JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING

Post Graduate Program
(MSc in Thermal System Engineering)

Evaluation of Thermal Energy utilization and CFD Modeling of aggregate preheating from Waste Heat for Hot Mix Asphalt production Plant

By

Tewodros Genene

A Thesis submitted to the school of post graduate studies of Jimma Institute of Technology, Faculty of Mechanical Engineering in partial fulfillment for the requirement of the degree Master of Science in Thermal Systems Engineering.

October, 2020

JIMMA, ETHIOPIA

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Declaration

I, the undersigned, declare that this thesis research entitled, "*Evaluation of Thermal Energy utilization and CFD Modeling of aggregate preheating from Waste Heat for Hot Mix Asphalt production Plant*", for partial fulfillment of the degree of MSc, in Thermal Systems Engineering at Jimma university, Jimma Institute of Technology is my original work, and has not been previously presented in any university for the award of degree.

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ABSTRACT

The energy utilization and better sources of energy reduction methods of hot mix asphalt plant are investigated in this thesis based in Ethiopia. In our country, with the increase of high way construction projects asphalt plants are playing vital role. The Asphalt Plant is system of mechanical equipment to produce the Hot Mix which is used for road paving at road construction site. There is a huge amount of fuel consumption of annually used in the production factory sites. The study for energy usage and utilization of waste heat for aggregate preheating is essential for energy reduction in asphalt concrete processing factory. The knowledge of effective plant energy management helps a company in terms of energy, ecology and economics.

In this study, evaluation of thermal energy utilization and CFD modeling of aggregate preheating from waste heat for hot mix asphalt production plant with a capacity of 40-60 ton/hr at the humidity of initial materials up to 5% is analyzed based on the site data's and recorded data's collected from the production factory in order to reduce the energy usage. The life cycle assessment method and the numerical simulation is used to show the possible techniques of energy consumption reduction. The life cycle assessment investigation involves four categories related to raw material production stage, asphalt mixture production stage, transportation and pavement stage.

The annual statistical data analysis shows that, the asphalt mixture production stage consumes 59% energy during the process. The total energy 272.03 MJ/ton is used by the production factory and asphalt mixture production consumes a large amount of energy for the aggregate drying, bitumen heating and storage for mixing process. This result shows that 8.333 kWh electrical energy is used for control and operation of electrical components and 6.33 liter of diesel fuel per tonne of a production. The aggregate moisture content is the main factor influencing the level of energy consumption during a production process. ANSYS FLUENT is used to simulate the utilization of exhaust gas thermal potential to heat the aggregate. By using 2D multiphase gas solid heat transfer model the temperature and heat transfer pattern between the gas and the aggregate is studied. The results are compared analytically and showed that it is possible to reduce the moisture content by heating the particles before entering into the rotary dryer. After pre heating the energy consumption will be reduced by 12.54% per one tonne of a production.

Key words: asphalt mix plant, aggregates, moisture content, bitumen, energy consumption, ANSYS FLUENT, multiphase

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NOMENCLATURE

Latin Letters

C_P	Specific heat capacity	[J/kg K]
D_p	particle diameter	[mm]
E	energy	[kWh]
E_{th}	Percentage thermal efficiency	[%]
e	Particle-particle restitution coefficient	[-]
g_0	Radial distribution function	[-]
h	Enthalpy	[J/kg]
H_{input}	Heat input	[kWh]
H_{loss}	Heat loss	[kWh]
J_{Vis}	Dissipation rate resulting from viscous damping	[-]
J_{slip}	Production rate due to the slip between gas and particle	[-]
K_{H_2O}	Mass of water generated in the combustion per unit mass of fuel	[-]
m	Weight	[kg]
m_a	Dry air mass flow	[kg/s]
m_{dcg},	dry combustion Mass	[kg/s]
m_F	Fuel mass flow	[kg/s]
$m_{S_{in}}$	Solid mass flow	[kg/s]
m_{vc}	Water vapor generated	[kg/s]
n	number of moles	[-]
Q	Heat	[kWh]
Q_c	convective heat transfer	[W]
Q_r	heat flux	[W]
R_{th}	thermal resistance	[K/w]
T_b	bitumen temperature	[°K]
T_{air}	ambient air temperature	[°K]
U	overall heat transfer coefficient	[W/ (m^2. °K)]
X	solids humidity	[%]

GREEK SYMBOLS

φ	air mass air-fuel ratio	[kg air/ kg fuel]
λ	stoichiometric ratio	[-]
$\propto$	Temperature coefficient	[W/m^2]
ρ_g	Gas phase density	[kg / m^3]
ρ_s	Solid phase density	[kg / m^3]
ε_g	Volumetric fractions of gas	[-]
ε_s	Volumetric fractions of solid	[-]
ω	Humidity ratio	[%]
Θ	Granular temperature	[°K]
γ_s	Dissipation rate due to particle collisions	[W/sec]
η	Energetic efficiency	[%]

ABBREVIATIONS

ASCON – Asphalt Concrete

ANSYS – Analysis System

AP – Asphalt Plant

CFD – Computational Fluid Dynamics

DEM – Discrete element method

EEM – Eulerian-Eulerian model

EOL – End of life

GHG – Green-house gas

HMA – Hot Mix Asphalt

LCA – Life cycle assessment

NAPA – National Asphalt Pavement Association

PG – Performance Graded

RTOs – Regenerative thermal oxidizers

WMA – Warm Mix Asphalt

1. INTRODUCTION

1.1 BACK GROUND

The study for energy usage in asphalt plant processing factory is essential for identifying better sources of energy reduction methods and modern techniques and tools developed for the use and operation of a plant. Reducing energy use is a benefit for the industry, in terms of cost and enables to use other sources of energy with low carbon emission, without affecting the production efficiency. The continued evolution of asphalt plants presents four challenges. These are energy efficiency, eco-friendliness, diverse options to meet needs, and high-level safety features to protect the people who operate and maintain the plant on a daily basis. The need for a reduced fuel consumption is to make efficient use of limited resources, and to maximize heat efficiency plant machinery. To reduce energy consumption in the asphalt mixture production process allows a better energy efficiency of Asphalt Plants. Asphalt plants are known to produce dust, noise, and smells. To meet environmental ordinances it is essential to reduce emissions from hot mix asphalt plants. Safer and easier to operate makes maintenance effective and increases machinery durability.

Figure 1: Asphalt Mixing Plant [1]

1.2 General Description of Asphalt Batching Plant

The batch-type asphalt plant is a manufacturing facility for producing hot mix asphalt (HMA). A Coarse and fine aggregate is removed from storage, or stockpiles, in controlled amounts and passed through a dryer where it is heated and dried. The aggregate then passes over a screening unit that separates the material into different size fractions and deposits them into bins for hot storage. The aggregate and mineral, when used, are then withdrawn in controlled amounts, to make up one batch for mixing. The entire combination of aggregate is dumped into a mixing chamber called a pugmill. Then the asphalt, which has also been weighed, is thoroughly mixed with the aggregate in the pugmill. After mixing, the material is emptied from the pugmill in one batch.

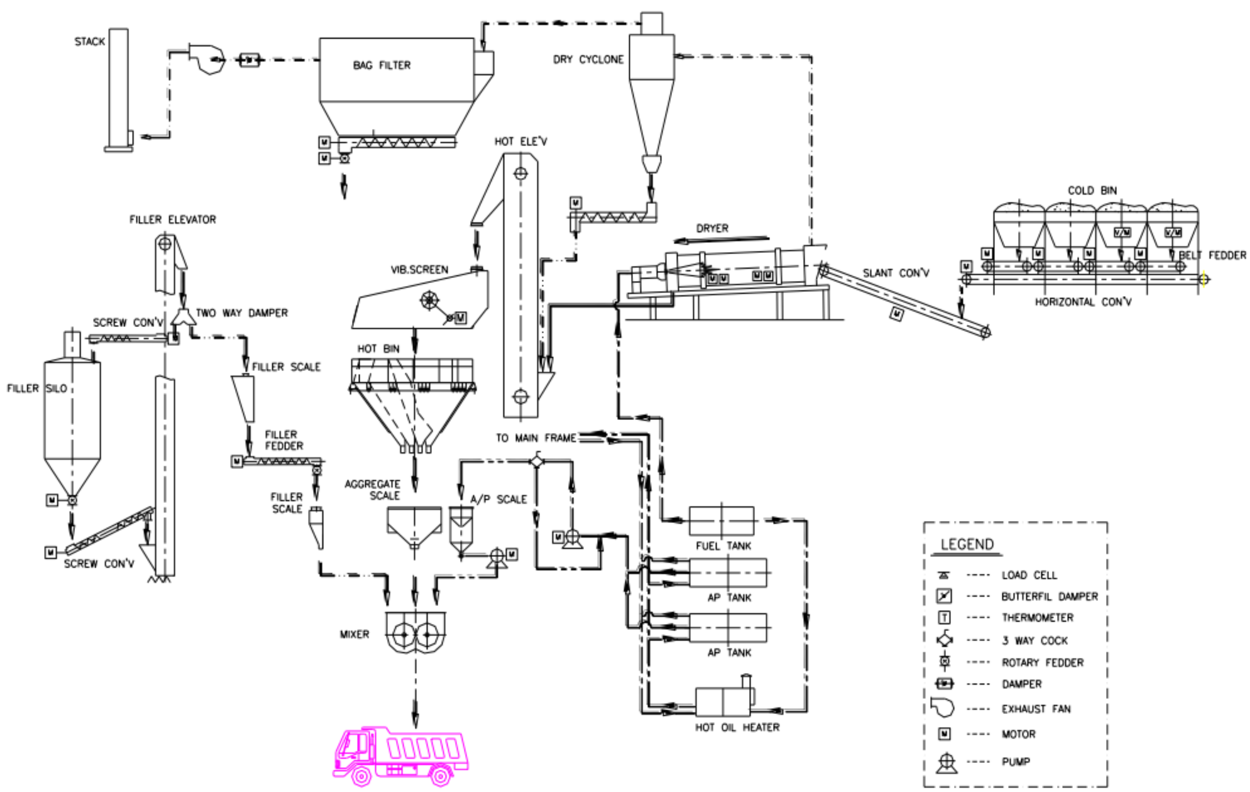


Figure 2: The Standard Operational Structure of Asphalt Plants [1]

Batch plants fall into three categories, depending on the degree of automation:

- ✓ Manual—Operators use air or hydraulic cylinders actuated by electric switches to operate supply bin gates, feeders, asphalt valves, the weigh box discharge gate, and the pug mill discharge gate.

- ✓ Semi-automatic—all operations are under automatic cycle control, including measuring and mixing, which frees the operator to coordinate other plant operations through remote control.
- ✓ Automatic—all principal components of the plant are automatically controlled by electrical circuits, which operate from preset batch weight data without manual assistance or monitoring, removing the human error factor from the batching operation. Input to controls is a computer program, batch plug, or preset dials containing design weights for each batch.

1.3 Importance of Energy Reduction on Asphalt Concrete Production

Asphalt is made up of a combination of well-graded, high-quality aggregate that has been heated and uniformly mixed together before it is coated with a measured quantity of asphaltic cement. A hot mix asphalt plant can either be a permanent, skid mounted, or portable plant. They are designed to heat, mix, and combine the aggregate and asphalt in the proper proportions to give the desired asphalt paving mix. After it is mixed, the material is compacted and densified by heavy rollers to produce a smooth, well-compacted surface for roadways, parking lots, racetracks, liners for reservoirs, landfills, and other contaminant areas (2).

Quality of asphalt concrete produced in plants is highly dependent on the materials used in production. Consequently correct storing and feeding of materials have high importance. Another important factor is to provide standard production and this is only possible by controlled, continuous feeding and enough storage in facility site. Drying process is the most expensive phase of production because of high fuel consumption. Furthermore, staying time of aggregate in the dryer, affects the whole capacity of the plant (3).

The standard water content in aggregates is 5%. If the water in the mixture is higher, output is lower and if highly moisturized aggregates are injected simultaneously, output is reduced. In order to achieve the maximum output if the burner is adjusted in the condition above a dryer will be damaged and the fuel consumption will be increased. Finally, lots of dust will be generated in a processing factory.

Asphalt Concrete is a composite material of mineral aggregate and asphalt binder, laid and compacted in layers. It is a typical material used in the construction of driveways, roadways, and airport runways. Given the flexible nature of Asphalt binder, Asphalt Concrete roads are considered a flexible pavement. Asphalt Concrete can be divided into three broad categories: Hot

Mix, Warm Mix, and Cold Mix Asphalt. These divisions describe the temperatures in which the Asphalt Concrete is mixed.

Hot-Mix Asphalt Concrete is produced at a central mixing plant and transported to the paving site in trucks. Heat is used to dry the aggregate, melt the asphalt so that it will coat the stone, and heat the mix so it can be spread and compacted. Hot-mix is the preferred pavement for any high quality, heavily traveled roads, but warm-mix asphalt may be used interchangeably.

Warm-Mix Asphalt Concrete (WMA) is produced using one of several technologies that allow the mixture to be mixed in a plant, placed, and compacted at temperatures of somewhere between 20 to 55 °C (35 and 100 °F) lower than typical Hot-mix. This lower temperature provides the benefits of paving in cooler ambient temperatures, hauling longer distances, using higher RAP percentages (with proper handling and processing), reducing fuel consumption, and reducing plant emissions. The technologies in use are typically variations of chemical and organic additives or some type of water-induced asphalt foaming process.

Cold Mix Asphalt Concrete is made at a mixing plant, but instead of asphalt binder, a cut-back asphalt or emulsified asphalt is substituted. The advantage of cold mix is that it remains workable until the solvent evaporates or until the water separates from the asphalt. It does not have to be kept hot and can be stockpiled for a period of time before use. Many years ago, when hot-mix plants were few and far between, paving mix often had to be hauled to the job site in railroad cars. As this could take days, cold mix was the only practical mix to use. Cold mix is used primarily for patching material during winter months when the mixing plants are shut down and hot-mix is not available.

Asphalt concrete is composed of three basic components – asphalt binder, mineral aggregate and air voids. Aggregates are generally classified into two groups – (1) coarse and (2) fine; together they normally constitute 90 to 95 percent by weight of the total mixture. Asphalt binders are classified by various grading systems and normally constitute 5 to 10 percent of the total mixture. Another very important, but often overlooked component of an asphalt mix is air voids.

- ✓ Asphalt—Composed of a Performance Graded (PG) binder or a variation, it constitutes 5 to 10%of the total asphalt concrete mixture by weight.

- ✓ Aggregates—An inert granular material such as sand, gravel, shell, slag, or broken stone, generally classified into two groups (fine and coarse), constituting 90 to 95% of the total asphalt concrete mixture by weight.

1.4 Utilization of Energy Potential and Benefits from Waste Heat recovery in the Asphalt Mixture Production

Bag filter is a dust collector, which interior is composed of one sector, automatically shaking dust off. Gas containing dust enters the interior of the dust collector through the inlet installed on the housing of the dust collector, the dust is collected on the exterior of the bag by passing the filter bag, and the collected and purified air goes up to the upper part of the dust collector and is discharged to the outside through exhaust fan. Bag filter of the asphalt plant is designed based on the aggregate with moisture content of 4 %. In the rainy season, temperature in the dust collector should be maintained 160℃ by reducing quantity of production, since it contains lot of moisture. The benefits from recycling the waste heat during asphalt mixture production can be seen in a direct and indirect ways.

1. Direct benefits: Linking the cycles into asphalt mix production would be possible to achieve savings in energy consumption and reduce amount of exhaust gas. Using part of the thermal energy from exhaust gases for heating mineral materials on dumps, moisture content of aggregates fractions will be reduce and, thus, time required for their preheating will be shorter.
2. Indirect benefits: The assessment of carbon emissions from the hot mix asphalt with the increase in the consumption of fuel is also necessary to reduce the energy cost and carbon emissions. Secondary heat recovery from regenerative thermal oxidizers (RTOs) exhaust gases that are available from 350°–400°F in asphalt coating plants. Control system for ovens to regulate the amount of make-up air used. This will require development of a system that controls the amount of make-up air, and hence the amount of heat wasted from the dryer [4].

The aggregate moisture is main factor influencing the level of energy consumption in the HMA production process. The reduction in aggregate moisture of 3% reduces energy consumption in drying by 55-60% [3].

National Asphalt Pavement Association (NAPA) presented opportunities for energy conservation in the HMA production process addressing specific actions that represent the largest potential for energy savings. Reducing aggregate moisture content is possible to achieve by sloping, paving or covering the aggregates [4].

Producers report energy savings up to 10% by insulating dryer shells or surfaces. Other proposed actions are reducing exit gas temperatures, reducing exit material temperatures, using alternative fuels, using more efficient hot-oil heater designs, employing more effective piping insulation, using more effective tank and silo insulation and using variable frequency drives in large motors. The minimization of energy requirements for manufacturing HMA and the associated lowering of asphalt plant emissions, have therefore become important issues (5).

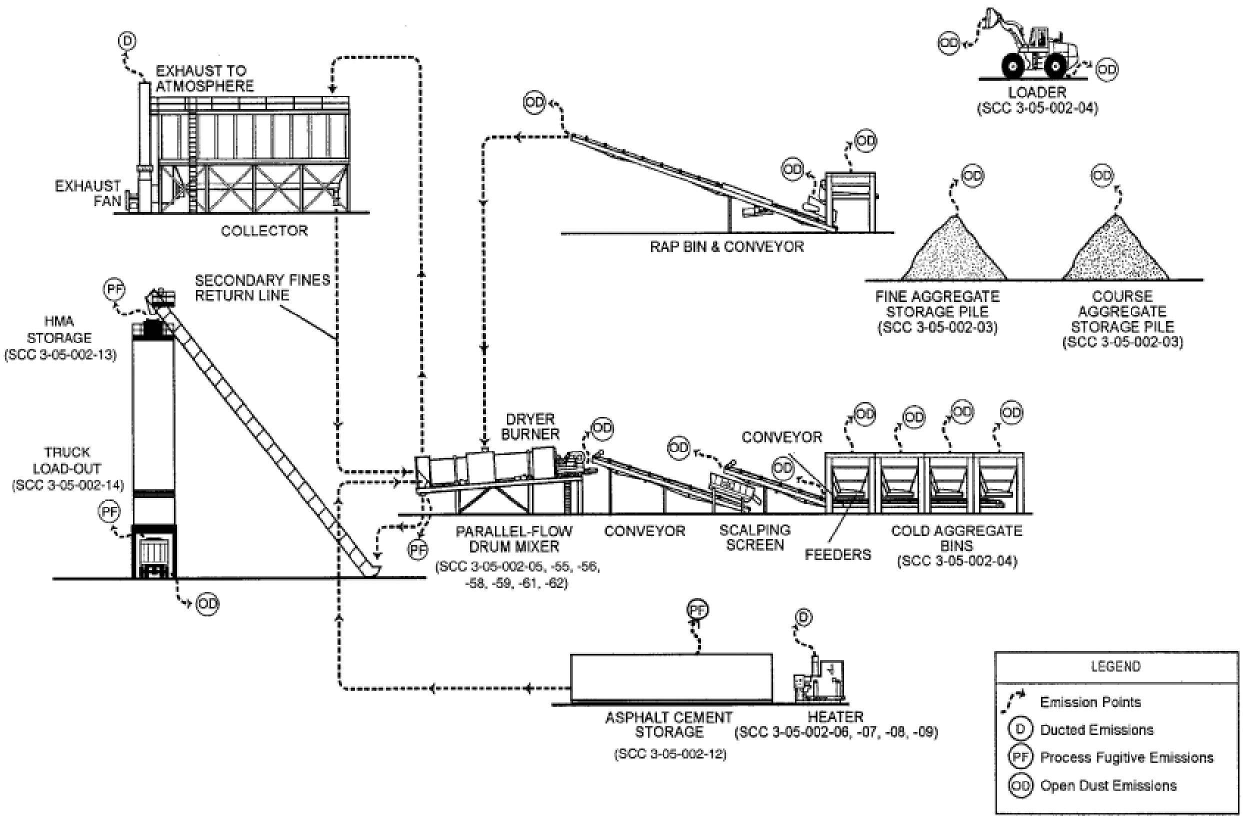


Figure 3: Emissions from each emission point and its associated emission factors [6]

Emissions from HMA plants may be divided into deducted production emissions, pre-production fugitive dust emissions, and other production-related fugitive emissions. Pre-production fugitive dust sources associated with HMA plants include vehicular traffic generating fugitive dust on paved and unpaved roads, aggregate material handling, and other aggregate processing operations. Fugitive dust range from 0.1 micro meters to more than 300 micro meters in aerodynamic diameter. On average, 5 percent of cold aggregate feed is less than 74 micro meter (minus 200 mesh). Fugitive dust that may escape collection before primary control generally consists of PM with 50 to 70 percent of the total mass less than 74 micro meters (7). In general, based on previous research results potential that occurs due to the production of HMA in asphalt plants is visible. Especially because of large amounts of unused energy created by heating a mineral mixture, which is released into the atmosphere in the form of exhaust gases.

1.5 Gas-Solid Modeling and Computational Models for Multiphase Flow

In the recent years, with advances in computing speed and parallelization technology improved software and multiphase algorithms. CFD has progressed substantially to a point where it can be used for prediction of complex multiphase flows. Today, CFD models play an increasingly important role in process design, control and/or optimization of complex multiphase systems [8]. This chapter describes the use of CFD to simulate drying in an aggregate pre heater designed to utilize the thermal potential of the exhaust gas used in the production of hot mix asphalt. Exhaust gases in the asphalt plant are released into the atmosphere through the exhaust gas pipe. These gases are a mixture of burnt gas (or fuel oil) from the burner and dust particles. At the end of the slightly inclined rotary dryer, there is a burner, which has the function of burning gas coming into the burner and producing the open flame directed to the rotary drier. The amount of open flame can be controlled (increased or decreased) by an asphalt plant operator. In the rotary drum, the aggregate fractions are heated to a temperature higher than 165 °C. By using waste gases emitted from the exhaust gas pipes into the atmosphere, their redirection and reuse can affect the cost of energy sources in the production of asphalt mixtures, and indirectly, reduce the amount of CO2 emissions into the atmosphere. To be properly coated by the asphalt binder aggregate must be completely dried. By using the emitted exhaust gas for increased drying efficiency moisture of an aggregate is removed.

The first step in solving any multiphase problem is to determine which of the regimes best represent the flow. Once that the flow regime is determined, the best representation for a multiphase system can be selected using appropriate model. There are three levels of modeling identified based on the spatial and temporal resolution of the models [9].

1.5.1 Direct Numerical Simulation

The DNS techniques are based on the local instantaneous conservation equations. These methods focus on the finest level, i.e. individual bubbles, small vortices behind bubbles and bubble-bubble interactions. All the closure equations for the forces acting on a bubble can be directly computed. However, these approaches are restricted to a single bubble or a few interacting bubbles due to very expensive computational requirements. The trajectories of the discrete particles are determined by the solution of Newton's equations of motion. The flow field around each particle is resolved based on the full Navier-Stokes equation (continuum DNS). The forces acting on particles are estimated by integrating the stresses on the surfaces of particles [10]. No empirical coefficients associated with the drag and lift forces are required in the DNS method. The fluid-solid coupling was achieved by the direct incorporation of the boundary condition (with a second-order method) at the surface of the particles.

1.5.2 EULARIAN-LAGRANGIAN METHOD

In contrast to the DNS methods, the Eulerian-Lagrangian approach requires closure relations to account for the interphase forces. The closure models can be obtained from empirical relations or from more sophisticated simulations with fine resolution. The fluid phase is treated as a continuum by solving the time-averaged Navier- Stokes equations, while the dispersed phase is solved by tracking a large number of particles, bubbles, or droplets through the calculated flow field. The trajectories of the particles are computed in the control volume. The dispersed phase can exchange momentum, mass and energy with the fluid phase [11]. The particle or droplet trajectories are computed individually at specified intervals during the fluid phase calculation. This makes the model appropriate for the modeling of spray dryers, coal and liquid fuel combustion, and some particle laden flows, but inappropriate for the modeling of liquid-liquid mixtures, fluidized beds or any application where the volume fraction of the second phase is not negligible. Due to the significant computational resources required, the Eulerian-Lagrangian approach becomes infeasible for the simulations of large industrial-scale reactors [12].

