DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

REUSE OF VAPOUR CONDENSATE IN CERAMIC INDUSTRY

by
Tuğçe YILDIZ ZEYBEK

October, 2019
İZMİR

REUSE OF VAPOUR CONDENSATE IN CERAMIC INDUSTRY

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"REUSE OF VAPOUR CONDENSATE IN CERAMIC INDUSTRY"** completed by **TUĞÇE YILDIZ ZEYBEK** under supervision of **PROF. DR. NURDAN BÜYÜKKAMACI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Prof.Dr. Nurdan BÜYÜKKAMACI

Supervisor

Dr. Öğr. Üyesi Ahmet ERYAŞAR

(Jury Member)

Prof. Dr. Ayşe FİLİBELİ

(Jury Member)

Prof. Dr. Kadriye ERTEKİN

Director

Graduate School of Natural and Applied Sciences

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Tuğçe YILDIZ ZEYBEK

REUSE OF VAPOUR CONDENSATE IN CERAMIC INDUSTRY

ABSTRACT

Ceramic production processes are raw material storage, blending, dry or wet grinding, milling, humidification or spray dryer, pressing, drying, glazing, firing, and separation, respectively. The raw materials are milled with water in wet grinding process. The mass to be pressed must be dried to certain moisture content and spray dryers are usually used for this aim. In the ceramic production facilities, a pressurized centrifugal spray nozzle system is generally used to atomize the solution. The spray dryer essentially consists of chamber, of which a shape and volume designed to allow heat exchange with the sprayed sludge and hot air/combustion gas. The finest particles in the spray drying chamber are first separated by cyclones and then by dust traps. Finally, the steam is discharged from the chimney.

Within the scope of this thesis, the reusability of this released steam after condensation was investigated. For this purpose, a ceramic production plant was selected as a pilot plant. There are 15 spray dryers in three different locations in the pilot plant. They have a total steam production capacity of 41,100 liters/hour at maximum capacity. The temperature of steam discharged from the chimney is in the range of 90-115 °C. It contains air, water VAPOUR, and suspended dusts. In the scope of the thesis, water recovery from steam by condensation and use of recovered water for the grinding of raw materials in the mill were investigated. In addition, the environmental impacts of the pilot plant in the existing conditions and in the case of water recovery from steam were determined by life cycle analysis approach.

Keywords: Ceramic, vapour, reuse, water, life cycle assessment

SERAMİK ENDÜSTRİSİNDE BUHAR KONDENSATININ YENİDEN KULLANIMI

ÖZ

Seramik üretim prosesi sırasıyla; hammadde depolama, harmanlama, kuru veya yaş öğütme, değirmen, nemlendirme veya püskürtmeli kurutucu, presleme, kurutma, sırlama, fırınlama ve ayırma işlemlerinden oluşmaktadır. Yaş öğütme işlemi yapıldığında hammaddeler değirmen içine su alınarak öğütülmektedir. Presleme işlemine alınacak olan massenin belli nem oranına sahip olacak şekilde kurutulması gerekmektedir ve kurutma işlemi için püskürtmeli kurutucular kullanılmaktadır. Seramik üretim tesislerinde çözeltiyi atomize etmek için genellikle basınçlı santrifüj püskürtücü meme (nozzle) sistemi kullanılmaktadır. Püskürtmeli kurutucu temel olarak şekli ve hacmi püskürtülen çamur ve sıcak hava/yanma gazı ile ısı alışverişini sağlayacak şekilde tasarlanmış bir hazneden oluşmaktadır. Püskürtmeli kurutma haznesi içindeki en ince taneler ilk önce siklonlarda daha sonra toz tutucular tarafından ayrılır. En son olarak buhar bacadan dışarı verilir.

Bu tez kapsamında, dışarı salınan bu buharın yoğunlaştırılarak yeniden kullanılabilirliği araştırılmıştır. Bu amaçla, bir seramik üretim tesisi pilot tesis olarak seçilmiştir. Tesiste 3 farklı lokasyonda toplam 15 adet püskürtmeli kurutucu bulunmaktadır. Maksimum kapasite ile çalışıldığında toplam 41100 litre/saat buhar oluşma kapasitesi bulunmaktadır. Bacadan atılan buhar sıcaklığı 90-115 °C arasındadır. İçeriğinde hava, su buharı ve asılı tozlar bulunmaktadır. Tez çalışması kapsamında, oluşan su buharının yoğunlaştıralarak su elde edilmesi ve bu suyun değirmenlerde hammadde öğütmede kullanılmak üzere kullanılması ile ilgili değerlendirmeler yapılmıştır. Ayrıca, pilot tesisin mevcut durumda ve buharın geri kazanılması durumundaki çevresel etkileri, yaşam döngüsü analizi yaklaşımı ile belirlenmiştir.

Anahtar Kelimeler: Seramik, buhar, yeniden kullanım, su, yaşam döngüsü analizi

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Sustainable production approaches have become an important issue in the industry due to the limited availability of clean water resources and the pollution/consumption of natural resources. When sustainable production is achieved, not only environmental gains are achieved, but also economic and social benefits.

