DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

HAZARDOUS WASTE AND RECOVERY

A CASE STUDY OF LIFE CYCLE AND ENVIRONMENTAL IMPACT ASSESSMENT OF GLASS WOOL

by
Nil AĞIL

March, 2011
İZMİR

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A CASE STUDY OF
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A Thesis Submitted to the
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By
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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"HAZARDOUS WASTE AND RECOVERY A CASE STUDY OF LIFE CYCLE AND ENVIRONMENTAL IMPACT ASSESSMENT OF GLASS WOOL"** completed by **NİL AĞIL** under supervision of **ASST. PROF. DR. ENVER YASER KÜÇÜKGÜL** and we certify that in our optinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

....

Asst. Prof. Dr. Enver Yaser KÜÇÜKGÜL

Supervisor

....
Assoc. Prof. Dr. Deniz Dölgen

(Jury Member)

....
Prof. Dr. Kadir Yurdakoç

(Jury Member)

Prof. Dr. Mustafa SABUNCU

Director

Graduate School of Natural and Applied Sciences

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ABSTRACT

The aim of this thesis is to investigate the behaviour and impacts of glass wool on the environment. Life cycle assessment of glass wool was also studied, from obtaining raw materials for manufacturing process to waste disposal (gas, liquid, solid wastes) during production process and after consumer use. Raw materials which are used for manufacturing glass wool properties have been defined and clasified according to Hazardous Waste Control Management (Environmental Protection Agency, [EPA], 1997). Glass wool types are described according to their chemical and physical properties and usage areas. Glass wool is generally used as an insulation material (thermal, noise, chemical and water insulations). They contribute to energy conservation while on the other hand they spread potentially hazardous gases.

Glass wool includes both inorganic and organic substances. The basic organic substances are phenol, formaldehyde and methanol.

Formaldehyde exposure has been associated with reproductive effects such as menstrual disorders and pregnancy problems in female workers. The EPA has classified formaldehyde as Class B1, probable human carcinogen, on the basis of findings of nasal cancer in animal studies and limited human data. Phenol has been shown to cause damage to the liver, kidney and cardiovascular system in animal studies.

Acute exposure to methanol (usually by ingestion) is well known to cause blindness and severe metabolic acidosis, sometimes leading to death. Chronic

methanol exposure, including inhalation, may cause central nervous system disturbances possibly leading to blindness. The available data is not sufficient to classify either phenol or methanol as to potential human carcinogenicity.

Formaldehyde phenol and methanol also are VOCs which are precursors to ozone formation. Ambient ozone can cause damage to lung tissue, reduction of lung function and increased sensitivity of the lung to other irritants.

The harmful effects of glass wool are investigated and possible actions to be taken are determined in this study.

Keywords: Glass wool, Life Cycle Assessment, Insulation, Recovery, Environmental Impact Assessment…

TEHLİKELİ ATIK VE GERİ KAZANIM

CAM YÜNÜNÜN YAŞAM DÖNGÜSÜ VE ÇEVRESEL ETKİ DEĞERLENDİRMESİ DURUM ÇALIŞMASI

ÖZ

Bu tezin amacı cam yününün çevreye olan etkilerinin ve davranışlarının incelenmesidir. Ayrıca bu çalışma kapsamında cam yününün yaşam döngüsü değerlendirilmesi yapılmıştır. Cam yünü üretimi için hammaddelerin elde edilmesinden, üretim esnasında ve tüketicilerin kullanımından sonra oluşan atıkların (gaz, sıvı, katı atıklar) bertarafına kadar değerlendirme çalışması yapılmıştır. Cam yünü üretiminde kullanılan hammaddeler Tehlikeli Atıkların Kontrolü Yönetmeliğine göre tanımlanmış ve sınıflandırılmıştır (EPA, 1997). Cam yünü türleri, kimyasal ve fiziksel özelliklerine göre ve kullanım alanlarına göre tanımlanmıştır. Cam yünü genel olarak yalıtım (ısı, gürültü, kimyasal ve su yalıtımı) malzemesi olarak kullanılmaktadır. Enerji korunumuna katkıda bulunurken diğer bir taraftan potansiyel olarak tehlikeli gazlar yaymaktadır.

Cam yünü hem inorganik hem de organik maddeler içermektedir. Temel organik maddeler fenol, formaldehit ve metanol'dür.

Formaldehit etkileri konusunda kadınlar üzerine yapılan çalışmalarda adet düzensizlikleri, hamilelik problemleri ile genetik etkiler gözlenmektedir. EPA, formaldehit'i B1 (insan üzerinde muhtemel kanserojen) olarak sınıflandırmıştır. Hayvanlar üzerinde yapılan çalışmalara ve vaka inceleme verilere bağlı olarak geniz kanseri bulgularına rastlanmıştır.

Fenol'ün; karaciğer, çocuklar ve kardiyovasküler sistemde zarara neden olduğu hayvanlar üzerine yapılan çalışmalarda gösterilmiştir.

Genellikle sindirim yoluyla alınan metanolün akut etkisinin (körlük ve metabolik asidos), bazı durumlarda ölümle sonuçlandığı bilinmektedir. Metanol'ün solunum yollarına kronik etkisinin, merkezi sinir sisteminde bozuklukla körlüğe yol açması mümkündür. Veriler, fenol ve metanolün insanlarda kansere neden olduğunu kanıtlamak için yeterli değildir.

Formaldehit, fenol ve methanol ozonu oluşturan uçucu organic karbonlardır. Çevredeki ozon, akciğer dokularında zarara yol açabilmekte, akciğer fonksiyonlarını azaltabilmekte ve akciğerin diğer tahriş edici maddelere hassasiyetini arttırabilmektedir.

Bu çalışma kapsamında cam yününün zararlı etkileri incelenmiş ve alınabilecek olası önlemler belirlenmiştir.

Anahtar Kelimeler: Cam Yünü, Yaşam Döngüsü Değerlendirmesi, Yalıtım, Geri Kazanım, Çevresel Etki Değerlendirmesi …

TABLE OF CONTENTS

Page

M. Sc. THESIS EXAMINATION RESULT FORM ii
ACKNOWLEDGMENTS iii
ABSTRACT iv
ÖZ vi

CHAPTER ONE – INTRODUCTION 1

1.1 Introduction 1
1.2 Goal of This Thesis 2

CHAPTER TWO – GLASS WOOL AND ENVIRONMENT 4

2.1 Glass Wool Composites 4
2.1.1 Chemical Properties of Glass Wool 4
2.1.2 Physical Properties of Glass Wool 5
2.1.3 Characteristics of Glass Wool Composites 6
2.1.3.1 Strength 6
2.1.3.2 Stiffness 6
2.1.3.3 Expense 6
2.1.3.4 Environmental Sustainability and Effects 7
2.1.4 Constituents of Glass Wool Composites 7
2.1.4.1 Resin System 7
2.1.4.2 Fillers 8
2.1.4.3 Reinforcements 9
2.1.5 Types of Glass Wool 9
2.1.6 Application of Glass Wool Composites 10
2.1.6.1 Glass Wool in Construction 11
2.1.6.2 Glass Wool in Transportation 12
2.1.6.3 Glass Wool in Medical Science 12

2.1.6.4 Glass Wool in Musical Instrument 13
2.1.6.5 Glass Wool in Hausehold Products 13
2.1.6.6 Glass Wool in Marine 14

CHAPTER THREE – LIFE CYCLE ASSESSMENT 15

3.1 Introduction to Product Life Cycle Concepts 16
3.1.1 Life Cycle Inventory 18
3.1.2 Life Cycle Impact Assessment 17
3.1.2.1 Key Steps of a Life Cycle Impact Assessment 20
3.1.3 Life Cycle Interpretation 21

CHAPTER FOUR – GLASS WOOL MANUFACTURING PROCESS 23

4.1 Process Description 23
4.1.1 Raw Materials Handling 23
4.1.2 Mixing 25
4.1.3 Melting 26
4.1.4 Fiberizers and Curing Oven 28
4.1.5 Forming 29
4.1.6 Resin Production 30
4.1.6.1 Raw Materials 30
4.1.7 Cooling 32
4.1.8 Cutting and Packaging 32

CHAPTER FIVE – MASS BALANCE OF GLASS WOOL PRODUCTION ... 34

5.1 Raw Material Consumption 35
5.2 Energy Consumption 35
5.3 Water Consumption 36
5.4 Resin Consumption 37
5.5 Factory Inputs and Outputs 37

CHAPTER SIX – ENVIRONMENTAL IMPACTS OF GLASS WOOL MANUFACTURING ... 41

6.1 Emission Estimation for Glass Wool Manufacturing ... 42
6.1.1 Emission to Air ... 42
6.1.1.1 Raw Materials Handling ... 43
6.1.1.2 Melting ... 44
6.1.1.3 Downstream Activities ... 49
6.1.1.4 Diffuse and Fugitive Emissions ... 51
6.1.2 Emission to Water ... 51
6.1.2.1 Characteristic of the Waste Water ... 53
6.1.3 Other Wastes ... 54
6.1.4 Energy ... 55

CHAPTER SEVEN – WASTE MANAGEMENT PLAN FOR GLASS WOOL57

7.1 Manufacturing Wastes ... 57
7.1.1 Air Emissions ... 57
7.1.1.1 Bag Filters ... 58
7.1.1.2 Impact Jets and Cyclones ... 58
7.1.1.3 Wet Scrubber ... 58
7.1.1.4 Wet Electrostatic Precipitators ... 58
7.1.2 Solid Wastes ... 59
7.1.2.1 Thermal Treatment ... 60
7.1.2.2 Chemical Treatment ... 61
7.1.3 Waste Waters ... 62
7.1.3.1 Waste Water Treatment ... 63
7.1.3.2 Activated Sludge Treatment ... 64
7.1.3.3 Extraction ... 66
7.2 End of Life Wastes ... 66
7.2.1 Reduce ... 68
7.2.2 Reuse ... 68

7.2.3 Recycle 68
7.2.4 Landfill 69

CHAPTER EIGHT – RESULTS AND DISCUSSION... 70

CHAPTER NINE – CONCLUSIONS.. 74

REFERENCES.. 76

APPENDICES 84

A.1 Symbols and Abbreviations 84

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Nowadays, the population of the whole world has reached approximately 7 billion people and has been increasing rapidly. The increasing world population requires more natural resources which are important for sustaining living standards. New products are being produced on the world everyday. Natural resources have been decreasing; on the other hand our existent sources are being polluted with technological development and industrial activities.

One of the greatest environmental problems is energy consumption. We need energy sources to sustain living quality. In the face of technological development and in parallel with the increase in world population, humanity is more dependent on energy day by day. Energy sources are consumed carelessly and rapidly. Energy management helps to improve environmental quality while energy consumption has to be kept underfoot. Insulation technology is the one alternative method used to conserve energy. Thus, energy management, by reducing the combustion of methane can reduce the amount of carbon dioxide in the atmosphere and help to reduce global warming as well.

Insulation technology is widely used in heating and cooling purpose and vehicles, buildings, bridges, ship building industries and also many sports goods. Insulation can contribute to energy conservation and on the other hand provide economical advantages. Insulation is non-corrosive and has low weight; in addition, glass wool is less expensive in cost when compared to other materials (such as polystyrene, polyurethane).

Although glass wool production has many advantages for energy conservation, it is also a hazardous material that threatens public health. Glass wool has not only some harmless inorganic material, but also complex and toxic organic compounds.

1.2 Goal of This Thesis

The purpose of this study is to investigate the impacts of fiber composites on the environment. Thus, Life Cycle Assessment (LCA) of glass wool is attentively observed in this project. It helps to provide grounds for decision makers, political bodies and consumers to make the right choice, which is more sustainable and safe for the environment in the long run.

Glass wool manufacturing creates emissions and also may pollute water sources. While determining types and quantities of wastes produced, methods can be chosen that give light to risk assessment for environmental factors. Furthermore, glass wool types change according to their purpose of use. Different types of glass wool also include some different raw materials, as well as different physical and chemical properties. The main purpose of using glass wool is electrical and thermal insulation besides mechanical, chemical, noise and water resistance.

Properties of glass wool are investigated in chapter one. Physical properties (characteristic strength, stiffness, environmental sustainability and effects…) and chemical properties such as mineral composition and organic compounds which includes resin system of glass wool are determined. Also, types of glass wool and their properties are discussed. Furthermore, application and their reasons for usage areas are discussed in this chapter.

In chapter two, we determined life cycle assessment’s general approach such as importance of life cycle analyses and theory of this study. Not only glass wool manufacturing process’s environmental effects are determined, but also beginning with raw materials handling which are used for manufacturing processes to waste quantity from manufacturing and end of life of glass wool wastes. Raw materials and natural sources usage and their quantity defined and the arising wastes and their disposal methods are discussed in this chapter. In terms of environmental and economical advantages and disadvantages are determined.

Glass wool manufacturing process is described in chapter three. Steps of the process and raw materials used are identified in this section. How many raw materials are used for the processes is indicated. We described that all units and their properties. Resin system which is using for glass wool production and its chemical formulation are described in this chapter. In addition process flow diagram is also given.

Mass balance during the glass wool manufacturing process is described in chapter four. The quantity of raw materials, water, and resin are identified in this chapter and the mass balance flow diagram is provided. Not only system inputs are given but also process outputs are determined.

Environmental effects of glass wool manufacturing are discussed in chapter five. Especially, air emissions which are composed from organic aromatic compound and their quantity are defined. Emission sources are also determined in this chapter. Also water pollution is come into question in this process. Water consumption and content are determined as well. The quantity and properties of solid wastes arising from manufacturing processes are determined.

Air emissions, water emissions and other wastes are determined during the manufacturing process in chapter six. Air emissions reduction techniques and solid wastes and water emissions decrement methods while generating glass wool are discussed in this chapter. On the other hand, recycling, reduction and reclamation methods are reviewed.

CHAPTER TWO
GLASS WOOL COMPOSITES

2.1 Glass Wool Composites

In this chapter, glass wool as an insulation product is detailed, examining their main properties, composition, classification and types of them. Applications of glass wool are also discussed and environmental impacts are illustrated.

Glass wool was first used in bricks manufacturing as reinforcing material in the third millennium BC. In the 1930's reinforced glass wool is used in U.S. in cement manufacturing. Composites were also used in 2nd World War when they were used to make ship hulls. In the 1950's for the first time glass wool was used in cars because of desirable properties (Tang et.al., 1997).

Nowadays, glass wool is used in electrical goods, sports equipment, railings, cars, ships, refrigerators and ovens in our homes and even in medical works.

A composite is usually made up of least two materials. The main materials are binding materials called "matrix" while the other material is the reinforcement material. The matrix may be metallic, ceramic or polymeric (Anstrom, 1997).

2.1.1 Chemical Properties of Glass Wool

Glass wool compounds largely involve inorganic substances such as aluminium and calcium silicates that are derived from rock, clay, slag or glass (International Agency for Research on Cancer, [IARC], 1988). Fibrous glass products are derived from powdered sand and largely consist of silicon and aluminum oxides. Glass wool also includes alkali metal oxides, alkaline earth oxides and metal oxides like ZrO_2 and Fe_2O_3 according to their area of use. On the other hand, glass wool consist metallic materials such as Arsenic, Chromium, Lead and organic compounds like formaldehyde, phenol, and methanol (EPA, 1997). These metallic and organic compounds cause health effects including carcinogenic, respiratory and nervous system defects. Glass wool consists 90% of glass and 10% formo-phenolic binders.

Table 2.1 Mineral composition of glass wool (Triange Interactive Marketing Association [TIMA], 1993).

Compositions	**Percentage Content in**
SiO_2	55-70
Al_2O_3	0-7
B_2O_3	3-12
K_2O	0-2.5
Na_2O	13-18
MgO	0-5
CaO	5-13
Ti_2O	0-0.5
Fe_2O_3	0.1-0.5
Li_2O	0-0.5
SO_3	0-0.5
F_2	0-1.5
BaO	0-3

2.1.2 Physical Properties of Glass Wool

The aim of usage of glass wool is mainly the insulation characteristics against chemical corrosion, water, noise and fire. The main physical properties are melting point, molecular weight and surface tension for glass wool composites. Other properties are density, modulus of elasticity, viscosity, thermal conductivity and heat capacity. According to their physical properties, they are classified as their usage areas.

Table 2.2 Physical properties of glass wool (Micoulaut, 2006).