1.5.3 EULARIAN-EULARIAN METHOD

In the Eulerian-Eulerian approach, each phase is treated as a continuous medium interpenetrating the other phase, and is represented by the macroscopic conservation equations, which are valid throughout the entire flow domain. Since the volume of a phase cannot be carried occupied by the other phases, the concept of the volume fraction is introduced. These volume fractions are assumed to be continuous functions of space and time and their sum is equal to one. This method is commonly known as the two-fluid model, or when more than two phases are considered, it is called the multi-fluid model [13]. This approach requires less computational effort than the Eulerian-Lagrangian approach. However, the discrete character of the dispersed phase is lost due to the averaging procedure. Conservation equations for each phase are derived to obtain a set of equations, which have similar structure for all phases. These equations are closed by providing constitutive relations that are obtained from empirical information or in the case of granular flows by application of kinetic theory. The two-fluid model has been widely used to simulate the gas-solid fluidized beds. To describe the solid properties, the kinetic theory of granular flow is usually employed.

1.5.4 Discretization Methods

Based on the way in which the flow variables are approximated and with the discretization processes there are three numerical solution techniques; finite difference, finite volume and finite element methods.

Finite difference method (FDM): A finite difference method (FDM) discretization is based upon the differential form of the PDE to be solved. Each derivative is replaced with an approximate difference formula (that can generally be derived from a Taylor series expansion). The computational domain is usually divided into hexahedral cells (the grid), and the solution will be obtained at each nodal point. The FDM is easiest to understand when the physical grid is Cartesian, but through the use of curvilinear transforms the method can be extended to domains that are not easily represented by brick-shaped elements. The discretization results in a system of equation of the variable at nodal points, and once a solution is found, then we have a discrete representation of the solution.

Finite volume method (FVM): A finite volume method (FVM) discretization is based upon an integral form of the PDE to be solved (e.g. conservation of mass, momentum, or energy). The PDE is written in a form which can be solved for a given finite volume (or cell). The computational domain is discretized into finite volumes and then for every volume the governing equations are solved. The resulting system of equations usually involves fluxes of the conserved variable, and thus the calculation of fluxes is very important in FVM. The basic advantage of this method over FDM is it does not require the use of structured grids, and the effort to convert the given mesh in to structured numerical grid internally is completely avoided. As with FDM, the resulting approximate solution is a discrete, but the variables are typically placed at cell centers rather than at nodal points.

Finite element method (FEM): A finite element method (FEM) discretization is based upon a piecewise representation of the solution in terms of specified basis functions. The computational domain is divided up into smaller domains (finite elements) and the solution in each element is constructed from the basic functions. The actual equations that are solved are typically obtained by restating the conservation equation in weak form: the field variables are written in terms of the basic functions, the equation is multiplied by appropriate test functions, and then integrated over an element. Since the FEM solution is in terms of specific basis functions, a great deal more is known about the solution than for either FDM or FVM. This can be a double-edged sword, as the choice of basic functions is very important and boundary conditions may be more difficult to formulate. Again, a system of equations is obtained (usually for nodal values) that must be solved to obtain a solution.

1.6 STATEMENT OF THE PROBLEM

In Ethiopia with the increasing rate of the construction of high ways and other construction projects the installation for asphalt plants at different areas of the country is playing a vital role in the road sector development.

In recent year's conservation of energy resources is a major concern of governments and citizens. By reducing energy use it's possible to benefit the industry without affecting the production efficiency. To provide a quality product a controlled, continuous feeding, drying and heating processes are needed. The aggregate drying process is the most expensive phase of production because of high fuel consumption. At the same time heating and storing asphalt use heating fuels. Diesel fuel is the primary energy sources in Ethiopia and with the increase of energy demand at the national level there is a huge amount of fuel consumption of annually used in the production factory sites. The study for energy usage in asphalt plant processing factory is essential for identifying better sources of energy reduction methods and the assessment of carbon emissions from the hot mix asphalt with the increase in the consumption of fuel. By applying exhaust gas recycling energy conservation techniques the higher initial costs will be turned into savings.

Thus, this thesis basically aims on improving the energy use in drying, heating and the continuous mixing processing. The performance based on the current production quality of the product, fuel consumption in the aggregate drying unit and asphalt heater units is evaluated to avoid improper damage to a component and operational failures. Computational fluid dynamics (CFD) modeling and simulation of the aggregate pre heating is used to show heat transfer pattern between the solid and gas across the dryer. The energy saving results will be compared with reduced amount of solid humidity during preheating. The aggregate pre heating will reduce the emission of toxic gases to the atmosphere during the production of asphalt mixture.

1.7 OBJECTIVES OF THE STUDY

1.7.1 General Objective

The general objective of this thesis is Evaluation of Thermal Energy utilization and CFD Modeling of aggregate preheating from Waste Heat for Hot Mix Asphalt production Plant in order to reduce energy usage during the production of asphalt concrete.

1.7.2 Specific objectives

The specific objectives of this research include:

- Determining the factors that affect the energy use in asphalt concrete production.
- Identifying and analyzing the energy losss in the continuous mixing process in to the various components.
- To improve the energy management of hot mix asphalt plants by increasing the production performance and the heating efficiency.
- To show the heat transfer and the patterns of energy use on the heating units used for manufacturing.
- To model drying in an aggregate pre heater designed to utilize the thermal potential of the exhaust gas used in the production of hot mix asphalt with the use of computational fluid dynamics (CFD).
- To minimize the factors for increased fuel consumption.

1.8 Scope of the study

This research is aimed on determining the activities or processes that consume the most energy by identifying how energy is utilized, based on the site data's and recorded data's collected from the production factory and Computational Fluid Dynamics (CFD) simulation of pre heating using exhaust gas in the production process. Prototype development and Experimental investigation is not included in this study, but it can be putted as a suggestion on the recommendation.

1.9 Expected Out Comes

The main expected results of this research are decreasing fuel consumption, the reduction of emission and financial loss without affecting production efficiency. By using waste gases emitted from the exhaust gas pipes into the atmosphere, their redirection and reuse, the optimization of energy utilization for heating is simulated using CFD.

1.10 SIGNIFICANCE OF THE STUDY

Due to the population growth, energy demand is increasing, resulting to the stressed primary energy sources covered by secondary energy imports. Diesel fuel is the main refined oil product in Ethiopia used for thermal power plants (oil power plant) and for private and public diesel generators in parts of the country, where electrical power from the national grid is an issue. There is a huge amount of fuel consumption of annually used in the production factory sites.
The aggregate drying process is the most expensive phase of production because of high fuel consumption at the same time causing emissions to the environment. Thus, this thesis basically aims on improving the excess fuel consumption on drying, heating and the continuous mixing processing through the use of the waste heat.

1.11 STRUCTURE OF THE THESIS

This section briefly describes the outline of the thesis and the summarized contents of the following chapters clearly.

Chapter one; Discuss about the General description and Introduction of the project, Importance of Energy Reduction in Asphalt Concrete Production, Utilization of Energy Potential and Benefits from Waste Heat Recovery in the Asphalt Mixture Production, Importance of the Problem, Objectives, Scope of the study, Expected outcomes and the overview of the study methodology.

Chapter two; Deals with Literature Review on history of asphalt plant and structural parameters in the basic Energy Utilization and Waste Heat Recovery concepts.

Chapter three; Gives an over view of the methodology used in the project with overall study methodology.

Chapter four; Describes Energy Performance Evaluation and Thermal Analysis of Hot Mix Asphalt Plant, Analysis of Energy Usage on Asphalt Plant, Annual Energy Consumption Statistics, Heat Transfer and Energy Loss in Bitumen storage tanks and heaters, Analysis of the Heat Transfer and Energy Loss on Aggregate Dryer, Energy Costs and Savings from Production Factory in detail.

Chapter five: Deals with gas solid heating Eularian granular multiphase model use of CFD to simulate drying in an aggregate pre heater designed to utilize the thermal potential of the exhaust gas used in the production of hot mix asphalt. Exhaust gases in the asphalt plant are released into the atmosphere through the exhaust gas pipe.

Chapter six: Discuss results achieved on energy consumption calculations performed up on asphalt plant to investigate thermal energy performance. Based on the application gas-solid flow the CFD validation is presented by using graphical displays and numerical out puts.

Chapter seven: summarizes the ways for improving the energy use in hot mix asphalt production factory and reduce the emission of toxic gases to the atmosphere.

2. LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

The modern use of asphalt for road and street construction began in the late 1800s, and grew rapidly with the emerging automobile industry as indicated by Virginia asphalt association. Since that time, asphalt technology has made giant strides. Today, the equipment and techniques used to build asphalt pavement structures are highly sophisticated. Surface dressings were initially used as surfacing for paved roads. The main use being a barrier against moisture ingress and dust control in paved roads. However, due to its very fast failure rate in the ever increasing traffic loads in Ethiopia it was replaced with Asphalt Concrete (AC). The AC as compared to the surface dressing has several advantages, the main point being AC is a structural layer while surface dressing is not. The design of an AC mix is done by combining aggregates of different sizes and mixing them with the optimum amount of bitumen. There is a large amount of energy consumption which is needed for the production of ASCON. It will affect the demand for a strongly growing need for refined oil imports (diesel, gasoline and kerosene) to the Ethiopian metropolitan areas.

With a population of 102 million, Ethiopia is second only to Nigeria (186 million) on the African continent in terms of population size. In 2015, at the end of the road network had reached 100,000km. It now stands at 121,171km, according to the roads ministry, including gravel roads. That represents a large expansion from 1990, when there were just 19,000km of roads. About 90% of them are asphalt. In Ethiopia there are many asphalt plants installed based on the needs for high ways and other construction projects. The Road Construction projects construct new roads and maintain the existing ones. This chapter is mainly concerned on the energy usage in asphalt plant processing factory considering the methods and materials used for production. It is essential for identifying better sources of energy reduction methods and modern techniques and tools developed for the use and operation of a plant. The components of Asphalt Batching Plant and the properties of the materials used for asphalt concrete production will be discussed in detail.

2.2 Types of Asphalt Concrete Plants

Asphalt concrete mixes made with asphalt cement are prepared at an asphalt mixing plant. Here, aggregates are blended, heated, dried and mixed with asphalt cement to produce a hot mix asphalt (HMA). There are two basic types of plants used to manufacture asphalt concrete:

- ✓ Batch plants, which make asphalt in batches as needed
- ✓ Drum plants, which make asphalt continuously

These two types of asphalt plants derive their names from their particular mixing operation. In the batch-type mixing plant, hot aggregate and asphalt are withdrawn in desired amounts to make up one batch for mixing. After thoroughly mixing, the material is discharged in one batch. In the drum-type mixing plant, the aggregate is dried, heated and mixed with the asphaltic cement in the drum in a continuous operation. Either system can store the asphalt for several days in heated storage silos.

2.2.1 Batch Plant Operation and Components

I) Cold Feed Bins

The cold aggregate feed is the first major operation in the batch-type asphalt concrete plant. The plant is equipped with multiple bins to handle different sizes of aggregates. Stockpiled aggregate is loaded into the cold feed bins for delivery to the aggregate dryer.

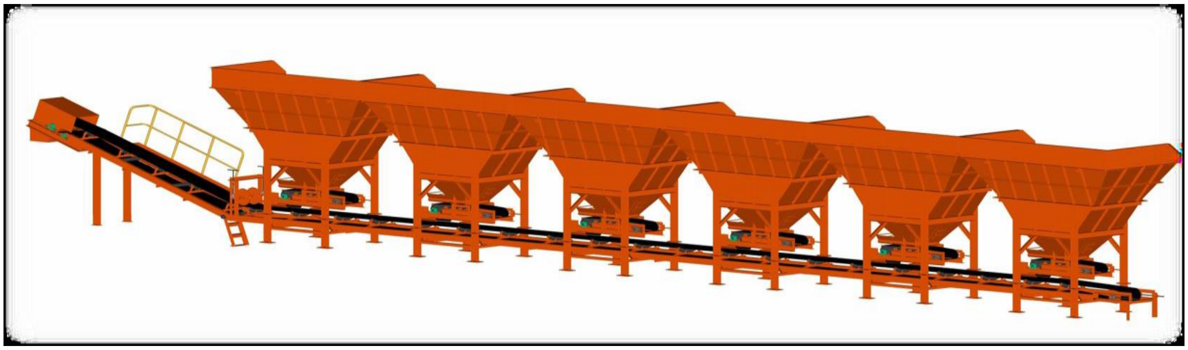


Figure 4: Cold feed bins [15]

II) Dryer/Heater

One of the basic units in any asphalt concrete plant is the dryer. It is a necessary part of the hot-mix operation because it dries and heats aggregates coming from the cold feed supply, thus making them suitable for mixing with asphalt. The dryer is a large rotating metal drum mounted at an angle and equipped with a gas- or oil-heating unit at the lower end. Hot gases from the burner pass from the lower end of the rotating drum out through the upper end.

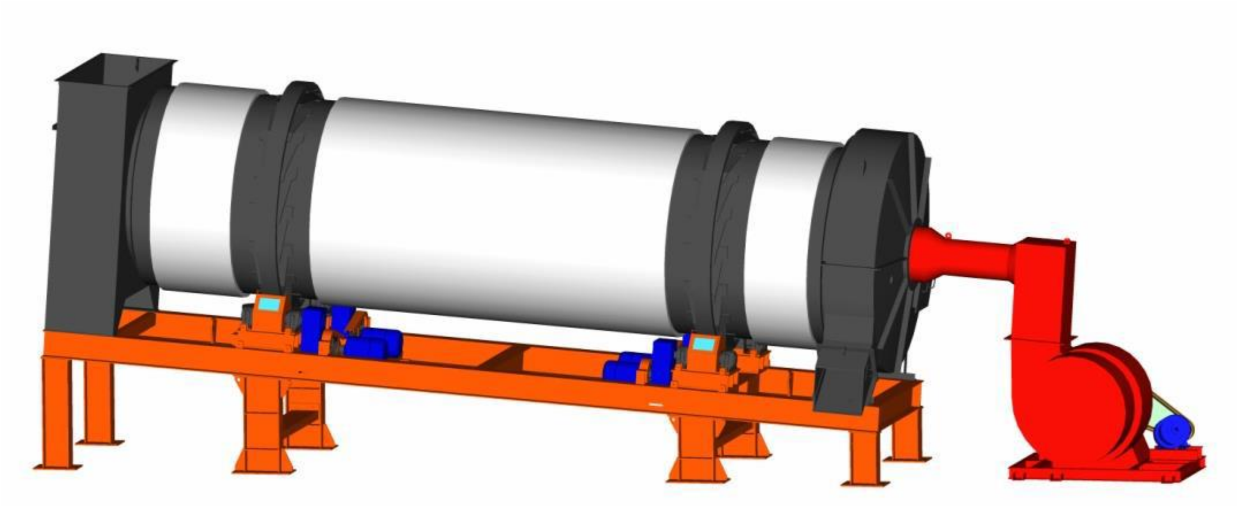


Figure 5: Direct fired rotary dryer [15]

III) EXHAUST GAS DUST COLLECTOR

The dust collector is comprised of the two main components listed below; each of these is described in detail as follows.

- ✓ The Primary (Multicone) Collector
- ✓ The Secondary Collector (Bag house)

The Primary (Multicone) Collector. The primary collector, also known as the multicone collector, is located between the dryer and the secondary collector. The primary collector uses a cyclone effect to collect larger dust particles and fine aggregate from the exhaust gases before they enter the more effective secondary collector.

The Secondary Collector (Bag house). The exhaust gases that pass through the primary collector are pulled by the exhaust fan through cylindrical fabric filter bags in the bag house. The bag house removes the fine particulate matter from the dryer exhaust gasses before the exhaust gasses are released to the atmosphere. With the use of a bag house, “fines” can be reclaimed and returned to the mixing unit. Exhaust from the dust collector enters the tower at the bottom and passes upward through a series of water sprays that remove the dust. Use of a wet wash system usually will increase fan requirements by 10 to 15% because of the pressure loss in the tower.

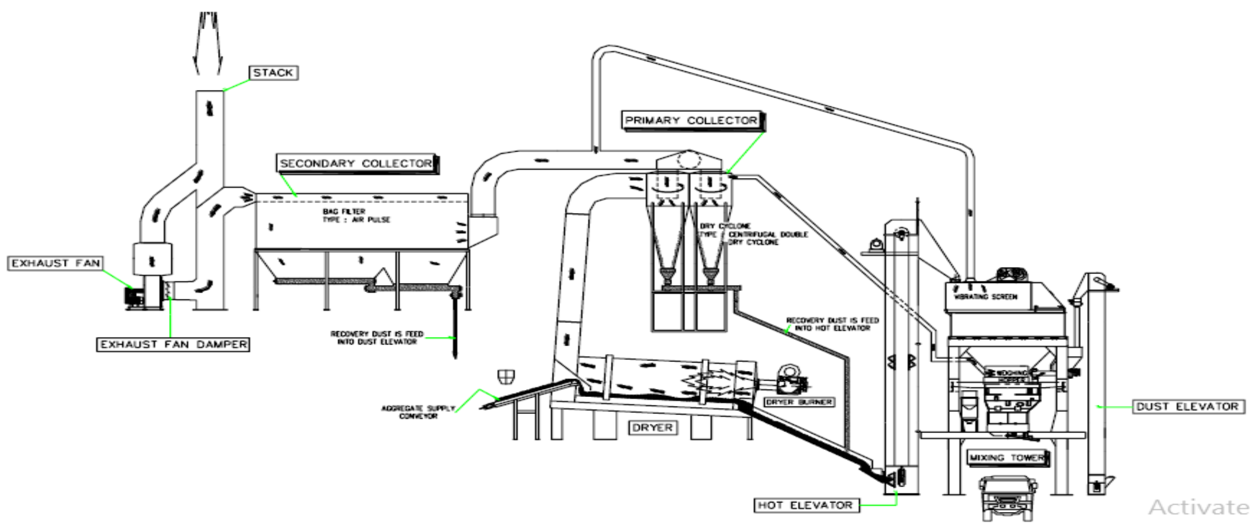


Figure 6: Dust Collector Arrangements [1]

IV) Batching Tower/Mixing Tower

The hot, dry aggregate enters the batching tower from the hot elevator. Inside the batching tower are the following components,

- ✓ Screening deck and screening unit
- ✓ Hot aggregate holding bins, also known as hot bins
- ✓ Asphalt weigh hopper
- ✓ Weigh bucket
- ✓ Pugmill

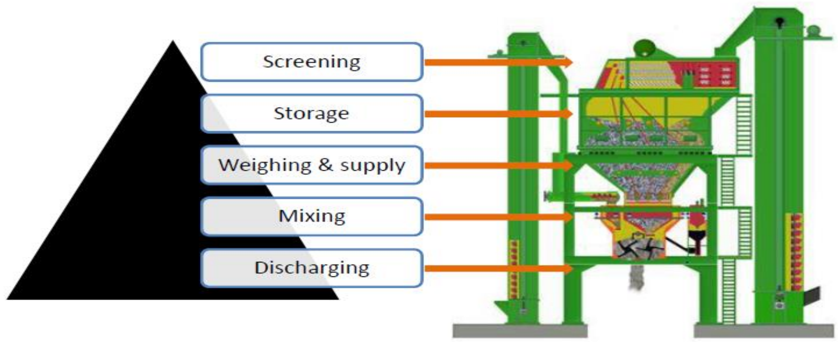


Figure 7: Mixing tower arrangement [15]

V) Screen Deck and Screening Unit. The screens in the screen deck separate the aggregate into various specified sizes. When the screening is complete, each size of aggregate resides in its own bin. The screens are critical to the plant's ability to produce mixtures that are uniform and to specification.

VII) Hot Aggregate Holding Bins/Hot Bins. Hot bins are used to temporarily store heated and screened aggregate in the various size fractions required until the predetermined amount of aggregate size is accumulated for a batch.

VIII) Aggregate Weigh Hopper. Batch plants have separate scales for the aggregate and asphalt. The weigh hopper is a large steel box attached to a set of scales. It is used to weigh the aggregate and hold it until the mixer is ready for a new batch. Nearly all of the newer plants use an electronic weighing system, which is often part of a computerized plant operating system.

IX) Pug Mill Mixer. A batch plant mixer consists of a mixing chamber, which is lined to reduce wear and two shafts with paddles. Asphalt is pumped into the mixer and sprayed over the aggregate through a spray bar. When the mixing is completed, a gate at the bottom of the mixer is opened and the completed mix drops into a truck.

2.3 ASPHALT DELIVERY

The asphalt supply system consists of storage tanks, a pump, circulating lines to carry the asphalt between the tank and the plant, a heating system to keep the asphalt hot enough to flow and a means of metering the asphalt into the mix. The asphalt needed to make a batch of mix is weighed into the asphalt weigh bucket. The aggregate is then dropped into the mixer, where after a few seconds of dry mixing, the asphalt is added.

2.3.1 Asphalt Storage Tanks

Asphalt is stored in tanks while awaiting delivery into the pugmill, where it is mixed with the aggregate. Asphalt storage at the plant should be equal to one day's output, and storage tanks should be calibrated so the amount of material remaining in the tank can be determined at any time. Since asphalt must be fluid enough for movement through the delivery and return lines, it must be heated. Heating is done by the circulation of steam or hot oil through coils in the tank. Asphalt cement in the tanks is kept heated between 150 ^{0}C (300 ^{0}F) to 180 ^{0}C (350 ^{0}F), depending on the grade and type of asphalt.

Figure 8: Asphalt storage tanks

2.3.2 Asphalt Binder Production

Asphalt Binders are produced at refineries during the distillation of crude oils or other petroleum products. Heating the crude oil in a still allows for it to separate into various fractions, known as distillates. The lightest distillates of the oil become gasoline; the middle is used for such products as diesel fuel, motor oil and kerosene. What remains in the still after everything else has boiled off may be processed into asphalt. Unfortunately for the asphalt industry advancements in petrochemical technology has given rise to alternate products, such as plastics, which can now be produced from the heavy residuum.

2.3.4 PERFORMANCE GRADED BINDERS

The Performance Grade specification is the current method for grading asphalt binders. These have names like PG 64-22. All grades start with the letters PG, which stands for "Performance Graded". The numbers are temperatures in degrees Celsius. For example, PG 64-22 is for use when the road temperature has a seven day average no higher than 64° Celsius and is not expected to a single day minimum lower than -22° Celsius, as shown in Figure. Computer programs such as LTPP Bind can be utilized to determine the appropriate binder to be used in a given region.

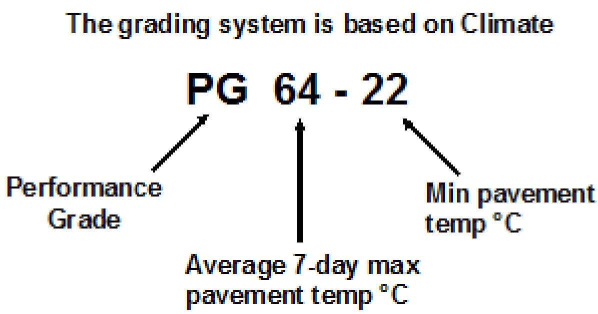


Figure 9: Performance Graded Binder System

The Performance Grade specification covers several grades for use in a variety of climatic conditions. Some of these grades are very similar to the traditional asphalt cement grades, others require additives. The usual additives are various types of polymers. Since these additives may be present, the Performance Grade specification is called a "Binder Specification" rather than as "Asphalt Specification".

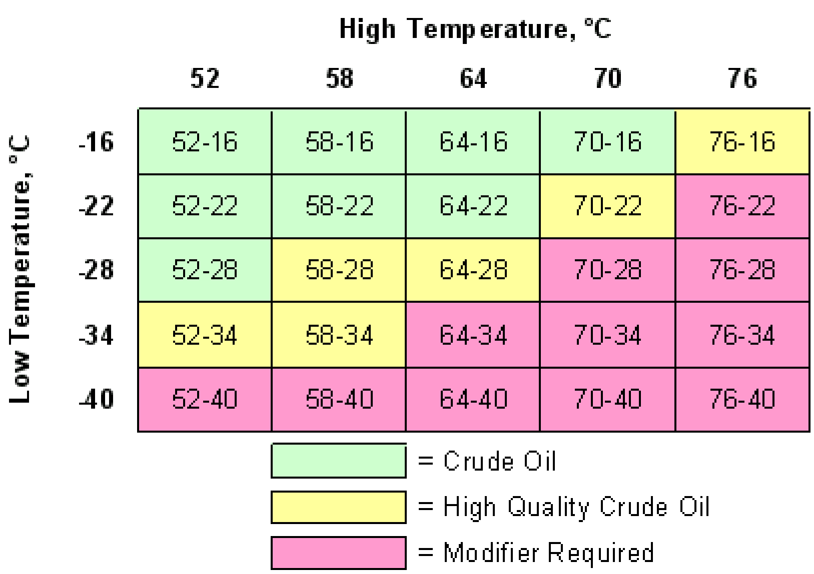


Figure 10: Binder Grade Chart

The purpose of evaluating asphalt binders is to find out how well they hold up when subjected to the conditions that can make a pavement fail. During the life of a pavement, the asphalt may be subjected to heat, cold, stretching, bending, and repeated heavy loads. Binders are tested under three different conditions. The initial tests are run on the asphalt as it comes from the refinery. Then the asphalt is conditioned (artificially aged in the laboratory) to duplicate the hardening that takes place as it goes through the mixing plant, and additional tests are conducted. This hardening is caused by the oxidation of the asphalt. Finally the binder is artificially aged again, this time to duplicate the hardening that takes place in the road, and more tests are conducted.

