 2020

2.4 Numerical and simulation of bus aerodynamics

Nowadays all many industries and research mainly use the ANSYS simulation because this software problem solver range is wider than other simulation programs. This program also makes analysis and give necessary data to users which can save time and leads to an efficient design. Also, ANSYS CFD (computational fluid dynamics) is used for the same reason as a make aerodynamic simulation. The most critical obstacle toward learning CFD is the fundamental knowledge and high level of expertise in software usage. ANSYS Fluent and ANSYS CFX solvers are used for CFD calculations and CDS post is used for extracting results. The CFD simulation is mainly based on Reynolds-Averaged Navier-Stokes (RANS) turbulence models. Both of the solvers have discretization

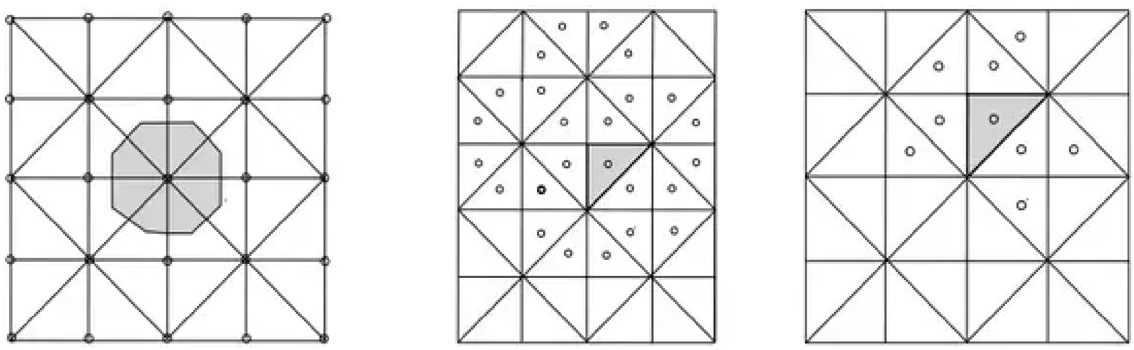


Figure 9: Finite Volume Methods. (7)

Discretization:

In Fluent, the volume of the elements are controlled by volume control which means the number of control volumes is equal to the number of elements (Cell-Centered). But CFX solver has different finite volume methods, it is called the Cell Vertex which volumes of controls are assembled around the nodes and each element are divided into sub volumes. The nodal values of elements can get the flux through each face. Once subdomain contributions evaluated, nodes will be accounting for each sub-volume around itself and the real volume of the control is assembled.

2.4.1 ANSYS Fluent

The Fluent solver is based on the center node FVM discretization technique and attempts both isolated and coupled solution methods. In this solver, there three Euler-Euler multiphase models are accessible for example, the Eulerian model, mixture model and VOF model (7). Also particle tracking model is available.

The discretization technique used for keep the interface sharp in VOF method. The discretization can change the results in other multiphase models as wells on the chosen of methods. Fluent has a number of discretization techniques implemented specifically for the volume fraction equations. Also, some method is available for the dimensional discretization of the other transport equations. To model interphase transfer there is both a number of drag models available along with other transfer mechanisms such as lift force, turbulent dispersion as well as airflow velocity.

This fluent give the three main access to dispersed phases with a two-fluid formulation. In default settings which can be assumed the dispersed has a constant diameter or diameter defined by a user-defined function. With those settings fluent don not considered the phenomena such as fusion and damages. There is also can be added module, Population Balance Model or the Interfacial Area Concentration (IAC). In the discrete method, the size of circulation is divided into a number of size intervals. This process has advantages when the rage of particles size are known in advance, on the other hand, it also has disadvantages which is quite computationally expensive when a large number of intervals is needed. The transport equations are solved for moments of the distribution, and that can be more computationally efficient with the fewer equations are solved in SMM (Standard Method of Moments).

Another method is QMOM (Quadrature Method of Moments), which process is based on the same approach as the SMM but Standard Method of Moment directly solve certain terms. Which means QMOM applicable to wide range of flow cases than SMM. If there is needed a more detailed description of the poly-dispersed, models offered in Fluent can be found in the ANSYS Fluent PBM (Population Balance Model) manually. Several options for modeling the growth, breakage and coalescence terms in the PBE are also available in the PBM module.

2.4.2 ANSYS CFX

The ANSYS CFX is the one the high-performance CFD There is only the two solvers are used for discretization based on FVM approach and implemented. There are two main fundamental models are available, homogeneous and an inhomogeneous model (7). The homogeneous is correlate with the VOF model. The inhomogeneous model is based on the Euler-Euler approach and can be used together with several sub-models to model dispersed flow and mixtures of no discrete fluid flows.

In ANSYS CFX, all transport equations which include the volume fraction equation are allowed to discretization methods also blending scheme and higher resolution schemes are accepted in first-order scheme related to types of phases, for an example continuous or dispersed fluid. There is also one model is useful for CFX which is called MUSTIG (Multiple Size Group). This model solves the problem based on the PBE which can describe changes in the disperse phase, in addition to the usual mass, momentum and energy equations.

ANSYS CFX uses an elements-based finite volume method, which first connects discretizing the dimensional domain using a mesh. The mesh is used to build up finite volumes, which are used for solve some problems such as mass, momentum and energy. All solutions variables and fluid properties are stored at the nodes. Each mesh node can control the mesh volume using the median dual ("defined by lines joining the centers of the edges and element centers surrounding the node"(8)).

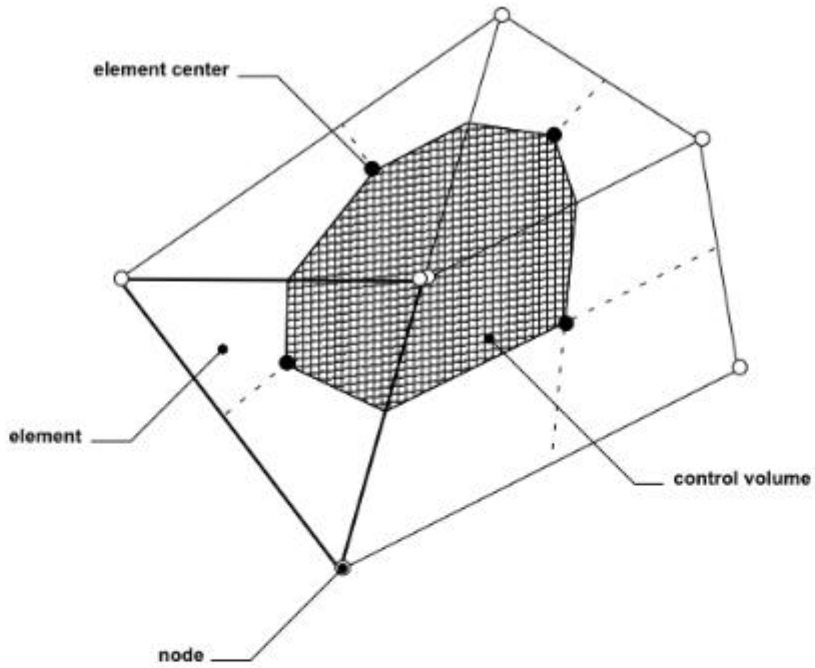


Figure 10: Definition of volume control

2.4.3 Total Pressure

The total pressure, $P_{total,}$ is decided as the pressure that would exist at a point if the fluid is brought spontaneously to rest such that the dynamic energy of the flow converted to pressure without losses. The conclusion Pressure and Total Pressure are absolute quantities and must be used to derive the Total Pressure when using an equation of state formulation(9).

Liquids and low-speed gas flow are related to the incompressible fluid pressure which is defined by Bernoulli's equations (8):

$$p_{tot} = p_{stat} + \frac{1}{2}\rho(U \cdot U)$$

Which is the sum of the static and dynamic pressures. When the flow is compressible, the total pressure is computed by starting with the second law of thermodynamics assuming that fluid state variations are locally isentropic.

$$dh = \frac{dp}{p}$$

dh -solved by constitutive relation and other side of parameter calculate by equation of state. For an ideal gas, combined with the constitutive relation and an equation of state are:

$$dh = c_p(T)dT$$

$$\rho = \frac{p}{RT}$$

Within this equation, all things substituted into the second law an assuming no entropy variations

$$p_{tot}{=}p_{stat}\exp(\frac{1}{R}\int_{T_{stat}}^{T_{tot}} \frac{c_p(T)}{T} dT)$$

Where T_{stat} and T_{tot} are the static and total temperatures respectively.

c_p- Specific heat capacity

Static pressure, CFX solves for relative static pressure in the flow field and it is related to Absolute Pressure.

$$P_{stat}$$

$$P_{abs} = P_{stat} + P_{ref}$$

Also, there is a Static temperature, T_{stat} is the thermodynamic temperature depends on the internal energy of the fluid. In ANSYS CFX, depending on the heat transfer model you select, also solver can estimate the either total or static enthalpy. The static temperature is calculated using enthalpy and constitutive relationship for the material under consideration (10).

Total temperature is derived from the concept of total enthalpy and is figured out the same way as static temperature, it is not including that total enthalpy is used in the property relationships.

Incompressible flow, the total pressure is defined as:

$$P_{tot} = P_{stat} + \frac{1}{2}\rho(U_{rel} \cdot U_{rel} - (\omega \times R \cdot \omega \times R))$$

2.4.4 Elements

The nodes and elements are the important part of finite element model. Before the meshing, the element types must be defined. The ANSYS contains more than 100 different element types in its element library. The elements that are available in ANSYS can be sorted in compliance with many different criteria, such as dimensionality, analysis discipline, and material behavior. ANSYS classifies the elements in 23 different groups(11). For example, the elements from four of these groups- specifically, structural, thermal, fluid and FLOTRAN CFD.

Structural: For this group of elements, the degrees of freedom (DOF) at the nodes are displacements. The structural analysis employs plane, link, beam, and pipe, solid and shell elements. All of the elements contains several element types with different degree of freedom.