Physical Properties	**Temperature (^{0}C)**	**Value**
Density	20	2.55 g/cm^3
Molecular weigt	-	60.08 g/mole
Melting point	-	1710 ^{0}C
Thermal conductivity	-	0.04 W/mk
Viscosity	1400	3.62 Pa.s
Heat capacity	20	50 J/(mol.K)
Modulus of elasticity	20	75 GPa
Surface tension	1300	290 mj/m^2

2.1.3 Characteristics of Glass Wool Composites

The characteristics of glass wool composites that have made them useful and unique are:

2.1.3.1 Strength

One of the most important characteristics of the glass wool composites is their strength. They are very hard and rigid they provide the required strength for all structures that they are used for such as buildings, ships in combination with low weight. Tensile strength is four to six times greater than that of aluminum or steel (Biswas et. al., 2002). Structures made of composites are 30-40% lighter than similar ones made of aluminum. The high strength, low weight and design flexibility allows them to be easy molded into structures that have such requirements.

The strength of glass wool may be hindered as a result of different environmental interaction. As recent study shows that the tensile and transerve strength of composite resins demonstrate lower values after storage and test in water as compared to dry condition due to its water absorption (Tani, 2002).

2.1.3.2 Stiffness

Other characteristic of glass wool that has made them popular is its stiffness to density ratio. The stiffness helps in building various structures. This is the reason that glass wool composites have various structural applications. The stiffness can be tailor made and usually depends on the spatial configuration of the reinforcements.

2.1.3.3 Expense

A lot of composites are manufactured at a lower cost as compared to other material such as steel, concrete etc. as for the glass wool composites, they may be competitive at initial cost that includes manufacturing cost, they are substantially less expensive in terms of installation cost and are far less costly to maintain. Thay have been found to be responsible for setting up cost effective structures (Umair, 2006).

2.1.3.4 Environmental Sustainability and Effects

Many researchers have observed that which natural sources and plants can provide raw materials for glass wool and how to make them more environmental friendly. The using of composites has reduced environmental impacts and these properties make it environmental friendly. Using glass wool in cars, buses, ships, buildings etc., it contributes energy saving and energy efficiency. On the other hand, glass wool includes aromatic organic compound which are cancer causing compounds besides mineral oxides. From these properties of them, they spread emission to the environment and affects human health slowly and unwittingly (Umair, 2006).

2.1.4 Constituents of Glass Wool Composites

The constituents of materials that make up the composites are resins, fillers, additives and reinforcements (e.g. Fibers).

2.1.4.1 Resin Systems

The resin is an important constituent in glass composites. The two classes of resins are the thermoplastics and thermosets.

Thermoplastic Resin: remains a solid at room temperature. It melts when heated and solidifies when cooled. The long chain polymers do not form strong covalent bond. That is why they do not harden permanently and are undesirable for structural application (Umair, 2006).

Thermosets Resin: will harden permanently by irreversible cross-linking at elevated temperatures. This characteristic makes the thermoset resin composites very desirable for structural applications. The most common resins used in composites are the unsaturated polyesters, epoxies, vinyl esters, polyurethaes and phenolics (Umair, 2006).

1. Epoxies: The epoxies used in mineral composites are mainly the glycidyl ethers and amines. Epoxies are generally found in aeronautical, marine, automotive and electrical device application. Although epoxies can e expensive, it may be worth the cost when high performance is required. It has also some disadvantages which are its toxicity and complex processing requirements. It is generally causing inhalation, skin and eye irritation.

2. Phenolics: The phenolic resins are made from phenols and formaldehyde and they are divided into resole (prepared under basic conditions) and novolac resins (prepared under acidic conditions). The phenolics are praised for their good resistance to high temperature, good thermal stability and low smoke generation. They have a disadvantage due to their brittleness and inability to be colored until now (Anstrom, 1997). Phenol also causes skin and eye irritation in low dose. In addition, they have cancer-causing effects when impressed in high dose (Umair, 2006).

2.1.4.2 Fillers

Fillers are added to the resin system for controlling material cost and improving its mechanical and chemical properties. Some composites that are rich in resins can be subject to high shrinkage and low tensile strength. Although these properties may be undesirable for structural applications, there may be a place for their use.

The three major types of fillers used in the composite industry are the calcium, carbonate, kaolin and alumina trihydrate. Other common fillers include mica, feldspar, wollastonite (natural calcium silicate), silica, talc and glasses. When one or more fillers are added to the properly formulated composite system, improved performance includes fire and chemical resistance, high mechanical strength and low shrinkage. Other improvements include toughness as well as high fatigue and creep resistance. Some fillers cause composites to have lower thermal expansion. Wollastonite filler improves on the fire resistance of flammability ratings. Some high strength formulations may not contain any filler because it increases the viscosity of the resin paste (Umair, 2006).

2.1.4.3 Reinforcements

Reinforcements are the solid part of composites which is reinforced in to the matrix. They determine the strength and stiffness of the composites. Most common reinforcements are fibers, particles and whiskers. Fiber reinforcement are found in both natural and synthetic forms. Fiber composite was the very first form of composites, using natural fiber such as straw was reinforced in clay to make bricks that for used for buildings. Particle reinforcements are cheaper and are usually used to reduce the cost of isotropic materials. Whiskers are pure single crystals manufactured through chemical vapor deposition and are randomly arranged in the matrix. They are also isotropic but this type reinforcement is very expensive. Among these reinforcement the long glass fiber (12 to 50 mm) are the ones most commonly used. There four kinds of fiber reinforcements and these are carbon fibers, aramid fibers, natural fibers and glass fibers (Umair, 2006).

2.1.5 Types of Glass Wool

Different types of glass are used for certain types of specialized purposes, and relatively small changes in the chemical composition of the can result in significant changes to its optical, electrical, chemical, mechanical properties. There are four main types of glass wool (IACR, 1988).

1.E-glass (Electrical Glass): This type of glass fiber is widely used and takes name form its good electrical properties but is prone to fractures in case of acustic emissions (Cowking, 1991). E-glass provides a high resistance to the passage of electricity and is a continuous filament type of fibrous glass developed for electrical applications that has excellent heat and water resistance (IARC, 1988). The high resistivity of E-glass is related to its low alkali oxide content.

2.C-glass (Chemical glass): Chemical glass is highly resistant to attack by chemicals such as hydrofluoric acid, concentrated phosphoric acid (when hot) and superheated water. The chemical resistance is determined by the relative amounts of acidic oxides (Si_2O, B_2O_3), basic oxides (CaO, MgO, Na_2O K_2O) and amphoteric oxides (Al_2O_3).

3. S-glass (High-Strength glass): High-Strength glass is almost completely composed of aluminum, silicon and magnesium oxides and finds use in sophisticated high technology applications where high tensile strength is required. Its tensile strength is typically 30-40% greater than E-glass. It is also an ideal material to make boat hulls, swimming pool linings, car bodies, roofing and furniture.

4. AR-glass (Alkali Resistance glass): Alkali Resistance glass contains high percentage of zirconium oxide, which makes this type of glass highly resistant to acidic and alkaline compounds.

2.1.6 Application of Glass Wool Composites

Sustainability of energy is coming into prominence as the growing population and increasing life quality in double time, attendantly advancing of energy sources. We have to consider how to perform those needs by making it available for all. There is a need to find economically and environmental friendly methods. Buildings, industrial facilities and vehichles are an important parts of energy policy with increasing the energy efficiency.

Increasing residential and commercial insulation can decrease energy consumption and widely used in homes, cars, buildings, industries, some treatment processes by environmental engineers and even in medical applications.

Especially thermal insulation is a mature technology that has changed significantly in the last few years. The use of insulation is mandatory for the efficient operation of any hot or cold system. It is interesting to consider that by using insulation, the entire energy requirements of a system are reduced. Most insulation systems reduce the unwanted heat transfer, either lost or gain, by at least 90% as compared to bare surfaces (Umair, 2006).

Application of glass fiber composites are represented by the following groups which are 70% total market value: automotive (23%), buildings and public works (21%), aeronaustics (17%) and sports (11%), (Jardine Enginnering Corporation, [JEC], 2005). North America represented 40% of the composites industry’s total market value with 35% for Europa, 22% for the Asia-Pacific region and 3% for the rest of the world.

2.1.6.1 Glass Wool in Construction

The widely and first known usage of glass wool was in construction applications. Common usage areas in construction are metal and wood roofs, between the roofs, partition walls, facades with aeration, solar collectors, ceiling floors and also in brick manufacturing. Straw reinforced clay bricks were used by Egyptian pharaohs, Israelites and Chinese centuries ago. The property of glass wool of being strong resistant to electrical application, thermal and acoustical and it has low weight makes it good building material. Its low weight helps in case of transportation of this material. Its light structure may help in earthquake prone region. Flexible concrete is also made using fiber reinforcement that can withstand earthquakes (Shelly, 2006).

Today glass wool reinforced composites are used in footbridges as well as bridges. The first fully instrumented all-composite two-lane vehicle bridge with an extensive health- monitoring system was installed in US. Nearly four year long continuous monitoring was carried out to demonstrate the performance of the bridge. Field monitored information was studied to evaluate the behavior and durability of composites in the harsh infrastructure environment. The evaluation showed the level of confidence in the long term field benefits of glass wool composites and technology (Farhey, 2006). Fiber reinforced to concrete is widely used in building and construction since 1980's.

During constraction one of the important thing to consider is insulation nowadays. It helps in reducing energy losses helps retain the internal temperature. Therefore an LCA on insulation materials was used to study the impacts of fiber glass used in construction. The study also addressed occupational health issues using approach similar to that for risk assessment.

2.1.6.2 Glass Wool in Transportation

Glass wool is being used in the automotive industry. The reason for their increasing demand in this industry is because the strength and stiffness in combination with low weight decreases the fuel consumption. It is said to save up to 27% of the weight in most of the structures (Nangia et. al, 2000). All vehicles from train to cars as well as bicycles are now using glass fibers. They are not only being used in the exterior but a lot of car parts are also being made from composites which include radiators, spoilers, door panels, hoods, hatchbacks, roof panels, bonnets, wing mirrors, rear light units, brake linings, ignition components. Internal parts and trim where they are the solution to lightness, freedom of shape, freedom of design, matching internal decor and providing thermal and sound insulation. They are used to mould interior components for buses, seat squabs and bases, car door liners, back panel of seats, parcel shelves (Umair, 2006).

2.1.6.3 Glass Wool in Medical Science

Glass wool have found their way into medical sciences where they have provided new alternative in the field of science for other materials. Previously broken bones were supported with metal rods surgically, which in some cases would cause problem such as bending, corrosion etc thus causing a threat to the patient. Similarly in the case of amputees they had to use artificial limbs that were very heavy, they were a cause of sores in diabetics. In the case of artificial limbs new lightweight and cheaper artificial limbs have been introduced. This has made mobility for amputees easier. It has also benefited the diabetic patients. Now amputees are also able to compete just like other athletes with artificial limbs that have shocks. Glass white wool is also used for immobilization of oxidized antibody attachment, as medical applications (Froes, 1997).

2.1.6.4 Glass Wool in Musical Instrument

One of the finest musical instruments is manufactured by glass wool. They are lightweight and have astonishing sound properties. A silent piano is a composite keyboard musical instrument fabricated on the basis of an acoustic piano, and a pianist can play a tune by piano tones or electronic tones. Glass wool resin is being used to make guitars and violins, as it is lightweight and resistant to environmental impacts, and damage. It has resonating properties similar to that of wood and has lower construction time and cost (Froes, 1997).

2.1.6.5 Glass Wool in Hausehold Products

Fiber composites have also made their way in to our homes on the basis of their useful properties. Manufacturing of the fireproof core of fire resistant doors and screens, insulating and fire-resistant materials with different characteristics are being used, including a large number of materials comprised of insulators based on different silica compounds, e.g. fly ashes, which can be reinforced by fibers and produce fire resistant products with good thermal stability at high temperatures. Furniture is now being produced which is made of glass wool. They are being used because they can easily be shaped into various beautiful and fashionable shapes. With the help of additives they can easily be colored according to our taste. Being lightweight it is preferred over heavy wooden and steel furniture. Various appliances in our homes are made from fiber composites such as vacuum cleaners, food processor etc. Bathtub swimming pools and other toiletries are also made from glass wool (Corbiere, 2001).

The layer of fiber composites is used to secure the landfill waste from leaching toxins into the environment. This is possible because of the strong structure of this layer, which is non-corrosive.

2.1.6.6 Glass Wool in Marine

Before composites and light aluminum structures were available, all boats and ships were made from wood. Therefore were very costly, vulnerable to environmental impacts and had a lot of maintenance problems. With complex structures such as ship wood was found to be very hard to shape as well. Fiber glasses boats are now much more famous because of their new interesting shapes, less cost, less maintenance etc. It was easily detected due to magnetic properties and was easily exposed to mines. With the advents of glass wool new light weight structures of warfare ships have been introduced which are fuel efficient, fast, fire resistant, non magnetic and with a minimum cost of maintenance. These ships can easily receive and send radar waves. Key fixtures and fittings of the boat are now being made from these materials. Steering wheels and wind transducers are some of the most recent areas of application (Commander, 1999).

CHAPTER THREE
LIFE CYCLE ASSESSMENT

As environmental awareness increases, industries and businesses are assessing how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. Many businesses have responded to this awareness by providing “greener” products and using “greener” processes. The environmental performance of products and processes has become a key issue, which is why some companies are investigating ways to minimize their effects on the environment. Many companies have found it advantageous to explore ways of moving beyond compliance using pollution prevention strategies and environmental management systems to improve their environmental performance. One such tool is LCA. This concept considers the entire life cycle of a product.

Life cycle assessment is a “cradle-to-grave” approach for assessing industrial systems. “Cradle-to-grave” begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product’s life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection.

The term “life cycle” refers to the major activities in the course of the product’s life-span from its manufacture, use, and maintenance, to its final disposal, including the raw material acquisition required manufacturing the product. Figure 3.1, illustrates the possible life cycle stages that can be considered in an LCA and the typical inputs/outputs measured (EPA, 2006).

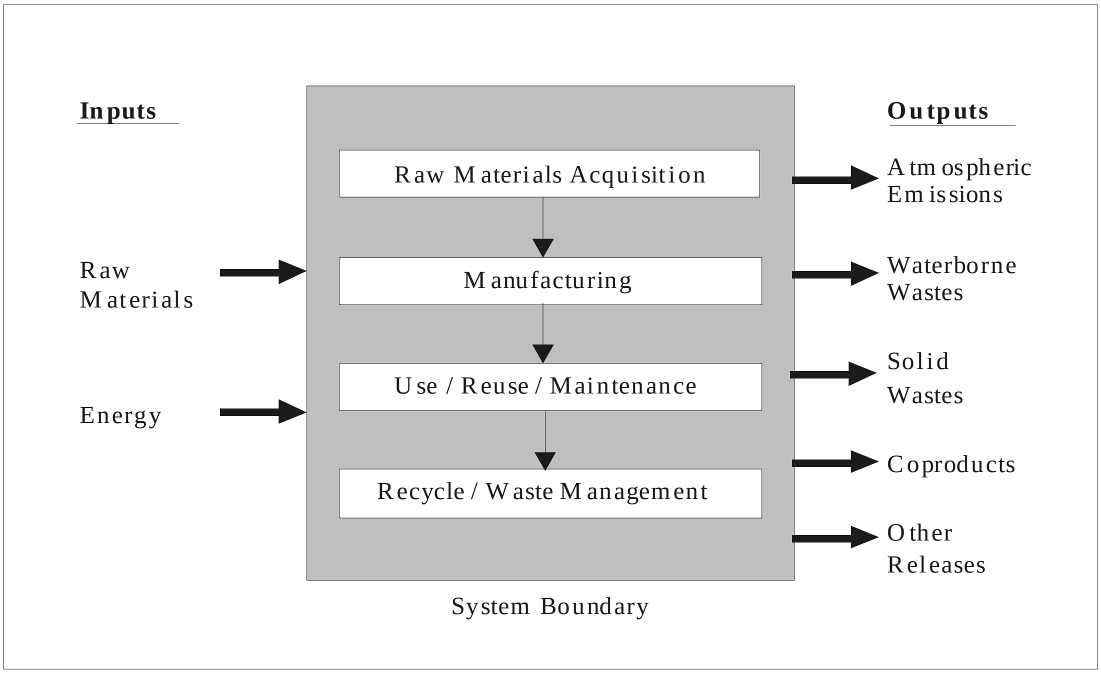


Figure 3.1 LCA system boundary (EPA, 1993)

3.1 Introduction to Product Life Cycle Concepts

The LCA process is a systematic, phased approach and consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation as illustrated in Figure 3.2.

1. *Goal Definition and Scoping* – Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.

2. *Inventory Analysis* – Identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, waste water discharges).