Asphalt binders are most commonly characterized by their physical properties. An asphalt binder's physical properties directly describe how it will perform as a constituent in asphalt concrete pavement. Asphalt binders are characterized by their properties at different temperatures and stages of life simulated by laboratory aging. Binder properties include the following:

I) Consistency

Consistency is the degree of fluidity or plasticity of binders at any particular temperature. The Consistency of binders varies with temperature. Binders are graded based on standard consistency at the design temperature for the project.

When the binder is exposed to air in thin films and is subjected to prolonged heating (e.g., during mixing with aggregates), the binder tends to harden. This means that the consistency or viscosity of the binder has increased for any given temperature. A limited increase is allowable.

II) Purity

Purity is a determination of the degree to which the binder is pure, or free from impediments such as moisture. Asphalt cement used for paving should consist of almost pure bitumen, which by definition is soluble in carbon disulfide. Refined binders are almost pure bitumen and are usually more than 99.5%soluble in carbon disulfide. Impurities, if present, are inert. Normally, the binder is free of water or moisture as it leaves the refinery.

III) Durability

Durability is the binder's resistance to the effects of traffic, water, air and temperature changes. It is a measure of how the asphalt binder's physical properties change with the normal weathering and aging (sometimes called age hardening) processes. Some qualities that complement a binder's durability are its resistance to swelling, stripping, oxidation and wear or abrasion.

IV) Adhesion and Cohesion

Adhesion and cohesion are two important and related properties of asphalt binders that can affect asphalt mixture performance. Adhesion is the binder's ability to stick to the aggregate in the paving mixture. Cohesion is the binder's ability to hold the aggregate particles in place in the finished pavement.

V) Temperature Susceptibility

Temperature susceptibility refers to the effect of temperature on the binder. All binders are thermoplastic; that is, they become harder (i.e., more viscous) as their temperature decreases and softer (i.e., less viscous) as their temperature increases. This characteristic is known as temperature susceptibility, and is one of a binder's most valuable assets. Temperature susceptibility is an important control parameter during the mixing, placement, compaction and performance of asphalt concrete. As the temperature increases, the binder becomes less viscous (i.e., more fluid).

VI) Aging and Hardening

Binders harden in the paving mixture during construction and over time in the pavement itself. This hardening is caused primarily by oxidation (i.e., the binder combining with oxygen), a process that occurs most readily at higher temperatures (e.g., mixing temperature) and in thin binder films (i.e., the film coating aggregate particles). Mixing is the stage at which the most severe oxidation and hardening usually occur. During mixing, the binder is both at a high temperature and in thin films as it coats the aggregate particles.

VII) Safety

Binder (asphalt) can be a safety hazard. Binders, if heated to a high enough temperature, will flash in the presence of a spark or open flame. The temperature at which this occurs is called the flash point. Specifications usually require that asphalt not flash below 446^0F (230 ^{0}C).

2.4 Aggregate

Aggregate is an inert material such as sand, gravel, shell, slag, or broken stone, or combination of these materials. Aggregate is usually stored in stockpiles, but may be kept in silos or bunkers before being inserted into cold feed bins.

2.4.1 AGGREGATE STOCKPILES

Aggregate should be stored on a clean surface and the various sizes should be separated. The main things to avoid are contamination, degradation, and segregation. Contamination occurs when things get mixed in with the stone. If the stockpile is placed on mud or dirt, the dirt will work its way up into the stockpile. Degradation means that the stone becomes smaller through wear or by being broken. This usually does not change the gradation enough to cause problems, but if it does, the way in which the stone is handled should be changed. For example, try to avoid using tracked vehicles on the stockpile. Segregation means that the aggregate has become separated by size. Segregation must be kept to a minimum because it can cause large variations in the gradation of the paving mix. A primary cause of aggregate segregation is cone shaped stockpiles [16].

2.4.2 GRADATION AND SIZES

i) Aggregate Sizes

• Coarse Aggregate – material that is retained on a No.4 sieve

• Fine Aggregate – material that passes the No.4 sieve

• Mineral Filler (Dust) – material that passes the No.200 sieve

ii) Gradation

Gradation is a measure of the size distribution of the aggregate. The size distribution is determined as the percent passing specific sieves. In the metric system the size of a sieve is given as the measurement between the screen wires on opposing sides. In the US customary system, the sieve sizes 3/8" and larger are also defined by the opening. Sieves smaller than 3/8" are defined as the number of opening per linear inch, i.e. a No30 screen has 30 openings in a linear inch of screen.

iii) Specific Gravity

The density or specific gravity of aggregates must be measured for the analysis of asphalt mixtures. Density is the mass of a material divided by its volume. Specific gravity is the density of a material divided by the density of water at a specific temperature. Using the metric system, density and specific gravity are numerically equal, since the specific gravity of water is "1". The specific gravity must be determined for the individual stockpiles and an equation may be used to calculate the blended specific gravity of the aggregates.

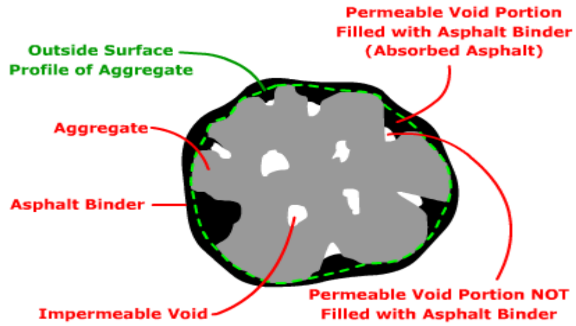


Figure 11: Definition Rock for Specific Gravity

Depending on the treatment of the volume of the aggregate, there are three types of specific gravity:

• Apparent Specific Gravity – the mass of the stone divided by the volume of the solid stone plus the internal voids.

• Bulk Specific Gravity – the mass of the stone divided by the volume of the solid stone plus the internal voids plus the volume of the external voids.

• Effective Specific Gravity – the mass of the stone divided by the volume of the solid stone plus the internal voids plus the volume of the external voids minus the volume of the absorbed asphalt. Determining the effective specific gravity can only be measured after the aggregate has been mixed with the binder.

2.5 REASERCH STUDIES

New knowledge and research results represent a significant, multifaceted contribution in terms of energy, ecology and economics. The energy-related contribution would be reflected in the increase of energy efficiency through the reuse of the energy potential of asphalt plant exhaust gases in the drying process of aggregates, ecological contribution would be the simultaneous reducing of the adverse impact of exhaust gases from asphalt plants on the environment, especially those pertaining to air quality. The economic contribution would be felt in the reduction of the cost of fuel (petroleum, gas, oil) required for heating the aggregate. All planned effects (contributions) are fully in line with the guidelines that prescribe the concept of sustainable development and reflect the potential and usability of the described model of management of thermal energy of exhaust gases in asphalt plants [17].

If the aggregate water content is increasing, combustion of the burner is decreasing. This is because inside water vaporized and the volume ratio of water and vapor becomes 1:1700. (The volume when water is changed into vapor at 100℃. If 200℃, it becomes 2200 times.) Therefore, lowering the water content is required in order to increase the plant output and to save fuels. If surface water is increased by 1%, the fuel consumption per 1Ton of ASCON is also increased by approximate 1ℓ. The water content of aggregates must be thoroughly controlled.

F. Yonar et al. Evaluated the performance of asphalt plants by making comparison between a real application case in Turkey and in the World. Production steps of asphalt plants are explained and the main tasks of plants are introduced regardless of production method, the main tasks of asphalt plants are compared for continuous and batch type plants. The plant types compared in terms of production performance, quality of product, quality control processes, efficiency and environmental tasks within conditions of Turkey. Finally, defects in aggregate gradation negatively affect the product's quality. These problems can be defeated in batch type plants, by the screening unit and hot bunkers. The most appropriate dyer must be chosen for the optimum capacity of the plant. Highest product quality may be provided by the optimum capacity [18].

Iain Gillespie; investigated the energy use at an asphalt coating plant based in Scotland, by identifying and quantifying the influence of factors that affect the energy use in asphalt production. The key finding is that the electrical consumption, fuel use and carbon cost was calculated as 8 kWh/tonne and 9 litres/tonne with a resulting estimated carbon emission of 28.8 $kgCO_2$/tonne. It was also found that it is more economical to have a daily plant throughput of at least 100 tonnes at the coating plant. The effect that sand moisture has on energy use was analysed and the results showed that fuel consumption increased by an average of 0.6 litres/tonne for each 1% increase in moisture content which equates to a carbon emission increase of 1.5$kgCO_2$/tonne. The impact that aggregate moisture content has on energy use was estimated as an average of 0.7 litres for each 1% increase in moisture content which equates to an estimated increase of 1.8$kgCO_2$/tonne. The primary key finding is that the monetary and carbon cost of fuel use is £6 per litre/tonne and 24.3 kg CO_2 per tonne which shows the higher carbon footprint of the fuel consumption when compared to the electrical consumption which was £0.56 per kWh/tonne and 4.5 $kgCO_2$ per tonne. When these values are totaled the estimated energy cost per tonne is £6.56 with a carbon emission of 28.8 $kgCO_2$ [19].

D. Peinado et al. employed energy and exergy analyses of a rotary dryer in a Hot Mix Asphalt (HMA) plant for heating and drying of the aggregates in the mixture. In the analysis, the exergy method in addition to the more conventional energy analysis, is employed to identify and evaluate the thermodynamic losses. The results show that, at design conditions, the plant performs with energy and exergy efficiencies of 0.89 and 0.18, respectively. The energy losses are mainly due to the flue gases. The exergy distribution indicates that the combustion and the heat transfer at different temperatures in the burner yield the highest exergy destruction in the process. A parametric study is conducted for the plant under various operational production parameters, including different humidities of the aggregates and filler content in aggregates, working temperatures and ambient conditions, in order to determine the parameters that affect the plant performance. It is shown that the solids humidity has a great impact on energy requirements. A better and sustainable use of the heat source employed in the dryer is proposed to avoid the high irreversibilities found. Furthermore, operating corrections in the mix or in the exhaust gas temperature are proposed to optimize the performance of the plant. It has been shown that the hot mix temperature and the solids humidity have great impact on the energy requirements for manufacturing HMA, although the influence on the energetic efficiency is low[20].

Xiaoyu Huang. et al. carried out analysis and prediction of energy consumption in hot mix asphalt, to decrease energy consumption in HMA, a prediction model of energy consumption was investigated employing kernel principal component analysis (KPCA) and a support vector machine (SVM). The purpose of the work is to optimize production and structure parameters of an HMA plant. The paper has analyzed various factors affecting fuel consumption in aggregate drying, which were measured. Based on KPCA, the main features affecting energy consumption were obtained. Results show that production, the temperature of the finished aggregate has the greatest influence on energy consumption. With the increase of aggregate temperature, the energy consumption is gradually increased. The flue gas temperature, production, and aggregate moisture content have a certain influence on the energy consumption, and the energy consumption increases with the increase of these factors. Drum pressure and airflow have positive or negative effects on energy consumption. The roller pressure and air flow have the best value in different production conditions. Controlled airflow and drum pressure are very important to energy savings. The difference between measured and predicted fuel consumptions was about ±5%, which meets the required prediction accuracy [21].

Zdravko Cimbola et al. conducted experimental analyses on the contribution of mineral mixtures dehumidification in reducing energy consumption and the possibility of using exhaust gas energy in the production process of asphalt mixture. The idea is to remove part of the moisture from the composition of mineral mixture using exhaust gas in the drying process. As part of the preliminary research stone material on a conveyor belt was exposed to convection drying taking into account air temperature, air velocity, belt speed, material layer thickness and drying time. For the experimental part of the project a laboratory device was structured consisting of drive fan unit / drying chamber with hot air, a device for measuring the mass of samples and devices for measuring the temperature of the samples. The speed of the conveyor belt allows exposure of the stone material to heat hot air for 30, 45 and 60 seconds. The temperature of the hot air was constant during each measurement simulate the conditions of heating hot air exhaust gas temperature by taking into account the thermal losses incurred by supplying exhaust gas to the conveyor belt. Measurements are provided for three air temperature achieved during experiment 33.1°C, 50.4°C and 71.7°C. First results show the energy potential of exhaust gas during the short-term drying process [22].

Kasthurirangan Gopalakrishnan et al. investigates the technical feasibility of using a hybrid wind energy system as a clean source of energy for operating an entire Hot-Mix Asphalt production facility. Since wind blows intermittently, the extracted wind energy will be stored in the form of hydrogen which is considered a lightweight, compact energy carrier, for later use, thus creating a ready source of electricity for the Hot-Mix Asphalt plant when wind is not present or when electricity demand is high. In the proposed innovation, a wind turbine will be installed on site at the HMA plant which will harness energy from the blowing wind. The goal is to use the power generated from the wind turbine to meet the load demand of all components (or at least the major energy consumers) of the HMA plant. Excess wind power will be diverted to the electrolyzer to generate hydrogen which can be stored using different options, the most feasible ones being compressed energy storage and metal hydride hydrogen storage. A hydrogen storage based wind energy plant constructed on site will house the hydrogen storage tanks [23]. Federico Autelitano et al. conducted an analytical-sensory characterization, mainly based on AOS approach, of asphalt emissions generated during the various stages of road pavement construction. The analytical and sensory analyses have firstly demonstrated the effective application of these instruments in the pavement engineering sector: an odor fingerprint of asphalt emissions, specific for each type of binder and temperature class, was determined. During the various stages of asphalt paving mixtures production and placement, as a result of the asphalt heating, gaseous blends characterized by an intrinsic complexity of substances and compounds are emitted into the atmosphere. The photoionization analyses confirmed as temperature represents the crucial factor in the generation of such emissions. A pseudo-hyperbolic relationship between the release of airborne substances, in the form of VOCs, and the heating temperature was identified. Specifically, a significant increase in asphalt emissions was registered for temperatures greater than 130 ^{0}C, that is, those typical of production and placement of traditional HMA mixtures. Moreover, a positive correlation between the amount of VOCs in the headspaces and the content of the more volatile fractions (saturated and aromatic) in the asphalt solid matrix was revealed [24].

Krishnareddygari Prathima et al.describes various air pollution emissions during the production of asphalt concrete. A 120 MTH plant was taken as a case study for this purpose. A gas flow of 0.5 m^3/s is emitted with CO (6 ppm), NO2 (0.1 ppm), SO2 (2 ppm) and other toxic gases (2.5 ppm). A dust emission of 1.2 mg/m^3 is emitted and is controlled by dust settling chamber. A stack height of 15m is required for complete dispersion in the atmosphere based on CPCB guidelines [25].

Laurédan Le Guen et al. present a physical model dedicated to the evolution in temperature and moisture of granular solids throughout the drying and heating steps carried out inside a rotary drum. An initial experimental campaign to visualize inside a drum at the pilot scale (i.e. 1/3 scale) has been carried out in order to describe the granular flow and establish the necessary physical assumptions for the drying and heating model. 1D model was developed using the energy and mass balance equation, along with a suitable coupling between heat and mass transfer at the aggregate scale. The model was validated with respect to gas temperature values, since a suitable evolution was obtained with the two approaches for different techniques (hot- and warm asphalt techniques). Nevertheless, a complete validation still needs to be performed on the entire set of parameters [26].

Peinado et al. analysed energy and exergy of a rotary dryer in HMA production in asphalt plant. The parametric study had shown great impact of HMA temperature and moisture on the energy requirements for producing of HMA, although the influence on the energetic efficiency was low [27].

Sivilevičius concluded the required temperature of HMA production, thus energy consumption, depends not only on the moisture and on temperature of mineral materials, fuel quality but also depends on the structure of asphalt mixing plant [28].

Grabowski et al. analyzed test and measurements results (in two time phases) of the energy consumption during HMA production. Results shown that reduction in overall aggregate moisture content of about 1% decreases the real oil consumption by about 18%. Also concluded the organizational changes in the work system of asphalt mixing plant may significantly influence the energy consumption in the HMA production without additional financial costs [30], [31].

Androjić analysed share of moisture in mineral mixture and energy consumption and concluded that increase in the temperature of a mineral mixture results in reduced natural gas consumption per ton of asphalt mixture produced. Based on boundary temperature curves the removal of 1% of moisture in mineral mixture resulted in 13.13% to 4.51% energy savings for material heating.

2.6 Scientific Gap

On the biases of literature survey, most of the studies on energy consumption are aimed on the experimental and theoretical area of the hot mix asphalt production plant. This results vary according to the production mode, service life of the mixing plant. Therefore, it is basically necessary to investigate energy utilization and better ways of energy reduction methods by identifying the most energy consuming process. In this study, the evaluation of thermal energy utilization is analyzed and the CFD modeling results are used to compare the minimization of energy used during aggregate drying process.

3. STUDY METHODOLOGY

The purpose of this section is to give an over view of the methodology used in the project with the sub sequent section content reflecting this methodology. The overall study methodology for this research work includes Analytical studies and Numerical Simulation. The numerical simulation will be carried out using Commercial CFD code ANSYS Fluent 16.

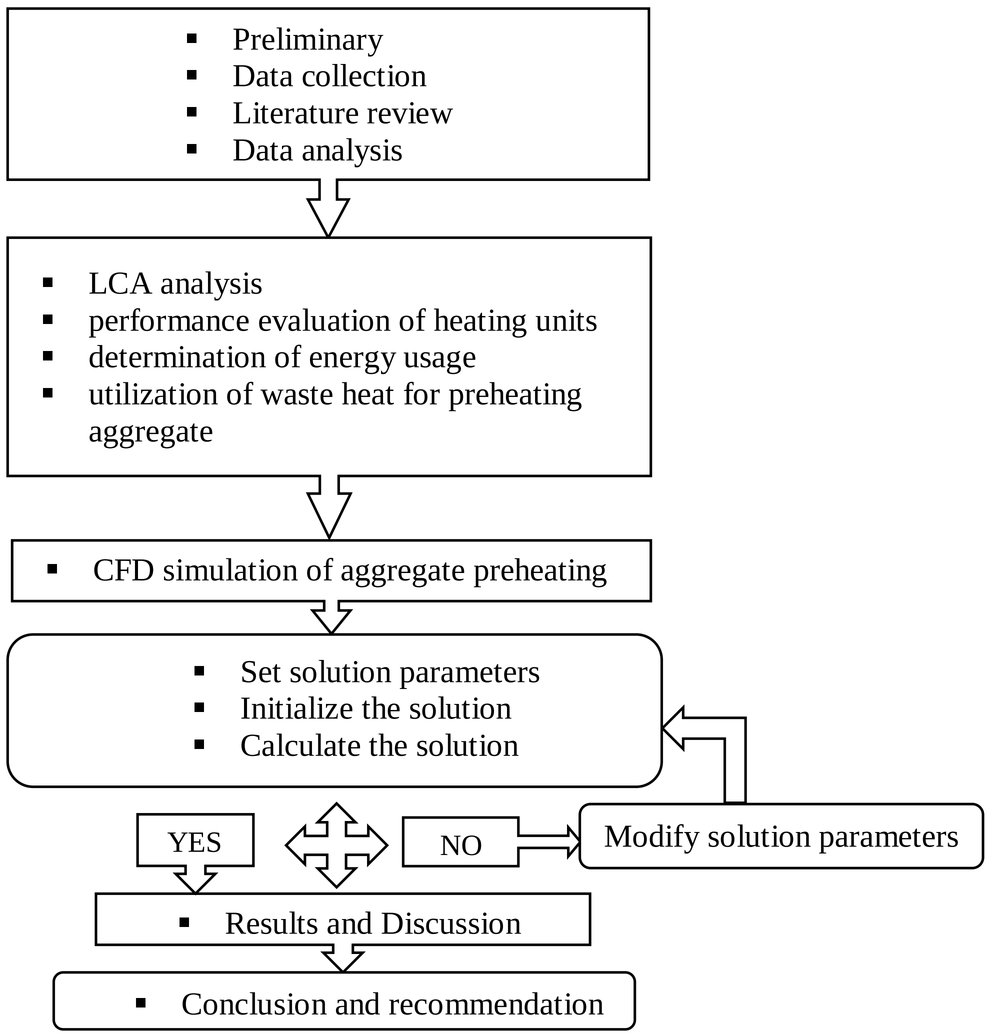


Figure 12 : Research flow diagram

3.1. Preliminary

There are two methods used for energy consumption data, to acquire the unit energy consumption. Field measurement, the transport vehicle and construction machinery energy consumption data is obtained from technical inspection done during the production. Records, the hot mix asphalt plant production data is gathered by reviewing and analyzing technical reports in accordance with the standards and, equipment usage reports from the site. In the introduction phase, the activities are below:

a. Observation: The observation can be performed based on the sources from field study. Field study is used to find out the condition in the company directly. In this phase the interview process with the supervisor and asphalt plant operators is to happen. The interview result is important to find out the image of the first condition and the problem occurred in the company.

b. The problem formulation and the objectives of the research: In this phase the problem in the production of the asphalt concrete and energy use will be identified. The identification held after the directly observation has been done. Based on the problem identification, the purposes of this observation are to minimize the consumption of energy and increase the production efficiency.

3.2. Data Collection

Data which is used in the observation is primary and secondary data. Primary data is the data which is procure from the source directly without expediter.

- Plant output and product based on the interview and observation with the employee.
- Machine specification, production slot, specification standard of product based on the interview and the observation with the asphalt plant operators.
- Production machine, raw material, and production process observation with the operator.
- Total fuel consumption of the plant which are based on the questionnaire's result.

Secondary data is the data which is procure from the other source. Secondary data is procure from the specification and asphalt plant operation and maintenance manual. By reviewing and analyzing technical reports in accordance with the standards and, equipment usage reports from the site.

3.3. Data Processing and Analysis

In this section there are 5 phases, such as Define, Measure, Analyze, Improve, and Control. DMAIC used as the problem solving method because this method is appertain as repaired process and the process which is effective to improve the quality. The phase of DMAIC explains below:

3.3.1 Define

In this phase, undertake an energy audit to collect the data on the overall site energy consumption and coating plant consumption. Document key aspects of the plant and obtain information on metering. Create a process flow diagram of the coating plant. Obtain information on current mixtures used at the coating plant.

3.3.2 Measure

Measure phase is the second operational step which is used to increase the quality based on the DMAIC method. The processing time for every process is obtained from the observations. The observations data for every process are going to be displayed on the controlling monitor.

3.3.3 Analyze

Analyze is the phase which is used to look for the main problem and the root cause of the problem. In this phase the activities or processes that consume the most energy. It is an important step towards determining how energy is utilized in the construction processes. Analytical evaluation of thermal energy utilization and heater efficiency is used for the coating plant.

3.3.3.1 LIFE CYCLE ASSESSMENT

Life cycle assessment is the factual analysis of a product's entire life cycle in terms of sustainability. It is a methodology that has been developed to evaluate the environmental impacts with respect to their process, their materials and energy use throughout the whole life cycle. With LCA, you can evaluate the environmental impacts of your product or service from fabrication to the end of its life, including the possible recycling methods. In this study with the integration of CFD simulation tool the LCA method is used to find the impact of excess energy utilization resulting from construction methods, energy concepts, components and products.