Thermal: This class of the elements, the node with the degrees of freedom can represent the temperature. This thermal groups can working with the links to solids and shell subgroups. The structural discipline can explain the type of the groups and classified from the considerations. There are two thermal elements are used in this group, 3-D thermal and 2-D thermal.

Fluid: Groups of the elements are depending on the degrees of freedom appear as a pair, velocity-pressure or pressure-temperature, at the nodes. This groups are working on the two and three dimensional acoustic, thermal- fluid coupled pipe, and contained- flied types of elements.

FLOTRAN CFD: This kind of groups of elements working principle is similar to the previous one, except it is based on the method of computational finite difference.

2.4.5 Modeling and Meshing

The 3-D model of the physical system is transferred to the solid model. In model generation with ANSYS, the main principle is to design a finite element mesh of physical methods. There are two main tracks in ANSYS to generate the nodes and elements of the mesh: (1) direct generation and (2) solid modeling and meshing.

Indirect generation, all single nodes created by inputting their coordinates followed by comparison of the elements through the necessary information. In the Engineering problems need high number of nodes and elements for solving the problem, for that case direct generation is not possible to use.

Solid modeling includes the designed geometrical bodies, such as lines, areas, or volumes that shows the real geometry of the problem. They also can be meshed by ANSYS automatically. A solid model can be created by using either entities or primitives. The entities mention the key points, lines, areas, and volumes. But primitives are based on the geometrical shapes.

Each entity can be formed by using the lower ones and it can be automatically related with its lower entities. When entities are create by key points and moving up, approach is mentioned to as bottom-up solid modeling. On the other hand primitives are used, lower order key point, lines, and areas are automatically generated by ANSYS. Boolean or similar process can be applied to the primitives to generate the complex geometries.

The mesh Solid Modelling use the finite element analysis. Therefore, the main function of the Solid Modeling is create the mesh of the geometry, precise and qualified as possible. Mesh analysis is always made after finishing the Solid Modeling also the meshing can be pre-shaped only after the specification of element types. ANSYS has several options to assist in meshing. These includes Smart Sizing, and Mapped Meshing.

Mapped Meshing:

Mapped meshing is the one of the wide used meshing methods in ANSYS. This method used for only in two and three-dimensional problems (no line elements). The two and three-dimensional models meshed with the quadrilateral are elements or hexahedral volume elements.

The mapping mesh can generates regular and computationally well behaving. But every area and/or volume cannot be mapped meshing. The all volume and area must be regular in mapped meshing. This regularity is controlled by two properties of the solid modelling: the number of sides, lines and volume areas and number of division on opposite sides which can be an equal to the number of divisions. Which means if the area three sides it can be considered by 3lines, then the number of divisions in all three lines must be equal and even. Also it is same as 4 lines defined by the area, the opposite sides have to same number of divisions. This idea same as for mapped meshing of volumes. The volume of the areas are similar to the volume of the tetrahedron (4), prism (5), or hexahedrons (6). Following steps can create mapped meshing in ANSYS:

Main Menu > Preprocessor > Meshing > Mesh > Areas > Mapped > 3 or 4 sided
Main Menu > Preprocessor > Meshing > Mesh > Volumes > Mapped > 4to 6 sided

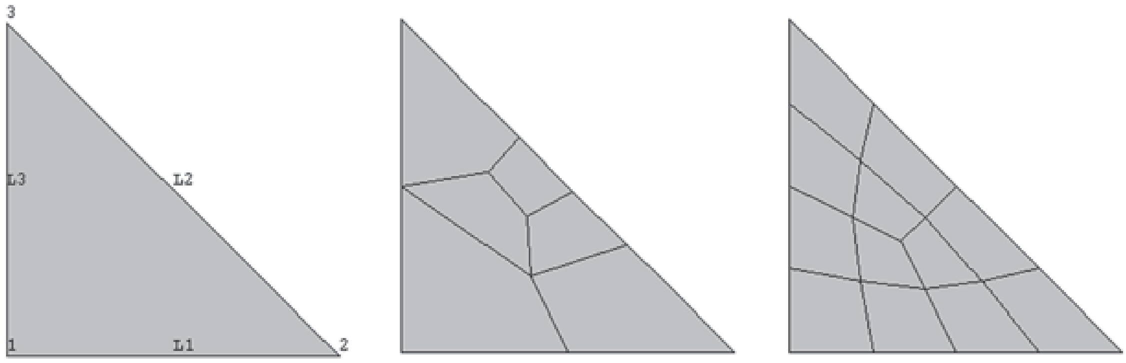


Figure 11: Triangular area (left) and corresponding free (middle) and mapped (right meshes) (11)

From the Figure 11 that the mapped mesh delivers elements with controlled and desirable aspect ratios. When the number of the volume or areas is not match to the side numbers that given above, that is maybe still be a way to mapped mesh these entities.

Chapter 3 Airflow Simulation of Bus

Airflow simulation was conducted by ANSYS software which has 17 analysis systems. In this thesis, only 2 solvers were used for making the aerodynamic simulation. Three dimensional and model of the bus was built using AutoCAD drawing program. Subchapters will bring the main process of simulation, comparison simulation of different design and results.

3.1 Numerical simulation process

In this section, analysis of an object from an initial model to observe the aerodynamic drag and turbulent flow through small changes in the design. This ANSYS simulation program help for making the product ensures that promise, with every products and every order. This test consists of the design of the bus in computer-aided CAD and meshing with CFD analysis using the ANSYS CFX. ANSYS CFD simulation software creates simulation computer models of structure, electronic, or machine components to simulate strength, toughness, elasticity, temperature distribution,

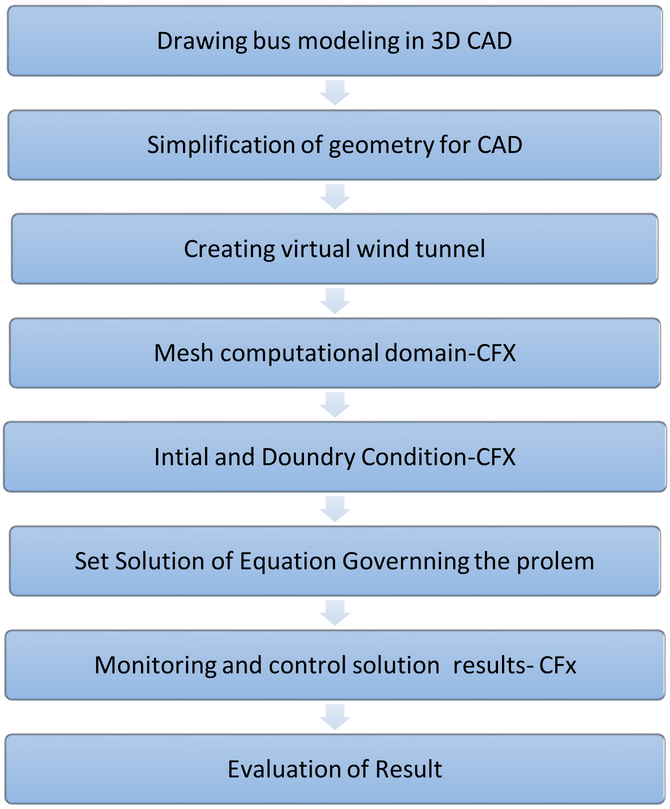


Figure 12: Methodology

electromagnetism, fluid flow, and other attributes(10). Most simulations are achieved using the ANSYS Workbench. This Workbench can break down larger structures into small components that are each modeled and proved independently. AutoCAD is one of the technical drawing software and many engineers use CAD programming for 3D modeling. Also, that testing techniques use the 2 different system which is CFD techniques or wind tunnel testing. This study is followed by the CFD methodology (Figure 12).

3.2 Geometric Model

Daewoo BS 106 (Figure 13) is selected in this thesis which is produced in Korean. This bus is used in many countries for service and public transport also Daewoo BS 106 poplar in Ulaanbaatar. This object was used to carry out the CFD and aerodynamic parameters such as airflow around the bus, pressure and velocity distribution around the bus.

Figure 13: Daewoo BS 106

3-D model of bus was modeled on Computer aided design (CAD) software with the actual measurement Table 2.More standard specification attached on appendix. Bus is modeled in with specification, which means bus drawn by any without any detail things for example there is no mirror, no ventilation system case on the bus and down parts of bus. Because there is limitation to drawing detail things on the AutoCAD and airflow couldn’t influenced by this small parts.

AutoCAD can creating products such as Architecture, electrical drawing as wells as AutoCAD Civil 3D. The AutoCAD is limited by number of file such as .DMG and .DXF which is hard to export and import. This creates the problems when using other programs

Performance	
Max Speed	Non-city: 102km/h City: 86km/h
Grade ability (tanα)	Non-city: 0.37 City: 0.29
Min Turning Radius	9.9m

Weight (kg)	
Permissible G.V.W	16500
Curb Weight	9015
G.V.W	Inter-City : 12005 City :15775

Internal Dimension (mm)	
Inside Length	9908
Inside Width	2380
Inside Height	1970

External Dimensions (mm)	
Overall Length	10410
Overall Width	2490
Overall Height	3225
Wheel Base	5200
Body Overhang (Front)	2100
Body Overhang (Rear)	3110
Tread (Front)	2050
Tread (Rear)	1853

Table 2: Bus dimensions

And exporting the program to an AutoCAD format- geometry, color and effects are most often. So that 3D modeling is converted ".DMG" to ".SAT" format, ANSYS Design can read the few format then ".sat" file is one of theme. This format can be used in the CFD software to analyze shape of the vehicle for the analysis.

3.3 3-D modelling and Meshing

3-D model of the measured exemplary was created in AutoCAD 2019 and ANSYS 2019 Design modeling (Figure 14).The geometry has been simplified in any parts where the shape will not affected the results of the analysis. The fluid domain of 1000 mm x 1000mm x 1000mm was created around the bus. ANSYS workbench 2019 R1 and ANSYS CFX operating system appliance were used to generate the mesh also solve the fluid dynamic problems. ANSYS CFX is a high performance computational fluid dynamic (CFD) software tool that delivers reliable, accurate solution for wide range of CFD and multi physical application quickly.