The ceramic sector has an important place in our country and the world depending on the construction sector activities. Developments in the world economy and construction sector are also directly determining in the ceramics sector (Economy and Strategy Consultancy Service, 2017).

The ceramic production process consists of raw material storage, blending, dry or wet grinding, milling, humidification or spray dryer, pressing, drying, glazing, baking, and quality separation packaging process. In a wet grinding process, raw materials are milled by taking water into the mill. The mass to be pressed must be dried to a certain moisture content. For this purpose, spray dryer is generally used in ceramic production facilities. The finest particles in the spray drying chamber are first separated by cyclones, then by dust traps, and finally, steam is released from the chimney.

In addition to raw materials, there is a high consumption of water and energy in ceramic production. The average water consumption per square meter of the ceramic tiles produced is approximately 20 L and the energy consumption is approximately 32 kWh (Mezquita, 2017). To reduce water and energy consumption, recovery practices are carried out. In this context, clean production methods such as reducing raw material use, reducing water use, increasing energy efficiency, reusing old/broken ceramic coatings, recycling uncooked/cooked ceramic waste, packaging recycling, energy recycling, and water recycling are used. It is common practice in this sector to reuse of reclaimed waters and treatment sludges in the production.

1.2 Aim and Scope of the Thesis

In this study, it was aimed to investigate the techniques that can be applied for water recovery from water VAPOUR released to air in a ceramic factory and the availability of the use of recovered water in the production. Considering the amount of generated VAPOUR in the pilot plant, the applicable condensation techniques and reuse potential of the condensate were investigated. In addition, the environmental impacts of the pilot plant in the existing conditions and in the case of water recovery from steam were determined by life cycle analysis approach.

CHAPTER TWO
CERAMIC INDUSTRY

2.1 Ceramic Production

The so-called ceramic material is defined as a class of inorganic non-metallic solid that is exposed to high temperatures during its production. Generally, ceramics are composed of carbides, nitrides, and oxides. Phosphides, selenides, silicides, tellurides, and borides are added to ceramics. Ceramic materials are heat resistant. This is because ceramics are treated with high temperatures. (European Environment Agency, 2007).

When it comes to ceramics, it should be known that they are synthetic materials having a crystal structure. When we look at the past, it is seen that ceramics are used in the production of works of art and storage of products. Therefore, ceramics have an important place in daily life and industry. Today, the ceramic industry continues to develop and is located at many points in our lives. Manufacturers depend upon ceramics to create everything (building components, electronics, etc.). The ceramic industry covers lots of things from small-scale artisan selling clay pots to an international corporation supplying a line of semiconductors.

Ceramic use history goes back for many years. When archaeological studies are examined, it is seen that ceramic products are mostly found and shed light on scientific studies. Since the beginning of the 20th century, researches have been carried out to increase the usability of ceramic products and synthetic ceramics have been developed as a result of the researches. At the beginning of the 21st century, the use of ceramic materials in small-scale products that manufacturers wanted to use in the field of nanotechnology provided a solution (wiseGEEK, n.d.). As can be seen, ceramic products are found in all areas of life.

In the first years of the use of ceramic products, only soil and clay were used. In order to provide ease of use and use of ceramics for different purposes, the strength of the ceramics had to be increased. Afterward, they were not content with clay and soil but also used stone, quartz, and porcelain. These also helped increase strength and durability (wiseGEEK, n.d.). The studies carried out for the development of ceramic products have made ceramics useful in many areas in the modern world.

The ceramic products are subjected to incineration to ensure their strength before final use. Ceramics containing products such as soil, clay, quartz can be used for different purposes. Ceramics can be treated by using different materials and different processes.

After ceramic products are treated, they have long-lasting, abrasion-resistant, high strength, heat, and fire-resistant, electrical resistance (European Union, n.d.). We can see that products with high electrical resistance are used in high voltage lines.

When ceramic products are manufactured, they have different sizes, shapes, and colors by using various raw materials and auxiliary materials and firing them at different times and temperatures. Even though the process stages of ceramics such as technical ceramics, floor and wall tiles, ornamental items, bricks and roof tiles, ceramic sanitary ware are different, the formation principles are the same for all.

As a rule, the raw materials are mixed and cast pressed or pressed into a mold. Water is regularly used to thoroughly mix and shape. This water eVAPOURates in the dryers, and the products are either manually placed in the furnace — especially in the case of periodically operating furnaces — or placed in carriages that are moved through continuously operating tunnel or roller furnaces. Rotary kilns are used for the manufacture of expanded clay aggregates.

It is very important that the furnaces operate at the right temperature and speed so as not to cause scrap in the products. Using the wrong temperature and speed may result in differences in shape and size, crack formation and product breakdown. After the firing process, the cooling process should not be sudden. This process should be slow and controlled to protect the ceramic structures. Finally, the product checked for quality control, packaged and storage (CER-BREF, 2007).

Main sectors based on the production of ceramic products;

- floor and wall tiles,
- ceramic sanitary ware,
- refractory products,
- ornamental items,
- bricks and roof tiles
- technical ceramics, etc.