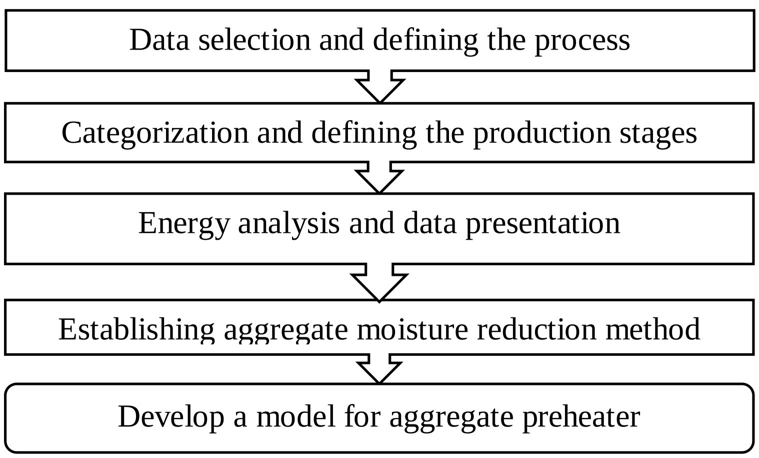


Figure 13: steps to develop the LCA analysis

3.3.4 Improve

Improve phase is use to improve the performance of production process by minimizing the excess fuel consumption and increase heater efficiency using the exhaust gas as a pre heater. The two dimensional Gas-Solid Heating CFD Modeling used to simulate drying in an aggregate pre heater designed to utilize the thermal potential of waste gases emitted from the exhaust gas in the production of hot mix asphalt and indirectly, reduce the amount of CO_2 emissions into the atmosphere.

3.3.4.1 CFD Modeling in Gas-Solid Heating

The computational fluid dynamics using Eularian granular multiphase model with heat transfer is used for predicting the temperature distribution along the dryer by heating solid with a gas at 398K. A two fluid model an Eulerian-Eulerian model (EEM) incorporating the kinetic theory of granular flow is selected as the modeling technique. The material properties of fluid and particle is chosen for the model from the fluent data base so that it can be used for the primary and secondary phases. At inlet of the dryer is gas superficial velocity for primary phase, while the secondary phase is zero inlet velocity. Lowering moisture of aggregates is achieved by the heat transfer from the exhaust gas and the solid particle. By using analytical calculation the moisture evolution is compared with numerical results of temperature distribution.

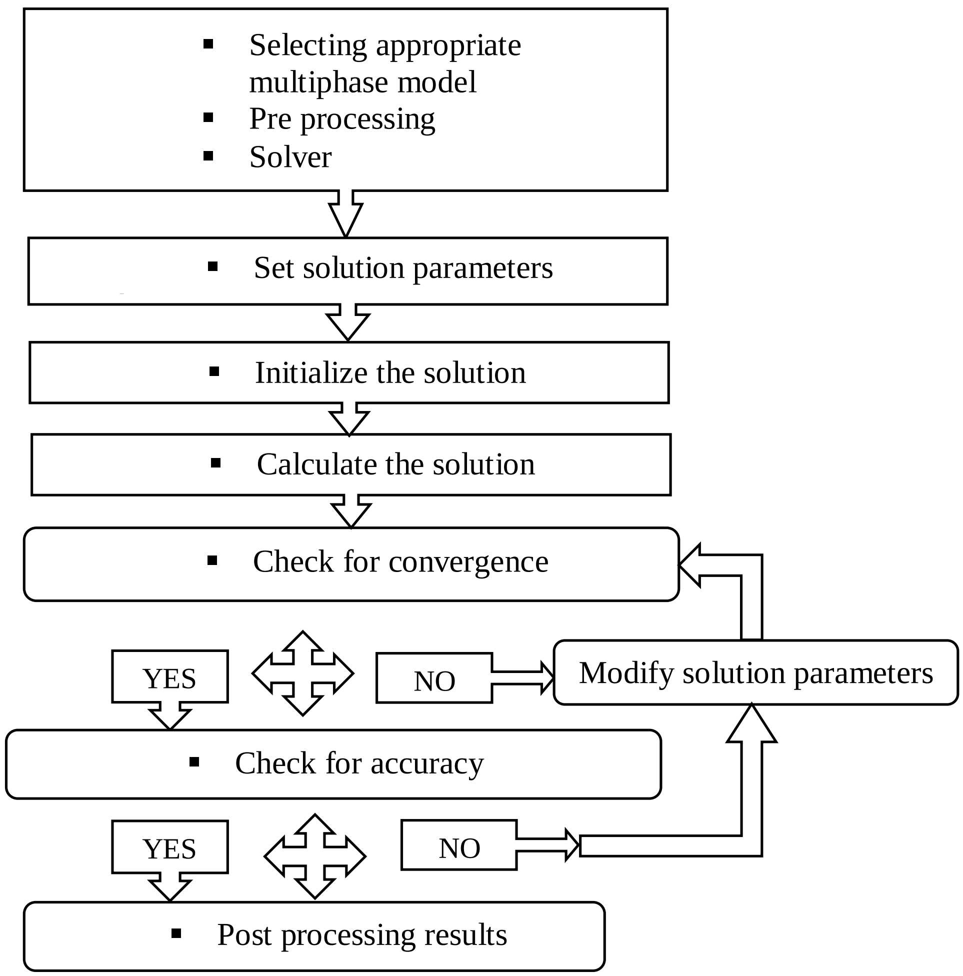


Figure 13: CFD parameters flow chart

3.3.4.2 PREHEATER DESCRIPTION

The idea is to remove part of the moisture from the composition of mineral mixture using exhaust gas in the drying process. Stone material on a conveyor belt is exposed to convection drying taking into account air temperature, air velocity, aggregate material diameter and drying time. Using a preheater in the asphalt plant at the location where the incline conveyor belt is positioned, so that the preheater could use the thermal potential of the exhaust gases for drying the stone material. The stone material will lose a certain percentage of moisture by passing through the preheater over a certain time. The asphalt batching plant has maximum capacity 60 tonne per hour.

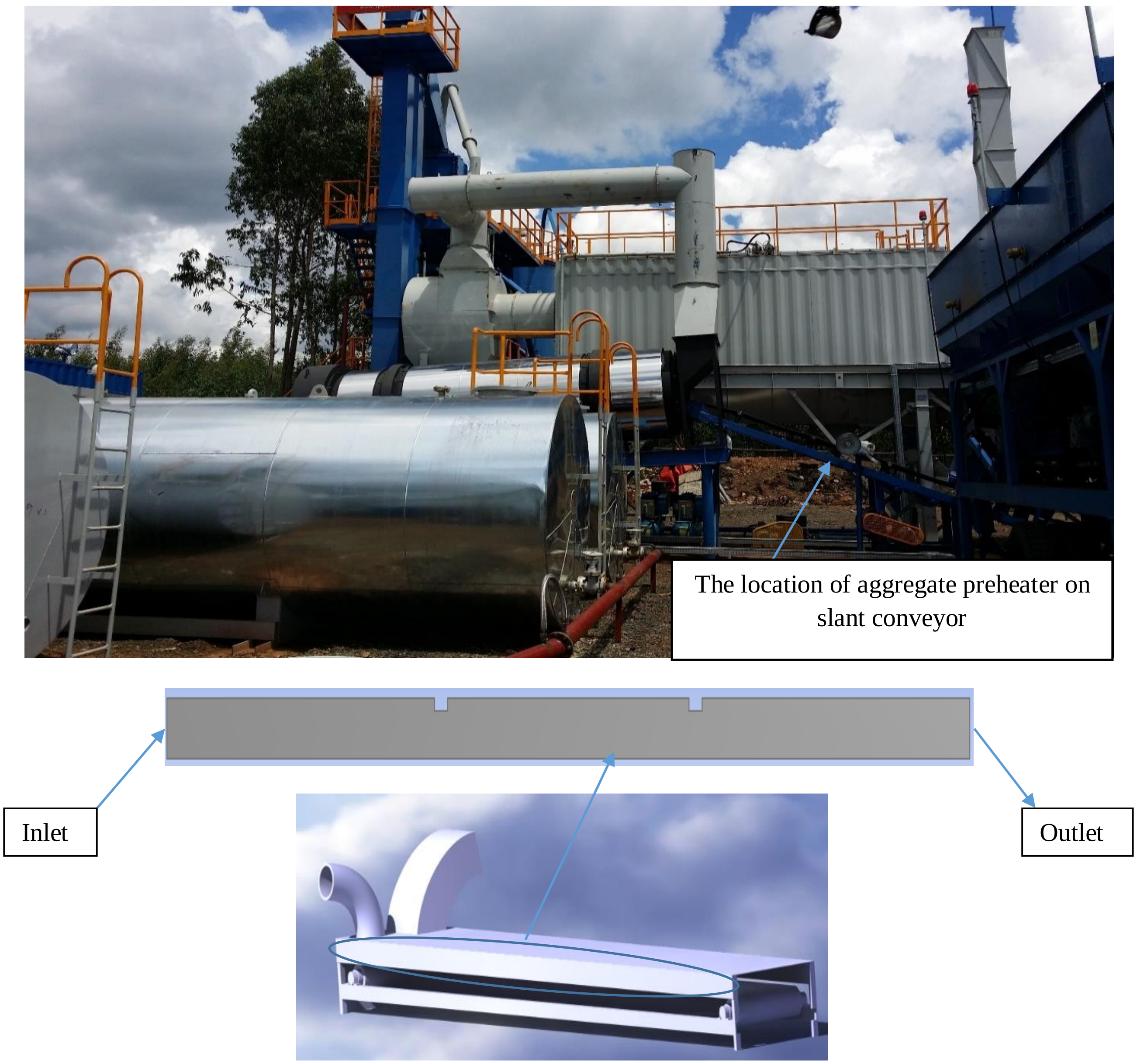


Figure 14: 3D Model of Aggregate Preheater

3.3.5 Control

In this phase, the methodologies and techniques to control drying and heating of the continuous mixing processing will be implemented. In normal working conditions of about 70% of the asphalt plant capacity, the open flame is between 1/2 and 3/4 of the total length of the rotary drum. The burner should be operated in stability in the adequate temperature range of 120 ~ 200^{0}c, since, in case of continuous operation in the low temperature under 110 ^{0}c, sulfur in the fuel of diesel and moisture are chemically reacted to form sulfuric acid and may cause corrosion inside the bag filter casing. In the rotary drum, the aggregate fractions are heated to a temperature higher than 165 °C. The amount of open flame can be controlled (increased or decreased) by an asphalt plant operator.

3.4 Study Area

The hot mix asphalt batching plant is located in jimma zone in the area called Deneba 300 kms far from Addis Ababa the capital city of Ethiopia. This research is based on a plant with an output capacity of 40-60 ton/hr.

A Google map approximate location of Asphalt Plant Site Location

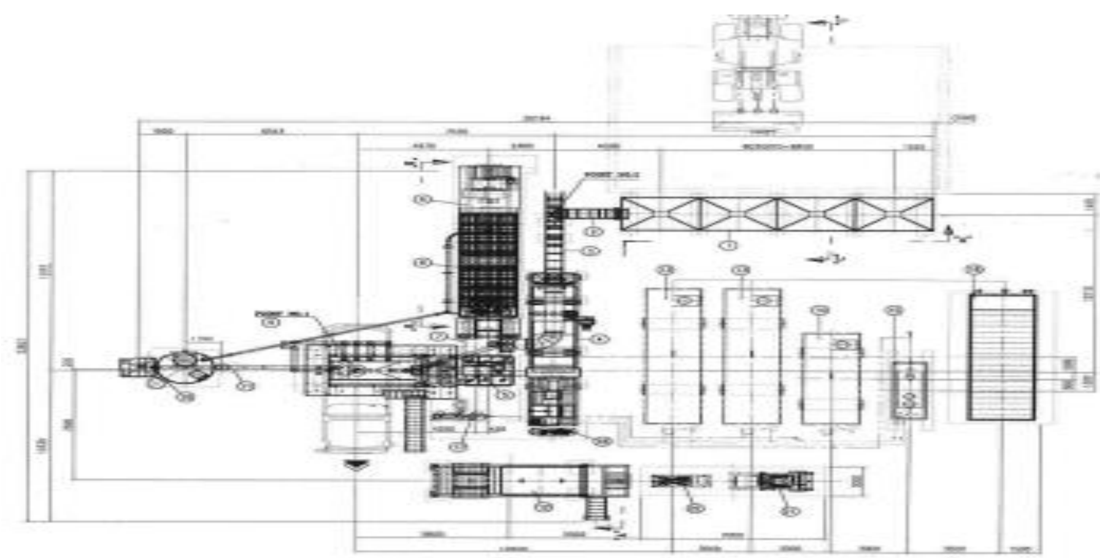


Figure 15 : Asphalt plant lay out

Table 1: Technical Specifications of the hot mix asphalt plant

Specification	**MASTER BATCH 800**
Nominal capacity at the humidity of initial materials (sand and broken stone) up to 4%, tons/h	40-60
Installed power, kW, maximum	450
Capacity of feeder bins, pcs.xm^3	5x8=40
Feeders types	belt-type, adjustable via frequency converter
Width of the conveyers belt, mm	605
Drying drum, Ø×L, mm	1550x6000
Power of drying drum drive, Kw	45
Power of burner, MW	12
Fuel type	liquid
Type of screen	inertial, self-balanced with two electric vibrators
Power of screen drive, Kw	2x7.6=15.2
Area of screen sieves 5/6 screen decks, m^2	25/28
Number of fractions of batched rock material, pcs.	5-6
Capacity of rock materials batcher, kg	1000
Capacity of mineral powder and dust batcher, kg	250
Capacity of bitumen batcher, kg	250
Capacity of hot rock materials bin, m^3	20
Heat insulation of hot rock materials bin	Available
Maximum mass of a batch, kg	1000
Power of mixer drive, kW	75
Capacity of mineral powder unit bin, m^3	10
Capacity of dust unit bins, m^3	20
Area of bag filters filtration, m^2	550
Total capacity of bitumen tanks, m^3	2x30=60
Type of bitumen heating element	Coil pipe with thermal oil
Total area of the coil pipe heat exchange in one tank, m^2	25

4. ENERGY PERFORMANCE EVALUATION AND THERMAL ANALYSIS OF HOT MIX ASPHALT PLANT

Effective energy management helps a company keep costs down and stay competitive. Companies can differ in the amount of energy they use even when they belong to the same industry, operate under the same market conditions, and use the same equipment. Plant energy assessments determine where and how much energy is consumed, and identify steps to improve the facility's energy efficiency and save money. The assessment can focus on the whole site and specific systems and processes. Sound, plant-wide energy management combined with energy–efficient technologies offer additional benefits, such as improved product quality, increased production, and process efficiency [32].

A life cycle usually begins at the extraction point of raw materials and energy carriers from nature. Nowadays, global warming is considered as a very serious problem on the earth. The problem has resulted in studies focusing on the reduction on energy consumptions and green-house gas (GHG) emissions of pavements constructions as well as other human activities (33). Typically, an LCA model of pavement consists of the following components: material, construction, use, maintenance and rehabilitation (M&R), and end of life (EOL).

4.1 ANALYSIS OF ENERGY USAGE ON ASPHALT PLANT

The overall energy consumption evaluation provides proper results of total thermal energy utilized on the process factory. The investigation involves four stages closely related to the diesel fuel and electrical energy usage including raw material production stage, asphalt mixture production stage, asphalt mixture transportation stage and construction stage. The raw materials are ingredients used for a production of hot mix asphalt. The drying and heating process is also required before mixing the mineral components. After mixing the hot mix asphalt product is transported to the paving site for paving and rolling process. The whole process consumes a large amount of energy which mainly supplied by diesel fuel. The diesel generators are also used to supply electrical energy for electrical controlling systems. This indicates the role of fuel energy is high for production of the mixture.

The Fuel Energy Density of Diesel Oil is 38.6 MJ/litre or 1182 Litre/Tonne or 45.6 GJ/tonne and 1 KWh is 3.6 MJ. The energy consumption of transport vehicle and construction energy consumption can be obtained by multiplying the power of transport vehicle or construction machinery by working hours. Based on the energy data statistics, the total annual consumption is summarized in to the amount per unit tonne of production energy utilization. This helps to understand the difference in the quantity of diesel fuel and electricity usage at each stage.

4.1.1 RAW MATERIAL PRODUCTION STAGE

Raw materials of the asphalt pavement engineering in the statistical cycle in this paper include bitumen, aggregate and dust. Because bitumen is one of the many petroleum products made from crude oil, and refining crude oil is a complex procedure, proper allocation of the environmental flows from the entire crude oil acquisition through refining process to asphalt production is difficult. Some rock dust is needed in a paving mix. It fills the spaces between the coarse aggregate particles, reducing the need for asphalt and adding stability. Too much dust causes problems. The dust coats the coarse aggregate so that the asphalt cannot stick to it, or it may combine with the asphalt making it brittle [34]. The amount of dust generated depends on the type of aggregate used and plant's dust collecting system.

The aggregate required for pavement production is produced using two crushing plants and filler is produced using a sand making plant. The annual aggregate and filler production and total fuel consumption analysis is listed in the table below.

Table 2: Annual Energy Consumption of Aggregate and Filler Production

Production Month	Aggregate (t)	Filler (t)	Electricity (KWh)	Diesel fuel (l)	Energy Consumption (MJ)
April 2019	8640	480	69120	4320	415584
May 2019	7020	390	56160	3510	337662
June 2019	9720	540	77760	4860	467532
July 2019	5130	285	41040	2565	246753
August 2019	6480	360	51840	3240	311688
September 2019	4860	270	38880	2430	233766
October 2019	3348	186	26784	1674	161038.8
November 2019	5886	327	47088	2943	283116.6
December 2019	2700	150	21600	1350	129870
January 2020	4860	270	38880	2430	233766
February 2020	8100	450	64800	4050	389610
March 2020	7992	444	63936	3996	384415.2
Total	74736	4152	597888	37368	3594801.6
Unit energy consumption	1	1	7.6	0.5	45.6

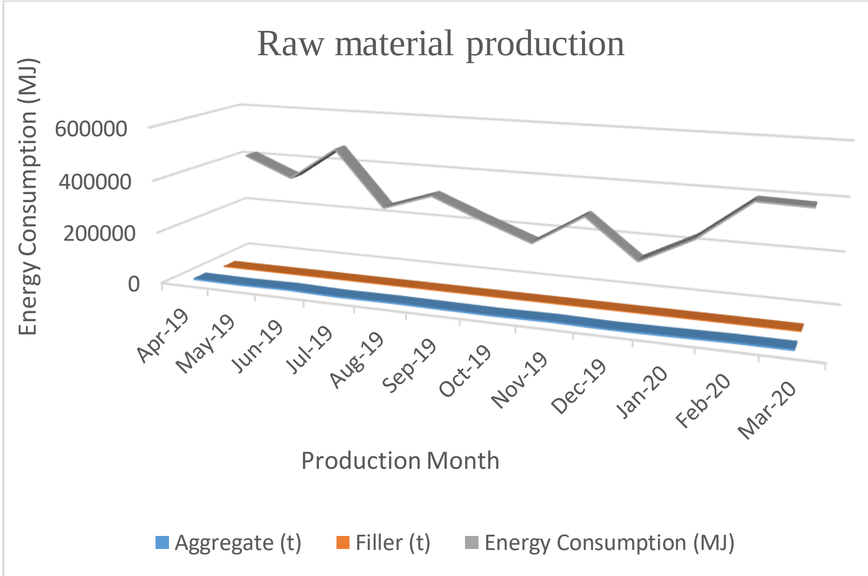


Figure 16: Annual raw material production

4.1.2 ASPHALT MIXTURE PRODUCTION STAGE

The factors influencing the energy consumption of mixing plants include production mode (continuous production, intermittent production), service life of the mixing plant and water content in aggregate etc. The batch type plant implements scaling and mixing operations for each production. The mixing ratio change, and the temperature and mixing time control based on mixtures can be managed precisely [35].

The capacity calculation method

Output Q = Mixer capacity (TON) X △BATCH quantity

Aggregates, heated in the proper temperature, are injected into the hot bin and then injected into the mixer through the scale bin.

The optimal control temperature for ASCON productions are as follow:

Heated and dried aggregates (150℃ ~ 170℃)

Mixtures (ASPHALT) 145℃ ~ 165℃

Funnel temperature (90℃ ~ 110℃)

The temperature of the dryer outlet is usually higher than the temperature of the hot bin by 20~30℃.The standard water content in aggregates is 5%.

Table 3: Annual Energy Consumption of Asphalt Mixture Production

Production Month	Asphalt Mixture (t)	Electricity (KWh)	Diesel fuel (l)	Energy Consumption (MJ)
April 2019	9600	80000	41600	1893760
May 2019	7800	65000	33800	1538680
June 2019	10800	900000	46800	2130480
July 2019	5700	47500	24700	1,124,420
August 2019	7200	60000	31200	1420320
September 2019	5400	45000	23400	1065240
October 2019	3720	31000	16120	733832
November 2019	6540	54500	28340	1290124
December 2019	3000	25000	13000	591800
January 2020	5400	45000	23400	1065240
February 2020	9000	75000	39000	1775400
March 2020	8880	74000	38480	1751728
Total	83040	692000	359840	16381024
Unit energy consumption	1	8.333	6.33	197.67

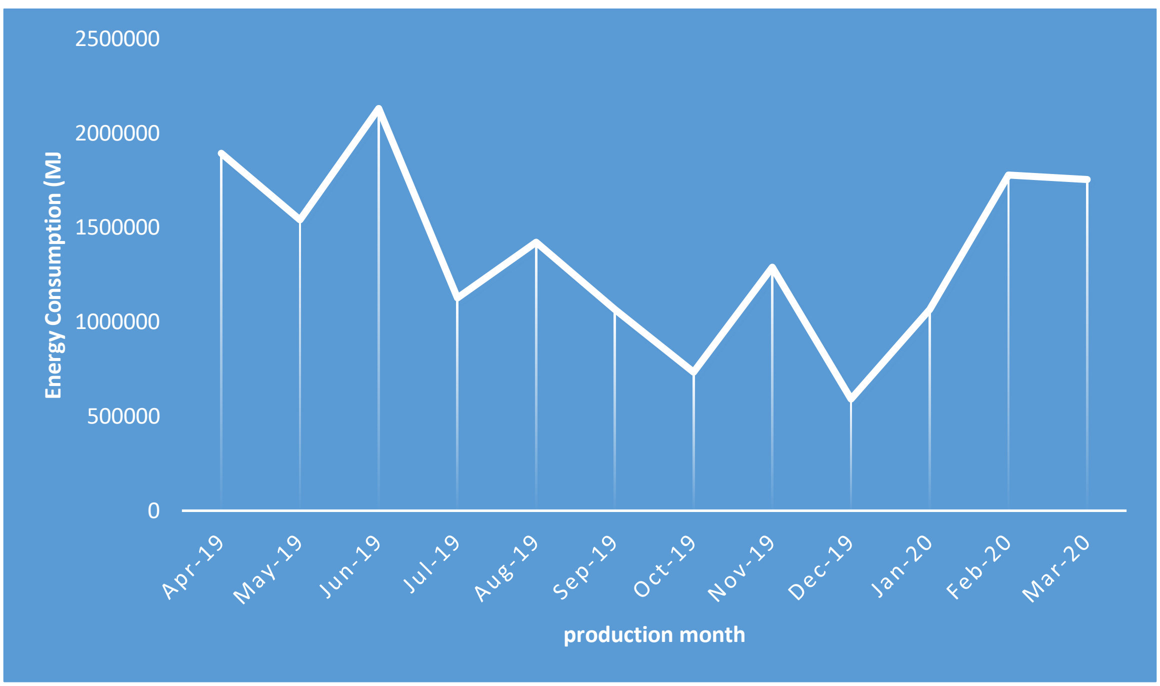


Figure 17: Annual asphalt mixture production

4.1.3 ASPHALT MIXTURE TRANSPORTATION STAGE

The energy consumption for asphalt mixture transportation is mainly generated in the process of transporting the mixed asphalt mixture from the mixing plant to the construction site. The energy consumption in this process mainly involves the load capacity of the transport vehicle, total volume of the asphalt mixture transported, shipment distance and the traffic conditions [36]. The cycle capacity C of a piece of equipment is defined as the number of output units per cycle of operation under standard work conditions. The capacity is a function of the output units used in the measurement as well as the size of the equipment and the material to be processed. The cycle time T refers to units of time per cycle of operation. The standard production rate R of a piece of construction equipment is defined as the number of output units per unit time. Hence:

$R = C/T$ or $T = C/R$

Generally speaking, the smaller the load capacity is, the more the total volume of the asphalt mixture will be; and the longer the shipment distance is, the larger the fuel consumption during the process of transporting asphalt mixture will be. In the actual production process, the output of asphalt mixture is closely related with quantities and it is hard to artificially reduce the output.