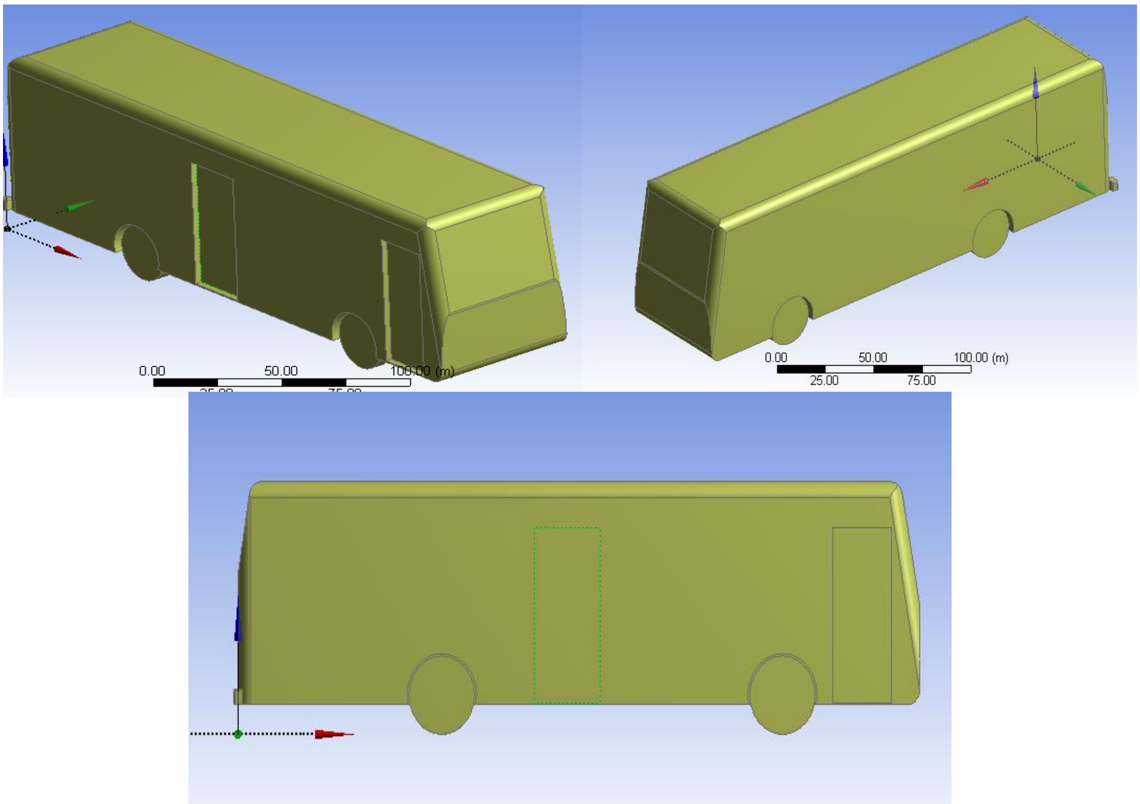


Figure 14: 3-D modeling with simplified

Automatic Meshing

ANSYS has automatic mesh generation as a mentioned in section 24..5 which is one of the most powerful features. ANSYS meshes the 3D model can independent existence upon execution of a "convenient" command. With automatic meshing, user can administer specific linking for mesh density and shape. If there is no links are selected by the user, ANSYS used the default process. The following menu path are used for automatic mesh generation after 3D model generation.

Mesh using Area Elements

This preference is used for model utilizing 2-D elements, and its need existing area. The steps shows the making the mesh areas:

Main Menu>Preprocessor>Meshing>Mesh>Areas>Mapped

Main Menu>Preprocessor>Meshing>Mesh>Areas>Free

Auto Meshing can be adapted by the Mapped or Free Meshing methods. If free meshing is chosen, the second option is necessary, bringing up a Pick Menu asking the user to either enter the area number through the text field or pick area from the Graphic Window.

Mesh using volume Elements

Also ANSYS meshing the based on the volume elements which is used for models using 3D elements, and it needs existing volumes. The option is almost same as, meshing using area elements but just change the mesh to volume.

Main Menu>Preprocessor>Meshing>Mesh>Volume>Mapped

Main Menu>Preprocessor>Meshing>Mesh>Volume>Free

It is possible to control the mesh density of the domains defined by 3-D model operation in ANSYS. The needed mesh density can be carried out by:

- Defining a target element edge size on the domain boundaries.
- Defining a default number of element edges on all lines.
- Defining the number of element edges on specific lines.
- Using smart sizing.
- Using mapped meshing.

The surface mesh is created by the ANSYS CFX solver. That airflow simulation solver provides complete mesh flexibility and supported mesh types includes triangular, quadrilateral, tetrahedral, pyramid, and prism (edge). AutoCAD geometry is allowed to ANSYS Workbench with the converted format. ANSYS design modeler and mesh it automatically or manually with the ANSYS Mesh component. The mesh calculating domain is designed to free block boundaries which is consists of an inlet, outlet, bus and free slip wall. The domain range was depend on dimension of bus and this mash created on geometry of bus as well as on the surface of the domain.

The mesh is created on the surface of domain and design of the bus (Figure 15). In that study surface bodies had as base format for triangular mesh (Figure 16). Other parameters are kept default for finish the process Table 3.

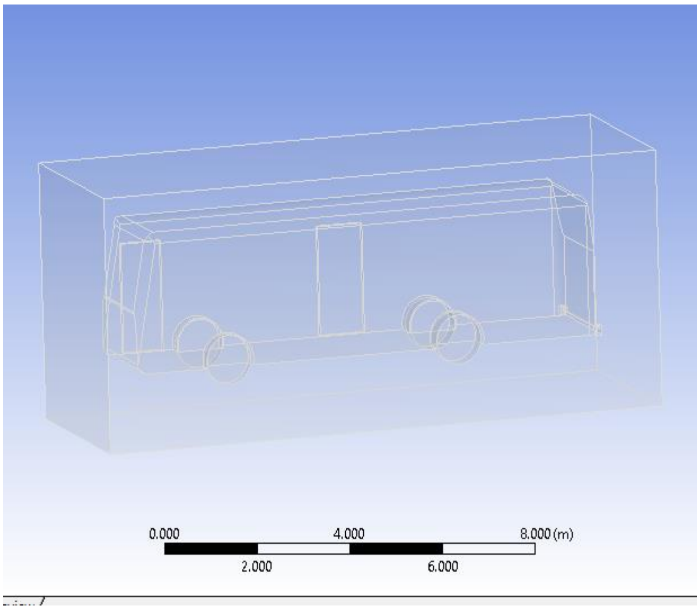


Figure 15: Inside enclosures

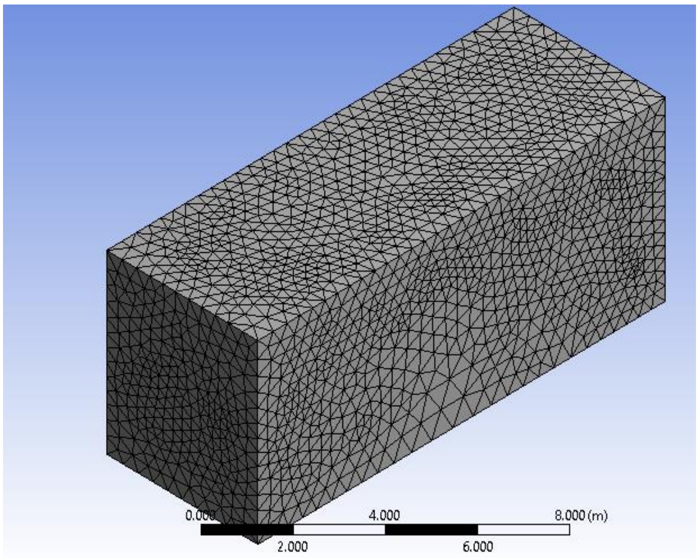


Figure 16: Mesh Model Scheme

Mesh size could create by medium and fine relevance also fine mesh size relevance would give a better result than coarse. In this analysis maximum mesh size was 1.43 m which coarse mesh was used for meshing because of the limited number of elements mesh in the mesh.

CFX-Pre is largely determined by the primitive regions import with the mesh. During the importing ANSYS mesh files (.cmdb/ .dsdb files), it is can select Detection

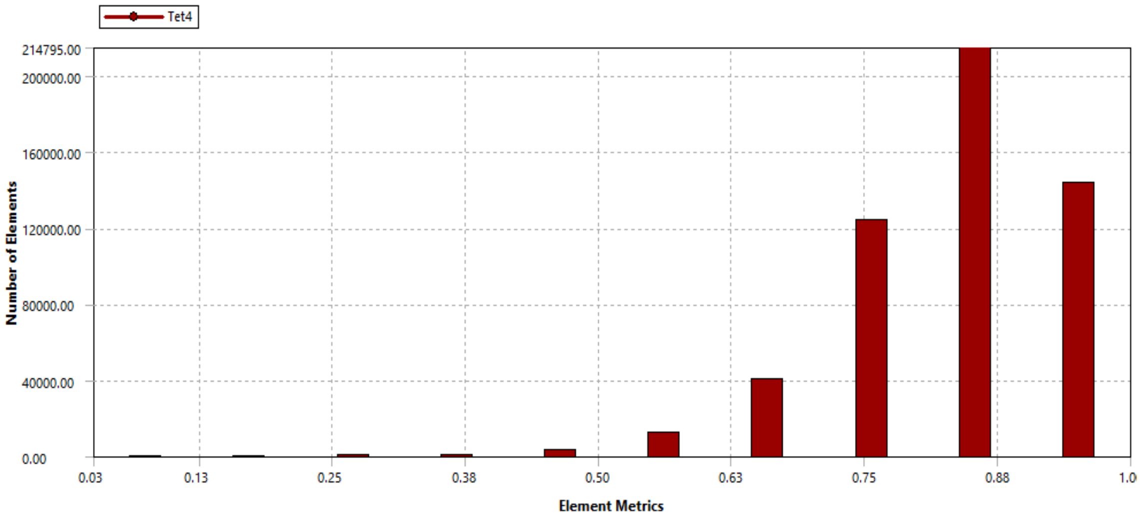


Figure 17: Number of mesh elements

Method>Read to read contact information from the file. CFX-Pre uses the mechanical application unity detection methods to calculate which mesh volume should be placed within each mesh assembly and which 2D regions are connected. 99867 nodes and 540392 (Figure 17) elements are used for making accurate calculation.