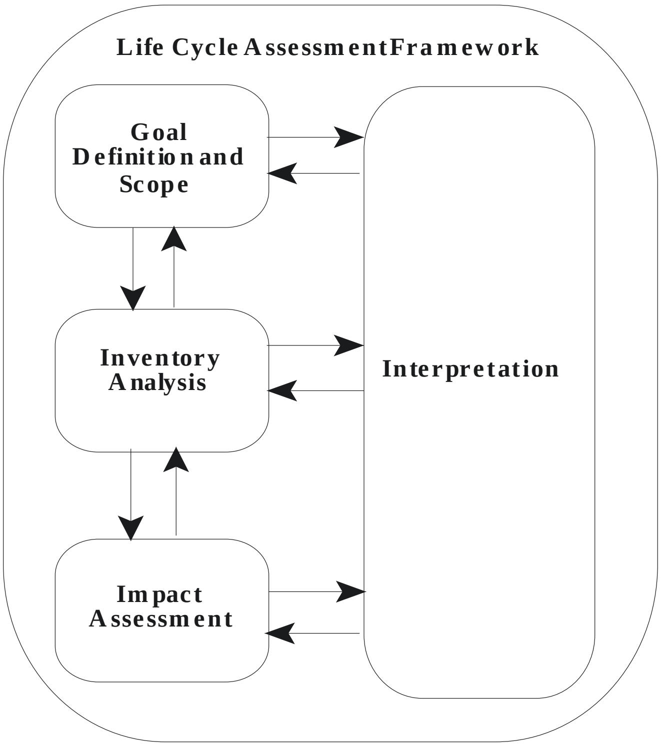


Figure 3.2 Life cycle assessment framework (ISO, 1997)

3. *Impact Assessment* – Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.

4. *Interpretation* – Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

Life cycle framework is shown in Figure 3.3 provided by the articles. Definition of manufacturing process is determined in glass wool manufacturing process in chapter four. Inventory analyze is studied in mass balance of glass wool production in chapter five and environmental impact assessment is studied in chapter six.

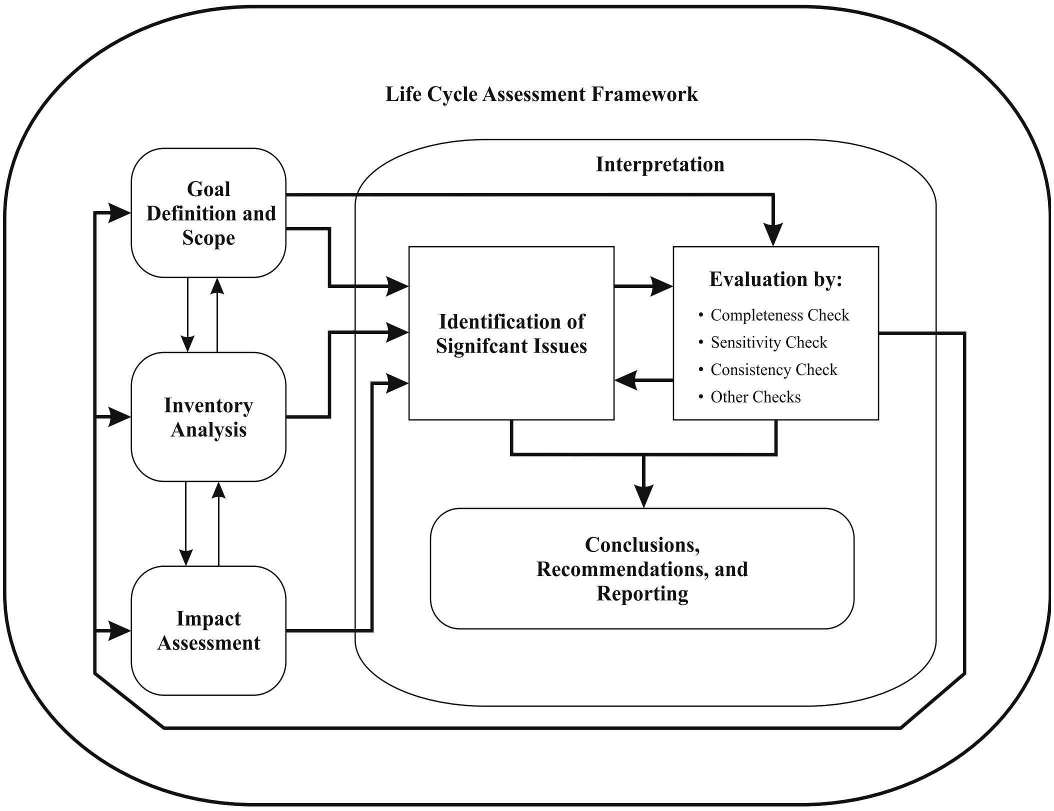


Figure 3.3 Life cycle assessment framework (EPA, 2006)

3.1.1 Life Cycle Inventory

A life cycle inventory is a process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of a product, process, or activity.

In the life cycle inventory phase of an LCA, all relevant data is collected and organized. Without an LCI, no basis exists to evaluate comparative environmental impacts or potential improvements. The level of accuracy and detail of the data collected is reflected throughout the remainder of the LCA process.

Life cycle inventory analyses can be used in various ways. They can assist an organization in comparing products or processes and considering environmental factors in material selection. In addition, inventory analyses can be used in policy-making, by helping the government develop regulations regarding resource use and environmental emissions.

An inventory analysis produces a list containing the quantities of pollutants released to the environment and the amount of energy and material consumed. The results can be segregated by life cycle stage, media (air, water, and land), specific processes, or any combination thereof.

- Develop a flow diagram of the processes being evaluated.
- Develop a data collection plan.
- Collect data.
- Evaluate and report results (EPA, 2006).

Step 1: Develop a Flow Diagram

A flow diagram is a tool to map the inputs and outputs to a process or system. The "system" or "system boundary" varies for every LCA project. Quantities of Inputs and outputs of glass wool manufacturing is given in mass balance of the glass wool manufacturing process in chapter 5.The goal definition and scoping phase establishes initial boundaries that define what is to be included in a particular LCA; these are used as the system boundary for the flow diagram. Unit processes inside of the system boundary link together to form a complete life cycle picture of the required inputs and outputs (material and energy) to the system. Figure 3.4 illustrates the components of a generic unit process within a flow diagram for a given system boundary (EPA, 2006). The mass balance and enviromental impact assessment chapters are studied according to methodology of system boundary.

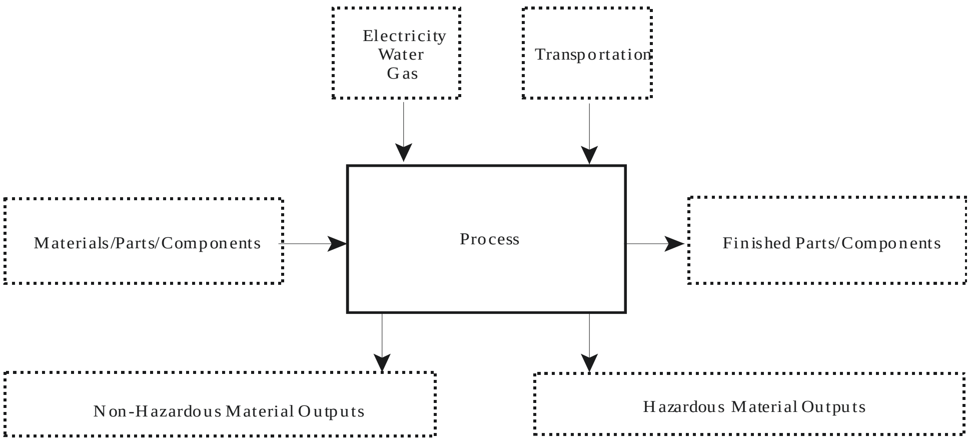


Figure 3.4 Generic system boundary (EPA, 2006).

Step 2: Develop an LCI Data Collection Plan

As part of the goal definition and scoping phase the required accuracy of data was determined. When selecting sources for data to complete the life cycle inventory, an LCI data collection plan ensures that the quality and accuracy of data meet the expectations of the decision-makers. In this step, data quality goals, data sources and types data quality indicators are identified (EPA, 2006).

3.1.2 Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) phase of an LCA is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the LCI. Impact assessment should address ecological and human health effects; it should also address resource depletion. A life cycle impact assessment attempts to establish a linkage between the product or process and its potential environmental impacts. Environmental effects of glass wool manufacturing is explained in detail.For example, what are the impacts of 9,000 tons of carbon dioxide or 5,000 tons of methane emissions released into the atmosphere? Which is worse? What are their potential impacts on smog? On global warming?

3.1.2.1 Key Steps of a Life Cycle Impact Assessment

The following steps comprise a life cycle impact assessment.

1. *Selection and Definition of Impact Categories* - identifying relevant environmental impact categories (e.g., global warming, acidification, terrestrial toxicity).

2. *Classification* - assigning LCI results to the impact categories (e.g., classifying carbon dioxide emissions to global warming).

3. *Characterization* - modeling LCI impacts within impact categories using science-based conversion factors (e.g., modeling the potential impact of carbon dioxide and methane on global warming).

4. *Normalization* - expressing potential impacts in ways that can be compared (e.g. comparing the global warming impact of carbon dioxide and methane for the two options).

5. *Grouping* - sorting or ranking the indicators (e.g. sorting the indicators by location: local, regional, and global).

6. *Weighting* - emphasizing the most important potential impacts.

7. *Evaluating and Reporting LCIA Results* - gaining a better understanding of the reliability of the LCIA results.

Inventory Data × Characterization Factor = Impact Indicators (EPA, 2006).

3.1.3 Life Cycle Interpretation

Life cycle interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the LCI and the LCIA, and communicate them effectively. Life cycle interpretation is the last phase of the LCA process.

ISO has defined the following two objectives of life cycle interpretation:

1. Analyze results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases of the LCA, and to report the results of the life cycle interpretation in a transparent manner.

2. Provide a readily understandable, complete, and consistent presentation of the results of an LCA study, in accordance with the goal and scope of the study (EPA, 2006).

CHAPTER FOUR
GLASS WOOL MANUFACTURING PROCESS

4.1 Process Description

The glass industry includes a variety of manufacturing facilities. Facilities range from those engaged in primary glass manufacturing, to those that create glass products.

Glass wool manufacture consists of the following stages:

- Raw material preparation
- Melting
- Fiberizers and curing oven
- Forming
- Resin production
- Curing
- Cooling (not always present)
- Cutting and packaging.

4.1.1 Raw Materials Handling

The basic materials for glass wool manufacture include sand, soda ash, dolomite, limestone, sodium sulphate, sodium nitrate and minerals which contains boron and alumina as shown in the table.

Table 4.1 The characteristic formulations of glass wool (European Commision, 2008)

Glass wool Components	%
SiO_2	57 - 70
Alkaline oxides	12 - 18
Earth alkaline oxides	8 - 15
B_2O_3	0 - 12
Iron oxides	< 0.5
Al_2O_3	0 - 5
TiO_2	Trace
P_2O_5	0 - 1.5

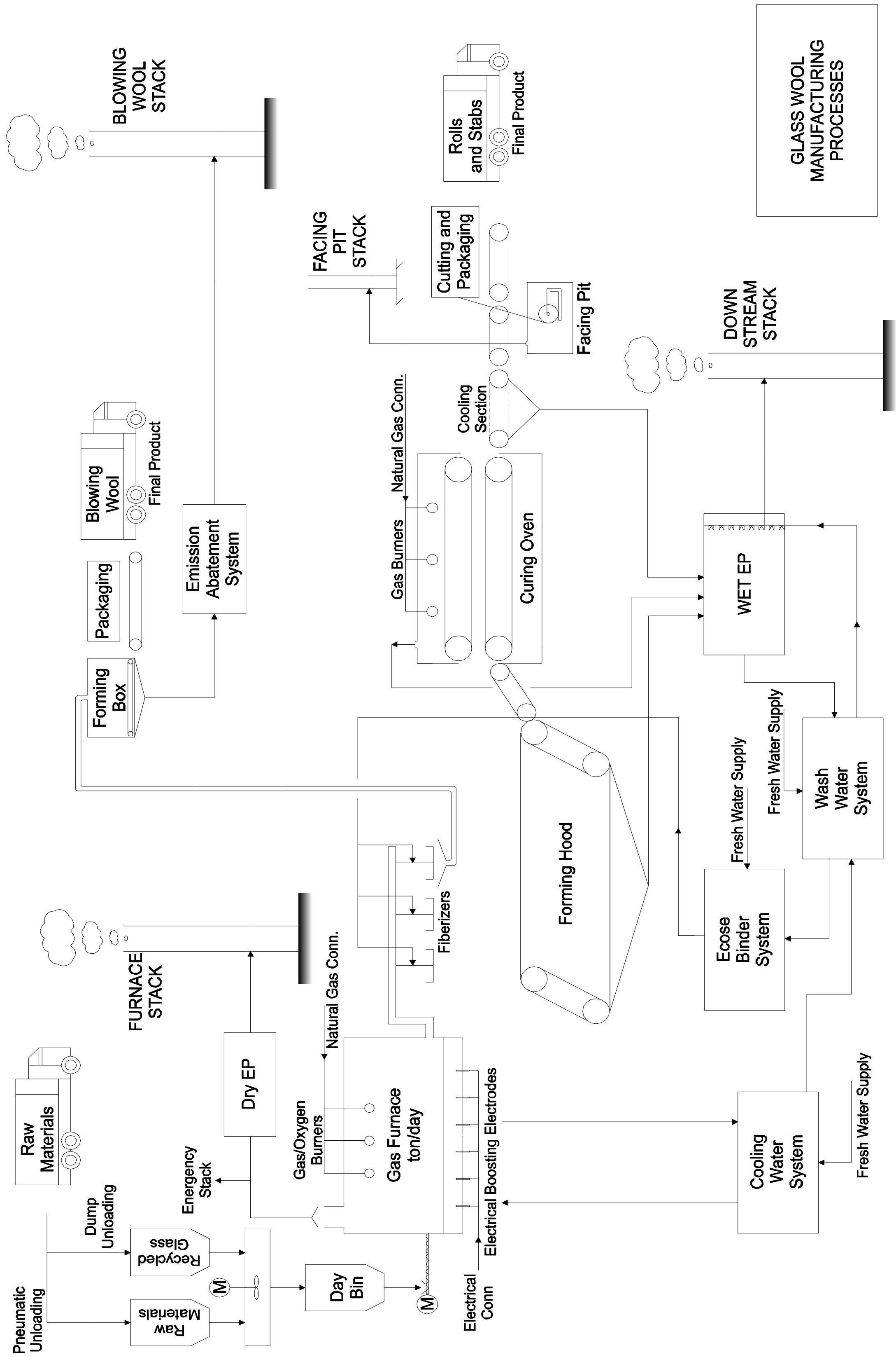


Figure 4.1 Glass wool manufacturing process

Raw materials for the glass batch are weighed, mixed and conveyed to the glass melting furnace. Cullet crushed recycled glass is a primary component in most batches and is required by Executive Order for Federal Agency purchases and by law in certain States. (EPA, 1997).

Glass wool manufacturing process is given in figure 4.1. Raw materials and recycled glasses are unloaded from track and they are mixed and conveyed to the manufacturing process. After mixing process they are conveyed to the melting furnaces and then fiberizing unit. Cooling water is prepared in downstream activity and used for both melting and fiberizing units. Fiberized glass are transmited to forming unit and then cutted and packaged. Resin is prepared in downstream activity. It is added to fiberizing unit for fiber bonding with glass wool.

4.1.2 Mixing

Wool fiberglass products are primarily used as thermal and acoustical insulation for buildings, automobiles, aircraft, Appliances, ductwork and pipes. Other uses include liquid and air filtration. Approximately 90 percent of the wool fiberglass currently produced is for building insulation products.

The major output mass flow is the product, which may be from 55 to 85% of material input, for 75 to 95% for glass wool processes. And important factor in this is the recycling of process residues which significantly increases the efficiency of raw material utilization. The losses arise through solid residues, aqueous wastes and emission to air.

The chemical composition of glass wool can vary widely, and is conventionally expressed in terms of the oxides of the elements it contains. It is difficult to identify a ‘typical’ batch composition for any of the main types of mineral wool, i.e. glass wool, stone wool or slag wool. The basic raw materials are selected end blended to give the final desired glass compositions following melting. The percentage of each raw materials are selected and blended to give the final desired glass compositions following melting. The percentage of each raw material in the batch can vary significantly, particularly where sustainable amounts of recycled materials are used. The two principle methods of mixing are wet mixing and batch agglomeration. Materials are mixed in a rotating pan or drum. The mixed material is moved to holding hoppers above the melting furnace by conveyor belts. These hoppers are situated above the furnace and the material is fed into the furnace by a pusher-type apparatus. This step differs somewhat from facility to facility (European Commission, 2008).