Table 4: Annual Energy Consumption of Asphalt Mixture transportation

Production Month	Asphalt Mixture (t)	Total volume (ton/Km)	Average hauling distance (Km)	Diesel fuel (l)	Energy Consumption (MJ)
April 2019	9600	316800	33	23760	917136
May 2019	7800	288600	37	21645	835497
June 2019	10800	453600	42	34020	1313172
July 2019	5700	17100	3	1282	49504
August 2019	7200	50400	7	3780	194544
September 2019	5400	54000	10	4050	156330
October 2019	3720	44640	12	3348	129232.8
November 2019	6540	98100	15	7357	283980.2
December 2019	3000	51000	17	3825	147645
January 2020	5400	102600	19	7695	297027
February 2020	9000	216000	24	16200	625320
March 2020	8880	248640	28	18648	719812.8
Total	83040	1941480	-	145610	5620546
Unit energy consumption	1	-	-	1.75	67.68
Unit energy consumption (ton/Km)	-	1	-	0.075	2.895

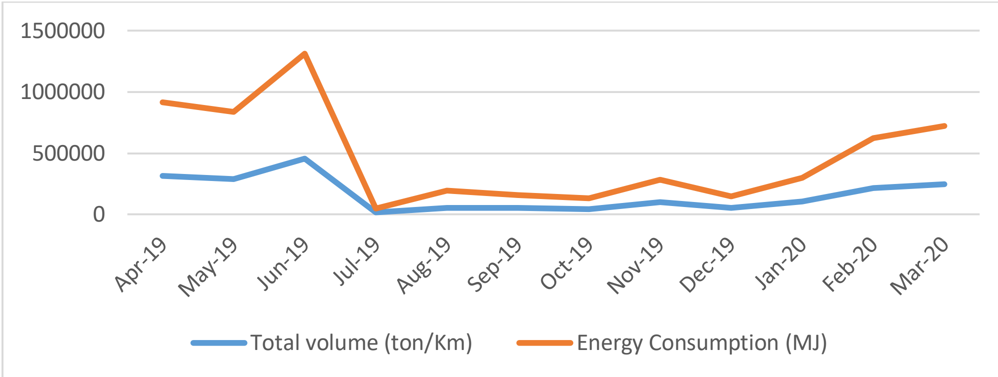


Figure 18: Annual transportation energy consumption

4.1.4 ASPHALT MIXTURE PAVING STAGE

The energy consumption of construction equipment is mainly generated in the asphalt mixture paving and rolling processes. The energy consumption in these processes mainly involves the types of construction machinery and construction technology [37]. Asphalt pavement construction machineries include pavers, double drum rollers, rubber tire rollers etc. To start the paving operation, the paver is positioned properly onto the road. The screed of the paver is lowered onto block of the same depth of the loose asphalt mat that is going to be laid on the road. After that, the block can be removed and paving can start. Rollers should be moved in a slow but uniform speed to achieve the best result.

Table 5: Annual Energy Consumption of Asphalt Mixture Paving

Production Month	Asphalt Mixture (t)	Diesel fuel (l)	Energy Consumption (MJ)
April 2019	9600	6192	239011.2
May 2019	7800	5031	194196.6
June 2019	10800	6966	268887.6
July 2019	5700	3676	141893.6
August 2019	7200	4644	179258.4
September 2019	5400	3483	134443.8
October 2019	3720	2399	92601.4
November 2019	6540	4218	162814.8
December 2019	3000	1935	74691
January 2020	5400	3483	134443.8
February 2020	9000	5805	224073
March 2020	8880	5727	221062.2
Total	83040	53559	2067377.4
Unit energy consumption	1	0.645	24.9

4.2 Annual Production Statistics

The reinforcement of this composite is the graded aggregates which constitute approximately 90% in mass of the mixture. The matrix consists of a mastic composed by the bitumen, the filler and, sometimes additives; where the bitumen is the 5% of the mixture, and the filler the remaining 5%. Although, these proportions can vary depending on the recipe of the mixture. The total annual production of asphalt mixture as well as the total consumptions of asphalt and aggregate calculated in accordance with total production of asphalt mixture and bitumen aggregate ratio is given in Table

Table 6: Annual Material Consumption

Production Month	Asphalt Mixture (t)	Bitumen	Aggregate	Filler
April 2019	9600	480	8640	480
May 2019	7800	390	7020	390
June 2019	10800	540	9720	540
July 2019	5700	285	5130	285
August 2019	7200	360	6480	360
September 2019	5400	270	4860	270
October 2019	3720	186	3348	186
November 2019	6540	327	5886	327
December 2019	3000	150	2700	150
January 2020	5400	270	4860	270
February 2020	9000	450	8100	450
March 2020	8880	444	7992	444
Total	83040	4152	74736	4152

4.3 Heat Transfer and Energy Loss in Bitumen storage tanks and heaters

Bitumen should always be stored and handled at the lowest temperature possible, consistent with efficient use. Bitumen in all of asphalt mixing plant (AMP) is stored at the temperature of 160 °C, and its temperature shall be the same in the whole system. Storage and preparation for use of bitumen necessary for HMA mixture production is an energy-consuming and expensive process. Bitumen of various marks is usually stored at the temperatures of 150–170 °C.

Figure 19: Hot thermal oil heater

At higher temperatures and lower viscosities pumping is optimized; whereas at lower temperatures and higher viscosities pumping efficiency decreases rapidly. Thus viscosity and its control by temperature is an important consideration in respect to all handling operations. The minimization of bituminous hardening during storing, transportation and mixing depends on careful control of binder temperature. The heat required to raise asphalt temperatures is given by;
Heat required = weight x specific heat x temperature difference.

$Q = \mathrm{m} \cdot C_P \Delta T$……………………………………………………………. (1)

During the asphalt mixing process two bitumen storage tanks having capacity of 30,000 liters each are filled with binder. Weight – 0.95 kg per liter, Specific heat – 0.53KJ/kgK. Temperature is raised and maintained for 24 hours. 1000 liters at 0.95 kg per liter is 950 kg, heat required to raise 1 kg of bitumen one degree is 0.53KJ/kgK the total amount of heat required to heat the asphalt from 298K to 433K is;

$$Q = \mathrm{m} \cdot C_P \Delta T$$

$$Q = 950\mathrm{kg} * 0.53\mathrm{KJ/kgK} * (433 - 298)K$$

$$Q = 67.97\ MJ$$

Systems with hot oil heaters are the most versatile systems. They can be used for virtually any type of plant, any size of plant and for any type of asphalt material including PMACs. Moreover, hot oil heaters rival direct-fired tanks in thermal efficiency. While some issues—such as the thermal efficiency of asphalt heating—may seem less important than considerations for drying aggregate, all are important in the long run. The thermal efficiency of a hot oil heater relates the amount of heat that the burner produces to the amount of heat actually transferred to the thermal fluid flowing through its coil.

$$E_{th} = \left(\frac{H_{input} - H_{loss}}{H_{input}}\right) x\ 100 \quad \ldots\ldots (2)$$

Where; E_{th} is the percentage thermal efficiency (net), H_{input} is the heat input and H_{loss} is the heat loss.

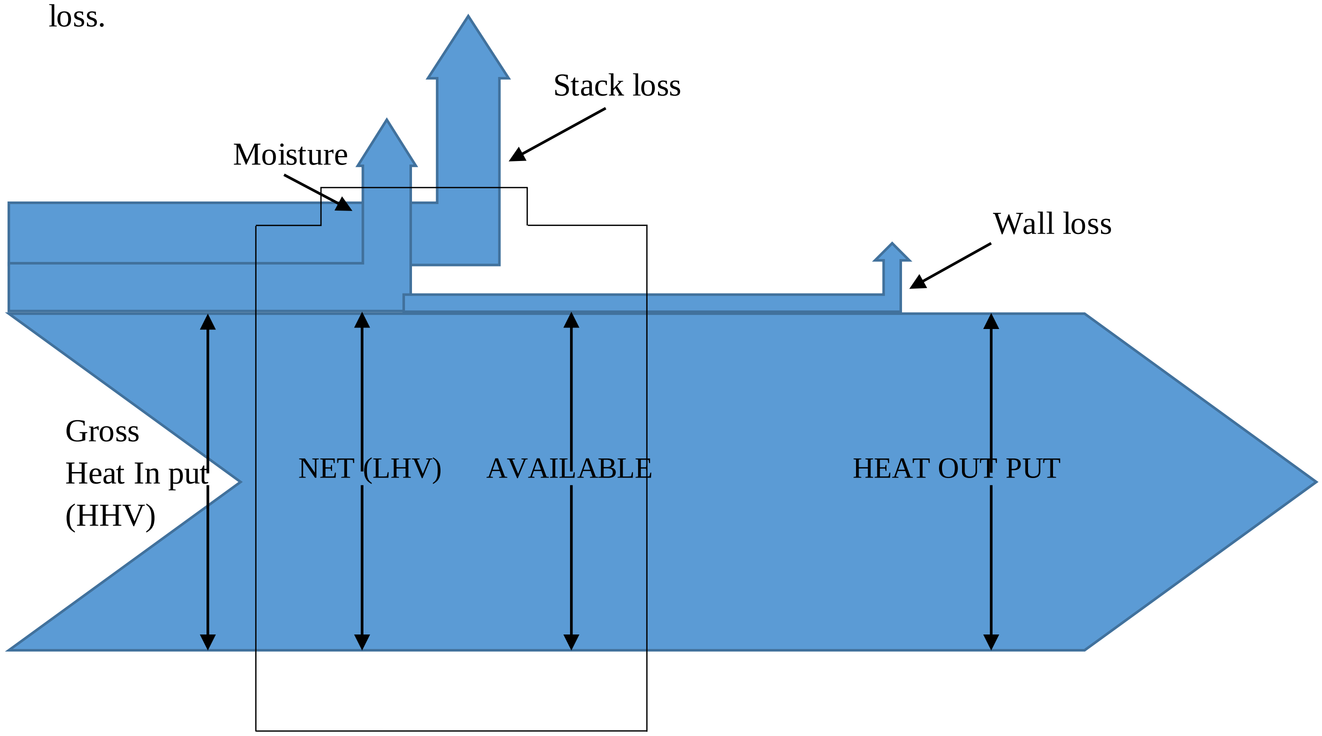


Figure 20: Heater Thermal Efficiency

The most important factors influencing on the rate of heat flow in a bitumen tank is bitumen content and temperature in a tank; however, the flow is impacted by other factors as well. In a bitumen tank heat may be transferred in three ways: through conduction, convection and radiation. In convection, heat is transferred by liquid or gas. Convection heat transfer is always related to the conduction heat transfer all liquids and gases are more or less conductive to heat. The rate of convection heat transfer is calculated as follows:

$$Qc = AU\,(T_b - T_{air}) \quad \ldots\ldots (3)$$

Here Q_c – convective heat transfer, W; U – the overall heat transfer coefficient W/(m^2 .°K); T_b – bitumen temperature, °K; T_{air} – ambient air temperature, °K.

Suppose the process of heat transfer is stationary, then heat transfer coefficient U is equal to:

$$U = \frac{1}{\frac{1}{\propto_1} + \frac{\sigma_1}{\lambda_1} + \frac{\sigma_{insul}}{\lambda_{insul}} + \frac{\sigma_3}{\propto_1} + \frac{1}{\propto_2}} \quad \ldots\ldots (4)$$

Here $\propto_1$ – the individual convection heat transfer coefficient for bitumen, W/m^2.°K; σ_1 – steel wall thickness, m; λ_1 – the thermal conductivity of the steel, W/m.°K; σ_{insul} – insulation thickness, m; $\boldsymbol{\lambda_{insul}}$ – the thermal conductivity of the insulation, W/m.°K; σ_3 – tin sheet thickness, m; $\boldsymbol{\lambda_3}$ – the thermal conductivity of the tin sheet, W/m.°K; $\boldsymbol{\propto_2}$ – the individual convection heat transfer coefficient for ambient air, W/m2 .°K.

Thermal radiation propagates through the vacuum of space. The heat of the hotter part of the body turns into radiation energy and propagates by electromagnetic waves in all directions. When it is transferred to another body, it may sink and become heating energy. Bitumen of average temperature T_b and heat transfer coefficient $\boldsymbol{\propto_1}$washes from one side through a multi-layered wall, the thickness of which are $\boldsymbol{\sigma_1}$, $\boldsymbol{\sigma_{insul}}$, $\boldsymbol{\sigma_3}$ heat conductivity coefficients $\boldsymbol{\lambda_1}$, $\boldsymbol{\lambda_{insul}}$, $\boldsymbol{\lambda_3}$ and surface area A; whereas on the other side it is exposed to air at T_{air} and $\boldsymbol{\propto_2}$, $T_b > T_{air}$. The temperatures of wall surfaces are not known, but it is clear that $T_{s1} > T_{s2} > T_{s3} > T_{s4}$, as $T_b > T_{air}$.

It is possible to transfer heat by radiation from one place to another in two cases: when the surfaces of the bodies are parallel and when one body surrounds the other. In the first case and in the case under investigation the heat flow is calculated according to Stefan-Boltzmann law:

$$Q_r = \varepsilon_s C_o A_1 \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \quad \text{...} (5)$$

Here Q_r – heat flux, W; T_1, T_2 – body surface temperature, °K; $\boldsymbol{\varepsilon_s}$– emissivity is the ratio of a surface's ability to emit radiant energy compared with the ability of a perfect black body of the same area at the same temperature.; C_0 – Stefan-Boltzmann constant (5.67 W m^{-2} $°K^{-4}$).

The total heat flux due to convection and radiation is calculated:

$$Q = Q_{RAD} + Q_{CONV} \quad \text{..} (6)$$

When the general heat flow is determined, the amount of energy necessary to restore the workable bitumen temperature may be calculated due to radiation and convection.

4.3.1 Calculation of Heat Losses

The heat flow through pipe insulation with outer diameter d_o and inner diameter (of the insulation equal to outer diameter of the pipe) d_i is l

$$Q_r = \frac{2\pi k l \Delta T}{\ln\left({d_0}/{d_i}\right)} \quad \text{..} (7)$$

Where l is the length of the pipe, k is the thermal conductivity of the insulation material, and $\boldsymbol{\Delta T}$ is the temperature difference between the inner and outer walls of the insulation ($\boldsymbol{\Delta T}$ may be approximated as the temperature difference between the temperature of the fluid in the pipe and the ambient temperature).

In the case of a composite pipe (e.g. a metal pipe with several layers of lagging) the most convenient approach of calculating for the heat flow is to express the relationship between heat loss (transfer) and temperature difference in terms of a thermal resistance R_{th}.

Therefore,

$$Q_r = \frac{\Delta T}{R_{th}} \quad \text{...} (8)$$

For each insulation layer the thermal resistance R_{th} is defined as

$$R_{th} = \frac{1}{2\pi k l} \ln\left({d_0}/{d_i}\right) \quad \text{..} (9)$$

Thermal resistance of a fluid film on the inside and outside surfaces can be treated by using the equation

$$R_{outside} = \frac{1}{K_{ho} A_o} \quad \text{...} (10)$$

Where A_o is the outside surface area, given by $2\pi r_o$, and K_{ho} is the heat coefficient for the outside surface.

$R_{inside} = \frac{1}{K_{hi}A_i}$ …………………………………………………………… (11)

Where A_i is the inside surface area, given by $2\pi r_i$ and K_{hi}- is the heat coefficient for the outside surface.

The total resistance to heat flow is then expressed as

$R_{Tth} = \frac{1}{K_{hi}A_i} + \Sigma \frac{1}{2\pi kl} \ln\left({}^{d_0}/_{d_i}\right) + \frac{1}{K_{ho}A_o}$ ……………………………. (12)

4.3.2 Calculation of rate of heat losses at Bitumen

Internal diameter of mild steel pipe = 0.15 m
External diameter of mild steel pipe = 0.17m
Length of pipe = 10 m
Heat transfer coefficient of Bitumen = 649525.9 W/m^{2}K
Thermal resistances for mild steel = 0.06645 K/w
Total resistance to heat flow is calculated as;

$$R_{Tth} = \frac{1}{\pi * 649525.9 * 0.15 * 10} + 0.06645 \frac{\text{K}}{\text{W}} + \frac{1}{\pi * 0.17 * 50 * 10} = 0.07 \text{ K/W}$$

The rate of heat loss by bitumen is given by

$$Q = \frac{(413 - 298)}{0.07} = 1.643 \text{ KJ}$$

4.3.3 Calculation of rate of heat losses at Thermia B

Internal diameter of Thermia b mild steel pipe = 0.1 m
External diameter of mild steel pipe = 0.12 m
Thermal conductivity of mild steel = 48.2 W/mK
Length of pipe = 10 m
Heat transfer coefficient of Bitumen = 226.163 W/m^{2}K
Thermal resistance for mild steel = 0.06645 K/w
Total resistance to heat flow

$$R_{Tth} \frac{1}{\pi * 226.163 * 0.1 * 10} + 0.06645 \text{ K/w} + \frac{1}{\pi * 50 * 0.12 * 10} = 0.073 \text{ K/W}$$

The rate of heat loss by Thermia B as it is pumped to the storage tank is computed as;

$$Q = \frac{(473 - 298)}{0.073} = 2.4 \text{ KJ}$$

The heat loss by bitumen and Thermia B is 1.643 + 2.4 = 4.043 KJ
The thermal efficiency of asphalt heating relates the amount of heat that the burner produces to the amount of heat actually transferred to the thermal fluid flowing through its coil is calculated as;

$$E_{th} = \left(\frac{H_{input} - H_{loss}}{H_{input}}\right) x\ 100$$

$$E_{th} = \left(\frac{67.97 - 4.043}{67.97}\right) x\ 100$$

$$E_{th} = 94.05\%$$

4.4 Analysis of the Heat Transfer and Energy Loss on Aggregate Dryer

The HMA is manufactured in asphalt plants which are an assembly of equipment that performs the following operations: store and feed the HMA constitutive materials, process them if necessary, dose and mix the materials, and store the final product. This work will be concerned with the three main constitutive materials: the aggregates (comprising the fine and coarse aggregates) the bitumen and the dust filler. The aggregates, separated by sizes, are stored in bins where the initial volumetric dosing is made. Later, they are dried and heated up to an appropriate temperature to mix them efficiently. This process is made at a direct fired rotary dryer. The binder is stored in tanks, which are maintained at enough temperature to reduce its viscosity.

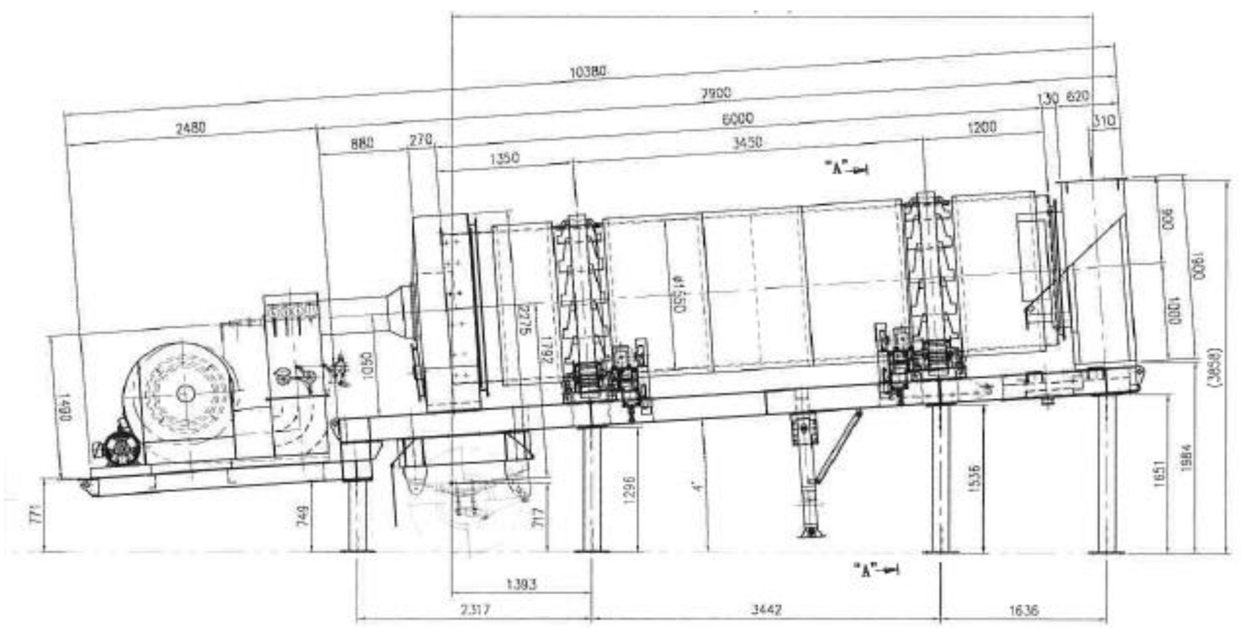


Figure 21: Aggregate dryer

4.4.1 Governing Equations of Heat Transfer

Particle temperature evolutions due to heat conduction among particles are shown as:

$$m_P C_P \frac{dT_{P,i}}{dt} = \sum \dot{Q}_{Pi-Pj} + \dot{Q}_{Pi,source} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(13)}$$

Where the rate of heat conduction flux by particle contacts is $\dot{Q}_{Pi-Pj}$; $\dot{Q}_{Pi,source}$ is the rate of heat conduction flux by other sources; m_P,C_P ,$T_{P,i}$, are the particle mass, specific thermal capacity, and temperature respectively;

4.4.2 Thermodynamics balance

Thus, rotary drum may be considered as an open system at steady state obeying to a thermodynamics balance from several assumptions:

$$\dot{W} + \dot{Q} = \dot{m}\left[\left(h_{out} + \frac{V_{out}^2}{2} + gz_{out}\right) - \left(h_{in} + \frac{V_{in}^2}{2} + gz_{in}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(14)}$$

The combustion operation produces a flame and hot gases essential for the drying and heating materials. The energy supplied by combustion can be expressed according to:

$$\dot{Q}_{fuel} = \dot{m}_{Fuel} \cdot LHV \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(15)}$$

Where $\dot{m}_{Fuel}$ the fuel is mass flow rate and LHV is the Low Heating Value of fuel. Gas combustion volume flow depends on the fuel used. The diesel fuel is mass flow rate for heating aggregate is 5.33 lit/min and the LHV for one liter diesel fuel is 38.6 MJ. Therefore; the energy supplied by combustion is;

$$\dot{Q}_{fuel} = 5.33lit * 38.6\text{MJ/lit}$$

$$\dot{Q}_{fuel} = 201.4MJ$$

The fuel mass flow,m_F can be determined from the energy balance, depending on the solid mass flow of solids to be processed in the plant, $m_{S_{in}}$. In particular, the mass of water generated in the combustion per unit mass of fuel, K_{H_2O} is around 0.05 % wt of the fuel. The air–fuel ratio is simply the ratio of the amount of air in a reaction to the amount of fuel. The reaction between diesel fuel oils and atmospheric air mass air-fuel ratio φ of 14 kg air/ kg fuel with a stoichiometric ratio λ to be 2.5. For a given mass of fuel, m_F, the necessary dry air, m_a, the water vapor generated, $\boldsymbol{m_{vc}}$, in combustion and the dry combustion, gases Mass , m_{dcg}, can therefore be calculated as:

$$m_a = \lambda \cdot \varphi \cdot m_F \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(16)}$$

$$m_a = 2.5 * 14kgair/kgfuel * 5.33kg$$

$$m_a = 186.6\ kg$$

$m_{vc} = \mathrm{K_{H_2O} m_F}$ …………………………..……………………… (17)

$m_{vc} = 0.05 * 5.33\mathrm{kg}$

$m_{vc} = 0.2665\ \mathrm{kg}$

$m_{dcg} = (1 + \lambda \cdot \varphi\ \mathrm{K_{H_2O}})\mathrm{m_F}$ ………………………….…………. (18)

$m_{dcg} = (1 + 2.5 * 14 * 0.05) * 5.33$

$m_{dcg} = 14.66\ kg$

The mass of solids, m_s, entering the dryer can be divided in two: the mass of the aggregates, m_{ag}, and the mass of the aggregate dust (filler), $m_{ag,d}$. When the aggregates are dried and heated in the rotatory dryer, part of the aggregate dust is elutriated with the flue gases, $m_{e,d}$, and the rest is retained with the solids, $m_{r,d}$. Since the HMA recipe specifies the content of dust filler in the final mixture, $m_{m,d}$, which is larger than the amount of dust filler retained in the solids, an extra amount of filler, $m_{i,d}$, has to be injected in the mixing tower. This injected filler will be either commercial filler dust or part of the elutriated dust recovered in the bag filter. It is useful to define the mass fraction of the filler at the different steps of the process: the mass fraction of filler at the entrance of the dryer, f_{ag}, retained in the aggregates, f_r, or elutriated with the flue gases, f_e, are calculated as the ratio of mass of the dust to the solids mass, m_s, whereas the mass fraction of the filler in the final mixture, f_m, is defined as the ratio of the dust in the HMA to the mass of aggregates and filler in the mixture ($m_m = m_{ag} + m_{r,d} + m_{i,d}$).