Sizing	
Use Adaptive Sizing	No
Growth Rate	1.2
Max Size	1.43 m
Mesh DE featuring	Yes
DE feature Size	3.575e-003 m
Capture Curvature	Yes
Curvature Min Size	7.15e-003 m
Curvature Normal Angle	18.0°
Capture Proximity	No
Bounding Box Diagonal	14.3 m
Average Surface Area	5.5804 m²
Minimum Edge Length	4.5255e-003 m

Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Meshes	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Default (6.435e-003 m)
Generate Pinch on Refresh	No

Statistics	
Nodes	99867
Elements	540392

Table 3: Parameters for meshing

There is some limitation with the making meshing

- Mesh adjustment is limited to apportion 2^31-1 1 words of 4 byte integer stack space; this limits the maximum problem size for mesh adaption to approximately 80 million elements (structured) and 200 million elements (unstructured)
- Mesh adaption can't be used in multi-domain simulations or in cases with domain interfaces, elapsed time control, or external solver coupling. Also transient is cannot used for mesh adaption,
- The quality of existing mesh can't improve by methods
- The mesh may not be coarsened such that original mesh elements are combined.
- The method used is not well-suited to meshes with many high-aspect ratio elements, because it can only refine elements in an isotropic manner.
- Mesh process can't stop during the process.

3.4 Parameters of simulation and solutions

This study was carried out in wind bellowing to front of bus. In this simulation only straight wind condition was considered at 11.5 m/s. Which means inlet speed is replaced by constant wind speed conditions. There is no gauge pressure applied at the outlet conditions. And other parameters used in making analysis are listed in Table 4. This all units measured by SI system (m, kg, N, s, V, A and Degrees rad/s).

Boundary	Boundary conditions	Values
Inlet	Constant velocity	V = 11.5 m/s
Outlet	Average Static Pressure	P = 0 Pa
Wall	Free slip wall	V = 0 m/s
Bus Body	No slip wall	-

Table 4: Parameters of simulation

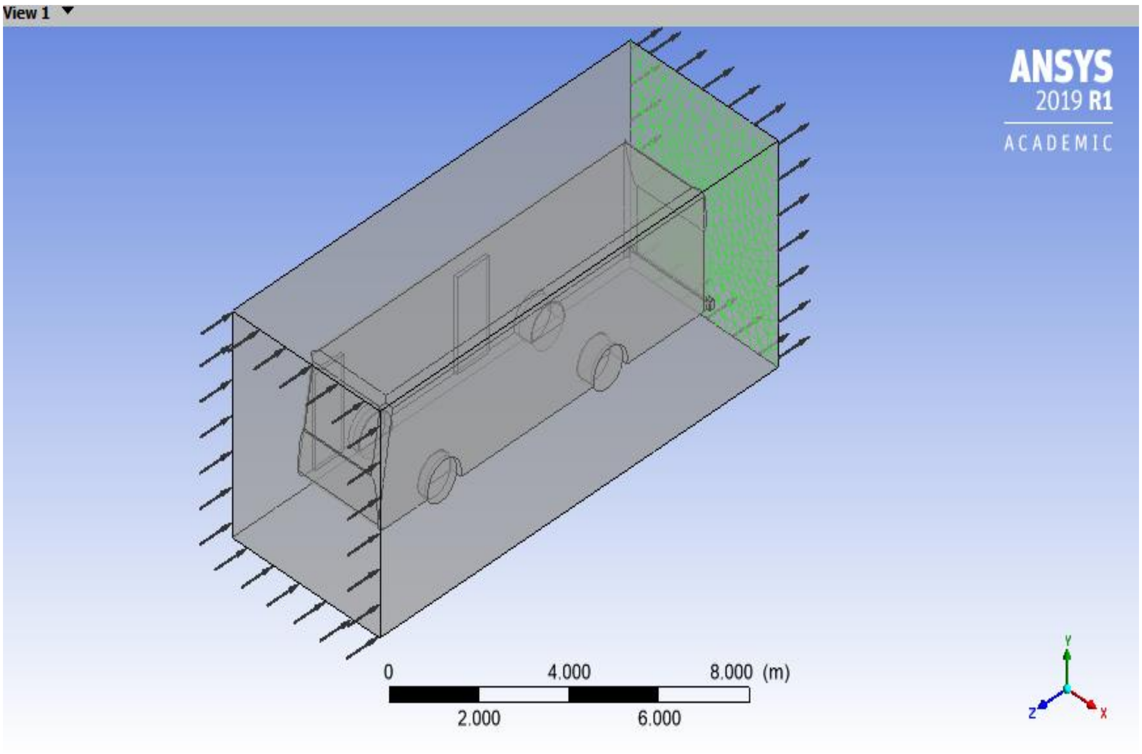


Figure 18 : Domain

The flow chart shown below illustrates the general field solution process used in the CFX solver Figure 18. There two numerically intensive operations are working on the field equations.

1. “Coefficient Generation: The nonlinear equations are linearized and assembled into the solution matrix.
2. Equation solution: The linear equations are solved using an Algebraic Multigrain method” (9).

During the calculation process, iteration is monitored by the physical time scale or time step for steady and ephemeral analyses, respectively. There is only inside (linearization) of iteration is completed per outside of iteration in steady-state analyses, although inner iterations are finished per time step in short-term analyses.

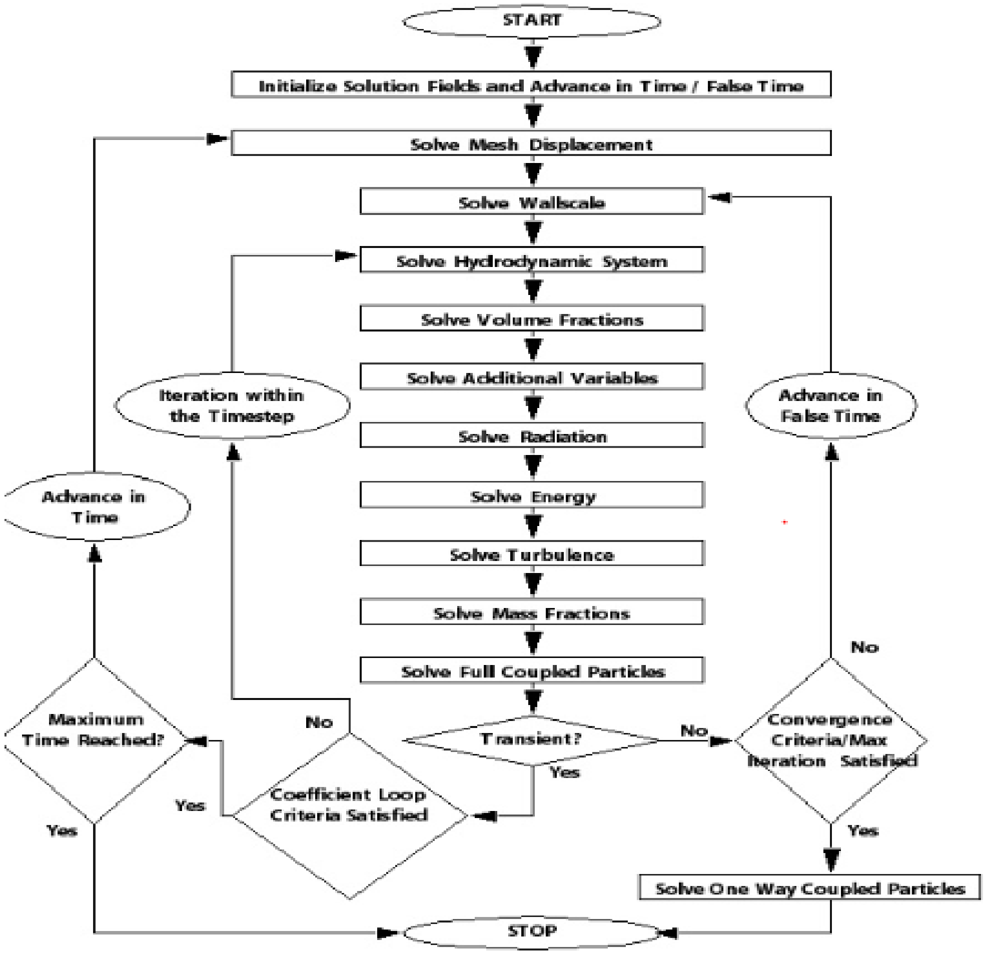


Figure 19: Iterations process

3.5 Results and discussion of the simulation.

In this section, velocity vectors, airflow path lines and pressure distributions results are analyzed. A model evaluation of change in velocity direction due to the turbulent flow is also explained in this section. Figure 20 show the pressure distribution on the bus surface also front of the bus windshield and cowl affected by high pressure. Corn of the windshield is more less pressure acting.