4.1.3 Melting

Glass wool furnaces are predominantly air-gas-fired, but with a substantial number of electrically-heated furnaces and a smaller number of oxy-gas-fired furnaces. The type of melting unit used depends on the quantity and quality of glass to be processed. Glass melting furnaces can be categorized by their fuel source and method of heat application into 4 types: recuperative, regenerative, unit, and electric melter. Electric furnaces melt glass by passing an electric current through the melt. Electric furnaces are either hot-top or cold-top. The former use gas for auxiliary heating and the latter use only the electric current. Electric furnaces are currently used only for wool glass fiber production because of the electrical properties of the glass formulation. Unit melters are used only for the "indirect" marble melting process, getting raw materials from a continuous screw at the back of the furnace adjacent to the exhaust air discharge. There are no provisions for heat recovery with unit melters. In an electronically controlled mixing facility, glass shards, quartz sand, lime, dolomite, nephelite, soda and sodium borate are mixed according to a formula designed especially for the facility. The homogeneous mix is then melted in a melting furnace with controllable electrodes at a temperature of approx. 1400 °C (1500 to 1700°C).

The recuperative, regenerative, and unit melter furnaces can be fueled by either gas or oil. The current trend is from gas-fired to oil-fired. Recuperative furnaces use a steel heat exchanger, recovering heat from the exhaust gases by Exchange with the combustion air. Regenerative furnaces use a lattice of brickwork to recover waste heat from exhaust gases. In the initial mode of operation, hot exhaust gases are routed through a chamber containing a brickwork lattice, while combustion air is heated by passage through another corresponding brickwork lattice. About every 20 minutes, the airflow is reversed, so that the combustion air is always being passed through hot brickwork previously heated by exhaust gases.

Although there are many furnace designs, furnaces are generally large, shallow, and well-insulated vessels that are heated from above. In operation, raw materials are introduced continuously on top of a bed of molten glass, where they slowly mix and dissolve. Mixing is effected by natural convection, gases rising from chemical reactions, and, in some operations, by air injection into the bottom of the bed. Flat glass manufacturers usually have the largest furnaces, followed by container glass manufacturers, and glass fibre manufacturers. The size and depth of the furnaces differs appreciably depending on the process. Fibreglass manufacture may rely more on electric melting to enable them to more accurately control the furnace conditions, but container and flat glass manufacturers tend to use gas as the primary fuel. Some facilities will have additional electric melting to assist the gas firing.

Glass fibres are made from the molten glass using one of two methods. In the rotary spin process, which dominates the fibreglass sector, centrifugal force causes molten glass to flow through small holes in the wall of a rapidly rotating cylinder to create fibres that are broken into pieces by an air stream. The flame attenuation process uses gravity to force molten glass through small holes to create threads that are attenuated, (or stretched to the point of breaking) by hot air or flame. the wools have an average diameter of 3 to 7 μm, and each of the wools has a length between 10 and 200 mm. Preferably, the molded product has a multilayer structure in a direction orthogonal to the longitudinal direction of the wools, and the average diameter of the fibers or wools of a first layer differ from each other.

After the glass fibres are produced, they are sprayed with a chemical resin to hold them together, collected on a conveyor belt in the form of a mat, cured and packaged.

There are two kind of melting processes as “direct” and “indirect”. In the "indirect" melting process, molten glass passes to a forehearth, where it is drawn off, sheared into globs, and formed into marbles by roll-forming. The marbles are then stress-relieved in annealing ovens, cooled, and conveyed to storage or to other plants for later use. In the "direct" glass fiber process, molten glass passes from the furnace into a refining unit, where bubbles and particles are removed by settling, and the melt is allowed to cool to the proper viscosity for the fiber forming operation (European Commission, 2008).

4.1.4 Fiberizers and Curing Oven

The glass wool produced in the furnace will pass through the fiberizers where the glass fibre mat is formed and where the binder (Ecose) is applied. A stream of molten glass flows from the furnace along a heated refractory lined forehearth and pours through a number (usually one to ten) of single orifice bushings into specially designed rotary centrifugal spinners. The fibre mat is then cured in the curing oven.

For any given glass wool production line, the capacity of the spinner affects the efficiency of the manufacturing operation. The larger is the spinner the more efficiently can the same volume of output be produced. The spinner capacity chosen by an installation will depend on the size of the furnace with which it is associated. The type of spinner used varies between operators and so the technology used varies from site to site. It is a proprietary technology and therefore an individual operator will use its own technology, which may not necessarily constitute BAT.

Primary fiberising is by centrifugal action of the rotating spinner with further attenuation by hot flame gases from a circular burner. This forms a veil of fibres with a range of lengths and diameters randomly interlaced. Specific filament diameters in the range of 5μm to 24μm are obtained by precisely regulating the linear drawing speed (which may vary from 5 m/s to 70 m/s). The veil passes through a ring of binder sprays that spray a solution of phenolic resin based binder and mineral oil onto the fibres to provide integrity, resilience, durability and handling quality to the finished product. The resin coated fibre is drawn under suction onto a moving conveyor to form a mattress of fibres. The binder content on the filaments is typically in the range of 0.5% to 1.5% by weight. The coating material will vary depending on the end use of the product. The coated filaments are gathered together into bundles called strands that go through further processing steps, depending on the type of reinforcement being made. The strands can undergo either conventional or direct processing. In conventional processing, the strands are wound onto the rotating mandrel of the winder to form "cakes" up to 50 kg in weight. For some applications the cakes can be processed wet, but for most they have to pass through drying ovens. The ovens are heated by gas, steam, electricity, or indirectly by hot air.

This mattress passes through a gas-fired oven at approximately 250 °C, which dries the product and cures the binder. The product is then air cooled and cut to size before packaging. Edge trims can be granulated and blown back into the fibre veil, or they can be combined with surplus product to form a loose wool product (European Commission, 2008).

4.1.5 Forming

After the glass fibers are created (by either process) and sprayed with the binder solution, they are collected by gravity on a conveyor belt in the form of a mat. The purpose of the binder is to hold the fibers together and its composition varies with type.

Two method of forming fibers are used in the industry. In the rotary spin (RS) process, centrifugal force causes molten glass to flow through small holes in the wall of rapidly rotating cylinder. In the flame attenuation (FA) process, molten glass flows by gravity from a small furnace or pot to form threads that are then attenuated (stretched to the point of breaking) with air and/or flame (European Commission, 2008).

4.1.6 Resin Production

During the formation of fibers into a wool fiberglass mat (the process known as "forming" in the industry), glass fibers are made from molten glass, and a chemical binder is simultaneously sprayed on the fibers as they are created. The binder is a thermosetting resin that holds the glass fibers together. Although the binder composition varies with product type, typically the binder consists of a solution of phenol-formaldehyde resin, water, urea, lignin, silane, and ammonia. Phenolic resins are made from purely synthetic materials. Phenol-formaldehyde resins are formed by chemical reaction between phenol and formaldehyde solutions (Wang et. al., 1995).

4.1.6.1 Raw materials

Phenol-formaldehyde resins are general purpose thermosets formed mainly by the polycondensation reaction between phenol and formaldehyde solutions. The three major raw materials for making phenolic resins are:

- Phenol - C_6H_5OH
- Formaldehyde - CH_2O
- Hexamethylene Tetramine - $(CH_2)_6N_4$

-Phenol

Phenol is primarily obtained from the fractional distillation of coal tar and various synthetic processes. There are at least six known commercial synthetic processes for making phenol of which the four most common are Cumene, Rasching, Dow and Sulfonation (Gardziella et. al., 2000). The most common process is Rasching for phenol production.

-Rasching Process

The rasching process passes benzene, hydrogen and air over a heated copper catalyst at 200-300 ^{0}C. The intermediate product is chlorobenzene and water in the gaseus state. The water hydrolyses the chlorobenzene when passes over hot silica catalyst at 500 ^{0}C to phenol and HCl.

1. $C_6H_6 + HCI + ½ O_2 \longrightarrow C_6H_5CI + H_2O$ ....(4.1)

Cu/Fe (catalyst)

Benzene + Hydrogen Chloride → Chlorobenzene + Water

2. $C_6H_5O + H_2O \longrightarrow C_6H_5OH + HCI$ ....(4.2)

SiO_2 (catalyst)

Chloro Benzene + Water → Phenol + Hydrogen Chloride

-Formaldehyde

Formaldehyde is produced by the controlled catalytic oxidation of methyl alcohol (methanol). The result is the dehydrogenation of methanol to formaldehyde. In the process, a mixture of methanol vapor and air is passes over a heated copper oxide catalyst at 300 ^{0}C to 600 ^{0}C to produce a mixture of formaldehyde and water. The product is at 37% solution formaldehyde that is subsequently enriched to a 40% solution known as formalin (Gardziella et. al., 2000).

3. $CH_3OH + ½ O_2 \longrightarrow HCOH + H_2O$ ....(4.3)

CuO (catalyst)

Methanol → Formaldehyde + Water

Production of Phenol-Formaldehyde Resin

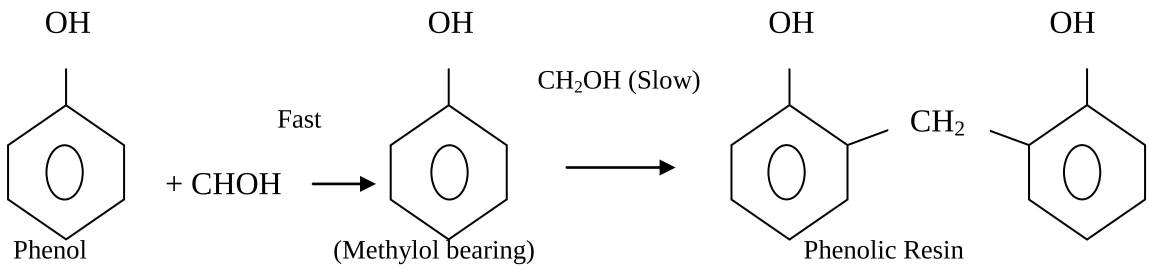


Figure 4.1 Phenol- Formaldehyde resin

Water content of this resin is approximately 50%.

4.1.7 Cooling

Some products do not require curing and/or cooling. (For instance, flame attenuation manufacturing lines do not have cooling processes.)

Some of the parts in the process (Rotary Spin Reactor) need to be cooled down with water. To do so, open cooling towers will be used. The typical cooling power is 6000 kW (EPA, 1997). There is also an independent cooling water system which cools down the molten glass when the fibers production is stopped. The glass is transformed in cullet and re-used afterwards in the furnace as raw materials (European Commision, 2008).

4.1.8 Cutting and Packaging

The glass wool is finally cut and package before dispatched as finished product to storage. The mat is then cut into bats of the desired dimensions and packaged (European Commision, 2008).

Glass Wool Production Flow Diagram

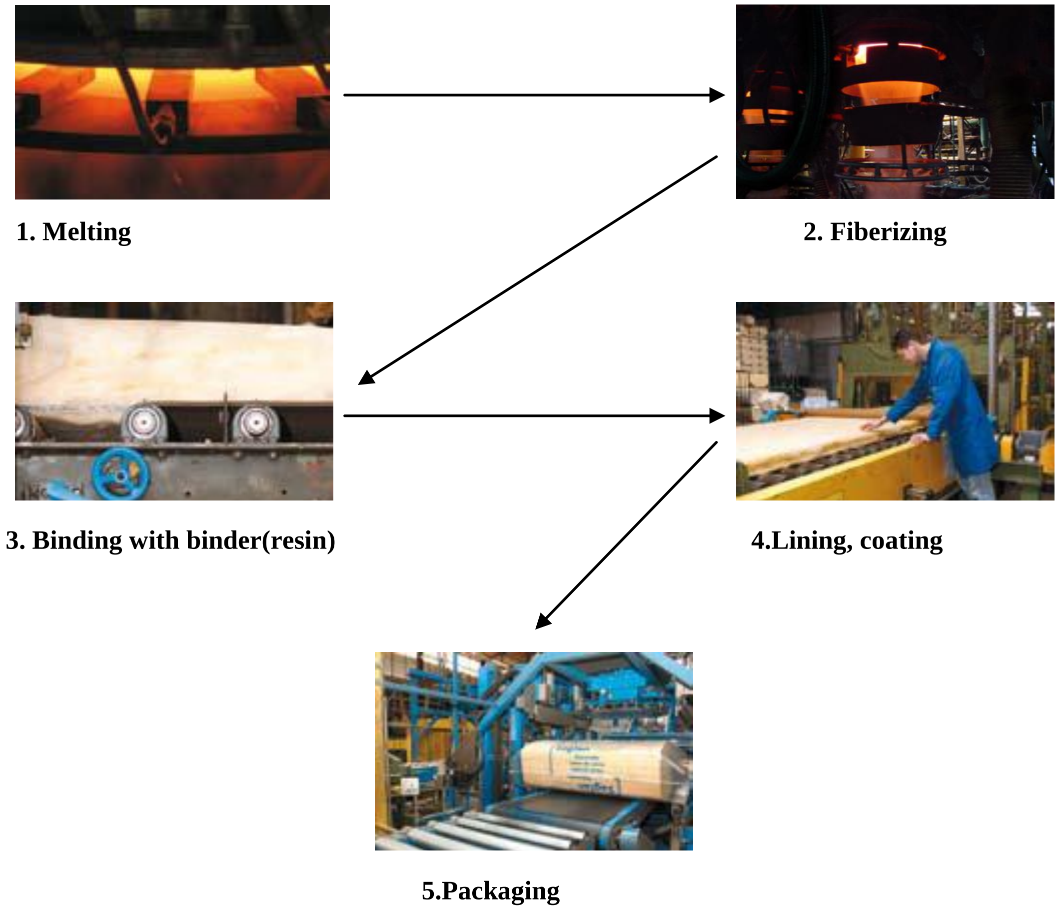


Figure 4.2 Glass wool production flow diagram

CHAPTER FIVE
MASS BALANCE OF THE GLASS WOOL PRODUCTION

Material quantities, as they pass through glass wool processing operation can be describes by material balance. Materials and energy which are used for process are estimated and can be determined cost and environmental effects of process.

Life cycle inventory is applied in this chapter. Raw materials requirements, energy requirements and water requirements data are collected and reviewed.

Material and energy balances are very important in an industry. Material balances are fundamental to the control of processing, particularly in the control of yields of the products.

Material and energy balances can be simple, at times they can be very complicated, but the basic approach is general. Experience in working with the simpler systems such as individual unit operations will develop the facility to extend the methods to the more complicated situations, which do arise. The increasing availability of computers has meant that very complex mass and energy balances can be set up and manipulated quite readily and therefore used in everyday process management to maximize product yields and minimize costs. The first step is to look at the three basic categories: materials in, materials out and materials stored.

There are basic equations below:

Mass In = Mass Out + Mass Stored ....(5.1)

Raw Materials = Products + Wastes + Stored Materials ....(5.2)

These equations can be used for estimating consumption, energy losses, emission estimation, waste estimation and cost estimation. In this chapter, amount of material (raw material, water, resin…) and energy consumption which are used for manufacturing glass wool will be estimated (Edgar et. al., 2008).

Glass wool includes 84-98% raw material and 2-16% resin.

5.1 Raw Material Consumption

Glass wool includes both inorganic and organic substances. Inorganic materials are sand, dolomite, soda, limestone and other minerals. Organic materials are composed of resin system.

Table 5.1 Raw material use in glass wool production (TIMA, 1993)

Raw Materials	**kg/100 kg raw material**
Sand	44
Dolomite	9
Granite	6
Soda	12
Limestone	9
External cullet	20

5.2 Energy Consumption

The predominant energy sources for glass wool melting are natural gas and electricity. Natural gas is also used in substantial quantities for fiberising and curing. Electricity is used for general services and light fuel oil, propane and butane are sometimes used as backup fuels. There are a number of oxy-gas fired furnaces applied to the sector.

The three main areas of energy consumption are melting, fiberising and curing. The split can vary greatly between processes and is very commercially sensitive. Table 5.2 shows the total energy consumption in glass wool production, with breakdown into the main process areas. The values for fiberising, curing and other consumption are estimates.

Table 5.2 Energy use in glass wool production (European Mineral Wool Manufacturer Association, [EURIMA], 2007)

	Glass wool
	GJ/ tone finished product
Total energy consumption	9-20
	% of total energy
Melting	20-45
Fiberising	25-35
Curing	25-35
Other	6-10

Direct energy consumption for electrical melting is in the range of 3.0 to 5.5 GJ/tone finished product. Energy consumption for electrical melting is approximately one third of that required for 100% air-gas melting and the relative energy consumption of each process stage can be estimated accordingly (European Commision, 2001).