4.4.3 Mass and energy balance calculations

To establish the energy balance, we have distinguished the dry combustion gases,m_{dcg}, and the water vapor mass flow, $m_{V_{out}}$at the dryer outlet. The later is divided in the contributions of the air inlet humidity,$m_{V_{in}}$, the drying process, $\boldsymbol{m_{vD}}$, and the combustion generated water, m_{vC}.

The mass flow of liquid water associated to a wet solid is expressed as $m_w = Xm_s$. The solids humidity at the outlet, X_{out}, is also related to the solid mass, m_S. The atmospheric water vapor content is $m_V = \omega m_a$, we have:

$m_{v_{in}} = m_a \omega_{in} = \lambda\varphi\omega_{in} m_F$………………………….………… (19)

$m_{v_{in}} = 186.6\ kg * 0.005$

$m_{v_{in}} = 0.933\ kg$

For the solid humidity at the inlet of 5% weighting 1 tonne (1000kg) of wet aggregate, the mass of liquid water associated to a wet solid is;

$$m_{w_{in}} = x_{in} m_{S_{in}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

$$m_{w_{in}} = 0.05 * 1000\ kg$$

$$m_{w_{in}} = 50\ kg$$

For the solid weighting 1 tonne (1000kg) of wet aggregate with 0.5% mass fraction of the elutriated with the flue gases, f_e the solid mass, m_S at the out let is;

$$m_{S_{out}} = (1 - f_e) m_{S_{in}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

$$m_{S_{out}} = (1 - 0.005)1000kg$$

$$m_{S_{out}} = 995\ kg$$

The mass of the elutriated with the flue gases, $m_{e,d}$ in the solid mass is given by;

$$m_{e.d} = f_e m_{S_{in}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

$$m_{e.d} = 0.005 * 1000\ kg$$

$$m_{e.d} = 5\ kg$$

To dry the solid weighting 1 tonne (1000kg) of wet aggregate the solids humidity at the outlet, X_{out}, is 0.5% and at the inlet is 5% the mass of vapor at the outlet is calculated as;

$$m_{V_{out}} = m_F(K_{H_2O} + \lambda \cdot \varphi\omega_{in}) + m_{S_{in}}(X_{in} - X_{out}) \ldots\ldots\ldots\ldots\ldots (23)$$

$$m_{V_{out}} = 5.33kg(0.05 + 2.5 * 14 * 0.004) + 1000kg(0.04 - 0.005)$$

$$m_{V_{out}} = 0.7462kg + 35kg$$

$$m_{V_{out}} = 35.7462kg$$

The energy balance in a control volume can be stated as:

$$\frac{dE_{CV}}{dt} = \sum_{in}(m_i h_i) = \sum_{out}(m_i h_i) + Q = \left(W_{CV} + p\frac{dV_{CV}}{dt}\right) \ldots\ldots\ldots\ldots (24)$$

at a steady state and without any work interaction(The work needed to rotate the drum is around 1/200 the thermal power introduced by the burner.):

$$\sum_{out}(m_i h_i) = \sum_{in}(m_i h_i) - Q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (25)$$

The computation of the enthalpies is done considering ideal solid, ideal liquid and ideal gas models with constant specific heat. The dry combustion gases composition has been calculated from the mass fraction composition for a typical fuel. The mean value of the calculated specific heat of the dry combustion gases with this composition is compared with the one computed from the dry air composition. The difference is below 1%, so the same value is used for fresh dry air and dry combustion gases.

Figure 22: Energy balance in the dryer.

The Latent and Specific Heat Analysis for drying the solid aggregate; At the average ambient temperature24°C (297K), latent heat of vaporization of water 2,257kJ/kg Specific heat of water 4.186kJ/kg.K [38] and average mixing temperature 165°C (438K). Given that the boiling point of water: 100°C (373K), Specific heat of sandstone aggregate: 0.92kJ/kg.K and Specific heat of sand: 0.8kJ/kg.K.

Energy required to heat 1kg of water to vaporization

$q = \mathrm{m}.h_{fg} + \mathrm{m} \cdot C_P \Delta T$ ……………………………,,,,,…………… (26)

$q = 1kg * 2257kJ/kg \; + \; 1kg * 4.186kJ/kg\ K\ (373 - 286)$

$q = 2257KJ/kg + 364.182KJ/kgK(87)$

$q = 2621.182$ KJ

Energy required to heat 1 kg of sandstone aggregate to average mixing temperature

$q = \mathrm{m} \cdot C_P \Delta T \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots . . (27)$

$q = 1\ kg * 0.92kJ/kg\ K\ (438 - 286)$

$q = 139.84\ KJ$

Energy required to heat 1kg of sand to average mixing temperature

$q = \mathrm{m} \cdot C_P \Delta T$ ………………………………………………….. (28)

$q = 1kg * 0.8kJ/kg\ K\ (438 - 286)$

$q = 121.6\ KJ$

To estimate the drum dryer/mixer heat loss due to convective and irradiative losses with an internal temperature of 100°C. The aggregate drying Drum Material is Mild Steel with Outer radius of 1.55m and length 6m.

$Q = Q_{RAD} + Q_{CONV}$ …………………………………………………. (29)

$Q = \sigma\varepsilon A(T_1^4 - T_2^4) + hA(\Delta T)$ … … … … … … … … … … … … . … … … (30)

$Q_{RAD} = \sigma\varepsilon A(T_1^4 - T_2^4)$

$Q_{RAD} = (5.67 * 10^{-8}) * 0.26(\pi * 1.55 * 6)(373^4 - 294^4)$

$Q_{RAD} = 5415\ W$

For a forced convection air flow across a cylinder

$T_{film} = (\frac{T_{fluid} + T_{surface}}{2})$ ……………………………..……………. (31)

$$T_{film} = (\frac{373K + 294K}{2})$$

$T_{film} = 333.5\ K$

$Re = \frac{\rho v l}{\mu}$ ………………………………………………………… (32)

$$Re = \frac{(1.0689 * 0.4 * 1.55)}{1.99 * 10^{-5}}$$

$Re = 33{,}302$

For 4,000 < Re <40,000 $Nu = 0.193Re^{0.618}Pr^{0.33}$

$Nu = 0.193Re^{0.618}Pr^{0.33}$ ………………………………………. (33)

$Nu = 0.193(33{,}302^{0.618})(0.721^{0.33})$

$Nu = 108$

$$Nu = \frac{hl}{k_{air}}$$

Rearranging the above equation $h = \frac{Nu\ k_{air}}{l}$

$$h = \frac{108 * 0.027861}{1.55}$$

$$h = 1.94W/m^2K$$

$$Q_{CONV} = hA(\Delta T)$$

$$Q_{CONV} = 1.94 * (\pi * 1.55 * 6)(373 - 294)$$

$$Q_{CONV} = 4{,}477.8\,W$$

$$Q = Q_{RAD} + Q_{CONV}$$

$$Q = 5{,}415\,W + 4{,}477.8W$$

$$Q = 9892.8W$$

The estimated heat loss from the surface of the drum mixer is 9892.8 W which for a hourly period equates to a fuel loss of 9892.8 W * 60 *60 = 35.6 MJ.

For every hour of operation 35.6 MJ = 0.92 liter fuel loss will be estimated.

In the dryer, two main streams have to be considered: one associated with the aggregates to be dried, which includes the dry solid flow, the elutriated filler flow, and the solids humidity (liquid and gas phase), hereinafter named process stream (p). The other, associated with the combustion, which includes the gases used to heat and dry the aggregates and the fuel in liquid phase, hereinafter named combustion gases stream (cg).

We can separate the contributions of each stream:

$$E_p = m_{S_{in}}[(1 - f_e)C_{ps}\left(T_{S_{out}} - T_{S_{in}}\right) + C_{pw}\left(T_{S_{out}} X_{out} - T_{S_{in}} X_{in}\right) + (X_{in} - X_{out}) * \left(h_{fg}^{Tr} + C_{pv} T_{a_{out}}\right) + f_e * C_{ps} * \left(T_{e,d} - T_{S_{in}}\right) + \left(C_{pw} - C_{pv}\right)(X_{in} - X_{out})\ T_r] \quad (34)$$

$$E_p = 1000kg[(1 - 0.005)0.92KJ/kgK(433K - 283K) + 4.18KJ/kgK(433K * 0.005 - 283K * 0.05) + (0.05 - 0.005) * (2547KJ/kg + 1.750KJ/kgK * 433K) + 0.005 * 0.92KJ/kgK * (433K - 283K) + (4.18KJ/kgK - 0.8KJ/kgK) * (0.05 - 0.005)283k]$$

$$E_p = 1000kg[(137.31KJ/kg) + (-50.1KJ/kg) + (148.7KJ/kg) + (0.69KJ/kg) + 44.87KJ/kg]$$

$$E_p = 281470KJ = 78.2KWh$$

$$E_{cg} = m_F[(1+\lambda\varphi)C_{pa}(T_{a_{out}} - T_{a_{in}}) + K_{H_2O}(C_{pv} - C_{pa})(T_{a_{out}} - T_r) + \lambda\varphi\omega_{in}C_{pv}(T_{a_{out}} - T_{a_{in}}) + (C_{pa}T_{a_{in}} - C_{pv}T_F) + (C_{pv} - C_{pa})T_r] - LHV^{T_r} \ldots\ldots (35)$$

$$E_{cg} = 5.33[(1+2.5*14)1.007KJ/kgK(433K-295K) + 0.05(1.750KJ/kgK - 1.007KJ/kgK)(433K-283K) + 2.5*14*0.004*1.750KJ/kgK\,(433K-295K) + (1.007KJ/kgK*295K - 1.750KJ/kgK*295K) + (1.750KJ/kgK - 1.007KJ/kgK)*283K - 35.9KJ/kgK]$$

$$E_{cg} = 5.33[(36)(138.97K) + 0.05(0.743KJ/kgK)(150K) + 0.245(138K) - 219.185 + 210.3KJ/kgK] - 35.9MJ$$

$$E_{cg} = 2.5KWh$$

Figure 23: Dryer burner

The terms $(C_{pa}T_{a_{in}} - C_{pF}T_F)$ and $K_{H_2O}T_{a_{out}}\ (C_{pv} - C_{pa})$ are small corrections due to change of composition. They have opposite signs so their global effect is small in comparison with the other terms. Applying equation (17) and taking into account that the only heat exchange with the ambient is the thermal losses ($\dot{Q} = \dot{Q}_{loss}$), then we can obtain:

$$\dot{E}_p + \dot{E}_{cg} + \dot{Q}_{loss} = \dot{E}_{burner} \quad \ldots\ldots (36)$$

$$\dot{E}_{burner} = 78.1KWh + 2.5KWh + 9.893KWh$$

$$\dot{E}_{burner} = 90.493KWh$$

4.4.4 Energetic efficiency

In order to define task efficiencies, we have to define which part of the energy is actually used for the process purpose. The used thermal power is the one employed in heating and drying the aggregates that are effectively used in the final HMA mixture. There are two main sources of waisted thermal power related to the filler in aggregates. One is the consequence of the initial composition of the aggregates, in which the filler is often in excess with respect to the definition of the mix recipe. This filler enters the dryer, it is heated but afterwards rejected from the process, and therefore its energy content is lost. The other source is consequence of the fact that the elutriated filler mass flux cannot be accurately controlled, and therefore a fraction of the reclaimed filler must be reinjected with a lower temperature. We then write the used and waist thermal powers as:

$$\dot{E}_{used} = \dot{m}_S\Big[(1 - f_e)C_{ps}\big(T_{S_{out}} - T_{S_{in}}\big) + f_i C_{ps}\big(T_{fi} - T_{S_{in}}\big) + C_{pw}\big(X_{out}\,T_{S_{out}} - X_{in}T_{S_{in}}\big) + (X_{in} - X_{out})\Big(h_{fg}^{Tr} + C_{pv}T_{a_{out}}\Big) + \big(C_{pw} - C_{pv}\big)(X_{in} - X_{out})T_r\Big] \quad \text{.......................... (37)}$$

$$\dot{E}_{used} = 1000kg[(1 - 0.005)0.92KJ/kgK(433K - 283K) + 0 + 4.18KJ/kgK(433K * 0.005 - 283K * 0.05) + (0.05 - 0.005) * (2547KJ/kg + 1.750KJ/kgK * 433K) + (4.18KJ/kgK - 0.8KJ/kgK) * (0.05 - 0.005)283k]$$

$$\dot{E}_{used} = 1000kg[(137.31KJ/kg) - 50.1KJ/kg + 149.93KJ/kg + 43.04KJ/kg]$$

$$\dot{E}_{used} = 280270KJ = 77.86KWh$$

$$\dot{E}_{waist} = \dot{m}_S\big[(f_e - f_i)C_{ps}\big(T_{S_{out}} - T_{S_{in}}\big) + f_i C_{ps}\big(T_{e,d} - T_{fi}\big)\big] \quad \text{.............................. (38)}$$

$$\dot{E}_{waist} = 1000kg[(0.005)0.92KJ/kgK(433K - 283K) + 0]$$

$$\dot{E}_{waist} = 1000kg[(0.005)0.92KJ/kgK(433K - 283K) + 0]$$

$$\dot{E}_{waist} = 0.192KWh$$

Finally, the efficiency can be defined as:

$$\eta_t = \frac{\dot{E}_{used}}{\dot{E}_{burner}} \quad \text{.. (39)}$$

$$\eta_t = \frac{77.86KWh}{90.493KWh}$$

$$\eta_t = 86\ \%$$

4.5 Energy Costs

The aggregate moisture is main factor influencing the level of energy consumption in the HMA production process. To establish a point for comparing the energy expenditures for different aggregate moisture we need an estimate of the energy expended. Taking the ambient temperature to be 25 ^{0}c and the mixing temperature as 160 ^{0}c. Initially, 1000kg of the supplied coarse dry aggregate has 1000/99kg by weight of water and 1000kg of the supplied fine dry aggregate has 1000/24kg by weight of water. Thus, 1000kg mix of the supplied 600 kg coarse dry aggregate 400 kg of fine dry aggregate contains;

=0.6 x 1000/99 + 0.4 x 1000/24

=22.72 kg of water per tonne of aggregate

Heating the 1000 kg of aggregate from 15 ^{0}c to 160 ^{0}c requires:

1000 kg x C_{agg} x 145 = 1000 kg x 0.85 x 145 = 123250 KJ = 123.25 MJ

Heating the 22.72 kg of water from 15 ^{0}c to 160 ^{0}c requires:

= 22.72 kg x [C_{h2o} x 90 + L_{vap} + C_{vap} x 55]

= 22.72 kg x [4.191 kj/kg^{0}c x 90 + 2270 kj/kg + 1.85 kj/kg^{0}c x 55]

= 22.72 kg x [2748.94 kj/kg] = 62455.9 KJ= 62.5 MJ

The net energy supplied by heavy fuel oil represents the energy needed to heat the aggregate, and is 185.75 MJ/tonne of mix. In a tonne of mix containing 5% by weight of bitumen, we have 950 kg of aggregate and 50 kg of bitumen. To heat the bitumen from 25 ^{0}c to the mixing temperature of 150 ^{0}c, the heat energy required is;

= 50 kg x C_{bit} x 135

= 50 kg x 0.53KJ/kgK x 135 =3577.5 KJ= 3.8 MJ

A portion of the energy consumption (3.8MJ) would be needed to heat the bitumen, and the rest would be used in running the asphalt plant. The heat in put for one tonne of hot mix is 189.55 MJ. In the next chapter the contribution of exhaust gas for reduction of energy costs and the possibilities in energy saving is analyzed. By exposing the aggregate to the heat of exhaust gas before transporting in to the dryer and by making to lose part of the moisture the possible effects will be predicted using computational fluid dynamics gas solid heating model. The potential of exhaust gas energy is used for pre heating the aggregate, by taking the size of the aggregate and the exhaust gas heating time in to account.

5. COMPUTATIONAL FLUID DYNAMICS MODELING OF AGGREGATE PRE HEATER

5.1 GEOMETRY AND MESHING

The aggregate falls on a small infinite conveyor belt beneath the pre-dispensers that has a regulated speed of rotation. The aggregate fraction mix travels on the infinite conveyor belt to the incline belt. The inclined conveyer has 6 meter overall length and 0.75 meter width. With the incline belt, the aggregate mixture is transported to the rotary drum for drying. The ANSYS Design Modeler Work Bench 16.0 was used to make the 2 D Rectangular geometry with the height of 6 m and width 0.25 m. Fine Mesh size of 0.01m was taken in order to have 20352 nodes 19629 elements for the whole geometry. Similarly a mesh size of 0.001 cm was also used in order to have better accuracy. Using smaller mesh size requires smaller time steps and more calculation per iteration for the solution to converge. By dividing across the height with two baffles are used having a width and height of 25mm in 2 meters gap. The baffles are used to pressurize hot air passing through the particle by increasing the gas velocity [39]. These baffles are inserted into the preheater wall at equal distance to hold the gas so that they fall across the dryer cross-section as a way of initiating gas-solid contact.

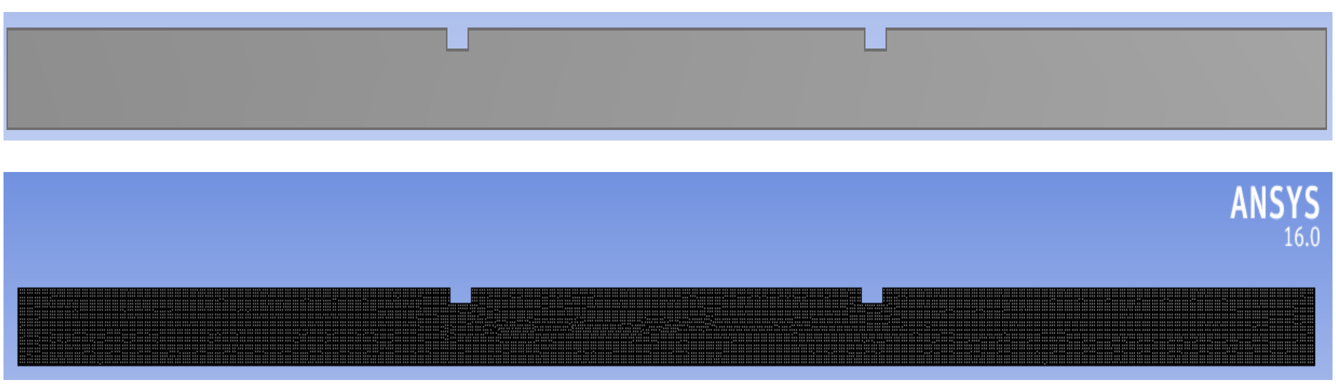


Figure 24: 2D Geometry and Fine Mesh Created

5.2 Gas-Solid Heat Transfer Physical Assumptions

The aggregates are assumed to be spherical particles. The exchange areas between the gas and the environment, Sge, and between the dryer and the environment, Sse, depend on aggregate distribution within the cross-section. The Sgs exchange area, which is related to the transfer between gases and solids. Where ms and mg represent respectively the linear solid mass density and the linear gas mass density, while C_{ps} and C_{pg} denote respectively the specific heat capacity of solids and gases at constant pressure. C_{pvap} is the specific heat capacity of water vapor at constant pressure, Lv the latent heat of vaporization for water, h_{gs} the heat transfer coefficient between gas and solid, h_{gs2} the heat transfer coefficient between gas and the surface of the granular bed, h_{se} the heat transfer coefficient between the dryer and the environment, and lastly h_{ge} the heat transfer coefficient between gas and the environment. The energy balance equation is given as;

$$C_{ps}\frac{dT_s}{dx} = \frac{1}{V_s}[\left(\frac{S_{gs}}{m_s} * h_{gs} * (T_g - T_s)\right) + \left(\frac{S_{gs2}}{m_s} * h_{gs2} * (T_g - T_s)\right) - \left(\frac{S_{se}}{m_s} * h_{se} * (T_s - T_{ext})\right) - \frac{\dot{m}}{m_s} * L_v] \ldots\ldots (40)$$

$$C_{pg}\frac{dT_g}{dx} = \frac{1}{V_s}[\left(-\frac{S_{gs}}{m_g} * h_{gs} * (T_g - T_s)\right) - \left(\frac{S_{gs2}}{m_g} * h_{gs2} * (T_g - T_s)\right) - \left(\frac{S_{ge}}{m_g} * h_{ge} * (T_s - T_{ext})\right) - \frac{\dot{m}}{m_g} * C_{pvap} * (T_g - T_s)] \ldots\ldots (41)$$

$\left(S_{gs} * h_{gs} * (T_g - T_s)\right)$ is the heat transfer around solid particles, which is driven by convective heat transfer.
$\left(S_{gs2} * h_{gs2} * (T_g - T_s)\right)$ is the convective heat transfer between the solid bed area and gases.
$\left(S_{se} * h_{se} * (T_s - T_{se})\right)$ is the thermal loss around the solid bed. Since the temperature of solids differs from the outside temperature, thermal losses occur. This thermal loss consists of the conductive heat transfer through the drum wall, yet the transfer between wall and the outside is a mixed convective heat transfer. The equivalent heat transfer coefficient therefore depends on the coefficients of each heat transfer.

$\left(S_{ge} * h_{ge} * (T_s - T_{ext})\right)$ is a thermal loss relative to gas. It corresponds to the convective heat transfer between the gas and the outside.

h_{gs} is derived from the Nusselt number, as calculated at the solid particle scale, i.e.:

$$Nu_{gs} = \frac{h_{gs}\, d}{\lambda_g} \ldots\ldots (42)$$

In this case, the Nusselt number is estimated from the Ranz-Marshall correlation, after particle drying

$$Nu_{gs} = 2 + 0.58\,(Re^{0.5})(Pr^{0.33}) \ldots\ldots (43)$$

On the other hand, hgs2 is derived from the Nusselt number at the solid bed scale, i.e.:

$Nu_{gs} = \frac{h_{gs2}\, L}{\lambda_g}$………………………………………………………… (44)

The Nusselt number originates from a flat-plate correlation given that the transfer configuration lies on a flat plate (the solid bed area)

$Nu_{gs} = 0.023\,(Re^{0.8})(Pr^{0.33})$ ……………………………………… (45)

The solid bed is in contact with the wall, while a thermal loss exists between the solid bed and the outside. h_{se} is quantified by means of the following relationship:

$\frac{1}{h_{se}} = \frac{e}{\lambda_{wd}} + \frac{1}{h_{ext}}$………………………………………………………… (46)

where hext is the heat transfer coefficient between the external wall of the rotary dryer and the outside. For hge, the reflection pattern is the same, except that hgs is taken into consideration when assessing hge:

$\frac{1}{h_{ge}} = \frac{1}{h_{gs}} + \frac{e}{\lambda_{wd}} + \frac{1}{h_{ext}}$…………………………………………………… (47)

5.3 Aggregate Moisture Determination

The aggregate moisture content is the basic factor of energy consumption in the production process and applying the possible energy reduction method is required to lower the energy cost of manufacturing hot mix asphalt. This approach is also used for reducing fuel consumption of the hot mix asphalt plant. To calculate the reduced moisture content the following equation is used;

$w = \propto (0.0033\, t + 0.0155)\%$ …………………………………………… (48)

Where $\propto$, temperature coefficient, and t is is time.

Temperature coefficient, $\propto = 0.6348 e^{-0.0137T}$…………………………… (49)

At this point the moisture content reduction equation is extended by a coefficient β, and so we have:

$w = \propto \beta(0.0033\, t + 0.0155)\%$ …………………………………..………… (50)

Where β, velocity coefficient,

$\beta = 0.2485v - 0.0002$ …………………………………………………… (51)

Therefore,

$w = (0.6348e^{-0.0137T})(0.2485v - 0.0002)(0.0033\, t + 0.0155)\%$……..…… (52)
Where v is air flow rate in m/s.