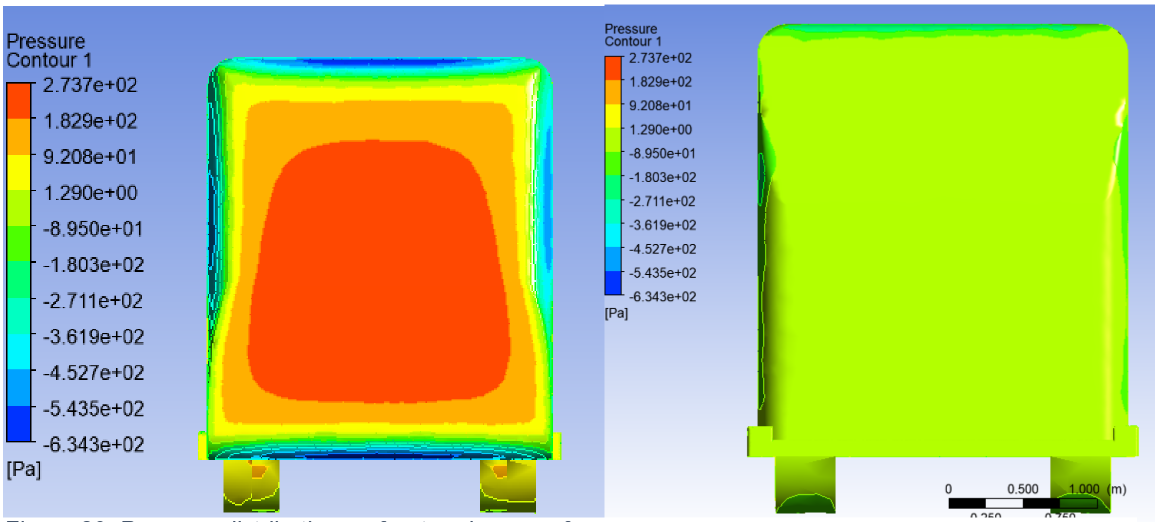


Figure 20: Pressure distribution on front and rear surface

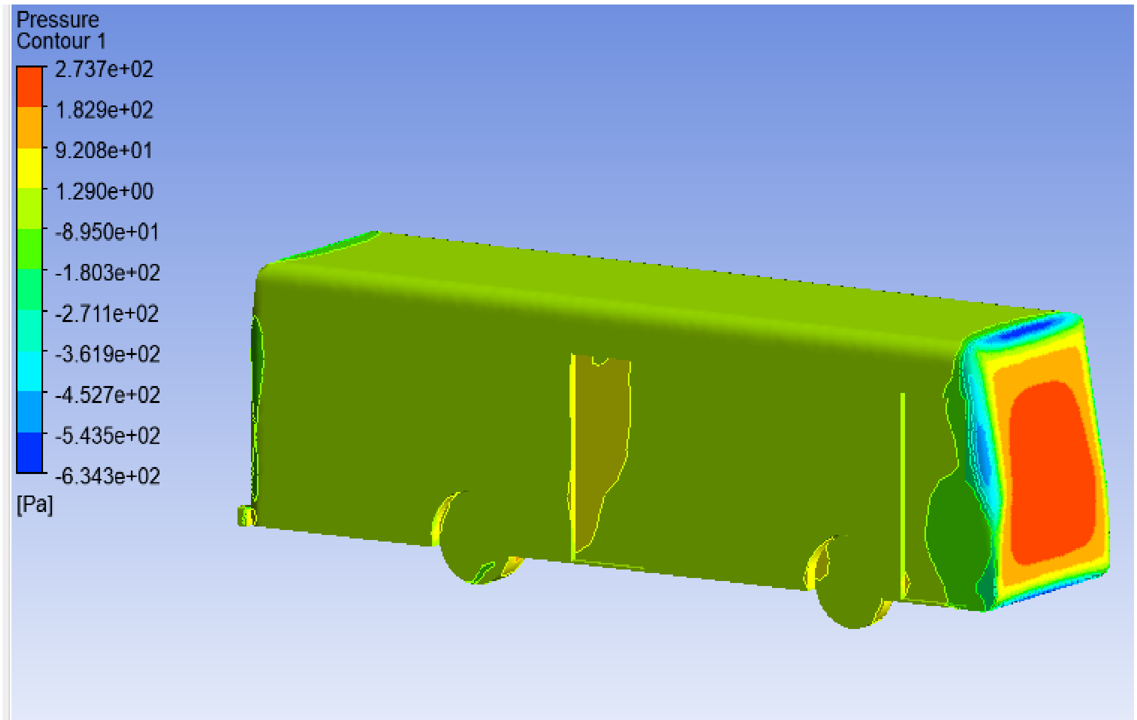


Figure 21: Pressure distribution on 3D

The velocity field affected by difference between the frontal and rear (Figure 19) pressure distribution on this two surface. Also this difference could change the pressure.

As expected, velocity streamline (Figure 22) create the low pressure behind the bus body which is turbulent flow speed is lower than air speed around the bus which creates the vortices. This vortices are created in the weak zone in behind the bus, there is two main vortices have nearly equal size (Figure 23).

So that motor should attached on back of the bus which can help for collecting dust from the air because much vortex is created back of the bus when bus is moving. In the back of the bus, turbulent flows are created opposite direction which can support for motor sucking the air with the less power.

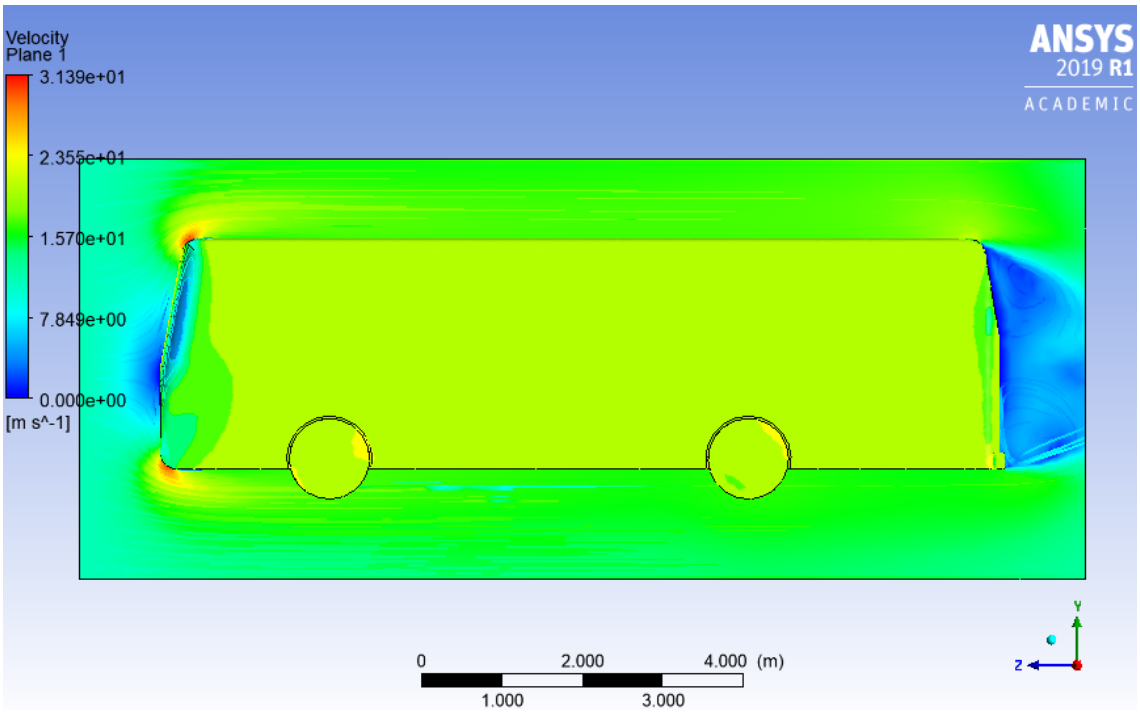


Figure 22: Airflow velocity

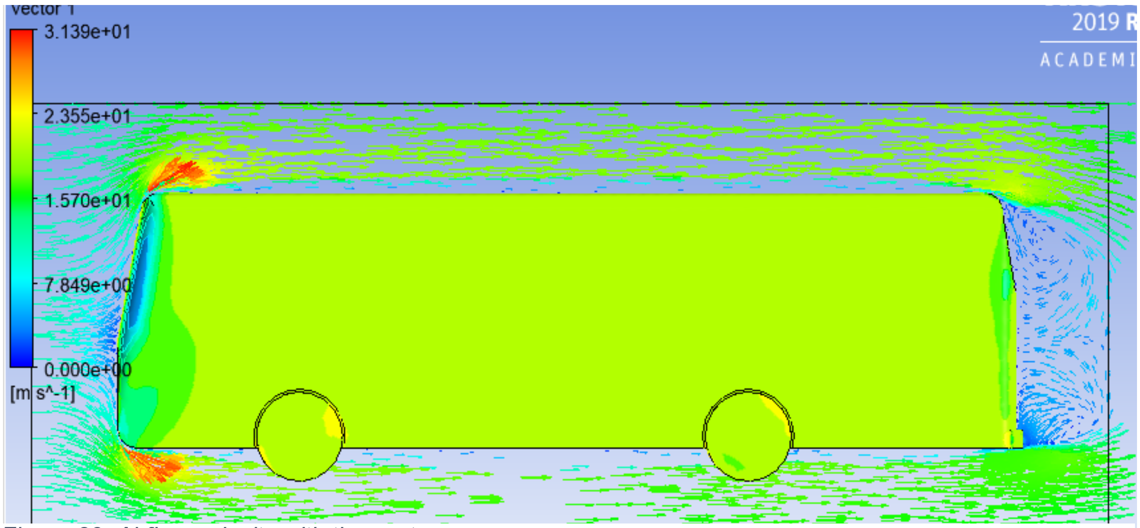


Figure 23: Airflow velocity with the vector

Chapter 4 Design and Performance of Filter

This chapter cover the all calculations based on the various formulas and design optimization has to be made on the current motor power of sucking and inlet airflow. Within that motor we sucked up dust from the air.

4.1 Calculation of motor power and work efficiency

This motor is working with 24v because bus can't produce more power than 24v. Which means if motor is chosen with the higher than limit the motor wouldn't work on the other hand this motor can broke if given power much higher than motor's regulation power. Based on that value motor power calculate with the formula. The consumed electrical power of the motor is defined by the following formula

$$P_{in} = I \times V$$

P_{in} - Input power, measured in watts (W)

I - Current, measured in amperes (A)

V- Applied voltage, measured in volts (V)

Motor supposed to do some work and two important values how powerful the motor is. It is motor speed and torque, the turning force of the motor. Output mechanical power of the motor could be calculated by using the following formula:

$$P_{out} = \tau \times \omega$$

Where P_{out}- Output power, measured in watts (W)

τ- Torque, measured in Newton meters (N*m)

ω- Angular speed, measured in radians per second (rad/s)

Also in this study rotational speed is already given so it is easy to calculate the angular speed.

$$\omega = \frac{rpm \times 2\pi}{60}$$

So ω- Angular speed, measured in radians per second (rad/s)

rpm- rotational speed in revolutions per minute

Therefore, efficiency of the motor is calculated as mechanical output power divided by electrical input power.

$$e = \frac{P_{out}}{P_{in}}$$

Thus this equation can extended:

$$e = \frac{\tau \times \omega}{I \times V} = \frac{\tau \times rpm \times 2\pi}{I \times V \times 60}$$

e- Efficiency of the motor.