Energy is also used for transportation for raw materials and products. Energy consumption for transportation is giving in Table 5.3 below:

Table 5.3 Energy consumption in transportation (European Commision, 2001).

Distance (× 1000 km)	Energy Consumption (MJ)
50	2500
100	4400
150	6500
200	8800

5.3 Water Consumption

A global water balance for a typical glass wool plant in normal operation gives a consumption of 3 to 5 m^3 of water per tone of glass wool produced. The water is used for cooling, leaning, for binder solution in glass wool process.

On the other hand, water is constantly re-circulated within the process wash water system so that the processes wash water system so that the internal flow of water actually used in glass wool process is much higher and may reach up to 100 m^3/tone of glass wool. The majority (approximately 70%) of this water flow is used in the forming section and their associated pollution control equipment. Water is also used for resin system. Resin includes % 50 water by mass (European Commision, 2009).

5.4 Resin Consumption

After the glass wools are formed sprayed with the binder solution, the purpose of the binder is to hold the fibers together and its composition varies with type. Phenolic resin is used for glass wool production and approximately 0.3 kg resin is used for 1 kg glass wool.

Resin includes organic substances such as phenol, formaldehyde, ammonia. Percentages of resin substances are given in the Table 5.4 below:

Table 5.4 Resin system percentage

Sunstances	kg/100 kg resin
Phenol	10
Formaldehyde	30
Urea	5
Ammonia	2.3
Sodiumhydroxide	0.7
Water	52

5.5 Factory Inputs and Outputs

Mass balance model which is part of Life Cycle Assessment is used for examine the system boundary. In glass wool sector, it is very important to determine the system inputs and out puts. Thus, raw material, water and energy consumption can be brought to light.

All kind of materials, natural sources (water, energy…) are determined in the table. Shortly, system inputs for glass wool manufacturing process are given in the table below.

Factory Inputs = Factory Outputs + Stored

9538.71 =8744.99 + Stored

Stored= 793.72 kg

Table 5.5 Inputs for glass wool manufacturing facility (UK Glass Manufacturing Industry, 2002).

Inputs	Total Consumption (kg) for 1 tonne Product
Raw Materials	
Sand	491
Soda Ash	127.3
Limestone	100
Dolomite	100
Saltcake	0.45
Steetly Clay	104.5
Granit	18.2
Total Feedstock	**1159.65**
Water	3500
Refractories	1.36
Combustion	
Natural Gas	259
Oxygen	245.45
Combustion Air	3431.8
Total factory Inputs	**9538.71**

Table 5.6 Outputs for glass wool manufacturing facility (UK Glass Manufacturing Industry, 2002).

Outputs	kg releases for 1 tonne Product
Air Emissions	
CO_2	718.2
N_2	2745.45
H_2O	722.73
NO_x	0.9
SO_x	1.8
Packed Products	1000
Water	3500
Refractories	1.36
Land fill	54.55
Total factory Outputs	**8744.99**

System input and output are determined in the table 5.5 and table 5.6 for glass wool manufacturing facility. But we didn’t investigate this facility on the basis of the units used. We have to determine that which unit consumed how many energy and water, and what are the resources of emissions. We can make provision for which unit must be controlled for emission reduction or reclaimed by this way. All of water and energy and resin consumption is determined for 1 kg fiber mat in figure 5.1 below:

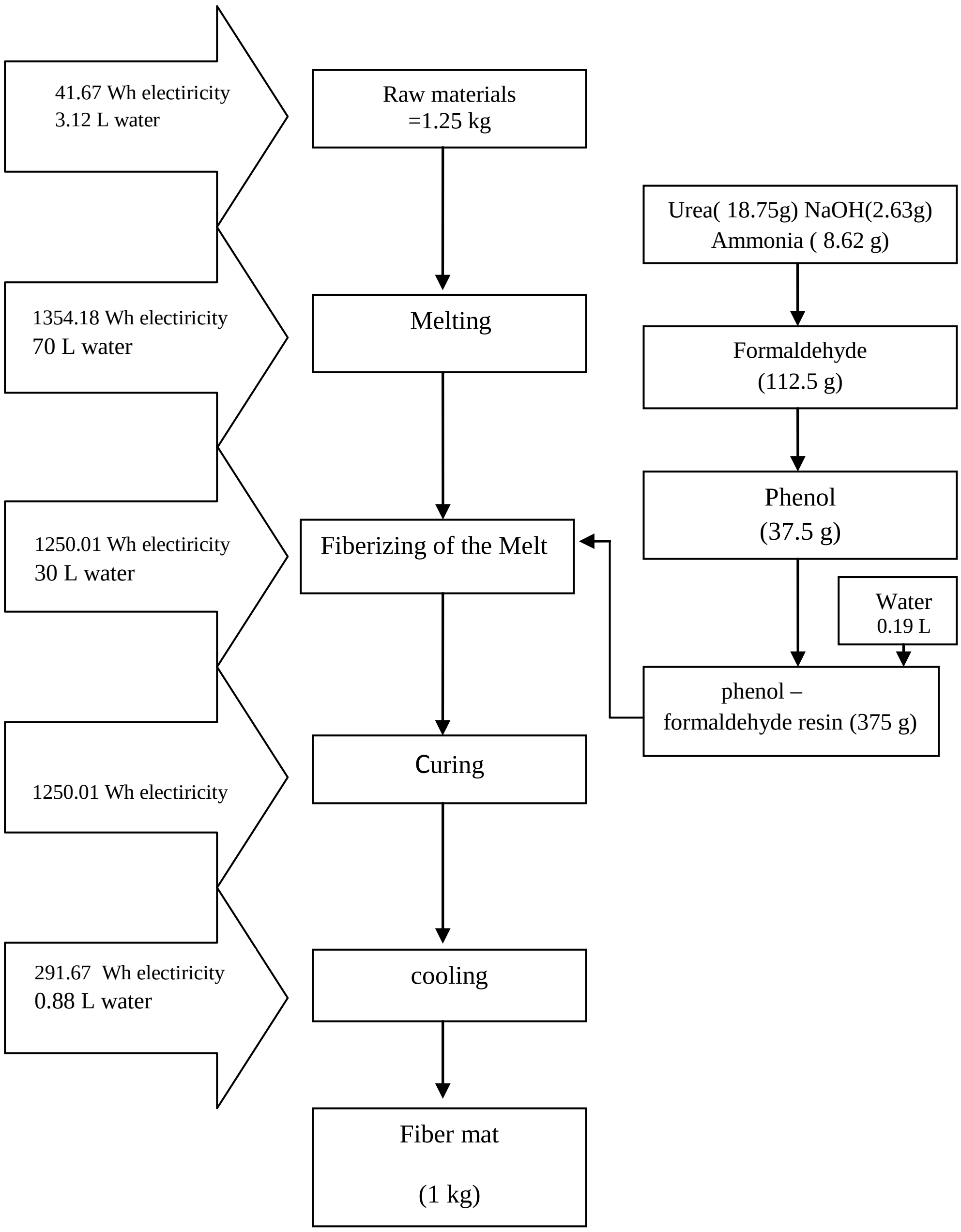


Figure 5.1 Mass balance of glass wool production

Raw material consumption, water and energy consumptions are estimated per 1 kg glass wool product in order to determine the numerical value in this study. Thus, consumption of natural resources are more comprehensible and can be argued. Amount of raw materials, water and energy consumption are computed below:

- 41.67 Wh energy is consumed for 1 kg raw material mixing and preparing and 3.12 L water is consumed for washing raw materials.
- 1354.18 Wh/kg raw materials energy is consumed for melting operation and 70 L water is used for cooling.
- 1250.01 Wh energy and 30 L water are consumpted for fiberizing unit.
- 1250.01 Wh energy is used for curing oven.
- 291.67 Wh electricity is consumed in cooling section.
- 50 g urea, 7.01 g NaOH, 22.98 g ammonia are used for 1 kg resin preparation.
- 300 g formaldehyde solution is consumed for 1 kg phenol-formaldehyde resin preparation.
- 100 g phenol solution is used for 1 kg phenol-formaldehyde resin preparation.
- 0,506 L water is used for 1 kg phenol-formaldehyde resin preparation.

Table 5.7 Energy and water consumption for 1kg fiber mat

Unit	Chemical (kg)	Water (L)	Energy (Wh)
Raw material	1.25	3.12	-
Melting	-	70	1354.18
Fiberizing	0.375	30	1250.01
Curing	-	-	1250.01
Cooling	-	0.88	291.67
Total	**1.625**	**104**	**2895.86**

CHAPTER SIX
ENVIRONMENTAL IMPACTS OF GLASS WOOL MANUFACTURING

Glass wool is the one of the most widely used insulation products. Insulation became significant owing to increase in population and technological progress in recent years. Especially glass wool is used as thermal and acoustical insulation materials in building, transportation, in industry applications. With increasing the quality of life, energy requirement and costs are continually rising day by day. Today builders and homeowners are looking for ways to make homes more energy efficient due to these reasons. A well insulated home is one of the most cost-effective ways to save energy and reduce heating and cooling. Most insulation systems reduce the unwanted heat transfer, either loss or gain, by at least 90% as compared to bare surfaces. With insulation, it is possible to invest energy efficiency and supply many economical advantages.

Glass wool is a composite material which includes phenol-formaldehyde resin. Resin system contributes required level of fire safety. In other words, the phenolic resins are preferred owing to their good resistance to high temperature, good thermal stability. Resin system includes organic and aromatic compounds such as phenol, formaldehyde, urea and methanol. Exposure to formaldehyde, methanol and phenol irritates the eyes, skin and mucous membranes and causes conjunctivitis, dermal inflammation and respiratory symptoms (EPA, 1997).

Formaldehyde exposure has been associated with reproductive effects such as menstrual disorders and pregnancy problems in women workers. The EPA has classified formaldehyde as Class B1, probable human carcinogen, on the basis of findings of nasal cancer in animal studies and limited human data. Phenol has been shown to cause damage to the liver, kidney, cardiovascular system in animal studies.

Acute exposure to methanol (usually by ingestion) is well known to blindness and severe metabolic acidosis, sometimes leading to death. Chronic methanol exposure including inhalation may cause central disturbances possibly leading to blindness.

Data are not sufficient to classify either phenol or methanol as to potential human carcinogenicity.

Formaldehyde phenol and methanol also are VOCs which are precursors to ozone formation. Ambient ozone can cause damage to lung tissue, reduction of lung function and increased sensitivity of the lung to other irritants (EPA, 1997).

Life cycle impact assessment's ideology is applied in this chapter. Air, water emissions and solid wastes are estimated.

6.1 Emission Estimation for Glass Wool Manufacturing

The major output mass flow is the product, which may be from 55% to 85% material input, 75% to 95% for glass wool processes. An important factor in this is the recycling of process residues which significantly increases the efficiency of raw material utilization. The losses arise through solid residues, aqueous wastes and emission to air (European Commision, 2009).

In glass wool sector, the most important pollutants are air emissions. Especially, melting process causes various air pollutants such as VOCs, NO_x, SO_x, HF, HCl, CO, CO_2 and these emissions are due to organic compounds contents. Air emissions releases from manufacturing process are quantified for 1 tonne glass wool product is determined in table 5.6 in chapter five. The table shows the most emission arised from N_2 and following CO_2 emissions. Air emission's reduction methods are investigated in chapter seven.

6.1.1 Emission to Air

<u>Emission Sources</u>

In the glass wool sector, the emissions to air can be divided into three parts;

- Raw materials handling
- Emission from melting activities

- Emission from downstream processes or line operations (Laban, 2004).

6.1.1.1 Raw Materials Handling

In glass wool processes, hoppers and mixing instruments are fitted with filter systems which decrease dust emissions to below 5 mg/Nm^3. Mass emissions from both filtered and unfiltered systems will clearly on the number of transfers and the amount of material handled. It should be noted that glass wool raw material batches tend to be dry and pneumatically conveyed. Therefore, the potential for dust emission from raw material handling may be higher than in some other sectors.

Production waste transformed into cement-bonded briquettes is often used in the batch formulation; typically, it contains around 0.22% suphur and can be used at up to 100% of the batch. A charge containing 0% cement briquettes and no blast furnace slag cab reach values from 500 to 1000 mg SO_2/Nm^3, and a charge containing 100% cement briquettes will emit from 2000 to 250 mg SO_2/Nm^3. Variations are due to the different contents of sulphur in coke, controlling techniques applied, flue-gas volumes, oxidation states inside the cupola, and on variations in sulphur content of the volcanic rock (diabase) used in process. In some Member States, total recycling of waste briquettes is not practiced, in order to limit SO_x emissions and ensure concentration values of below 1500 mg/ Nm^3. In these cases a recycling rate of about 45% is applied and the exceeding waste is treated (Germany). In other cases, emissions in the range of 1400-1800 mg SO_2 /Nm^3 are reported in spite of high recycling rates, which are between 85-100% (Denmark). The approach used by different Member States can be significantly diverse, based on the priority given to the outputs of the production cycle, the minimization of waste and energy reduction versus SO_x emission reduction (European Commission, 2009).

6.1.1.2 Melting

About 66 % of the glass-melting furnaces used in the wool fiberglass industry are all-electric, about 25% percent are gas-fired and about 9% are combination of gas and electric. Glass pull rates for furnaces range from 20 to 300 ton/d (EPA, 2008).

An increasingly important factor affecting the emissions from the melting process is the contribution from recycled materials. If fiber containing binder is recycled to the furnace, the organic component must be considered. In glass wool furnaces, it may be necessary to add oxidizing agents such as potassium nitrate, which may have the effect of increasing NO_x emissions. When high amounts of recycled cullet are used in the batch formulation, manganese (IV) oxide might be employed as oxidizing agent (EPA, 2009).

Table 5.1 Shows the full range of emissions from mineral wool melting furnaces in the EU-27, referring to the year 2005, with data given both in concentrations (mg/Nm^3) and emission factors (kg/tone melted glass). Data presented in the table show a wide range of emissions related to all type of installations, with and without abatement technique and operating condition is presented in the table below.

Table 6.1 Full range of emission from mineral wool melting furnaces (European Commision, 2009).

	Glass wool			**Stone wool**		
Type of furnace	**Electric**	**Recuperative**	**Oxy-gas**	**Cupola**	**Immersed electric arc**	**Fuel- fired**
Substance(1)	Mg/Nm^3 (kg/t)	Mg/Nm^3 (kg/t)	Mg/Nm^3 (kg/t)	Mg/Nm^3 (kg/t)	Mg/Nm^3 (kg/t)	Mg/Nm^3 (kg/t)
Particulate matter	0.2-128 (0.001-0.4)	0.3-35 (0.03-0.1)	0.2-20 (0.001-0.016)	0.25-1700 (0.04-3.5)	4-12 (0.006-0.02)	10 (0.02)
SO_x, as SO_2	0.4-120 (0.001-0.02)	1-30 (0.002-0.5)	0.5-115 (0.002-0.32)	4-2600 (0.01-4.8)	335-350 (0.4-0.5)	285 (0.45)
NO_x, as NO_2(2)	13-580 (0.5-2.0)	50-1200 (0.3-10.6)	9-240 (0.02-0.4)	35-615 (0.07-1.7)	80-150 (0.1-0.2)	815 (1.3)
HF	0.1-3.0 (0.001-0.01)	0.13-20 (0.001-0.05)	0.09-3.2 (0.001-0.01)	0.1-11 (0.001-0.02)	8 (0.01)	1.2 (0.002)
HCl	0.1-4.5 (0.001-0.02)	0.2-7 (0.001-0.06)	0.55-3 (0.001-0.003)	0.7-150 (0.001-0.26)	43 (0.05)	5 (0.008)
Average Nr. Of results	9	7	5	32	2	1

1. Concentration values are referred to 273 K, 1013 hPa and dry gases. Emission factors are expressed in kg per tone of melted glass.
2. The lower levels of NO_x are from oxy-gas fired furnaces.

In the Table 6.2, the values are related to dust emissions from electric and gas-fired furnaces applied in the production of glass wool are given. Data refer to measurements carried out one or more times on the melting furnaces of the survey, during the reference period (European Commission, 2010).

For the full range of data (100%), the average, minimum and maximum values are given.