Since aggregate in a drum mix operation is weighed before drying, moisture content of the aggregate must be determined. The weighing of aggregate and the metering of asphalt cement are interlocked electronically in drum mix operations. To ensure proper metering of asphalt cement, adjustments for aggregate moisture must be made. The moisture content of the aggregate should be determined, and proper allowance made for the water content, prior to mixing.

$$\text{Moisture Content} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$$

Table 7: The aggregate temperature at various conditions

The aggregate temperature at the DRYER inlet	25 ℃
The aggregate temperature at the DRYER outlet	170 ℃
Outside air temperature	25 ℃

Table 8: The relationship among the aggregate water content, the fuel consumption and the rate of drying capacity

Water Contents	Fuel Consumption	Rate of Drying Capacity
4%	6 ℓ/ TON	300 ℓ/ H
7%	7.84 ℓ/ TON	392 ℓ/ H
10%	9.6 ℓ/ TON	480 ℓ/ H
15%	12.4 ℓ/ TON	620 ℓ/ H

5.4 Gas-Solid Heating CFD Modeling

CFD modeling is based on the fundamental governing equations of fluid dynamics. Physical and numerical models are often used to optimize design and/or operating conditions, and provide the ability to trial changes to operating conditions and geometrical configurations without risk. CFD modelling can account for these complexities and use the actual fluid properties with chemical reactions, thus a wide range of variations in physical design and operational parameters can be tested and refined until a design that gives optimum performance is identified [40].

This section focuses on CFD modeling of gas-solid flow. Depending on the application and information required, gas-solid flow can be modeled at different length scales: at the particle scale or at the macro level by local averaging. The particle scale approach tracks the motion of individual particles using a discrete element method (DEM), and the flow of gas using a continuum based CFD model with local properties averaged over a number of computational cells. The computational fluid dynamics using Eularian granular multiphase model with heat transfer is used for predicting the temperature and moisture evaluation of aggregates. A two fluid model or more correctly an Eulerian-Eulerian model (EEM) incorporating the kinetic theory of granular flow is selected as the modeling technique [41].

5.4.1 Conservation of Mass (continuity equation)

The sum of volume fraction for gas and solid must equal to unity:

$$\varepsilon_g + \varepsilon_s = 1 \quad (53)$$

Where a subscript g and s stand for gas and solid phases.

The continuity equations for gas phase and solid phase are expressed as follows:

$$\frac{\partial}{\partial t}(\varepsilon_g \rho_g) + \nabla\left(\rho_g \varepsilon_g \vec{U}_g\right) = 0 \quad (54)$$

$$\frac{\partial}{\partial t}(\varepsilon_s \rho_s) + \nabla\left(\rho_s \varepsilon_s \vec{U}_s\right) = 0 \quad (55)$$

Where ρ_g is the gas phase density, $\rho_s$is the solid phase density, $\vec{U}_g$ is the gas phase velocity, $\vec{U}_s$ is the solid phase velocity, ε_g and ε_s are the volumetric fractions of gas and solid phases.

5.4.2 Conservation of Linear Momentum

The momentum equation for gas (g) phase is given as follows:

$$\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g \vec{U}_g\right) + \nabla\left(\rho_g \varepsilon_g \vec{U}_g \vec{U}_g\right) = -\varepsilon_g \nabla P + \nabla\left(\varepsilon_g \mu_{eff,g}\left(\nabla \vec{U}_g + \left(\nabla \vec{U}_g\right)^T\right)\right) + \rho_g \varepsilon_g g - M_{i,g} \quad (56)$$

The momentum equation for solid (s) phase is given as follows:

$$\frac{\partial}{\partial t}\left(\varepsilon_s \rho_s \vec{U}_s\right) + \nabla\left(\rho_s \varepsilon_s \vec{U}_s \vec{U}_s\right) = -\varepsilon_s \nabla P + \nabla\left(\varepsilon_s \mu_{eff,s}\left(\nabla \vec{U}_s + \left(\nabla \vec{U}_s\right)^T\right)\right) + \rho_s \varepsilon_s g - M_{i,s} \quad (57)$$

Where P is the pressure and μeff is the effective viscosity. The second term on the R.H.S of solid phase momentum equation is the term that accounts for additional solid pressure due to solid collisions. The terms Mi,g, and Mi,s of the above momentum equations represent the interphase force term for gas and solid phase, respectively.

5.4.3 KINETIC THEORY OF GRANULAR FLOW

For the kinetic theory of granular flow, the fluctuation energy of solid phase, also known as granular temperature, is obtained by solving the granular temperature transport equation [42]. To specify collisional energy dissipation, γs, due to inelastic collisions of particles and the granular conductivity, Ks, the equation is given as:

$$\frac{3}{2}\left[\frac{\partial(\propto_s \rho_s \Theta)}{\partial_t} + \nabla.(\alpha_s \rho_s U_s \Theta)\right] = (-p_s I + \tau_s):\nabla U_s + \nabla.(\kappa_s \nabla\Theta) - \gamma_s + J_{vis} + J_{slip} \quad (58)$$

Where Θ is the granular temperature, κ_s is the conductivity of granular temperature, γ_s is the dissipation rate due to particle collisions, J_{vis} is the dissipation rate resulting from viscous damping, and J_{slip} is the production rate due to the slip between gas and particle. These terms are modeled following Gidaspow. The solid bulk viscosity s and the solid shear viscosity s are calculated according to Gidaspow

$$\lambda_s = \frac{4}{3}\alpha_s^2 \rho_s d_p g_o (1+e)\sqrt{\frac{\Theta}{\pi}} \quad (59)$$

$$\mu_s KTGF = \frac{4}{5}\alpha_s \rho_s d_p g_o (1+e)\sqrt{\frac{\Theta}{\pi}} + \frac{10\rho_s d_s \sqrt{\Theta\pi}}{96\alpha_s g_o (1+e)}\left[1 + \frac{4}{5}\alpha_s g_o (1+e)\right]^2 \quad (60)$$

Where d_p is the particle diameter, e is the particle-particle restitution coefficient and g_0 is the radial distribution function. The solid phase pressure p_s is calculated following Lun et al.:

$$p_s = \alpha_s \rho_s \Theta + 2\rho_s \alpha_s^2 g_o \Theta(1+e) \quad (61)$$

The expression for g_0 is given following Sinclair and Jackson:

$$g_o = \left[1 - \left(\frac{\alpha_s}{\alpha_{s,max}}\right)^{\frac{1}{3}}\right]^{-1} \quad (62)$$

Where s,max is the particle packing limit.

5.4.4 Fluid-Solid Heat Exchange Coefficient

The fluid-solid exchange coefficient K_{sl} can be written in the following general form:

$$K_{sl} = \frac{\propto_s \rho_s f}{\tau_s} \quad (63)$$

Where f is defined differently for the different exchange-coefficient models (as described below), and $\boldsymbol{\tau_s}$, the "particulate relaxation time", is defined as:

$$\tau_s = \frac{\rho_s d_s^2}{18\mu l} \quad (64)$$

Where d_s is the diameter of particles of phase s.

All definitions of f include a drag function (C_D) that is based on the relative Reynolds number (Re_s). It is this drag function that differs among the exchange-coefficient models.

-For the Syamlal-O'Brien model

$$f = \frac{C_D R_e \alpha_l}{24 v_{r,s}^2} \quad (65)$$

Where the drag function has a form derived by Dalla Valle

$$C_D = \left(0.63 + \frac{4.8}{\sqrt{\frac{R_e}{v_{r,s}}}}\right)^2 \quad (66)$$

This model is based on measurements of the terminal velocities of particles in fluidized or settling beds, with correlations that are a function of the volume fraction and relative Reynolds number

$$R_{e_s} = \frac{\rho l d_s \left|\vec{v_s} - \vec{v_l}\right|}{\mu l} \quad (67)$$

Where the subscript l is for the lth fluid phase, s is for the sth solid phase, and d_s is the diameter of the sth solid phase particles.

The fluid-solid heat exchange coefficient has the form

$$K_{sl} = \frac{3\propto_s \alpha_l \rho l}{4 v_{r,s}^2 d_s} C_D \left(\frac{R_{e_s}}{v_{r,s}}\right) \left|\vec{v_s} - \vec{v_l}\right| \qquad (68)$$

Where $v_{r,s}$ is the terminal velocity correlation for the solid phase

$$v_{r,s} = 0.5\left(A - 0.06R_{e_s} + \sqrt{\left(0.06R_{e_s}\right)^2 + 0.12R_{e_s}(2B - A) + A^2}\right) \qquad (69)$$

With

$$A = \alpha_l^{4.14}$$

and

$$B = 0.8\alpha_l^{1.28}$$

for $\alpha_l \leq 0.85, and$

$$B = 0.8\alpha_l^{2.65}$$

for $\alpha_l > 0.85.$

This model is appropriate when the solids shear stresses are defined according to Syamlal et al.

-For the model of Wen and Yu, the fluid-solid heat exchange coefficient is of the following form:

$$K_{sl} = \frac{3}{4} C_D \frac{\propto_s \alpha_l \rho l \left|\vec{v_s} - \vec{v_l}\right|}{d_s} \alpha_l^{-2.65} \qquad (70)$$

Where;

$$C_D = \frac{24}{\alpha_l R_{e_s}}\left[1 + 0.15\left(\alpha_l R_{e_s}\right)^{0.687}\right] \qquad (71)$$

This model is appropriate for dilute systems.

-The Gidaspow model is a combination of the Wen and Yu model and the Ergun equation.

When α_l> 0:8, the fluid-solid exchange coefficient K_{sl} is of the following form:

$$K_{sl} = \frac{3}{4} C_D \frac{\propto_s \alpha_l \rho l \left|\vec{v_s} - \vec{v_l}\right|}{d_s} \alpha_l^{-2.65} \qquad (72)$$

Where $$C_D = \frac{24}{\alpha_l R_{e_s}}\left[1 + 0.15\left(\alpha_l R_{e_s}\right)^{0.687}\right] \qquad (73)$$

When $\alpha_l \leq 0.8,$

$$K_{sl} = 150\frac{\propto_s (1-\alpha_l)\mu l}{\alpha_l d_s^2} + 1.75 \frac{\rho l \propto_s \left|\vec{v_s} - \vec{v_l}\right|}{d_s} \qquad (74)$$

5.5 Initial and Boundary Conditions

For the Eulerian Model Defining Phases by choosing the appropriate material in the Phase Material list gives the necessary information for the primary and secondary phases and their interaction for an Eulerian multiphase calculation. Initial condition may not influence the steady state solutions that is desired in fluidized bed modeling. Notwithstanding, strategically chosen initial conditions help to ensure the convergence of the solution. There are two types of initial conditions: solids volume fraction in the bed and X-velocity of the gas phase. The solids volume fractions in the freeboard is initially set to zero (assuming only gas). They X-velocity of the gas phase in the fluidized bed is computed through a steady state volumetric flow rate balance in which the flow rate entering is linked to the flow rate leaving (having both solids and gas phase):

Boundary conditions: at inlet of the air velocity for primary phase, while the secondary phase is zero inlet velocity. At outlet of the fluidized bed is atmospheric pressure. No slip, wall boundary condition is applied to the gas phase, while the partial slip conditions is applied to the solid phase. The solid diameter specifies the diameter of the particles and using syamlal-obrien to compute the value. Granular Viscosity and Granular Bulk Viscosity specifies the kinetic part of the granular viscosity of the particles the solids bulk viscosity. For each secondary phase, set the volume fraction to be 0.6 and set its granular temperature298K. For an axis, outflow, periodic, solid, or symmetry zone, all conditions are specified for the mixture; there are no conditions to be set for the individual phases. For a wall zone, shear conditions are specified for the individual phases; all other conditions are specified for the mixture. For a fluid zone, all source terms and fixed values are specified for the individual phases.

Table 9: Summary of CFD input parameters

Particle Density (kg/m^3)	2900	Gas Density (kg/m3)	1.4
Particle Diameter (m)	0.01	Gas Specific Thermal Capacity (J/kg.K)	1010
Particle Specific Thermal Capacity (J/kg.K)	800	Gas Thermal Conductivity (J/K.s.m)	0.0457
Particle Thermal Conductivity (J/K.s.m)	920	Kinematic Viscosity (m2/s)	5.1e-5
Initial Particle Temperature (K)	298	Initial Velocity of Gas (m/s)	0.1
Time Step (s)	0.0001	Initial Gas Temperature (K)	398

5.6 SOLUTION METHOD

Eularian granular multiphase model with pressure based unsteady solver is used to predict the temperature and moisture evolution of aggregate using the exhaust gas in the drying process. For Eulerian multiphase calculations, FLUENT uses the Phase Coupled SIMPLE (PC-SIMPLE) algorithm for the pressure-velocity coupling. PC-SIMPLE is an extension of the SIMPLE algorithm to multiphase flows [43]. The velocities are solved coupled by phases, but in a segregated fashion. The block algebraic multigrid scheme used by the coupled solver is used to solve a vector equation formed by the velocity components of all phases simultaneously. Then, a pressure correction equation is built based on total volume continuity rather than mass continuity. Pressure and velocities are then corrected so as to satisfy the continuity constraint. The finite volume method divides the spatial domain into a number of contiguous control volumes or cells. A finite volume method, capable of handling complex geometries is applied. The discretization of the convective fluxes is first order upwind. Under transient formulation, the bounded second order implicit is used; this formulation would provide better stability, since time discretization would always ensure the bound for variables if available [44]. The material properties of fluid and particle is chosen for the model from the fluent data base so that it can be used for the primary and secondary phases. The gas (air) and solid has been injected at the base taking height of 0.25m gap between the wall and the conveyor. The variables to be investigated with regard to the correlation of drying time and moisture content for the fraction of stone material 10mm input moisture content 5 %. The EEM is adopted to undertake an investigation of the parameters of interest. Values used for parameters in the models are: maximum solids volume fraction (max s α) is set to 0.6, a value of 0.9 is used for the restitution coefficient (e). ANSYS/Fluent is used to solve the model equations by a finite volume method using the “phase couple SIMPLE” algorithm to handle pressure-velocity and phase coupling. A second order discretisation scheme is used for convection terms in the momentum equations while the QUICK scheme is used for the volume fraction equations. A time step of 0.0001 seconds is used to a Discretization Methods in CFD.

Region Adaption: the transport of solids through the dryer takes place by the movement of the conveyor. To clearly show the solid motions and gas flow distribution in the dryer separately the coordinates are set on the 2D model. The granular flow regime is marked at (x=1m and y=0.1m) and defined by the adaption in order to encompass the solid area. It is also used to patch the initial volume fraction of solids.

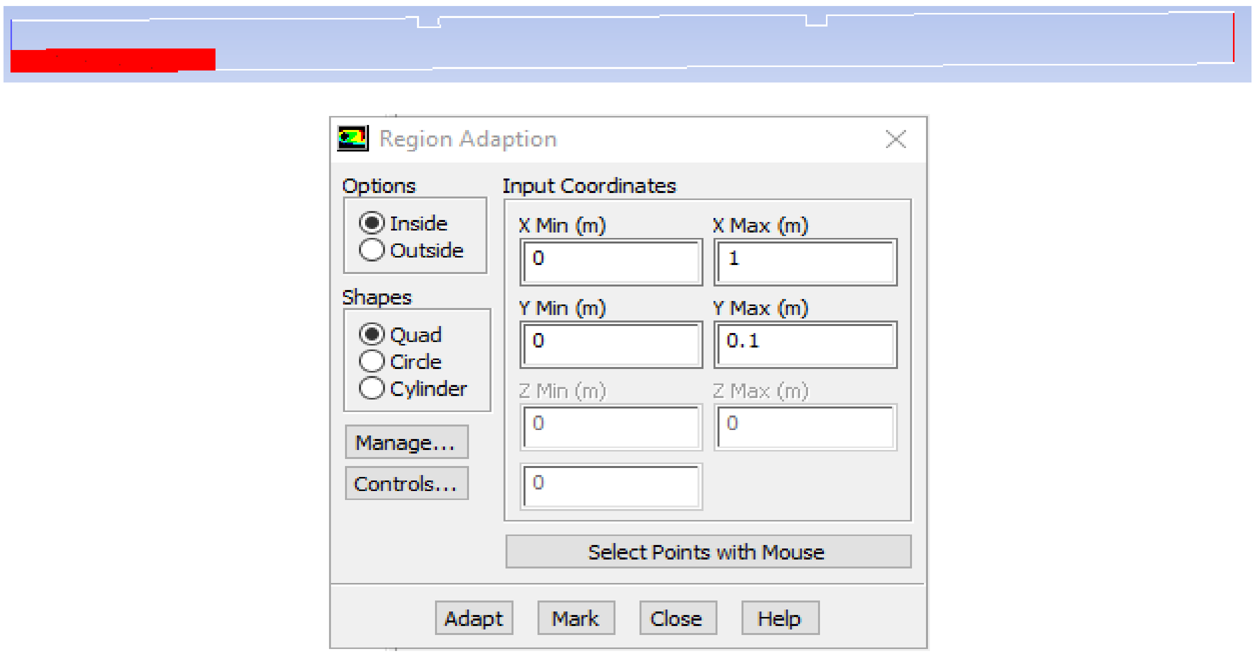


Figure 25: region adaption

6. RESULTS AND DISCUSSION

In this chapter results achieved on the energy usage of asphalt plant are presented and discussed. The first section basically reflects the macroscopic energy consumption results based on field measurement with equipment production data and microscopic energy consumption calculations performed up on asphalt plant to investigate thermal energy performance. This provides to identify basis for excess energy utilization and fuel consumption. The next section presents a methodology for energy saving and emission reduction by applying the exhaust gases to preheat the raw material in production of asphalt mixtures. Based on the application gas-solid flow the CFD validation is presented by using graphical displays and numerical out puts.

6.1 Annual Energy Consumption Statistics

The results show that the asphalt mixture production accounts for the largest proportion of the energy consumption and is far more than other stages. The asphalt mixture production energy consumption is 197.67 MJ/t. Compared to the mixture production, the energy consumptions of other stages are much less. For example, the energy consumption of the aggregate production is 43.07 MJ/t, the asphalt mixture transportation 3.86 MJ/t.KM and the asphalt mixture construction 24.9 MJ/t. stage. Within the statistical cycle of this study, the energy consumption of one ton of asphalt mixture from raw material production stage to construction stage is about 272.03 MJ.

Table 10: Annual Energy Consumption Statistics

Description		Unit Energy Consumption	Material Consumption (ton)	Annual Energy Consumption (MJ)	Energy Consumption Ratio (%)
Raw Material Production stage	Aggregate Production	43.07 MJ/ton	74736	3395090.4	12.27
	Filler production	2.53MJ/ton	4152	199711.2	0.76
Asphalt Mixture Production stage		197.67	83040	16381024	59.2
Asphalt Mixture Transportation stage		3.86MJ/KM	83040	5620546	20.3
Asphalt Mixture Paving stage		24.9MJ/ton	83040	2067377.4	7.47
Total		-	-	27663749	100.00
Total Annual Energy Consumption per tonne of asphalt Mixture		-	1		-

The total production energy expended to heat aggregate and bitumen and mix together in hot mix asphalt mixture manufacturing is 272.03 MJ/Ton. The study of the dryer system and investigation of the use of energy in asphalt mixing plants is essential. The energy analysis and losses in the production process involving the mixing of aggregates and bitumen heating helps to minimize energy consumption in HMA production.

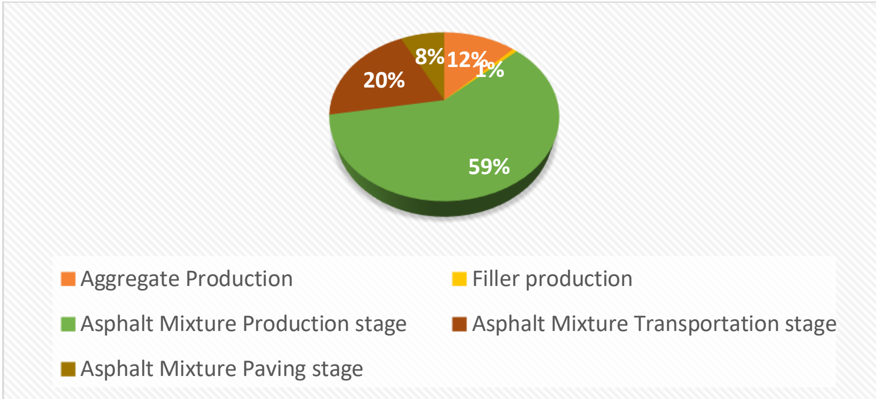


Figure 26: Annual energy consumption statistics

During the production of hot asphalt mixtures, there is considerable energy consumption which is used by electrical and diesel fuel energy source. Energy consumption in the process of drying and heating the mineral mixture is greater than other processes in transport and construction of asphalt mixtures.

6.2 Total production

The results of annual HMA production data clearly shows that, there is a close correlation between the increase in material quantity and the increase in fuel consumption and energy consumption. However, due to the outside temperature variations the production decreases when the moisture level increases in the wet season and increases when the moisture level decreases on the dry season. This indicates that both production and energy consumption are affected by moisture level.

Table 11: Annual Material Consumption

Production Month	Asphalt Mixture (t)	diesel (l)	Energy consumption (MJ)
April 2019	9600	67655.1	2611488
May 2019	7800	54969.8	2121834
June 2019	10800	76112.0	2937924
July 2019	5700	40170.2	1550571
August 2019	7200	50741.3	1958616
September 2019	5400	38056.0	1468962
October 2019	3720	26216.4	1011952
November 2019	6540	46090.1	1779076
December 2019	3000	21142.2	816090
January 2020	5400	38056.0	1468962
February 2020	9000	63426.7	2448270
March 2020	8880	62581.0	2415626
Total	83040	585216.9	22589371

6.3 Energy Savings

The results from energy performance evaluation and thermal analysis of hot mix asphalt plant indicates, the energy consumption in the process of drying and heating the mineral mixture is greater than other processes. Form the total energy 86 % is actually used for the process purpose in drying. It is affected by the drum dryer heat loss due to convective and radiative losses associated with process stream and combustion stream. The estimated heat loss from the surface of the drum mixer for an hourly period is 35.6 MJ.

Table 12: Energy Savings from the Reduced Aggregate Moisture

% of moisture	Energy required to heat 1 ton aggregate		Energy required to heat 1 ton hot mix asphalt concrete	
	Energy consumed (MJ/T)	Energy % reduced	Energy consumed (MJ/T)	Energy % reduced
5.0	201.4	0	205.1	0
4.5	193.5	3.9	197.3	3.8
4.0	185.7	7.76	189.5	7.6
3.5	177.9	11.6	181.7	11.4
3.0	170.1	15.5	173.9	15.2
2.5	162.3	19.4	166.1	19.03
2.0	154.5	23.3	158.3	22.8
1.5	146.7	27.1	150.4	26.6
1.0	138.86	31.0	142.6	30.44

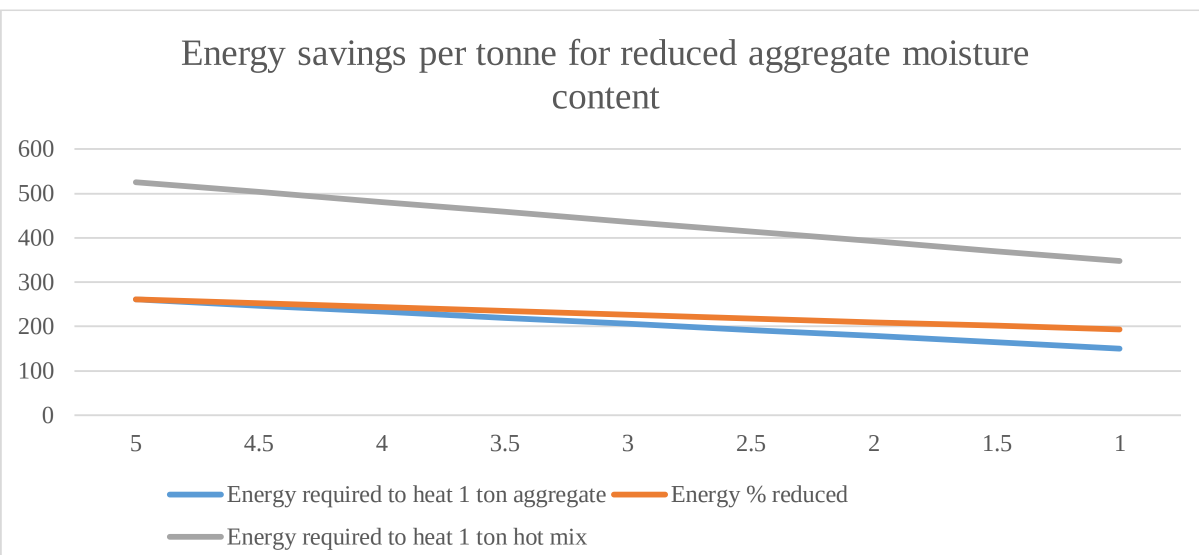


Figure 27: Energy saving per tonne for reduced aggregate moisture content

The results of thermal efficiencies of the aggregate dryer and bitumen heater relates thermal power used in heating and drying the aggregates is less effective than the amount of thermal power for heating the bitumen in the final HMA mixture. The energy analysis and losses in the production process involving the heating of aggregates for HMA production requires higher heat source and fuel consumption to release heat for drying asphalt aggregates. Aggregates are conveyed from stockpiles to dryers where they are heated to a temperature between 150 and 200 ^{0}C.