Specification of motor	
Size	350mm
Current	12.5 A
Static Pressure	100 PA
Warranty	13 Months
Specification	38*34*53
Voltage	24 V
Speed	3900/Rpm
Air Volume	1000m3/h

Table 5: Specification of motor

4.2 Design of air filter and filter case

4.2.1 Activated carbon filter

In this study, activated carbon air filter used for cleaning the air as attached on the bus. Which is carbon air filter is activated by additional processing to make it good at for trapping gas molecule. First, it is implanted with hot air, carbon dioxide, or steam, which creates a lattice of tiny pores in the carbon and increasing its surface area. This produce the more places for molecules to become cached and makes the carbon far more effective as a filter medium. A paper by the Ohio Environmental Protection Agency notes that a single gram of simulated carbon can have hundreds of square meters of internal surface area.

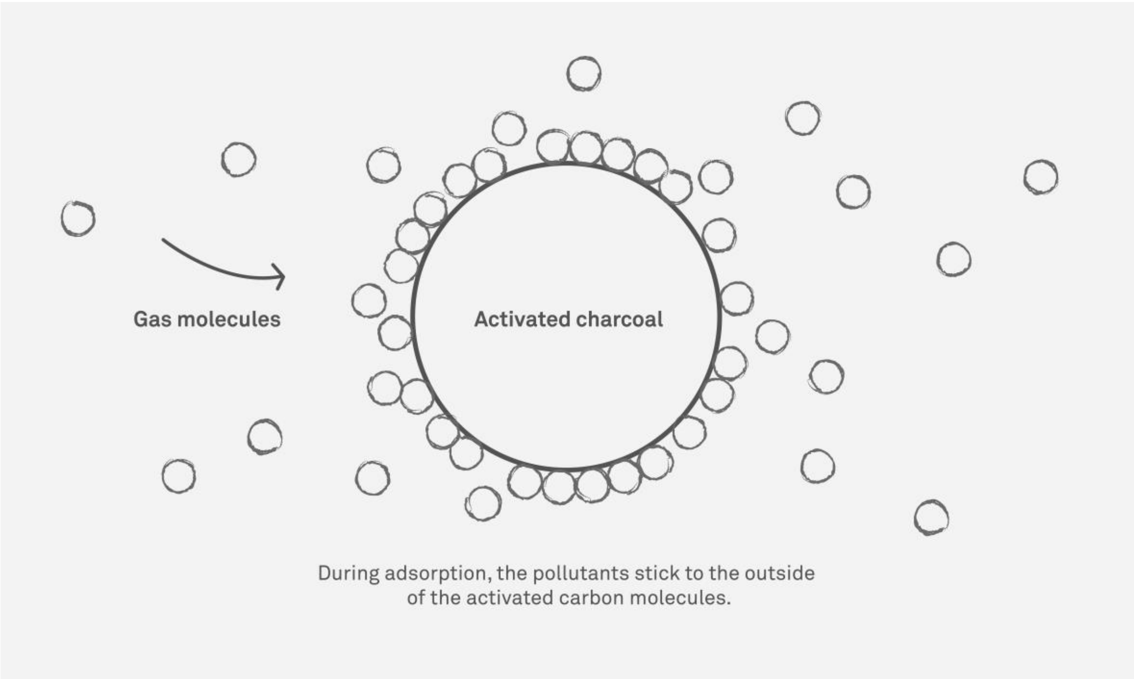


Figure 24: Activated charcoal (11)

Activated carbon air filters uses adsorptions process for removing pollutants from the air. Note that this is different from absorption (12). Absorption process is used for removing the liquid properties which means it doesn’t become a part of the absorbent on a molecular level a like a water for example when you absorb water with a sponge, the water does not become chemically bonded to the sponge. It is just fills in the spaces inside it.

4.2.2 Filter case

Filter case (Figure 25) location is designed by ANSYS CFX simulation result. Thus, best way to attached filter location was backside of the bus with the motor. Outside of the air is filtered out with the filter and motor. According to a result of simulation, there back side of the bus because velocity of stem line is lower than the other side which there is need motors for sucking the air. Before the attaching the filter, filter case should designed based on the motor size and limitation size of the bus hollow in back of the bus within AutoCAD software.

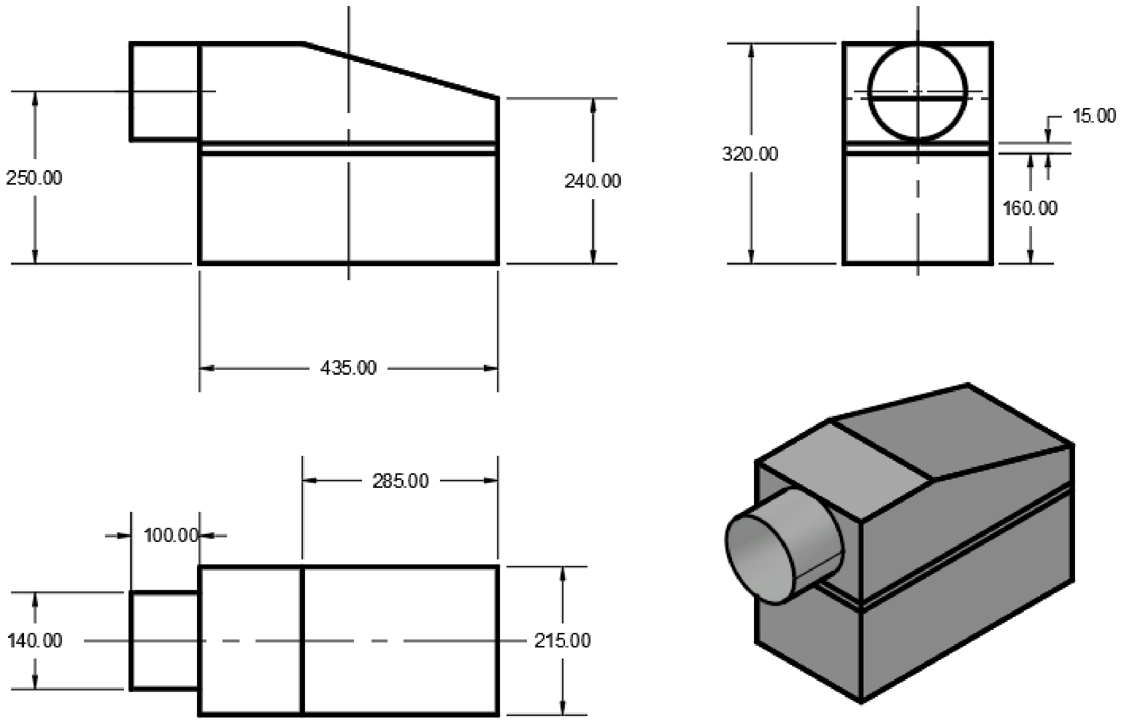


Figure 25: Filter case

Motor is located in bottom of the filter case and behind filter which is directly connected to the generator of the bus. Therefore, the motor will only operate when bus engine operates. Size of the filter case is limited by the space of bus in a back side.

Figure 26: Current filter case

4.3 Fabrication and Installation of Air Filter Prototype

Activated carbon filter is located inside of the filter case with the motor. And motor is attached inside of the filter case (Figure 27) which is connected to the bus battery and motor revolution is transferred into fan. As mentioned in the section 4.2, the working hour

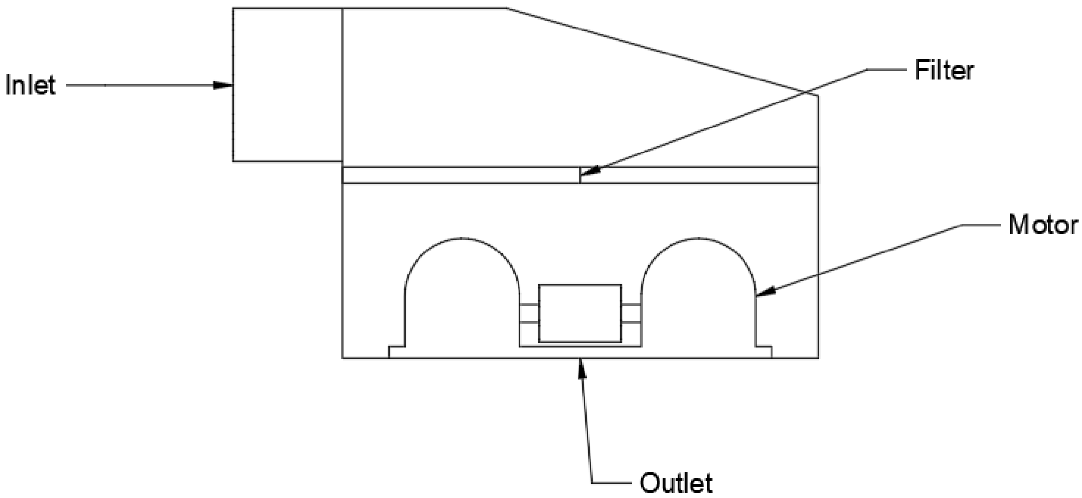


Figure 27: Scheme of filter case

of the motor depends on the operating time of the bus. Urban transportation service starts at 06:30Am to 22:30 PM along through approved routes and schedules. Therefore, motor could run the whole day. Air comes from the inlet of filter case sucked by motor Figure 29. More installation process show on the appendix A.