Table 6.2 Dust emission from melting furnaces for glass wool production (European Commision, 2009)

	Dust emissions from glass wool melting furnaces				
	Reported data	**N^o values**	**Mg/Nm^3, dry gas**		
			Average	**Min.**	**Max.**
Electric furnace					
No secondary abatement with bag filter	100%	15	33	0	188
	75%		37		
	50%		9		
	100%	19	36	0	274
	75%		47		
	50%		20	0	17
With ESP	100%	9	9		
	75%		15		
	50%		9		
Gas/air fired furnace					
No secondary abatement with ESP	100%	7	189	8	651
	75%		552		
	50%		29		
	100%	33	2	2	90
	75%		27		
	50%		15		
Gas/oxygen fired furnace					
With ESP	100%	21	5	1	19
	75%		6		
	50%		4		
With electric boosting and ESP	100%	27	7	1	76
	75%		8		
	50%		3		

In Table 6.3, the values concerning SO_x emissions from electric and gas fired furnaces for glass wool production are presented. Data refer to measurements carried out one or more times on the melting furnaces of the survey during the reference period (European Commision, 2009).

The full range of data (100%) is given with the average, minimum and maximum values. It can be observed that SO_x emissions tat SO_x emissions are significantly only in the case of fuel-fired furnaces.

Table 6.3 SO_x emissions from melting furnaces for glass wool production (European Commision, 2009).

	SO_x emissions from glass wool melting furnaces				
	Reported data	N°	Mg/Nm³, dry gas (as SO_2)		
			Average	Min.	Max.
Electric furnace					
No secondary abatement	100%	8	2	1	6
With bag filter	100%	12	5	0	13
With ESP	100%	8	3	0	14
Gas/air fired furnace					
No secondary abatement	100%	7	34	1	133
With ESP	100%	32	22	0	119
Gas/oxygen fired furnace					
With ESP	100%	17	10	0	63
With electric boosting and	100%	27	28	2	98

For the full range of data (100%), the average, minimum and maximum values are given. For a better understanding, values refer respectively to 75% and 50% of data are also presented, with the aim to exclude spurious data points as much as possible.

Table 6.4 NO_x emissions from melting furnaces for glass wool production (European Commision, 2009).

	NO_x emissions from glass wool melting furnaces				
	Reported data	**N^0**	**Mg/Nm3, dry gas (as NO_2)**		
			Average	**Min.**	**Max.**
Electric furnace					
No secondary abatement	100%	15	204	36	429
	75%		245		
	50%		175		
With bag filter	100%	21	234	4	670
	75%		442		
	50%		468		
With ESP	100%	9	514	13	107
	75%		970		
	50%		232		
Gas/air fired furnace					
No secondary abatement	100%	7	410	93	103
	75%		429		
	50%		356		
With ESP	100%	31	636	110	158
	75%		800		
	50%		601		
Gas/oxygen fired furnace					
With ESP	100%	20	119	7	244
	75%		170		
	50%		116		
With electric boosting and ESP	100%	27	215	82	691
	75%		242		
	50%		154		

Values presented in table 5.4 represent different operating conditions; in particular, the quantity of nitrates that may be added to the batch composition, when high levels of external cullet are used, may vary significantly. For these reasons, a comparison between data presented in the table is difficult and should be assessed together with additional information o the specific operational parameters.

In the table 5.5, the values concerning other emissions (HCl, HF, CO, CO_2) from electric and gas fired furnaces for glass wool production are presented. Data refer to measurements carried out one or more times on the melting furnaces f the survey, during the reference period (European Commision, 2009).

The full range of data (100%) is given with the average, minimum and maximum values. From the table it can be observed that HCl, HF emissions from glass wool melting furnaces are generally low.

Table 6.5 HCl, HF, CO and CO_2 emissions from melting furnaces for glass wool production (European Commision, 2009).

	Emissions of HCl, CO and CO_2 from glass wool melting				
	Substance	**N^0 values**	**Mg/Nm3, dry gas**		
			Average	**Min.**	**Max**
Electric furnace					
No secondary abatement	HCl	12	2	0	7
	HF	12	0.6	0.1	2.8
	CO	6	63	24	110
	CO2	4	6595	4572	8069
With bag filter	HCl	6	3	0	7
	HF	3	0.7	0.1	0.1
	CO	6	55	17	176
	CO2	1	20	20	20
With ESP	HCl	7	2	0	7
	HF	8	0.7	0.1	3.1
	CO	4	264	114	638
	CO2	-	-	-	-
Gas/air fired furnace					
No secondary abatement	HCl	4	6	5	7
	HF	4	2.4	0.6	3.3
	CO	3	165	61	280
	CO2	-	-	-	-
With ESP	HCl	32	3	0	19
	HF	32	3.0	0.1	20.0
	CO	8	7	1	20
	CO2	1	7	7	7
Gas/oxygen fired furnace					
With ESP	HCl	16	1	0	5
	HF	16	0.4	0	2.6
	CO	7	42	3	121
	CO2	-	-	-	-
With electric boosting and ESP	HCl	27	3	0	32
	HF	27	0.8	0.1	2.3
	CO	19	36	2	241
	CO2	16	101707	6811	1585

The EPA estimates that at the current level of control, 1770 Mg/yr (830 ton/yr) of metal HAPs and formaldehyde are emitted from glass melting furnaces and manufacturing lines in wool fiberglass plant nationwide. The HAPs released from glass melting furnaces include arsenic, chromium and lead an estimated 750 Mg/yr (830 ton/yr) of particulate matter also are emitted (EPA, 1997)

Table 6.6 Nationwide annual emission (The Capacity of 130 ton/yr) (EPA, 1997)

Source	Pollutants	Baseline Emissions (Mg/yr)	Emission Reduction (Mg/yr)a
Glass melting furnaces……	Metal HAP……….	0.3	0.01
RS Manufacturing Lines….	PM………..............	750	760
FA Manufacturing Lines…	Formaldehyde	1,220	530
All Sources………………..	Formaldehyde	550	0
	Total HAPs	1,770	530
	PM(Non-HAP)	750	760
	Total Pollutants	2,520	1,260

a: Emission reduction in the fifth year of the standard. Includes emission reduction from new sources.

6.1.1.3 Downstream Activities

Mineral wool products usually contain a proportion of phenolic resin-based binder. The binder solution is applied to the fibers in the forming area and is cross-linked and dried in the curing oven. The forming area waste gas will contain particulate matter, phenol, formaldehyde and ammonia.

The particulate matter consists of both organic and inorganic material, often with a very small particle size. Lower levels of VOC and amines may also be detected if they are included in the binder system. Due to the nature of the process, the gas stream has a high volume and high moisture content the releases from the oven will consist of volatile binder materials, binder breakdown products, and water vapor and combustion products from the oven burners.

After existing the oven, the product is cooled by passing a large quantity of air through it. This as is likely to contain mineral wool fibre and low level of organic material. Product finishing involves cutting, handling and packaging, which can give rise to dust emissions.

An important factor that has a major impact on emissions from forming, curing and cooling is the level of binder applied to the product, as higher binder content products will generally result in higher emission levels. Binder-derived emissions depend essentially on the mass of binder solids applied over a given time, and therefore, high binder content, and to a lesser extent high density products, may give rise to higher emissions. Products are normally classified as low, density products, may give rise to higher emissions. Products are normally classified as low, medium and high density, covering a range of between 10 and 80 kg/m3, with a binder content of 5-12%.

Table 5.7 below shows the full range of emission from downstream activities for glass wool plants in the EU referring to the year 2005 with values given both in concentrations (mg/Nm^3) and emission factors (kg/tone melted glass).

Table 6.7 Full range of emissions from downstream activities in the glass wool production sector (European Commisson, 2009).

	Emissions from glass wool down stream activities(1)			
Substance	**Combined fiberising,**	**Fiberising**	**Product**	**Product**
	Mg/Nm^3			
Particulate	4.4-128	11.4	65.2	12.5
	(0.11-5.23)	(0.68)	(0.27)	(0.04)
Phenol	0.25-20	1.63	0.81	
	(0.009-0.93)	(0.093)	(0.0034)	
Formaldehyde	0.3-16	1.71	1.13	
	(0.04-0.48)	(0.091)	(0.014)	
Ammonia	6.130	21.95	109	
	(0.3-6.5)	(1.13)	(0.69)	
Oxides of Nitrogen	7.7	5.82		
(NO_x)	(0.2)	(0.18)		
Volatile organic	2-47.5	11.2	20.1	
compounds	(0.11-2.76)	(0.56)	(0.09)	
Carbon Dioxide	5236			
	(194)			
Average nr. of results	15	3	3	1
1. Data refer to all types of emission control techniques.				

6.1.1.4 Diffuse/Fugitive Emissions

The main sources of diffuse/fugitive emissions in the mineral wool sector are related to the batch charging area and fore hearth channels (for glass wool only), the storage and preparation of the coating formulations and the cutting, handling and packaging operations. The type of melting furnaces used in the stone wool production are totally closed and do not present potential diffuse/fugitive emissions and there is no presence of fore hearths.

Local exhaust ventilation systems are often used to supply the necessary ventilation to the working area near the melting furnace with consequent discharge of the potential diffuse/fugitive emissions internally or externally.

Dedicated d enclosed spaces are normally adopted for the storage and preparation of coating formulations in order to limit the exposure of the workers to potential emissions.

Local exhaust ventilation systems are used for the cutting, handling and packaging of the finished products (European Commision, 2009).

6.1.2 Emissions to Water

Under normal operation conditions, the processes are net consumers of water and aqueous emissions are very low. Most processes operate a closed- loop process water system, and where practicable cooling water blow down and cleaning waters are fed into that system. If they are incompatible of if the volumes are too great, they may have to be discharged separately, but many plants have a holding tank to accommodate volume overloads, which can then be bled back into the system. Small amounts of contaminated waste water may arise from chemical bunds, spillages and oil interceptors, etc. and these are usually discharged to the process water system, transported for off-site treatment, or discharge to a sewer.

Water consumption areas are given below:

Process Cooling: The process cooling water system uses the cleanest water for recirculated non-contact water-jacket cooling of glass melting furnace electrode holders and glass fiber crown heads. An ion exchange water softener preconditions city water as system make-up for evaporative losses. The make-up and tail waters from process cooling fill a hot-water equalization pit that feeds a cooling tower. Cooled waters then fill a cold-water equalization pit for delivery through the water jackets. System blow down is drawn from the hot-water equalization pit in order to feed the wash water system and to control dissolved solids build-up. Softener brine discharges to the city sewers.

Wash Water: The wash water system recirculates plant wash down, fume scrubber blow-down, electrostatic precipitator wash water, and spent clean-in-place caustic pipe cleaning waters. The wash waters in the system are continually recirculated from an influent sump and equalization tank through a coagulant and flocculant-aided air flotation unit followed by a belt press to remove accumulated solids. The wash waters are drawn for reuse from the influent sump through a shaker screen. Blow down from the process cooling water system provides the make-up for evaporation and consumption losses. The only losses from the system are the removed solids and a blow down stream drawn from the air flotation unit as binder make-up water. Glass solids from the shaker screens and air flotation float are hauled off-site to a landfill as non-hazardous waste. The wash water quality depends on the numerous additives and contaminants into the process cooling and washes water systems. These additives and contaminants include urea-formaldehyde and phenolics-formaldehyde resins, decanol/octanol antifoaming agents, quarter nary salt coagulant, descalant, polymer flocculant, and three biocides (liquid bromine, and two methylated thiazoles).

Table 6.8 Wash water characteristics

Wash Water Characteristic	**mg/L**
BOD	1200
Ammonia	200
Total Phenolics	46
Formaldehyde	2.3

Binder Water: Wash water system blow down is consumed as make-up water for the binders that end up in the glass wool product.

Cullet Water: Contact cooling water to quench fiberglass recirculates through outdoor cullet water pits. The evaporative losses also result in mineral deposition on the quenched fiber (European Commission, 2008).

6.1.2.1 Characteristic of the Waste Water

The increasing demand for the insulation materials has increased the production of glass wool considerably. A poly condensation product of phenol and formaldehyde is used as an adhesive.

The waste water from the production plants contains phenol, formaldehyde, a poly condensation of these two compounds and glass threads. A typical analysis of the waste water is shown in the Table 6.9.

The large volume of process water system causes a potential for contamination of clean water circuits such as surface water and cullet quench water. If systems are poorly designed or not properly controlled, more serious emissions may arise. If wet scrubbing techniques are used, particularly chemical scrubbing, the effluent may not be compatible with the process water system, giving rise to a further waste system (European Commision, 2008).

Table 6.9 Analytical data for waste water from the manufacturing of glass wool (mg/L) (EPA, 2004).

Suspended solids	<30 mg/l
Chemical oxygen demand	100 - 130 mg/l
Ammonia	<10 mg/l
Sulphate	<1000 mg/l
Fluoride	15 - 25 mg/l
Arsenic	<0.3 mg/l
Antimony	<0.3 mg/l
Barium	<3.0 mg/l
Cadmium	<0.05 mg/l
Chromium	<0.5 mg/l
Copper	<0.5 mg/l
Lead	<0.5 mg/l
Nickel	<0.5 mg/l
Tin	<0.5 mg/l
Zinc	<0.5 mg/l
Phenol	<1.0 mg/l
pH	6.5 - 9
Mineral oil	<20 mg/l

6.1.3 Other Wastes

The main sources of solid waste for glass wool production are:

- Recycle batch spillages
- Glass wool cullet
- Dust collected from abatement systems directly to the furnace.

Part of glass wool waste cannot be recycled directly to the melting furnace, due to the presence of organic binder, unless appropriately treated for the removal of the organic fraction. Fibrous waste can e recycled by grinding and including it in the briquettes, but again this only occurs if a briquetted recycling system is in operation at the installation. However, edge trims are usually shredded and recycled to the forming area and, in some cases, the dry waste product can be shredded to produce a blowing wool product.

Cupola shutdown and tap out waste can theoretically be recycled through the briquetting system, but this is not common. This material is inert and can be used as filling material. The metallic iron which accumulates at the bottom of the cupola can be collected with appropriate special mould before it mixes with wastes, in order to avoid separation, which would cause dust emissions, and facilitate the possibility of external recycling of the material. The metallic iron from the waste can be sold as scrap iron, but there is little financial incentive to do this.

The high levels of recycling for the different wastes associated with the production cycle might cause emissions of metals from the melting process.

An estimate of the percentage of waste recycled in the mineral wool sector is not currently available. Table 6.10 below gives an indication of current practice; some plants apply recycling while others do not (European Commission, 2009).

Table 6.10 Glass wool sector solid waste generation and disposal (European Commision, 2009).

	Glass wool
Total waste generated as a percentage of product output	0-15%
Percentage of total waste recycled	5-100%
Percentage of total wasted disposed of off side.	0-100%

6.1.4 Energy

The predominant energy sources for glass wool melting are natural gas and electricity. Natural gas is also used in substantial quantities for fiberising and curing. Electricity is used for general services and light fuel oil, propane and butane are sometimes used as backup fuels. There are a number of oxy-gas fired furnaces applied to the sector.

The three main areas of energy consumption are melting, fiberising and curing. The split can vary greatly between processes and is very commercially sensitive. Table 6.11 shows the total energy consumption in glass wool production, with breakdown into the main process areas. The values for fiberising, curing and other consumption are estimates.

Direct energy consumption for electrical melting is in the range of 3.0 to 5.5 GJ/tone finished product. Energy consumption for electrical melting is approximately one third of that required for 100% air-gas melting and the relative energy consumption of each process stage can be estimated accordingly. With these values, the inherent error in such and estimate is very high, but they give and indication of the energy consumption (European Commision, 2007).

Table 6.11 Energy use in glass wool production (European Commission, 2007)

	Glass wool
	GJ/ tone finished product
Total energy consumption	9-20
	% of total energy
Melting	20-45
Fiberising	25-35
curing	25-35
other	6-10

A significant percentage of external cullet is commonly used in the batch composition in glass wool production with a consequent high influence on the furnace energy consumption. However, there are many technical constraints to the use of cullet, such as a suitable chemical composition and the presence of contaminants (organic materials, bulk metals, etc.)

CHAPTER SEVEN
GLASS WOOL WASTE MANAGEMENT PLAN

In this chapter sources of wastes will be defined from manufacture to the end of life of glass wool materials. It also provides an overview of the waste management options that are currently available for glass wool products or that could be adopted, prioritized according to the waste hierarchy of reduce, reuse, recycle, and recover.

7.1 Manufacturing Wastes

Glass wool manufacturing generates air emissions, water emissions, and solid wastes.