The combustion operation produces a flame and hot gases essential for the drying and heating materials. The energy supplied by combustion for drying one tonne of aggregate with 5% humidity is 201.4 MJ. The dryer incorporates two main streams. The process stream is associated with the aggregates to be dried, which includes the dry solid flow, the elutriated filler flow, and the solids humidity (liquid and gas phase). The combustion gases stream (cg), is associated with the combustion, which includes the gases used to heat and dry the aggregates and the fuel in liquid phase. The net energy supplied by heavy fuel oil to heat the aggregate, and is 185.75 MJ/tonne of mix. The used thermal power is the one employed in heating and drying the aggregates that are effectively used in the final HMA mixture.

On the other hand the results on analysis of the heat transfer and energy for bitumen heating shows less fuel consumption and heat required for heating the bitumen for HMA production. The heat loss by bitumen and Thermia B is 4.043 KW. The thermal efficiency of asphalt heating related to the amount of heat that the burner produces to the amount of heat actually transferred to the thermal fluid flowing through its coil is 94.05%. The total amount of heat required to heat 1000lit which weighs 0.95 kg per liter asphalt from 298K to 433K is 67.97 MJ. The calculated energy consumption to heat asphalt containing 5% by weight of bitumen in a tonne of mix needs 3.8 MJ heat energy.

6.4 Numerical Simulation Results

The results of Eularian granular multiphase model with pressure based unsteady solver is used to predict the temperature and moisture evolution of aggregate using the exhaust gas in the drying process. The solid particles initial temperature is 298 K with a diameter of 10 mm. The hot air enters at 398 K with 0.1 m/s initial velocity at the inlet. The wall temperature is assumed to be in adiabatic condition. The operating conditions effects at the inlet gas velocity, inlet gas temperature, inlet solid temperature and particle size on the drying process were investigated in the study. Results of the simulation were obtained after 60 second. Temperature at the gas side increases continuously and the solid decreases because of regenerative heat phenomenon. The increase of heating time will result higher particle temperature at the same heating gas temperature. The heat transfer between the particles and gas is only restricted to the granular flow regime and the gas flow on the free part of the dryer is higher as shown in the figure.

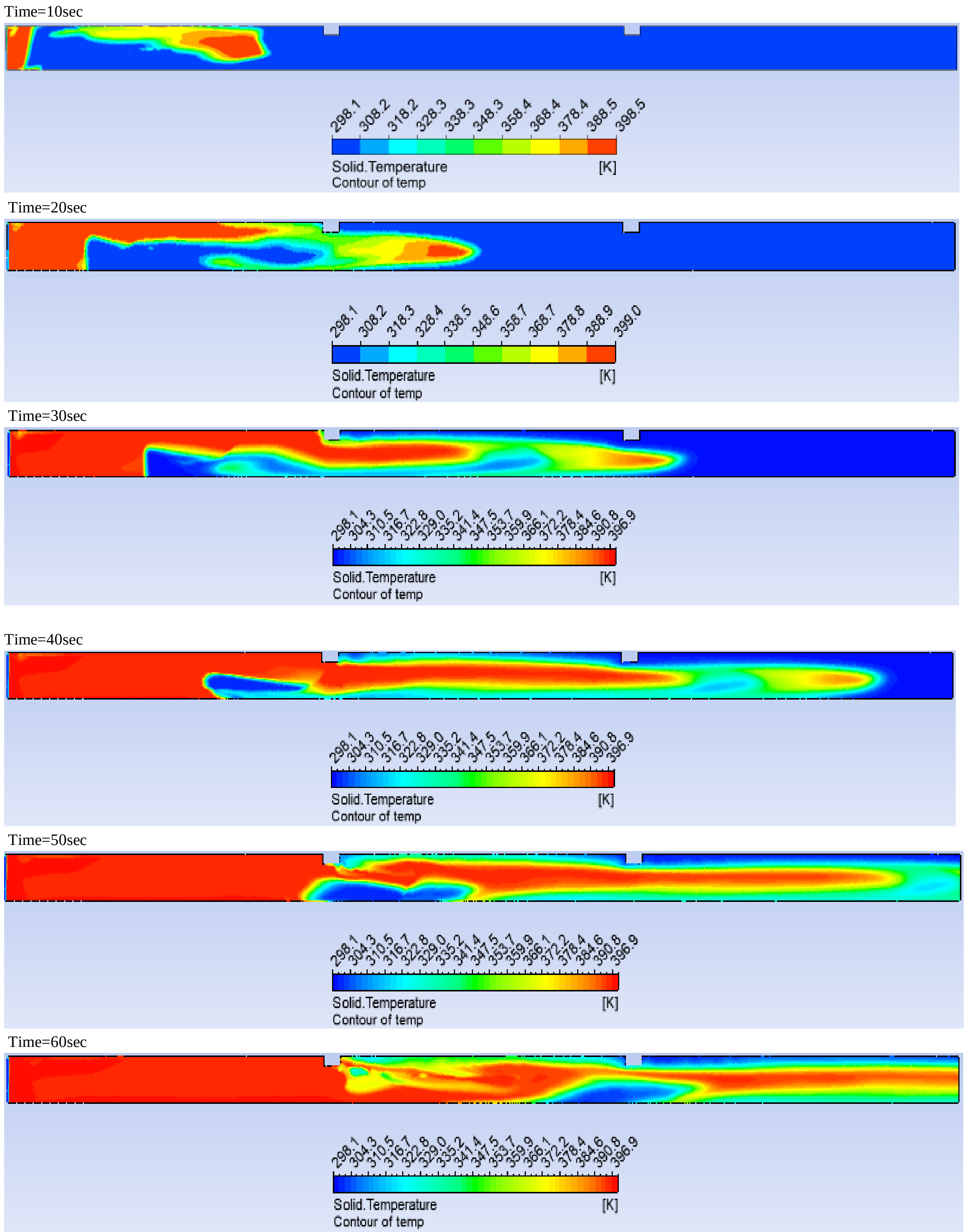


Figure 28: Particle temperature over time

6.5 PHASE DAYNAMICS RESULTS

The contours and vector illustrations represent the gas and solid particle phase dynamics for two different phases. The color scales given below each contours gives the values of pressure and air volume fraction corresponding to the color. The vector represent the velocity magnitude and direction of the flow pattern. The results of pressure distribution shows build up in astatic pressure at the granular phase caused by particle expansion due to higher temperature at the inlet with increasing heating time.

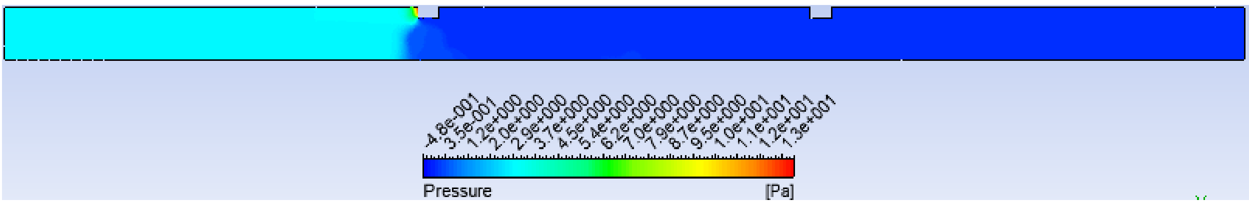


Figure 29: Pressure distribution

From figure the air velocity magnitude is increased as shown on the legend at some points in the middle due to the phase interaction between the solid and the fluid.

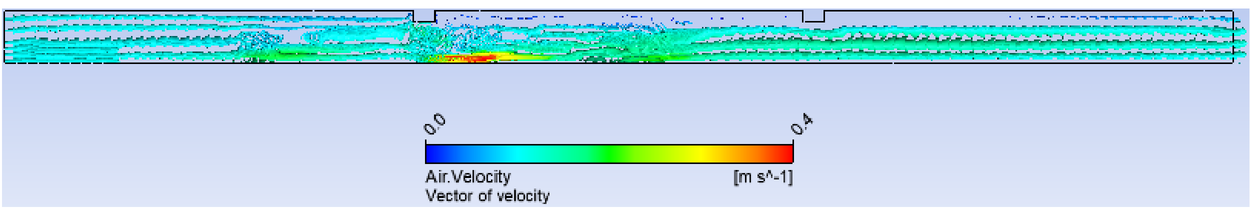
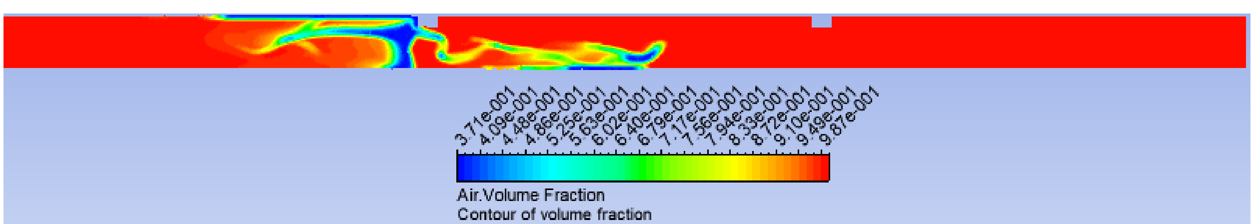


Figure 30: Air Velocity distribution

Figure 31 shows contours of volume fractions of air and aggregate and the gas hold up enhancement is larger compared to the aggregate. There is a relatively small volume fraction of air in the areas where the gas velocity is less. The air volume increases as temperature increases and it depends on gas temperature. The rate of heat transfer increases at the dryer cross-section, the baffles inserted hold the gas as gas-solid contact increases with solid volume fraction. The granular transport regime and solid flow is shown clearly solid volume fraction contour. The ranges of air volume fraction reach up to one in the free part of dryer where there is no granular particle flow motion.



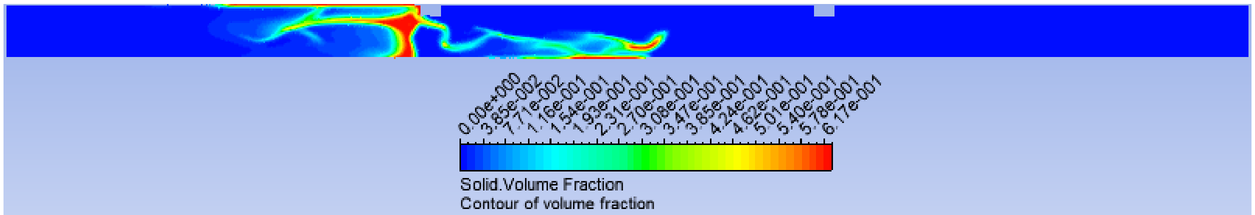


Figure 31: contours of air and solid volume fraction

6.6 Comparison of Numerical Temperature Profile and Moisture Content Reduction

The computational fluid dynamics modeling used for predicting the temperature evaluation of aggregates using Eularian granular multiphase model with heat transfer. Temperature distribution contour results has shown the various particle temperature ranges after heating for 60 sec The particle-particle interaction, emission and radiation of the gases have all been neglected, and the gas velocity is assumed to be the driving force for transfer phenomena. Moreover, this transfer depends on length, L along the dryer surface. Hence, the temperatures of solids and gases are solely dependent on the x-axis position. The mass transfer is not included in the model and the moisture content is evaluated with regression analysis.

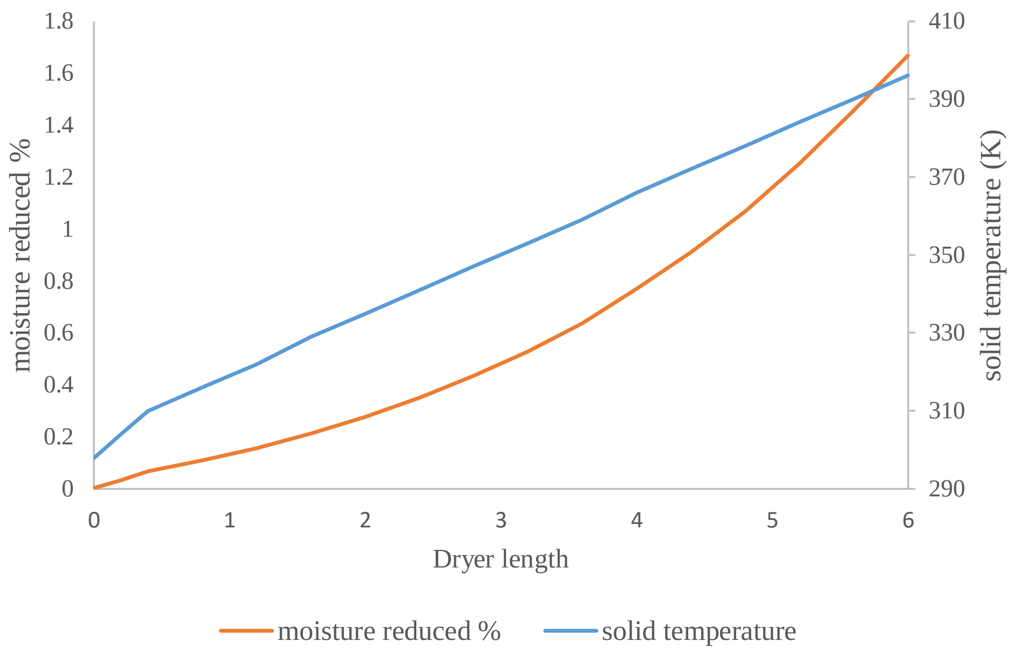


Figure 32: moisture content and aggregate temperature along the length of a dryer

For the aggregate moisture content calculation temperature coefficient and velocity coefficient parameters are used in the moisture content reduction equation.

In practical cases aggregate in a drum mix operation is weighed before drying, moisture content of the aggregate must be determined and proper allowance made for the water content, prior to mixing. The standard water content in aggregates is 5%. In the present study the energy potential of the exhaust gas has reduced 1.8% moisture of the solid. The heat in put for heating one tonne of aggregate is 201.4 MJ and for producing one tonne of hot mix is 205.1 MJ for 5% aggregate moisture content. After pre heating the aggregate and reducing to 3.2% the energy consumption will be reduced by 12.54% and becomes 176.05 for drying and 179.85 MJ for producing one tonne of hot mix. The energy saving for reduced aggregate moisture content is the basic factor of energy consumption in the production process and applying the possible energy reduction method is required to lower the energy cost of manufacturing hot mix asphalt.

7. CONCLUSIONS AND RECCOMENDATIONS

Applying energy conservation techniques for effective energy management helps a company keep costs down and offer additional benefits, such as improved product quality, increased production, and process efficiency. The asphalt plant processing factory uses higher amount of energy to dry the aggregate, melt the asphalt so that it will coat the stone, and heat the mix so it can be spread and compacted.

Thus, this chapter basically aims on summarizing the ways for improving the energy use in hot mix asphalt production factory and reduce the emission of toxic gases to the atmosphere during the production of asphalt mixture. The evaluation of operation performance based on the current production data provides a way to avoid improper damage to a component and operational failures.

7.1 CONCLUSIONS

The asphalt plant energy usage assessment data provides one year life cycle production and data of raw material production to the production and transportation. The data analysis method is under taken based on technical inspection on site and records of plant production data. The basic activities that consume the most energy is determined and energy reduction parameters have been developed. The aggregate moisture reduction by the use of exhaust gas is numerically analyzed. The major findings of this study is described includes the following areas.

- The asphalt plant energy usage analysis data for raw material production stage shows a unit energy consumption of 45.6 MJ/ton. This includes electricity consumption of 7.6 kWh and 0.5 lit/ton of diesel fuel. Asphalt mixture production stage unit energy consumption per tonne of production is 197.61 MJ/ton. This includes 8.33kWh electrical energy used for control and operation of electrical equipment’s and 6.33 lit/ton of diesel fuel to dry the aggregate and to heat the bitumen. The mixture production stage is influenced by the production mode, service life of the mixing plant and water content of the aggregate. The energy consumption data for asphalt mixture transportation is mainly generated in the process of transporting the mixed asphalt mixture. The unit energy consumption of transportation stage is 2.895 MJ/ton. The asphalt mixture energy consumption on the process of paving and rolling accounts 24.9 MJ/ton of product.
- The total energy consumption of production factory is 272.03 MJ/ton and the plant capacity is 40-60 ton/hr of hot mix asphalt. Therefore, the energy consumption per hour ranges from 10.9 GJ/hr to 16.32 GJ/hr of unit energy consumption per tonne of product.

- The annual statistical data shows that the raw material production 13%, asphalt mixture production 59%, transportation stage 20% and paving stage 8% of energy used by the electrical and diesel energy source. The net heat energy used during the production of mixture is 189.55 MJ. The aggregate drying requires 123.25 MJ/ton and 62.5 MJ energy is used the water. The bitumen heating uses 3.8 MJ and the rest is used in the operation process. Thermal efficiency evaluation of bitumen melting that is used for heating thermal oil is 94.05 and the rest will be lost by moisture, wall and stack loss. The aggregate is dried to an appropriate temperature using a direct fired rotary drier. By considering as an open system steady state condition, the energetic efficiency of the process is 86%. The rest will be lost with the elutriated dust in the exhaust gas and by the convective and radiative losses from the dryer.
- The second part of the study includes the numerical simulations carried out using commercial CFD code ANSYS FLUENT 16. The 2D Eularian Multiphase gas-solid heat transfer model is designed to pre heat the aggregate using the exhaust gas thermal potential.
- Phase-Coupled Simple (PC-SIMPLE) algorithm of multiphase flow is used by the ANSYS FLUENT to solve the model. A second order discretization scheme is used for convection terms in the momentum equation, while the Quick Scheme is used for the volume fraction equations. The results showed that it is possible to reduce the moisture content up to 1.8% by heating the particles before entering in to the dryer. After pre heating the aggregate and reducing to 3.2% the energy consumption will be reduced by 12.54% and becomes 176.05 for drying and 179.85 MJ for producing one tonne of hot mix.

7.2 RECCOMENDATIONS

This thesis work has shown the utilization of thermal potential in the production process of hot mix asphalt plant and CFD modeling to reduce the energy usage. Furthermore, the following recommendation can be addressed for future research work.

- It is recommended that asphalt plant industry can support it with experimental based investigation and compared against the actual usage.
- In the present CFD analysis, the model is assumed to be 2D but, in the future study 3D modeling analysis can be carried out.
- Finally by installing a prototype further investigation of and modification needs to be carried out on the production factory site.

8. REFERENCES

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APPENDIX

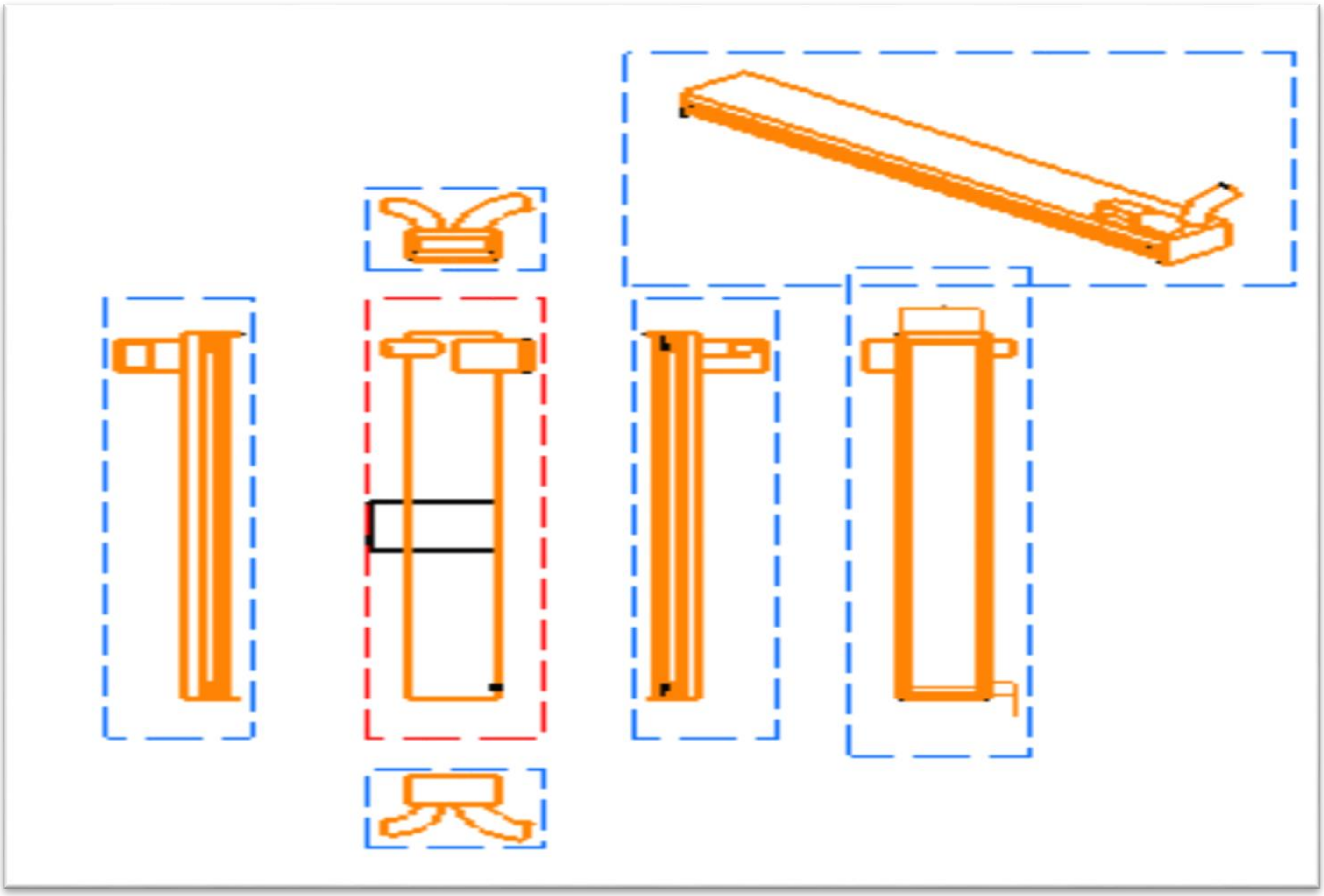
APPENDIX A

<u>Fuel consumption and production data sheet</u>

No	Equipment Type	Equipment id no	Material Description	Capacity (ton/hr)	Utilization in hr	Weekly Productivity (ton)	Fuel consumption(lt)
1							
2							
3							
4							
5							

APPENDIX B

AGGREGATE PRE HEATER LAYOUT



APPENDIX C

COMBINED GRADATION FOR WEARING COURSE

% passing										
AASHTO Sieve Size mm	20/13.2mm	13.2/5.0mm	5.0/0.0mm	Plant Dust	Blending Result	*Specification*		*Mix Tolerances*	Job Mix Formula	
						lower	*upper*			
26.5	*100.0*	*100.0*	*99.4*	*100.0*	*99.7*	*100*	*100*	±5.0	94.7	100
19.0	*100.0*	*100.0*	*62.8*	*100.0*	*81.0*	*85*	*100*	±5.0	76.0	86.0
13.2	*100.0*	*100.0*	*21.2*	*100.0*	*59.8*	*71*	*84*	±5.0	54.8	64.8
9.50	*100.0*	*99.0*	*5.7*	*100.0*	*51.7*	*62*	*76*	±5.0	46.7	56.7
4.75	*99.8*	*17.8*	*0.7*	*100.0*	*30.4*	*42*	*60*	±4.0	26.4	34.4
2.36	*74.5*	*2.0*	*0.4*	*100.0*	*20.0*	*30*	*48*	±4.0	16.0	24.0
1.18	*49.7*	*1.5*	*0.3*	*100.0*	*13.4*	*22*	*38*	±4.0	9.4	17.4
0.600	*32.8*	*1.2*	*0.2*	*100.0*	*8.9*	*16*	*28*	±4.0	4.9	12.9
0.300	*22.0*	*1.1*	*0.2*	*100.0*	*6.1*	*12*	*20*	±3.0	3.1	9.1
0.150	*15.3*	*1.0*	*0.2*	*100.0*	*4.3*	*8*	*15*	±2.0	2.3	6.3
0.075	*10.6*	*1.0*	*0.2*	*100.0*	*3.1*	*4*	*10*	±2.0	1.1	5.1
Blending proportion	*26*	*23*	*51*	*0.0*	*100*					

APPENDIX D

PHOTO ON ASPALT PLANT SITE