2.1.1 Wall and Floor Tiles

Ceramic tiles have been manufactured for thousands of years and essentially, the process remains unchanged. Tiles make a great choice when it comes to covering walls and floors. Tiles intended only for use as wall tiles are often lighter and thinner than floor tiles.

When the floor tile and wall tile are compared, the wall tile is thinner and the floor tile is thick and durable. Floor tiles are produced to carry loads such as pedestrian traffic to furniture. This is achieved by having a thicker and harder structure. The raw material used, the mold and pressure used during the peeling process, the glaze used in the glazing process and the temperature and speed in the firing process make the tile harder or softer. Floor tiles are expected to be non-slip as well as durable (Tile Devil, n.d.).

The raw material used for floor tile in the pressing process should be finer and formed by applying higher pressure. If the raw material has larger particles, it breaks against the high pressure applied during the pressing process.

Glazed floor tiles and glazed roofing tiles are resistant to water, high humidity, weather and stain, and have a hard protective glaze layer. Ceramics with these conditions are preferred in places such as bathroom, pool, laundry room and kitchen.

Wall tiles are suitable for walls only but floor tiles can go on either (Tile Devil, n.d.). Floor tiles are more durable and more laborious to make.

Ceramic tiles are very important as building materials. However, high energy and raw material consumption during production is causing environmental pollution (Ye, L., 2018).

2.1.2 Bricks and Roof Tile

Brick is a ceramic material which is used in structures consisting of clay, cement, sand and water (How products are made, 2009). Bricks are used in curved designs and are also suitable for structures in narrow spaces.

Figure 2.1 Brick structures (Ibstock, 2016)

Clay roof tiles are used in low slope roofs. Clay roof tiles are used in low slope roofs. These products are designed to provide a natural air flow inside a building. Some of these tiles have many types which are flat tile, concrete tile, large format tile, interlocking tile, low ceiling tile, pantiles, clay tile and double roman style tile .

2.1.3 Ornamental Items

Manufacture of household ceramics covers dishes, artificial and haberdashery products from porcelain, faience and porcelain. Typical ornamental items are cups, plates, vases, jugs, serving bowls and dishes (Figure 2.2).

Figure 2.2 Vase and decorative ornamental tile from Persian ceramics (Bidspirit, n.d.)

2.1.4 Refractory Products

A refractory material or refractory is a heat-resistant material. Refractory materials are fire resistant and can be used for a long time at temperatures above 500°C. Compared to metals, there are processes in which metals cannot be used, but ceramic materials are more suitable. Ceramic materials are more suitable because it has high strength and hardness, low density, low toughness, high elastic malicious, brittle, low thermal expansion and low thermal and electrical conductivity at high temperatures.

2.1.5 Ceramic Sanitary Ware

You will see ceramic sanitary ware, especially in the bathrooms. bathtubs, sinks, cabinets are examples of sanitary ware products. In Figure 3.1 we see the washbasin, which is one of these examples. Ceramic sanitary ware is easy to use and has high abrasion resistance. It can also be visually desired shape and color.

Figure 2.3 Sample of sanitary ware (wash basin) (Pinterest, n.d.)

Ceramic sanitary ware is produced in 10 stages similar to other ceramic products. These;

- Body preparation
- Glaze preparation
- Molding / Mould preparation
- Casting
- Drying
- Control & Spraying
- Firing
- Sorting
- Refire / Rework
- Packing

2.1.6 Technical Ceramics

Technical ceramics are designed to be used in technical applications with a much stronger and higher performance than decorative ceramics. Without them, there are many requirements from completely different sectors that would be impossible to fulfill. We see that technical ceramics are used in many sectors such as medical technology, the automotive industry, and mechanical engineering. (Figure 2.4).

Figure 2.4 Technical ceramic examples (Ceramtec, 2019)

2.2 Ceramic Industry in Turkey and the World

Italian and Spanish producers produced and sold close to 80% of all tiles in the EU. (Etekina, n.d.).

The construction sector has suffered a great deal of trouble in other countries during the recent economic crisis in Europe as well as in Turkey. Consequently, problems occurred in other sectors connected to the construction sector. Between 2008 and 2013, we see that total sales decreased by 23% to € 9,299 million (Etekina, n.d.). We see that the ceramic industry is struggling to survive on a global scale. In order to do this, it tries to minimize the production cost.

We see the traces left of the civilizations, which did live in Turkey, that left marks on (Turkish Ceramics, n.d.).

Turkish ceramic production began in the 1950s and grew with growth since the 1980s. Using new production technologies and attracting modern production lines, Turkey ranked ninth in the world in tile production and export. The decoration and pottery of the Hittites and Iznik's ornamented hand-painted tiles show us that it had a history of ceramic production until thousands of years ago (Mining Turkey, n.d.).

Major competitor countries in the ceramic industries are:

- China
- Italy
- Spain
- India
- Poland
- Russia
- Iranian
- Vietnam
- Turkey
- Egypt

The construction sector and the ceramic sector are progressing in parallel. The construction industry data around the world gives information about the ceramics industry. The construction sector has been developing since 1980 in Turkey and also ceramic industry.