Figure 28: Motor

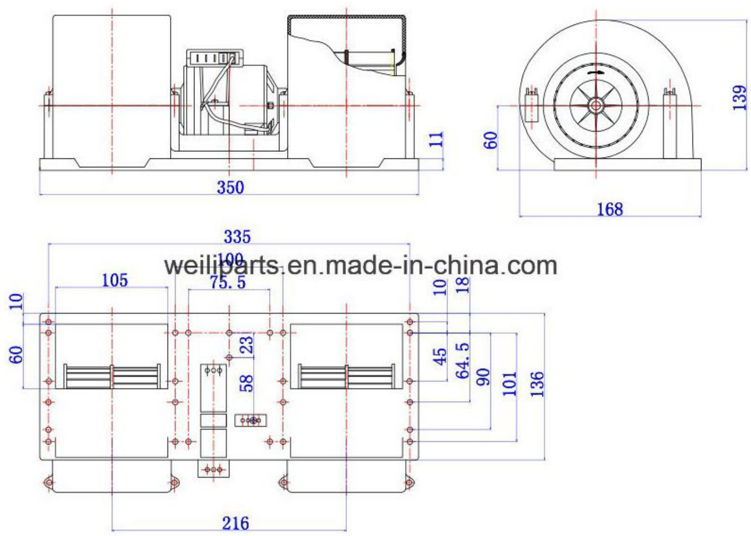


Figure 29: Scheme of the motor

4.4 Performance of filter

In this investigation, the chosen bus travels around the Ulaanbaatar's specific areas (Orbit to Ard bus station).This dust is collected in two different places and each process duration was one weeks with the working hour of bus. First process was dust are collected from the inside of motor section dusts. Another case was airborne is sampled from the back side of the bus, motor is connected with the hood. Activated filter shape was square (21.59x21.59 cm) and there are two filter are placed parallel in inside of the filter face. There is two filters was used for filtering the air for one week thus, in this study 4 filters are used for filtering the dust from the air.

Original filter weight was 135.6g and 138.09g. And first week the filter weight is increased to 153.22g and 150.99g respectfully. In the second week, this number was higher than the first week which was 216.88g and 182.69g. Thus, 30g of dust was collected in first week where the filter is attached beside of the engine. Then next week, inlet of filter case is changed to the outside of the bus as result was increased to 125g. After the collecting data, performance of the filter is calculated following steps:

	Original weight,(g)	First week with the dust, g	Second week with the dust, g
Filter one	135.96	153.22	216.88
Filter two	138.09	150.99	182.69
Overall PM2.5 weight		30	125

Table 6: Collected sample weight

$$V_{air,total=} capacity\ of\ the\ motor(m^3/h) * T_{total};$$

$$V_{air,total=} 1000\, m^3/h * 12 * 15.5 = 186{,}000 m^3;$$

$$Performance\ of\ the\ filter = \frac{W_{total}}{V_{air\ total}};$$

$$Performance\ of\ the\ filter = \frac{155g}{186{,}000 m^3} = \mathbf{833\ \mu g/m^3};$$

W_{total}- Weight of the collected PM2.5; g

$V_{air\ total}$- Overall air volume; m^3

T_{total}- working hour of motor, hour

4.5 Test Results.

Carbone activated air filters' performance is calculated in section (4.4).The bus running around the urban area with 31km per roaster. The bus operates 15 hours a day, for 6 days per week. In this study, dust is collected in only two weeks with the different inlet of the air Figure 27. Therefore, table 5 shows the different weight of the collected PM2.5 in each week.

First week, beside of the engine filter was collecting only 30g of PM2.5 from the air but on the other hand in second week, 125g of PM2.5 is collected on the filter. Which shows the outside of the air contains much PM 2.5 than inside of the motor section. Back side of the PM2.5 can be collected with the motor because the backside of the bus is create the vortex flow, because of behind the bus airflow velocity and pressures are much lower than other surface. So, it is not effective to collect the dust with own wind speed that is why, motor is attached on the bus for increasing the efficiency of the collecting dust.

In the second week, much higher PM2.5 is collected on the filter and the motor is working just one week with an operating hour. If working hour is extend more than one weeks, the efficiency of the air filter also increases. Also this filter is attached only one bus but there is, so many public transport operating on the Ulaanbaatar's urban areas. Which means, if filter is attached on the 70-80% of the all public transports within motor. It could be helpful for the research related to the analyses the air content of the particulate matters (PM_{10} and $PM_{2.5}$).

Chapter 5 Conclusion and Future Research

The background of the research was collecting the dust (PM_{10} and $PM_{2.5}$) analysis the air content of $PM_{2.5}$ and find a way to reduce the amount of the road dust using air filter which can be attached on public bus. Moreover, sources of the air pollution, 3-d modeling, airflow simulation, design of air filter prototype, efficiency of the motor, and filter characteristic have been studied.

The bus was modeled in 3-D using the AutoCAD software with the realistic measurements. Airflow simulation was implemented using ANSYS CFD software, as a result some of possible positions were selected. Initial parameters for the simulation configuration were applied from various sources available on the markets. However, ANSYS had some limitation because ANSYS student version is used for this thesis but it will not affect much on the simulation results as it is investigating airflow simulation.

Air filter prototype and motor installation work was conducted by the author and needed a little support from a few technicians. During the installation, motor was selected whose capacity was $1000m^3/h$. It was should be not a big motor because there was limitation of space for attaching the air filter case on back side of the bus. For that reason, filter case was limited and also filter size and motor sizes were selected according to the space limitation. Another restrictive condition was voltage of the motor. The moto with the input voltage of 24 voltage should be selected, because the bus generator can produce only 24 voltage.

The collected road dust by current filter prototype should be cleaned automatically or at least easily. Also, an air filter without any electric power should be designed relieve the owners of bus companies. They were concerned about that the air filter prototype using electric power might damage their bus engine, so they were reluctant to install the air filter prototype on their bus

Reference

1. Development Bank A. Urban Transport Development Investment Program (RRP MON 39256). 2011; Available from: https://www.adb.org/sites/default/files/linked-documents/39256-023-mon-ssa.pdf

2. Mongolia’s air polution crisis. 2018;

3. Guttikunda S. Urban Air Pollution Analysis for Ulaanbaatar, Mongolia. Ssrn. 2008;(June).

4. Allen RW, Gombojav E, Barkhasragchaa B, Byambaa T, Lkhasuren O, Amram O, et al. An assessment of air pollution and its attributable mortality in Ulaanbaatar, Mongolia. Air Qual Atmos Heal. 2013;6(1):137–50.

5. Guttikunda S. Urban Air Pollution Analysis for Ulaanbaatar, Mongolia. Ssrn. 2008;

6. WPRO | World Health Organization issues recommendations to tackle health impacts of air pollution in Mongolia. WPRO [Internet]. 2018 [cited 2019 Apr 23]; Available from: http://www.wpro.who.int/mongolia/mediacentre/releases/20180228_recommendations_air_pollution/en/

7. Stenmark E. On Multiphase Flow Models in ANSYS CFD Software. Chalmers Univ Technol. 2013;59.

8. CFX-Solver Theory Guide [Internet]. [cited 2019 Apr 26]. Available from: https://www.sharcnet.ca/Software/Ansys/17.2/en-us/help/cfx_thry/cfx_thry.html

9. ANSYS Inc. CFX-Solver Theory Guide. Release 14.5. SAS IP, Inc.; 2012.

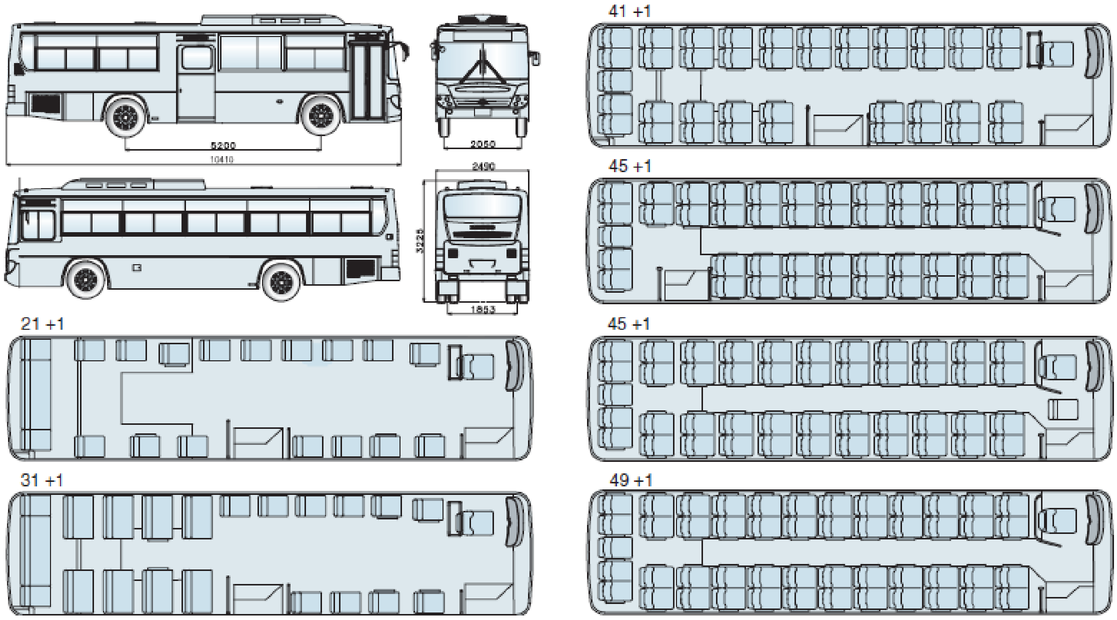
10. ANSYS. Structural nonlinearities, User’s guide for revision 5.5. 1997. p.

11. Enginnering D of A and M, Arizona TU of, Tucson A. The Finite Element Method and Application in Engineering Using ANSYS.