7.1.1 Air Emissions

Measurement and monitoring undertaken at facility may allow determining the control efficiency of the process steps that are part of the facility's operation. For instance, knowledge of the facility's equipment or measured data, a particulate matter and other emissions control efficiency can be assumed. Some pollution control equipment also decreases the emissions of particulate matter and air pollutants. Most of existing glass-melting furnaces are already well controlled. Some emission prevention methods are:

7.1.1.1 Bag Filters

Filter systems are used for many applications in industry due to their high efficiency in controlling the fine particulate matter. The basic principles of fabric filtration are to select a fabric membrane which is permeable to gas but which will retain the dust. The reverse air flow, mechanical shaking, vibration and compressed air pulsing methods are used for cleaning of bag filters. Bag filters re highly efficient dust collection efficiency of 95-99 % would be expected (European Commision, 2010).

7.1.1.2 Impact Jets and Cyclones

The continuous nature of glass wool production requires the use of a cleaning mechanism to prevent the build up sticky organic material and fibre in the extraction ducting and in the fan. This procedure provides high efficiency for cleaning and waste gas scrubbing (European Commision, 2010).

7.1.1.3 Wet Scrubber

Wet scrubbing systems can be used to control both gaseous and particulate emissions. Particle collection by liquid scrubbing occurs by three main mechanisms: inertial impaction, interception and diffusion. Trace gas removal by wet scrubbing occurs by absorption and to a lesser extent condensation. Absorption involves mass transfer between a soluble gas and a solvent in a gas-liquid contacting device. Experiences in the chemical industry suggest emissions below 10 mg/m^3 could be readily achieved for phenol, formaldehyde and ammonia (European Commision, 2009).

7.1.1.4 Wet Electrostatic Precipitators

In wet precipitators, the collected material is removed from the collector's plates by flushing with a suitable liquid, usually water, either intermittently or by continuous spray irrigation. Wet precipitators are useful for removing dust from wet gases with temperatures close to the dew point and for collecting liquid aerosols and sticky materials such as resinous particles and tars. The performance of wet precipitators is less dependent on particle properties as the moisture present in the gas precipitates readily and will assist the precipitation of a difficult dust (European Commission, 2009).

Table7.1 General achievable values for line emissions to air (mg/Nm^3). (European Commission, 2009).

Substance mg/Nm^3 (kg/tonne product)	**PM**	**Phenol**	**Formaldehyde**	**Ammonia**	**VOC's**	**Amines**
Fiberising and Forming						
Primary measures	100(3.6)	20(3.6)	15(0.5)	125(4.0)	50(2.2)	20(0.7)
Glass wool filter	20(0.7)	15(0.5)	10(0.4)	75(2.5)	25(1.0)	10(0.4)
Impact scrubber+cyclone	50(1.8)	15(0.6)	8(0.3)	65(3.0)	30(1.8)	15
Impact scrubber+cyclone+ WEP	20(1.2)	15(0.6)	8(0.3)	65(3.0)	30(1.8)	15
Impact scrubber+cyclone+ PBS	50(1.8)	12(0.5)	5(0.25)	50(2.5)	25(1.6)	10

7.1.2 Solid Wastes

Solid wastes from glass wool manufacturing are generally suitable for use in the manufacturing process, again. They can be reused through remelting into mineral wool production.

The waste generated during manufacturing of glass wool is number of chemicals in small concentrations such as silicon, calcium, aluminum, sodium and organic substances. On the other hand, it includes metallic substances such as copper, ferric, zinc, manganese...There are two methods to remove the polymering coating of the glass wool:

Thermal Treatment: involves exposing the glass to elevated temperatures in the presence of air to burn off the polymeric coating on the glass wool surface.

Chemical Treatment: involves contacting the glass fibers with chemical solutions at various temperatures to dissolve or degrade the polymeric coating.

The first step of the waste glass wool treatment is washing processes. Waste glass wools are washed and then put into thermal or chemical treatment processes.

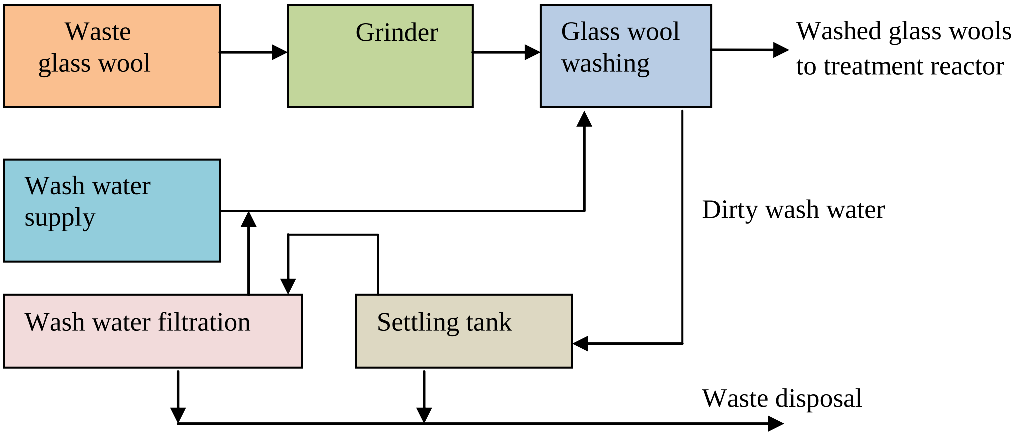


Figure 7.1: Design of the glass wool shredding and washing operation (Jody, B., 2002)

About 97% of the emissions are acetone, isopropyl alcohol, benzene, acrylonitrile and toluene. These should be easily oxidizable at elevated temperatures in an after burner or by mixing this gas stream with the exhaust from the melting furnace before heat recovery.

7.1.2.1 Thermal Treatment

Thermal treatment to remove the metallic particulates that might be trapped in it, and the particulates could be removed by washing. Therefore, washing of the glass fibers could be done after thermal treatment instead of before it.

This method is technically feasible and economically attractive for removing contaminants off of glass fiber waste so that it could be recycled into value added products. Washing the fibers before and/or after treatment reduces the metallic particulates of the fibers.

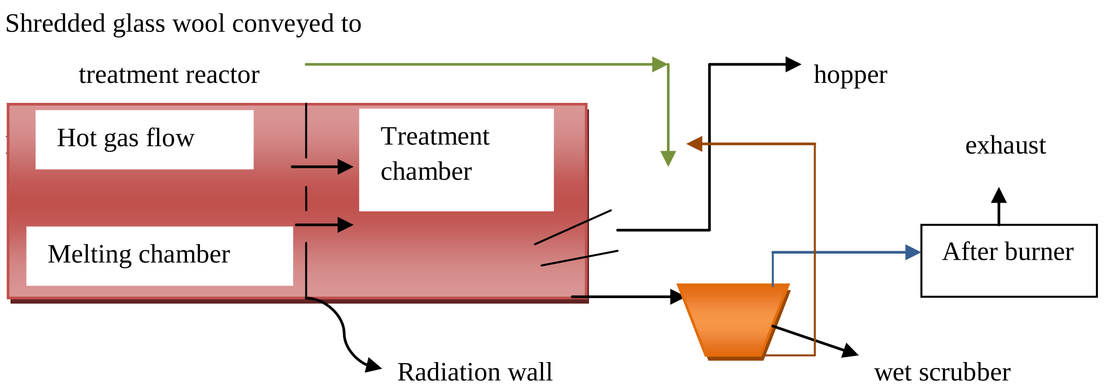


Figure 7.2: Schematic diagram of two chamber waste glass processing reactor (Jody, B., 2002).

7.1.2.2 Chemical Treatment

Hot tetraethylene glycol (TTEG) is used in this processes and it was successful in removing the coating layer off of the glass fiber surface. The required residence time was similar to that required by the thermal process and it tooks aproximately 30 minutes.

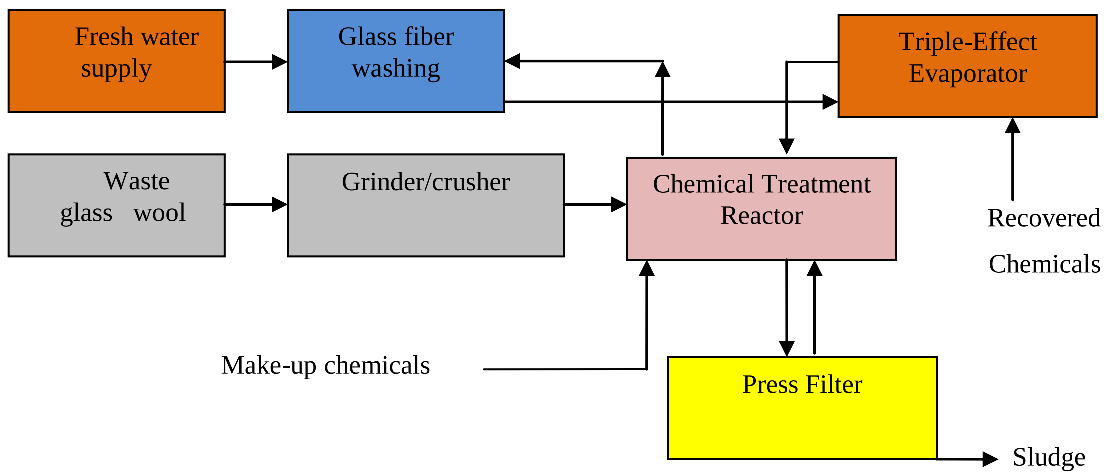


Figure 7.3: Design for the chemical treatment method (Jody, B., 2002).

This method is more expensive than thermal treatment methods. On the other hand, some chemicals are required in chemical treatment process and liquid wastes are arised. Wherefore, thermal treatment is the preferred more than chemical treatment method.

After the glass wools have treated, more than 99.5% of them recycled to the process.

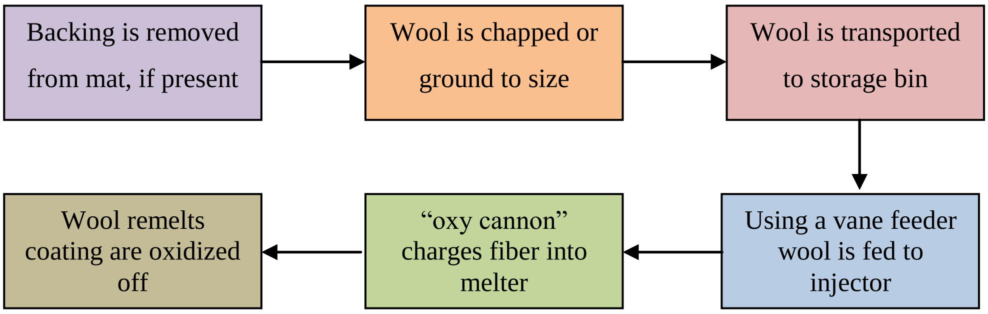


Figure 7.4 Simplified schematic diagram of the waste insulation glass wool recycling process (Jody, B., 2002).

7.1.3 Waste Waters

Water consumption is approximately 3 to 5 m^3/tone of product for glass wool manufacturing facility. Practically all of this water evaporates.

In any case, water is persistently re-circulated within side of the process wash water system. Internal flow of water used in the glass wool process is much higher and may reach up to 100 m^3/tone of glass wool. Most of water flow (about 70%) is used in the forming sections and their associated pollution control equipment.

The process wash water contains dissolved organic a solids (mainly fiber). Undissolved solids are removed in a plant by using cyclones, vibration screen filters, centrifugal filters or similar equipments. Water which contains dissolved organics are re-filtered and introduced to the binder mix to be combined with product.

Wash water characteristic are periodically monitored because the efficiency of flue gas scrubbing depends upon the concentration of dissolved solids.

For other water uses, treatment system is applied as industry standards such as air cooling, reverse osmosis, ion Exchange and de-oiling.

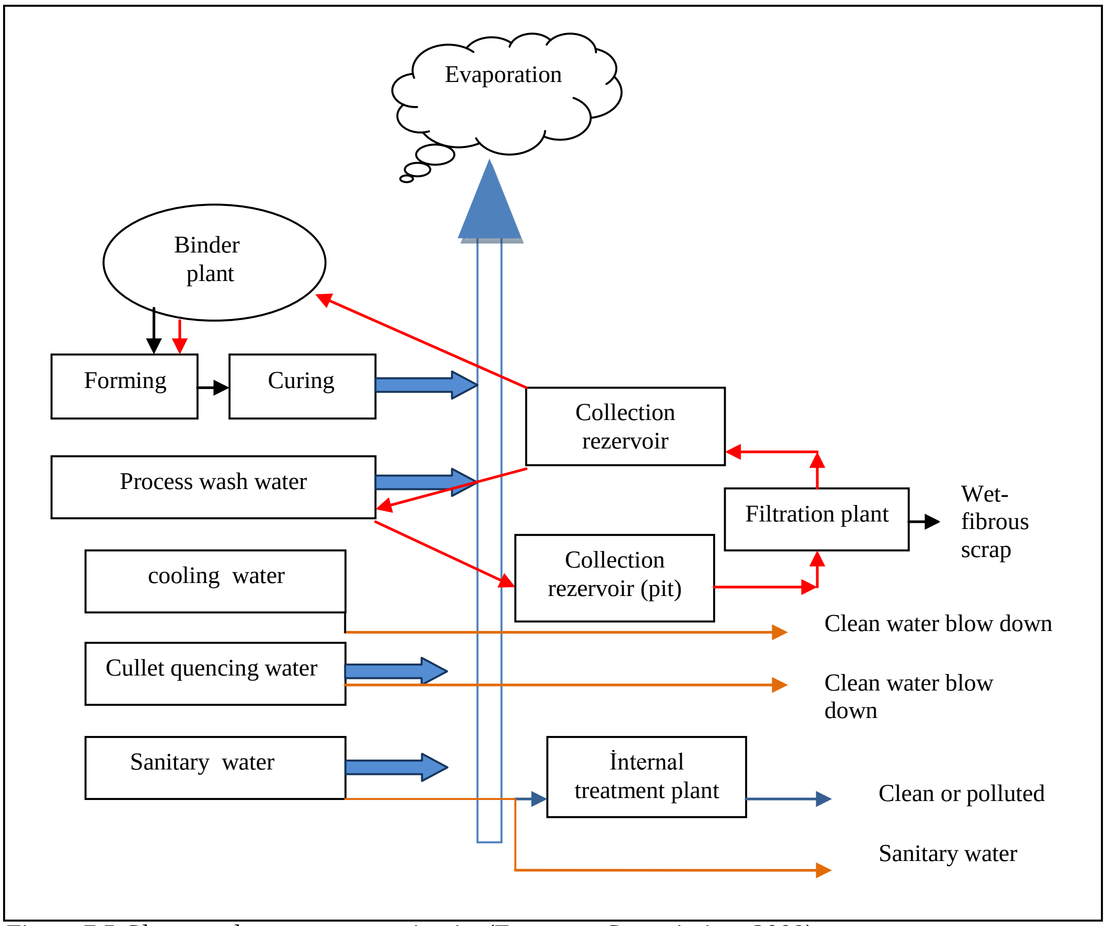


Figure 7.5 Glass wool process water circuits (European Commission, 2009).

Waste waters arising from binder plant cleaning, tank farm bunds or secondary cleaning operations may be recycled internally into the wash water system and treated before discharge to the sewer. The typical maximum waste water from the manufacturing is 50 m^3/day (European Commission, 2008).

7.1.3.1 Waste Water Treatment

Sodium hydroxide is added to the waste water and the half-condensed phenols will precipitate. The settling time of 3-6 hour is required. The waste water is then treated on a macroporous ion exchanger. Phenols are taken up as phenolate ions and after elution the phenols can be recovered. As phenols are insoluble in acid at a low pH it is possible to separate them from the elution liquid. Analytical data for the process are shown in Figure 6.6.

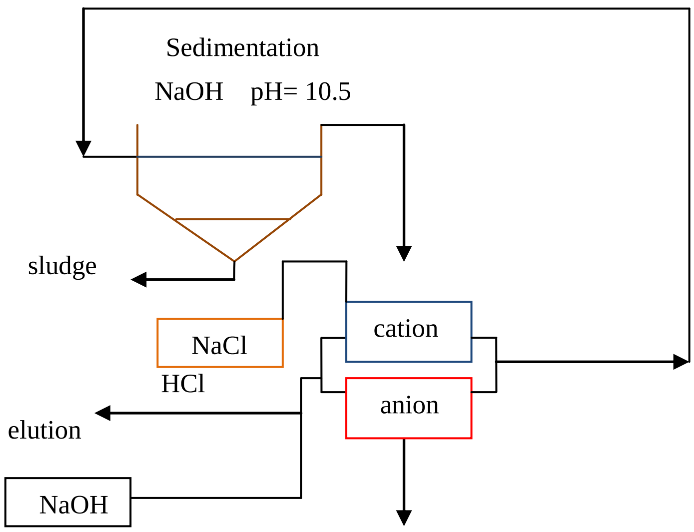


Figure 7.6 Flow sheet for a process suitablefor the treatment of waste water from the production of glass wools.