The Figure 2.5 shows construction expenditures worldwide.

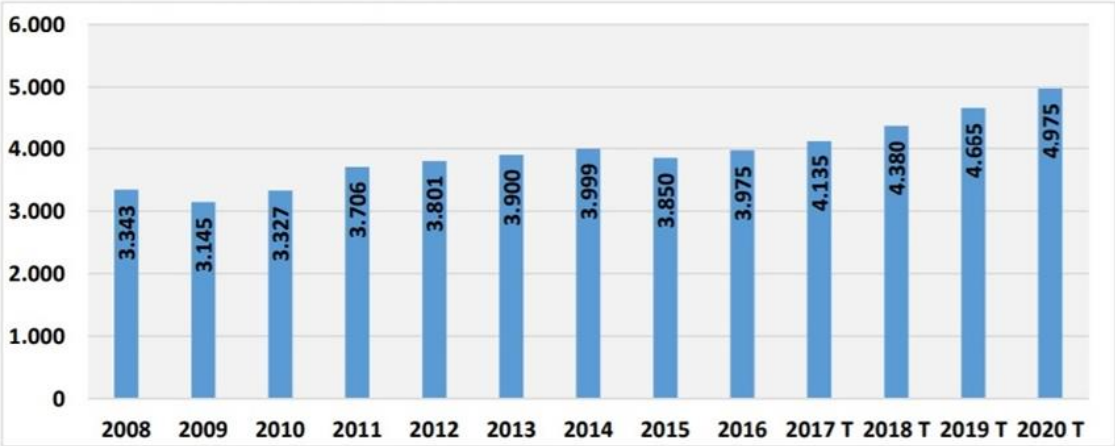

Figure 2.5 Worldwide construction expenditures (Billion dollars) (ESDH, 2017)

2.3 Ceramic Industry Wastes

In ceramic production, solid, liquid and gas forms are generated and most of these wastes can be recovered. The wastes that may occur in the ceramic sector are described below.

- Solid waste
- Liquid waste
- Gas waste.

2.3.1 Solid Waste

Treatment plant sludge (filter press cake) is formed. All of the sludge can be acquired at the ceramic product.

In the ceramic sector, raw and cooked scraps are also produced. Raw scrap can be reused as a raw material according to the recipe. However, the scrap that is formed after the glazing and firing process, which is called baked scrap, cannot be used again and is sent as waste.

Besides, damaged packaging wastes that are used for the transportation and protection of ceramics are also among the wastes.

2.3.2 Liquid Waste

During the production of ceramics, process wastewaters and domestic wastewaters are formed. There may also be other wastewater sources such as rainwater and wash water. The resulting process wastewater is generally treated in the treatment plant and reused in the process.

2.3.3 Gas Waste

There is waste gas formation in furnace burners and spray dryers. The waste gas from the furnaces is used for heat recovery. In this study, the recovery of water VAPOUR from spray dryers was investigated.

CHAPTER THREE
REUSE OF VAPOUR CONDENSATE

3.1 Water Reuse

Since ancient times, water has been used as a symbol with which to express loyalty and purity. Some cultures, such as the ancient Greeks, went so far as to worship the gods who were believed to live in the waters and command them. Entire cities were built taking into account the location and availability of clean drinking water. The gathering place was around the wells, which is probably the next trend in the construction of fountains in the center of the squares.

Humans use water for hydration, cleaning, and sanitation, agriculture, water sports, etc. Traditional and modern medicine uses a variety of psychological properties of water in different forms of hydrotherapy (the complex Greek word: hydro, water and therapy) (La Leva, n.d.).

When it comes to water, only drinking and domestic water should not come to mind. However, there are resources in nature that are the source of healing. It is known that water is a source of healing from past to present for the treatment of diseases. Historical records of cold springs claim to be "cured" from the fourteenth century.

We do not know the importance of water, known as a source of healing from the past to the present. Water resources such as rivers, seas, and oceans have been abused and polluted. A reduction in the population of marine and coastal life, the appearance of green algae in rivers, and the stench and mucus resulting from rotting in water are clear signs of the depth and extent of destruction caused by this. complex ecosystem (complex Greek word: eco, home, and system, a combination of things or parts forming a complex or integrated whole).

To understand the importance of water, it is necessary to know that 75% of the human body and 2/3 of the earth's surface are water (La Leva, n.d.). Water is indispensable for the digestion of the nutrients we eat and for the circulation in the human body. “Water is life” is such a common expression that we use it nearly like a cliché. However, this phrase is probably one of the most truthful messages that all creation testifies to. We can say “no life can be sustained without water” (Africa, n.d.). The importance of water is known in the regions where water scarcity is experienced, but we will face an irreversible problem after the resources are exhausted. From an early age, we learn how invaluable water is, but we still do not take a step to protect natural resources. We must act now and reduce pollution to leave a world to live for future generations.

We started to hear the term climate change a lot in our daily lives. climate change means changing the order of the world and endangering the living life. With the increase in drought and floods, the pressure on water resources is increasing day by day (Avrupa Çevre Ajansı, 2014). We need to use sustainable solutions to mitigate the impact of climate change. As a result of climate change, the average temperature of the world and the temperature of rivers, lakes, and oceans have increased and this effect is seen on glaciers. Despite the fact that the surface of the earth is 2/3 of water, the available water resources are decreasing day by day.