12. Activated Carbon Air Filters: Everything You Need to Know | Molekule Blog [Internet]. [cited 2019 Apr 28]. Available from: https://molekule.com/blog/activated-carbon-air-filter/

Appendix A:

BS106 Standard specification



Major Specifications

BODY STRUCTURE	RIVETLESS SKELETON, STEEL BODY
STEERING POSITION	LEFT HAND DRIVE
ENGINE MOUNTING	REAR
PASSENGER CAPACITY	NON-CITY : 45+1 PERSONS CITY : 21+(82)+1 PERSONS

External Dimensions (mm)

OVERALL LENGTH	10,410
OVERALL WIDTH	2,490
OVERALL HEIGHT	3,225
WHEEL BASE	5,200
BODY OVERHANG (FRONT)	2,100
BODY OVERHANG (REAR)	3,110
TREAD (FRONT)	2,050
TREAD (REAR)	1,853

Internal Dimensions (mm)

INSIDE LENGTH	9,908
INSIDE WIDTH	2,380
INSIDE HEIGHT	1,970

Weight (kg)

PERMISSIBLE G.V.W	16,500
CURB WEIGHT	9,015
G.V.W	INTER-CITY : 12,005 CITY : 15,775

Performance

MAX SPEED	NON-CITY : 102km/h CITY : 86km/h
MIN TURNING RADIUS	9.9m
GRADEABILITY(TANø)	NON-CITY : 0.37 CITY : 0.29

Frame

SEMI MONOCOQUE TYPE

Engine

MODEL	DE12, DIESEL
TYPE	4 CYCLE, WATER COOLED
NO. OF CYLINDER	6, IN-LINE
BORE & STROKE	123 X 155mm
DISPLACEMENT	11,051cc
MAX HORSE POWER	225ps/2,200rpm
MAX TORQUE	81.5kg.m/1,400rpm
COMPRESSION RATIO	17.1:1
AIR CLEANER	DRY SINGLE PAPER ELEMENT

Transmission

GEAR BOX: 5 FORWARD & 1 REVERSE

	1st	2nd	3rd	4th	5th	REV.
NON-CITY	5.405	3.447	1.739	1.000	0.738	5.650
CITY	6.571	3.807	2.201	1.463	1.000	6.240

Suspension

SEMI-ELLIPTICAL ALLOY STEEL HEAVY DUTY LEAF SPRING
WITH HYDRAULIC DOUBLE ACTING TELESCOPIC
SHOCK ABSORBER

Wheel & Tire

TIRE	10.00-20-16PR TUBE TYPE
WHEEL	7.00T-20 WHEEL

Steering

OPERATION	RECIRCULATED BALL WITH INTEGRAL POWER ASSISTED BY OIL
GEAR RATIO	22.4 :1
STEERING COLUMN	TILT & TELESCOPIC
STEERING WHEEL	2 SPOKE WHEEL WITH HORN BUTTON

Air Service

AIR PRESSURE	9.0kg/cm²
AIR TANK CAPACITY	MAIN 50L, BRAKE 25L+35L
AIR TAP FOR TIRE INFLATION	
AIR DRYER	

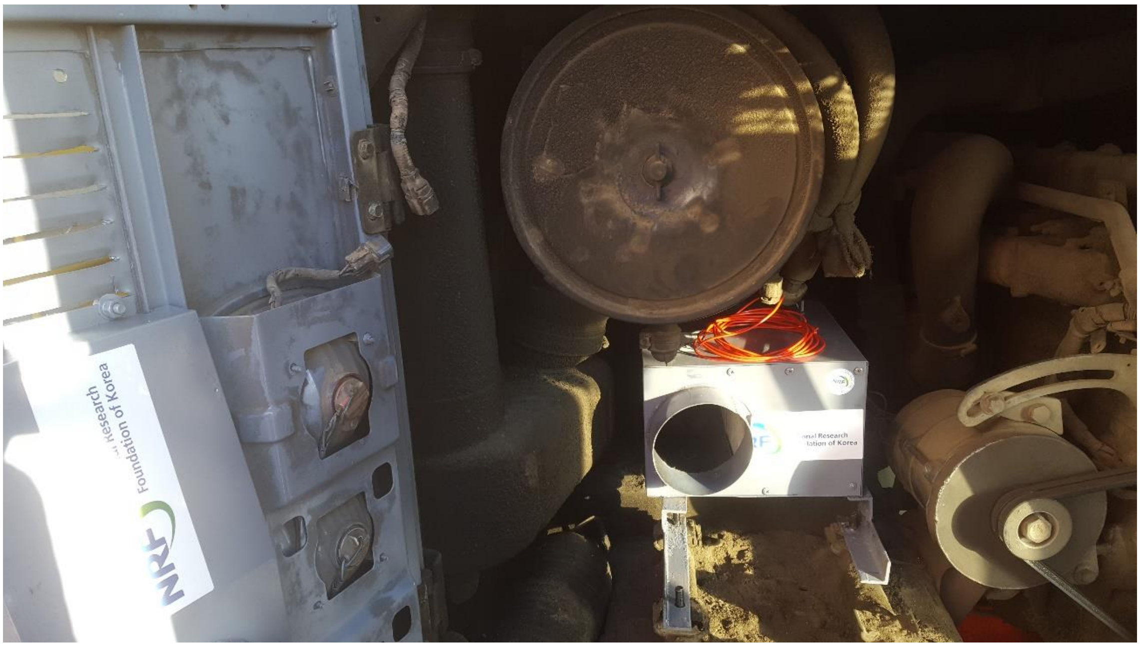
Brake

SERVICE BRAKE	FULL AIR DUAL CIRCUIT BRAKE SYSTEM
DRUM SIZE	FRONT 410mm, REAR 410mm
LINING (w/t)	FRONT 155/19mm, REAR 220/19mm
LINING MATERIAL	NON-ASBESTOS
PARKING BRAKE	SPRING ACTUATOR AT REAR WHEEL SPRING CHAMBER TYPE
AUXILIARY BRAKE	EXHAUST BRAKE-AIR OPERATED

Clutch

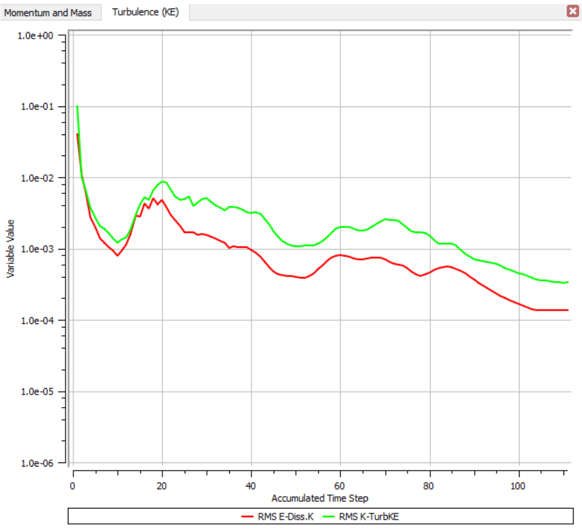
TYPE	DRY SINGLE PLATE WITH COIL SPRING DAMPER
FACING DIMENSION	OUTSIDE DIAMETER 430mm, THICKNESS 5mm
MATERIAL	NON-ASBESTOS

A location of the air filter case



Case inlet of the air with the activated carbon air filter

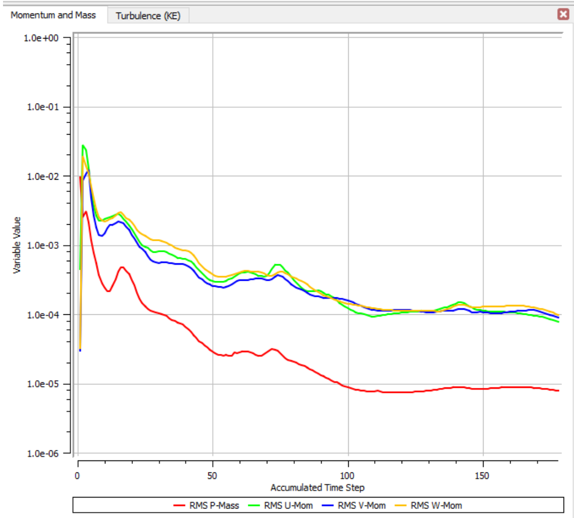
Appendix B:



Out File

```
No isolated fluid regions were found.

+--------------------------------------------------------------------+
|              The Equations Solved in This Calculation              |
+--------------------------------------------------------------------+

Subsystem : Momentum and Mass

  U-Mom
  V-Mom
  W-Mom
  P-Mass

Subsystem : TurbKE and Diss.K

  K-TurbKE
  E-Diss.K

CFD Solver started: Sat Apr 27 12:16:36 2019


+--------------------------------------------------------------------+
|                       Convergence History                          |
+--------------------------------------------------------------------+

======================================================================
|                       Timescale Information                        |
----------------------------------------------------------------------
|       Equation        |         Type           |     Timescale     |
+-----------------------+------------------------+--------------------+
| U-Mom                 | Auto Timescale         |      1.55960E-01  |
| V-Mom                 | Auto Timescale         |      1.55960E-01  |
| W-Mom                 | Auto Timescale         |      1.55960E-01  |
+-----------------------+------------------------+--------------------+
| K-TurbKE              | Auto Timescale         |      1.55960E-01  |
```

The Graphic: Accumulated time steps and turbulent flow



Out File

```
 Variable Updates               3.21E+01    8.9 %
 File Writing                   1.35E+00    0.4 %
 Miscellaneous                  7.11E+00    2.0 %
                                --------
 Total                          3.62E+02

 +--------------------------------------------------------------------+
 |                  Job Information at End of Run                     |
 +--------------------------------------------------------------------+

 Host computer:  BALJINNYAM (PID:11404)

 Job finished:   Wed May  1 13:59:12 2019

 Total wall clock time: 3.612E+02 seconds
             or: (          0:          0:          6:      1.240 )
                 (       Days:      Hours:    Minutes:    Seconds )

End of solution stage.

 +--------------------------------------------------------------------+
 | The results from this run of the ANSYS CFX Solver have been        |
 | written to                                                         |
 | E:/Desktop/Thesis/Simulation_BUS_pending/dp0_CFX_Solution/Fluid    |
 | Flow CFX_002.res                                                   |
 +--------------------------------------------------------------------+


 +--------------------------------------------------------------------+
 | For CFX runs launched from Workbench, the final locations of       |
 | directories and files generated may differ from those shown.       |
 +--------------------------------------------------------------------+


This run of the ANSYS CFX Solver has finished.
```