Table 7.2 Analytical data for untreated and treated waste water treatment process in accordance with Figure 7.6.

mg/L	untreated	treated	% efficiency
$KMnO_4$	5000	350	89
COD	8200	900	89
Phenol	325	20	93
Formaldehyde	600	240	60

In addition, activated carbon can be used instead of an ion exchanger. If the waste water does not contain high molecular weight organic compounds it is possible to use sodium hydroxide for the elution of the activated carbon.

7.1.3.2 Activated Sludge Treatment

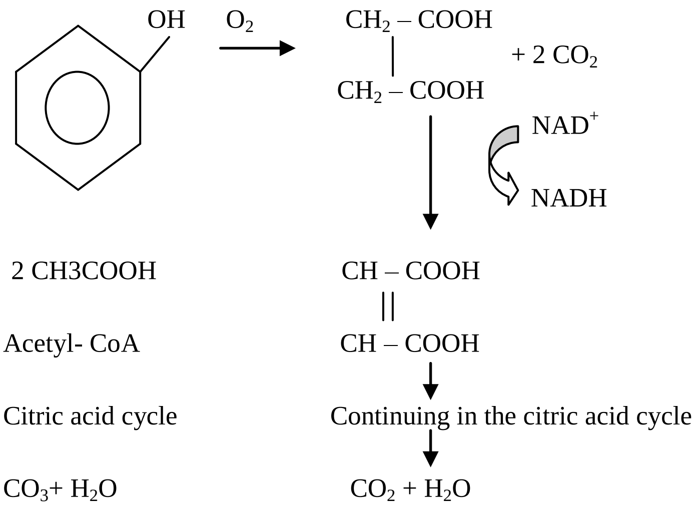
As the waste water has a high concentration organic material (like phenol, ammonium…) it is possible to use the activated sludge method for he waste water, must be used.

Phenol oxidizing bacteria, such as *Thioballicus* and *nitrifying bacteria* such as nitrobacter must be presented.

The biological oxidation of weak ammoniacal liquor from coke plants has been studied intensively. It has been found that it is possible to oxidize phenol, thiocyanate and ammonium to reduce cyanide, but it was necessary to acclimatize the activated sludge plant.

The preferred temperature range is 25-35 ^{0}C and the pH must often be adjusted before the biological treatment and it it generally necessary to add nutrients. The optimum ratio of BOD_5 to nitrogen and phosphorus is 100:15:1. It means that phosphorus is needed. Furthermore, magnesium sulphate and iron chloride must be added as small amounts of magnesium, iron and sulphate must be present.

The biological oxidation of phenol follows the processes:



The intermediates formed will be oxidized by the citric acid cycle to carbon dioxide and water is transformed to acetic acid, which is oxidized to Acetyl –CoA into the citric acid cycle (Kenneth et.al., 1983).

7.1.3.3 Extraction

Extraction can be used for the recovery of phenols and other organic material present in the waste water. As extraction media benzene, isopropyl ether, butyl acetate and the higher alcohols are needed. A survey of the distribution coefficients for the various solvents which can be used for the extraction of phenols are shown in the Table 6.3.

Table 7.3 Distribution coefficients of phenols

Solvent	Distribution Coefficient (Kd)
Light gasoline	0.2
Benzene	0.2
Diethyl ether	17
Dipropyl ether	17
Butyl alcohol	19
Isopropyl ether	20
Tricresyl phosphate	28
Ethylacetate	36
Isopropyle acetate	45
Butyl acetate	49
Xylenyldi phosphate	60
Mixture of higher	12

The extraction process removes a mixture of phenols, cresols, xylenols and pyridine bases from the waste water. This mixture is called raw phenol. A counter-current extraction followed by distillation for recovery of the solvents it the process generally used. The raw phenol which is produced after distillation of the solvents can be separated in to the different components by further distillation. If the waste water contains more than 2 g/L of raw phenol, it is profitable to use counter current extraction before biological treatment of the water (Kenneth et.al., 1983).

7.2 End of Life Wastes

Glass wools are powerful tools for the designer and the constructor to achieve high energy efficiency in buildings. However, there are also have side effects from the stage of their production until the end of their useful lifetime, when a building is rebuilt or demolished. Glass wool wastes are composed of tiny crystals that give both useful and hazardous characteristics. Their particles are very small, hard and chemically inert, so when inhaled they can cause injuries to the respiratory organs. They can be hardly or not at all taken out from the lungs and their years-long sedimentation causes internal injuries and various diseases that may result in death.

Figure 7.7 Glass wool wastes

There are three methods for waste disposal. These are: reduce (minimize), re-use, recycle, recover and finally disposal.

The possibilities of reusing them, or recycling them as well as the option of using then as primary energy sources and raw materials, in relation with their embodied energy (Dunster, A., 2007).

<u>Glass Wool</u>

Density (ρ) : 18-40 kg/m^3

Thermal conductivity factor ʎ (U) : 0.035-0.050 W/mK

Useful life time : 30-50 years

Glass wool can in theory be reused, if it is possible to remove them carefully from the building element. In most cases this is not possible, but in some cases it is used as raw material for the production of new products. In most cases, however, they are treated as waste which is fairly, due to the low content in organic carbon (less than 1.5%) and their high compressibility, which allows densities of up to 1000 kg/m^3, with a respective reduction in volumes.

7.2.1 Reduce

A reduction in the physical volume of glass wool required/used is not likely, as the trend in regulation is to increase the amount of insulation in buildings and the market share of each product type is likely to remain fairly constant that may bring about reductions (Dunster, A., 2007).

7.2.2 Reuse

Currently, waste glass wools can be reused through remelting into mineral wool production. Mineral wool manufacture may also use other industrial waste streams as raw materials such as the mineral by products of the iron and steel making processes.

They can be used as raw material in the manufacture of mineral wool, small volume speciality sales or landfill (Dunster, A., 2007).

7.2.3 Recycle

Glass wool is extremely difficult to recycle back into mineral wool production due to the presence of the organic coatings which would create emissions to air if heated.

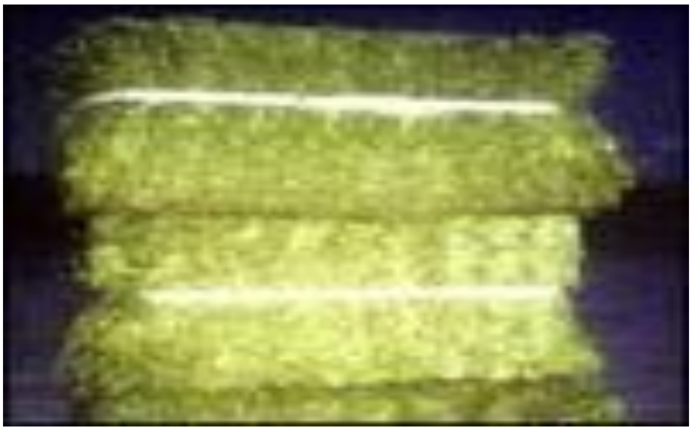


Figure 6.8 Waste mineral fiber bales

Waste mineral fiber is a bulky material. There is some organic content due to residual coatings on the fibers. It is generally classed (European Waste Catalogue) as “man-made vitreous (silicate) loose mineral fibers”. Its appearance is a solid that may be grey/green/yellow/pink in color dependent on using areas (Dunster, A., 2007).

7.2.4 Landfill

At present, the majority of insulation waste, whether from manufacturing, installation or end-of-life, will be landfilled polymeric materials that cannot be recycled may require thermal treatment (i.e. incineration) as a means of pretreating the waste (Soboroff et. al., 2002).

Glass wool waste is not regulated under RCRA Hazardous Waste Regulations. It may be disposed in landfill (EPA, 2010). All waste material should be placed in suitable containers as it is removed. If the material is wet, it should be placed in waterproof containers. The work area should be designated by the use of ropes and signs. Workers not involved in the removal work should not be allowed within 3 meters of the designated area (Dunster, A., 2007).

Storage Requirements: It must be stored in dry area and the area must be clean. The place must be prevented from dust emissions. Dust suppressants may be used in there.

Special Sensitivity or Incompatibility: Hydrofluoric acid will react with and dissolve glass. The wastes have to be kept off from acids.

Handling Precautions: Employees in charge have to use mask and gloves for their safety.

CHAPTER EIGHT
RESULTS AND DISCUSSION

We investigated glass wool materials which are used as insulation product, manufacturing process, and their physical and chemical properties, their areas of usage and environmental effects in this study. The sum and the substance of it, we analyzed the life cycle assessment of glass wool insulation materials. Furthermore, mass balance for glass production process is determined in this thesis study.

Glass wool is commonly used materials in constructions, transportation, sports goods and some industrial applications. Especially, they are preferred in household electrical appliances and buildings in our country because of their thermal and electrical insulation properties and they provide energy efficiency in contraction. However, alongside of their good properties, they can cause damage to human health and the environment if there are not made provision for pollution. The aim of waste management plan is reducing the negative influences and ramp up the production efficiency. It is very important to organize this plan to protect environmental balance and cope with environmental threats.

Glass wool is used as an insulation material and effects human health within used. Insulation is important in terms of energy efficiency. But it should not threat human health while it is used in construction and other applications.

The other method is the finding another alternative materials. Even if harmful effects of glass wool are degradable during the manufacturing processes and after used, it will be giving hamful effects to human as long as it is used in their life. Therefore, we have to find insulation materials which have less harmful effects.

There are many types of insulation materials. Especially, fiber composites such as cellulose, fiberglass, mineral wool and cotton includes lots of chemical compounds cause several diseases such as respiratory problems and cancer. They cause chronically health effects due to its inhalation constantly. The other basic insulation materials are extruded polystyrene, expanded polystyrene, foam rubber, polyethylene foam and polymeric bitumen membrane. Polystyrene and polyethylene materials are petroleum products.

In assessing the environmental characteristics of insulation materials, we need to consider a broad range of issues relating to the resources going into their production, manufacturing processes, pollutants given off during their lifecycle, durability, recyclability, and impact on indoor air quality. It is difficult to decide on one insulation material over another. There is some criterias that make it important in terms of environmental sustainability and good resistance properties of it. An insulation material should;

- ✓ Provide adequate insulation levels.
- ✓ have a lower R-value (thermal conductivity)
- ✓ Be chosen from high-recycled-content insulation materials.

One of the preferable insulation material due to has less harmful effects to the environment is polyethylene foam. Polyethylene is a petroleum product which comprise of polymerization ethylene. It doesn’t includes chemical resin and accordingly can be used an insulation material. It is recyclable materials and its disposal method is easier and cheaper than glass wool. It is used in various applications from food, electronic devices packages to insulation materials in our life.

Raw material consumptions for the production of low density polyethylene are shown in the table 8.1 below;

Table 8.1 Amount of consumed raw materials for 1 kg polyethylene production (Plastics Europe, 2007).

Raw Materials	Unit	Value
Minerals	g	2.7
Fosil fuels	g	1547.7
Uranium	g	0.004
Water usage	L	2.399
energy	kwh	11694

Wastes from polyethylene production processes are shown in the table 8.2 below;

Table 8.2 Amount of wastes from 1kg polyethylene production (Plastics Europe, 2007).

Wastes	Unit	Value
Non hazardous	kg	0.02
Hazardous	kg	0.004
Particulate matter	g	1.15
Nutrification	g PO_4 eq	2.399
Acidification	g SO_2 eq	42.1

Heat resistance is a value which is used for determining the insulation capacity of material. The higher the heat resistance, the better is the insulator. Thermal conductivity is the property of a material describing its ability to conduct heat. The lower the thermal conductivity, the better is the insulator. An important factor for determining the heat resistance of an insulating material is the thickness of that material, so the formula for determining it is as follows:

Thermal Resistance = Thickness /Thermal conductivity .... (8.1)

The comparison is easy indeed and could be obtained with a simple calculation on condition that the characteristics of both materials are equal i.e. same density and thickness.

Table 8.3 The closest comparable density of glass wool insulation to polyethylene insulation at equal thicknesses. (Arnonplast, 2004).

Unit	Polyethylene	Glass wool
Density (kg/m^3)	30	32
Thickness (m)	0.008-0.015	0.008-0.015
Thermal Conductivity($W/m.^0C$)	0.036	0.034
Thermal resistance ($m^2.^0C/W$)	0.22-0.41	0.23-0.44

As we can see, these table shows that the thermal resistance of Polyethylene insulation and glass wool insulation are almost the same.

Glass wool and polyurethane are compared in the table 8.4 in accordance with their thermal resistance properties.

Table 8.4 Comparison of glass wool and polyurethane according to their insulation properties (PU Europe, 2009).

Unit	Polyurethane	Glass wool
Density (kg/m^3)	32	17
Thickness (mm)	180	270
Weight(kg/m^2)	5.76	4.59
Thermal resistance ($m^2.^0C/W$)	0.15	0.15

The table shows that the glass wool and polyurethane have almost the same properties. Glass wool can be used at 270 mm thickness to supply same insulation capacity with polyurethane. On the other hand, polyurethane is required less energy during the production process comparing with glass wool (PU Europe, 2009).

All of the comparisons show that there are many insulation materials which can take glass wool’s place. Polyurethane and polyethylene insulation materials have almost the same properties with glass wool. These materials can be chosen for insulation applications.

CHAPTER NINE
CONCLUSION

The glass and glass wool industry has been growing since 1935 in our country (Türkiye Bilimsel ve Teknolojik Araştırma Kurumu, [TÜBİTAK], 2003). Glass wool has become preferable in recent years. We need more energy sources for providing energy efficiency due to technological development and population increase. Insulation has become more important in our life day by day. We use insulation materials everywhere (in construction, electrical household appliances, automobiles, etc.) in our lives. They prevent chemical corrosion, water damage, allow for noise insulation and prevent fire besides energy efficiency.

According to the Turkish Statistical Institute, glass wool production was 72,000 tonnes in our country in 2009 (Türkiye İstatistik Kurumu, [TÜİK], 2009). Also, Turkish Statistical Institute estimates that production amount is 73,500 tonnes with rate of increase 2% in 2010. In this context, we can assume natural sources are consumed and emissions are released during the manufacturing processes. 73,500 tonnes of glass wool was produced in 2010; approximately 84,500 tonnes of raw materials, 27,600 tonnes of phenol-formaldehyde resin, 7,800,000 tonnes of water and 3.5×10^8 kWh electricity have been consumed. In addition to natural source consumption, we can estimate the emissions levels arising from manufacturing processes. 130,000 kg of air emissions 4,000,000 m^3 water emissions arise from the glass wool manufacturing processes. Moreover, 900 tonnes of solid waste is generated.

Glass wool is widely used in our life due to its insulation properties. Usage of it can not be prevented, but some measures may be taken by producers. Here, the responsibility falls to producers, the Ministry of Environment and Forestry and to the consumer. If they work together to prevent pollution from manufacturing, in use and after use, emission reduction may be achieved. Therefore, people working in this sector and consumers must be instructed about the importance of glass wool's environmental effects.

Glass wool manufacturing processes are supervised under the Environmental Impact Assessment Regulations and it is determined that this activity causes environmental pollution. According the regulation some necessary precautions must be taken for preventing adverse environmental effects.

Life cycle assessment provides an opportunity to analyze industrial systems. Alongside investments purposes, the assessment seeks to give a picture of contributions to human lives and harmful effects for human beings and nature. Life cycle assessments start with raw materials handling and cover use of the material to final disposal methods. Life cycle assessment is also investigated investment option to increase efficiency in the industry.

Life cycle and environmental impact assessment of glass wool is studied in this thesis. Consequently insulation is important for energy efficiency and environmental sustainability. While the insulation material is chosen, it is important to investigate its environmental effects. In selection of the right insulation material help issues are more important than the economical issues.

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APPENDICES

A.1 Symbols and Abbreviations

Symbols	Abbreviations
ABS	Acrylonitrile Butadiene Styrene
BAT	Best Available Technology
EPA	Environmental Protection Agency
EUIMA	European Insulation Manufacturers Association
FA	Flame Attenuation
HAP	Hazardous Air Pollutant
IARC	International Agency for Research on Cancer
IBFD	Inter Body Fusion Devices
ISO	International Organization of Standardization
JEC	Jardine Engineering Corporation
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
NAIMA	North American Insulation Manufacturers Association
NESHAP	National Emission Standards Hazardous Air Pollutants
PE	Polyethylene
PS	Polystyrene
PU	Polyurethane
RCRA	Research Conservation and Recovery Act
RS	Rotary Spin
TIMA	Triangle Interactive Marketing Association
TTGE	Tetra Ethylene Glycol
VOC	Volatile Organic Compound