Pollution of resources, as well as reuse of water used, will reduce pressure on resources. Widespread reuse of domestic wastewater, which is called gray water and collected from shower and washbasins other than phosphoric waste, will also reduce the pressure on water.

Re-use of water is important while our resources are depleted quickly. Wastewater can be an important source of water in places where population density is high, in arid regions and where quality water is limited (Demir et al., 2017).

The reuse of wastewater reduces energy consumption, conserves water resources, preserves surface water quality and reduces water supply costs.

3.2 Condensation

Condensation can be called the conversion of water VAPOUR in the air into water. (Figure 3.1). For a material to condense, it must exceed the VAPOUR pressure at the surface temperature at which condensation occurs. If VAPOUR is condensed, heat is generated. The surface temperature increases as long as this temperature is equal to the temperature of the surrounding VAPOUR (Britannica, 2019).

Condensation is the opposite of eVAPOURation. Condensation can occur in two ways. One of them is cooling the air to dew point or making it saturated with water VAPOUR so that it cannot hold any more water (National Geographic, n.d.).

The dew point is the temperature at which condensation occurs. The air temperature should reach or increase the dew point in a natural way, as is often the case at night. The droplets we see on cars, grass and houses in the morning occur as a result of this event (Byju’s, n.d.).

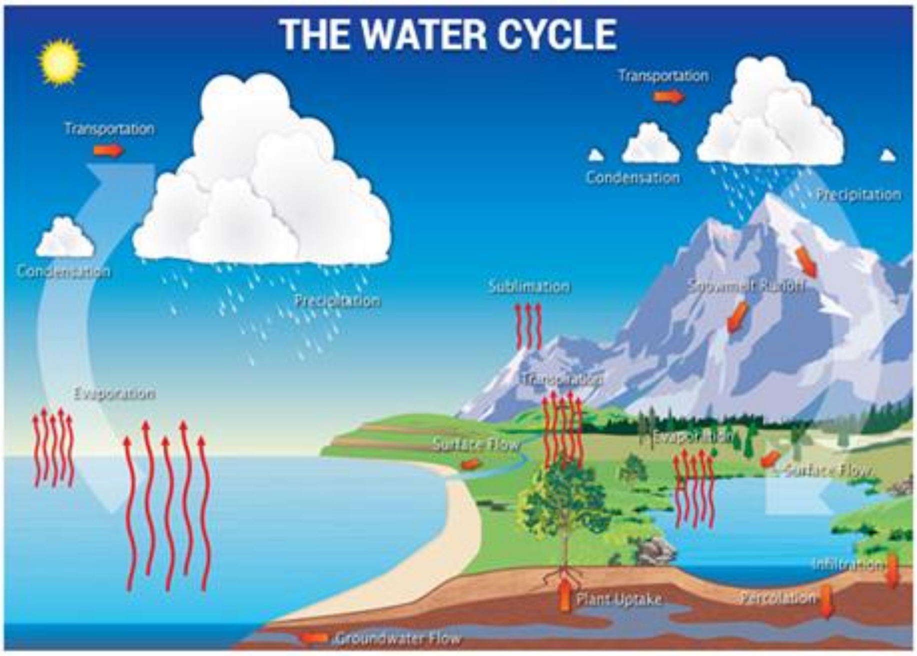

Figure 3.1 The water cycle (Byju’s, n.d.)

Condensation occurs when the water phase returns from the gaseous state to the liquid state. When the pressure is high and the temperature is low, all gases can condense. If the condensate gas pressure is higher than the pressure of the liquid gas state, condensation can also occur without the effect of temperature (Byju's, n.d.).

3.2.1 Condenser Types and Properties

Condenser and heat-transfer devices are used to make the liquid VAPOUR. Condenser is used for condensation. In the cooling system within the condenser, the heat taken from the eVAPOURator by the refrigerator is taken from the system during the compression process in the compressor. Thus, the refrigerant is pressurized to become liquid and expanded again to bring heat from the eVAPOURator.

We can briefly explain the working principle of the condenser as follows. Condensation of VAPOUR and gases on the surface occurs in the form of a "drop or film formation depending on the surface characteristics". In the case of dropwise condensation, much higher thermal conductivity coefficients can be achieved (4-8 times more than film formation). This is preferable, however, in practice, since the refractory properties and production of the condenser are limited by economic factors, only film-like condensation occurs and, to a lesser extent, the formation of droplets and condensation. The heat exchange in the condenser can be thought to occur in three phases. They are;

- Heat recovery
- Refrigeration condensation
- Overcooling

Condensers are used in a variety processing, including distillation, refrigeration, and power generationThe condensers create a pressure difference and thus allow condensation to occur, ignoring the effect of temperature. This increases plant efficiency and reduces specific vapour consumption. Air or water is used as the cooling medium in the condensers.

The various types of condensers are:

- Air-Cooled Condensers (ACC)
- Water-Cooled Condensers (WCC)
- EVAPOURative (Water and air cooled) Condensers
- Membrane Condensers

Which type of condenser is selected depends on the following factors:

- Capacity of the system
- Type of refrigerant used
- Whether there is plenty of water supply, etc.

In small refrigeration units, air-cooled condensers are mostly preferred (Soyer, 2018)

3.2.1.1 Air-Cooled Condensers (ACC)

Air-cooled condensers are widely used and widely used technology. The majority of recent studies examining ACC performance focus on the effects of meteorological conditions (Owen et al., 2017).

In air-cooled condensers, heat from the condenser is removed directly to the surrounding air. Thus, the condensing temperature is a function of the ambient air dry-bulb temperature.

An obvious advantage of air-cooled condensers compared to water-cooled condensers is that water cooling is not required. Consequently, air-cooled condensers are a common choice for heat removal in geothermal power plants where there is not enough.

The main disadvantage of air-cooled condensers compared to water-cooled condensers is usually higher capital costs; water is a better medium for heat transfer than air, so air-cooled power plants usually require more equipment to remove heat (Chiasson, 2016).

Usually, aluminum finned tubes are single-row condensation tubes, which are brazed by aluminum fins and are cooled by air. As they are cooled by air, water is not required for the main cooling of the power plant. A schematic diagram of an air-cooled condenser is given in Figure 3.2.

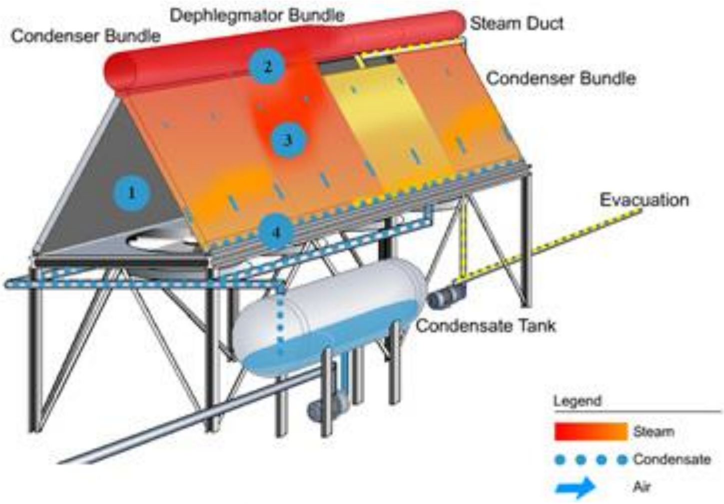

Figure 3.2 Air cooled condenser (EPS Engineering, n.d.)

Types of air cooled condensers are;

- Direct-contact
- Integral-fin

3.2.1.2 Water-Cooled Condensers (WCC)

Water-cooled condenser (WCC) water VAPOUR is used to remove low-grade heat during water VAPOUR condensation. Water-cooled condenser systems (WCC) are widely used in commercial sectors to improve energy efficiency (Lee, 2007).

In principle, it is possible to cool the atmospheric air by using compressed air. The region of the finned tubes is used to transfer heat when the cooling air goes outside the tubes, and the condensing medium, steam, flows inside the tubes. Forced air flow is provided by the propeller. The fan is driven by an electric motor with a gearbox. Water-cooled condenser types are given in Figure 3.2 and 3.4.

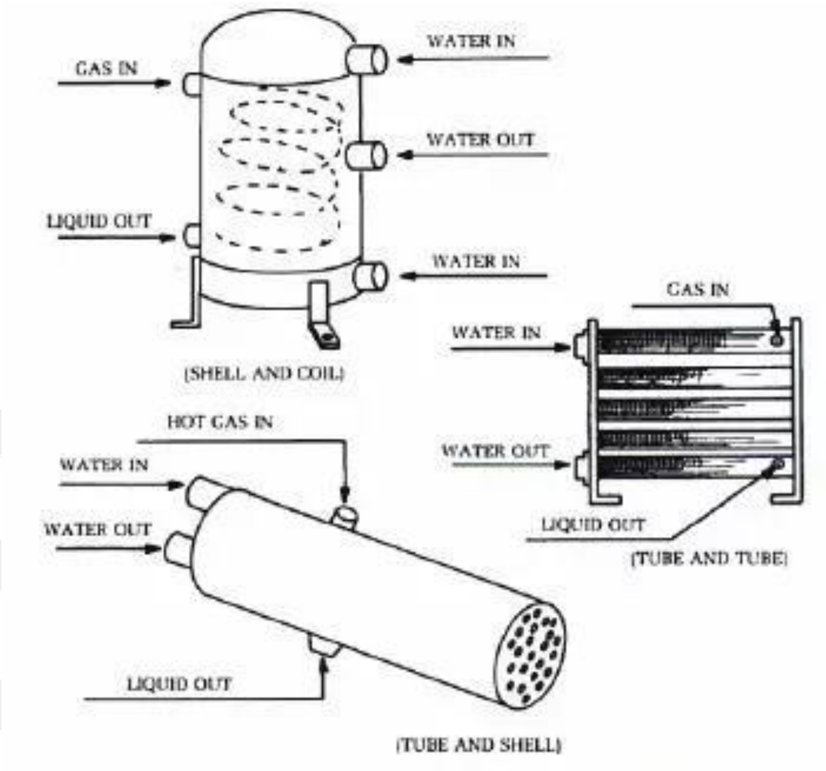

Figure 3.3 Water cooled condenser (Ref-wiki, 2010)

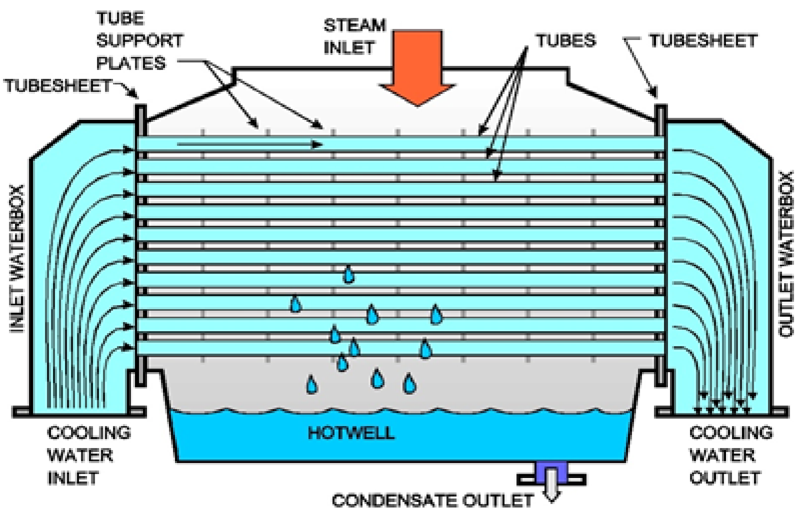

Figure 3.4 Power plant surface condenser (Water-cooled condenser)

The operating costs of water-cooled and air-cooled power plants should also be analyzed and the cooling towers maintenance costs should be taken into consideration (Chiasson, 2016).

Types of water-cooled condensers are;

- Direct-contact
- Shell and tube

3.2.1.3 EVAPOURative (Water and air cooled) Condensers

In the eVAPOURative condenser, the condensing heat, which comes from the refrigerant inside the tube, is discharged into the humid air in both sensible and latent form (Wei et al., 2019) (Figure 3.5). In recent years, intensive efforts have been made to use eVAPOURative condensers in small residential cooling systems.

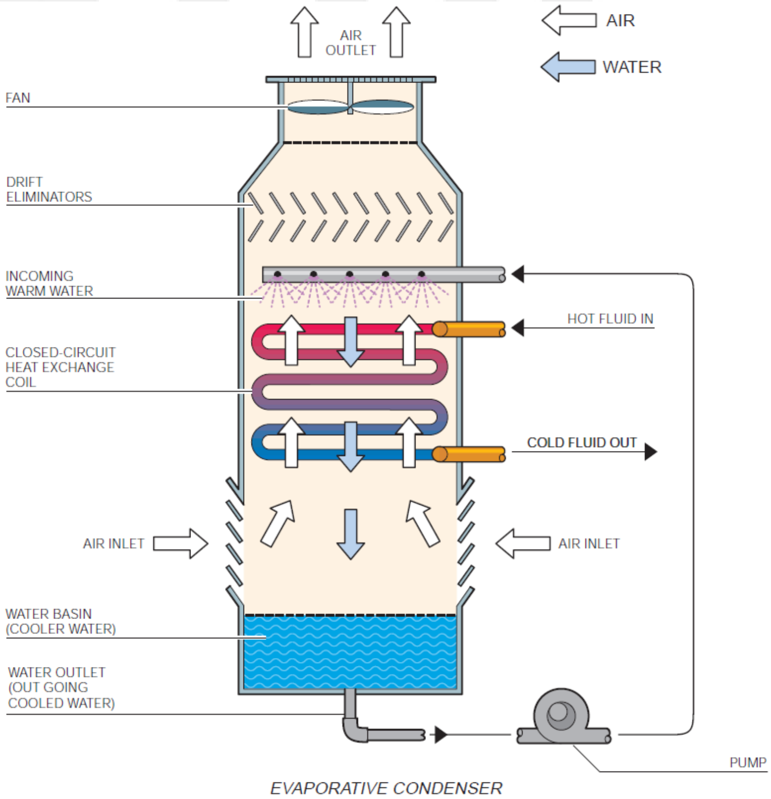

Figure 3.5 EVAPOURative condenser

Convective air passes through a tube bundle, covered with a film of sprayed water, which pushes the limiting condensation temperature of the eVAPOURative condenser to the temperature of a moist air ball. Horizontal tube with counter flow air flow is the most popular design of eVAPOURative condensers (Wei et al., 2019).

3.2.1.4 Membrane Condensers

MC has innovative technology over other condenser types and microporous membranes are used to increase the condensation and recovery of water VAPOUR. (MDPI, n.d.)

The separation of the VAPOURized wastewater containing the industrial gases from the gases can be done with the help of membrane capacitors (Macedonio et al., 2019). Figure 3.6 shows the diagram of the membrane capacitor process for recovery eVAPOURated "waste" water from flue gases as raw materials.

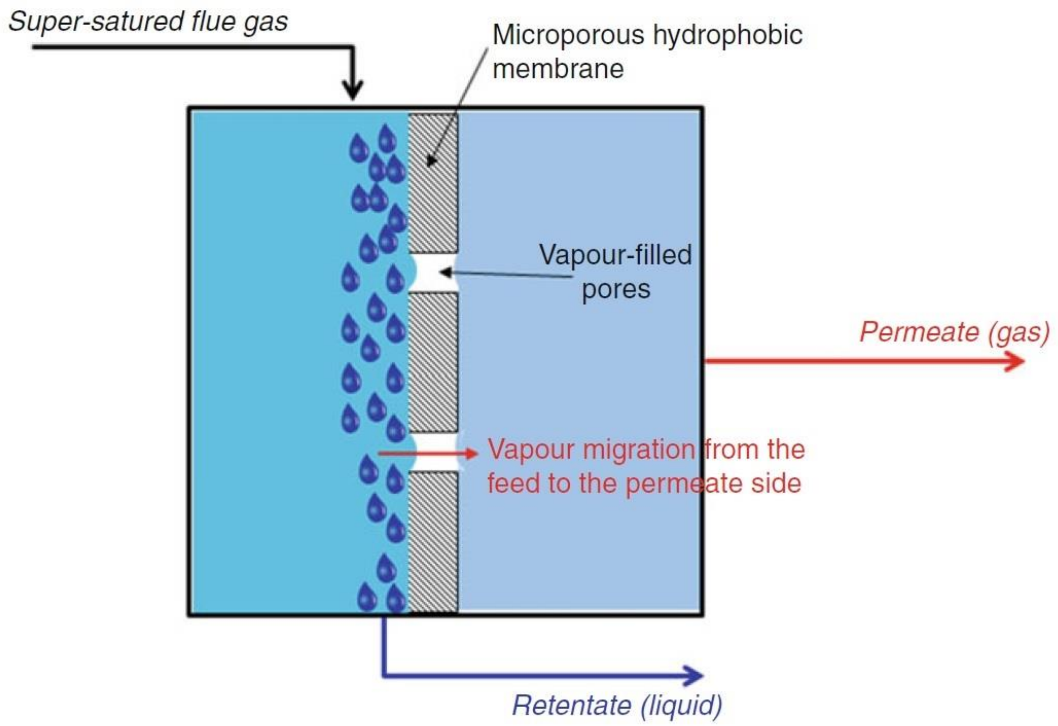

Figure 3.6 Membrane condenser principle (Macedonio et al., 2019)

One of the biggest advantages of using a membrane condenser is that there is no concern about water quality. The membrane is made of almost any chemical resistant polymer, eliminating the concern of corrosion. The MC minimizes energy consumption due to the large difference in boiling point between gases and water compared to a dense membrane consumption and high-pressure requirements in the second process (Macedonio et al., 2019).

3.3 Reuse of Vapour Condensate Applications

Water is one of the biggest factors affecting human life. While it is one of the main needs of all kinds of living organisms, it is also one of the most important sources of the industry which is one of the factors affecting human life.

Condensation is the liquid that occurs when the VAPOUR changes from VAPOUR to liquid. During heating, the condensate is the result of thermal energy known as latent heat, steam transfer to a heated product, line or equipment.

Depending on the industry in which the condensate occurs, there are available areas.

Condensate can be reused in many different ways. The hot condensate can be directed back to the boiler aerator and used as heated feed water. It can be used for preheating for any heating system or in cleaning applications such as equipment and floor cleaning(TLV, n.d.). It may also be used in other applications in such a way that the sector used may be needed.

Re-use of hot condensate saves energy and is important for the conservation of water resources.

10 to 30 percent of the heat energy contained in the steam contains a significant amount of detectable and reusable heat at condensation density.

Directing the high-temperature condensate into the boiler requires less heat energy, allowing water to be converted into steam and maximizing boiler output.

Low-contaminated wastewater from the food industry has a high potential for reuse. (Filtration&Seperation, 2000) In the food sector, a large amount of industrial water is produced at a low level of pollution. The reuse of the condensate processes of nanofiltration and ultrafiltration can be used. Using the example of steam condensate from the dairy industry, it was shown that it is possible to obtain water that meets the quality standards of drinking and make-up water by applying a combination of processes including pre-treatment (cartridge filtering and UV disinfection) and two membrane stages (nanofiltration) (Suarez et al., 2014).

CHAPTER FOUR
CASE STUDY: A CERAMIC TILE MANUFACTURING PLANT

4.1 Introduction to Pilot Plant

A pilot plant was chosen as a tile production facility. In the facility, floor and wall tiles are produced in a closed area of 102.286 m2. The property operates three shifts (24 hours). Tile production is achieved by masse (granule) preparation, pressing (forming), glazing, firing(drying), quality control and packaging processes. Also, glaze production to be used in glazing departments is made. The production flow scheme at the facility is given in Figure 4.1.

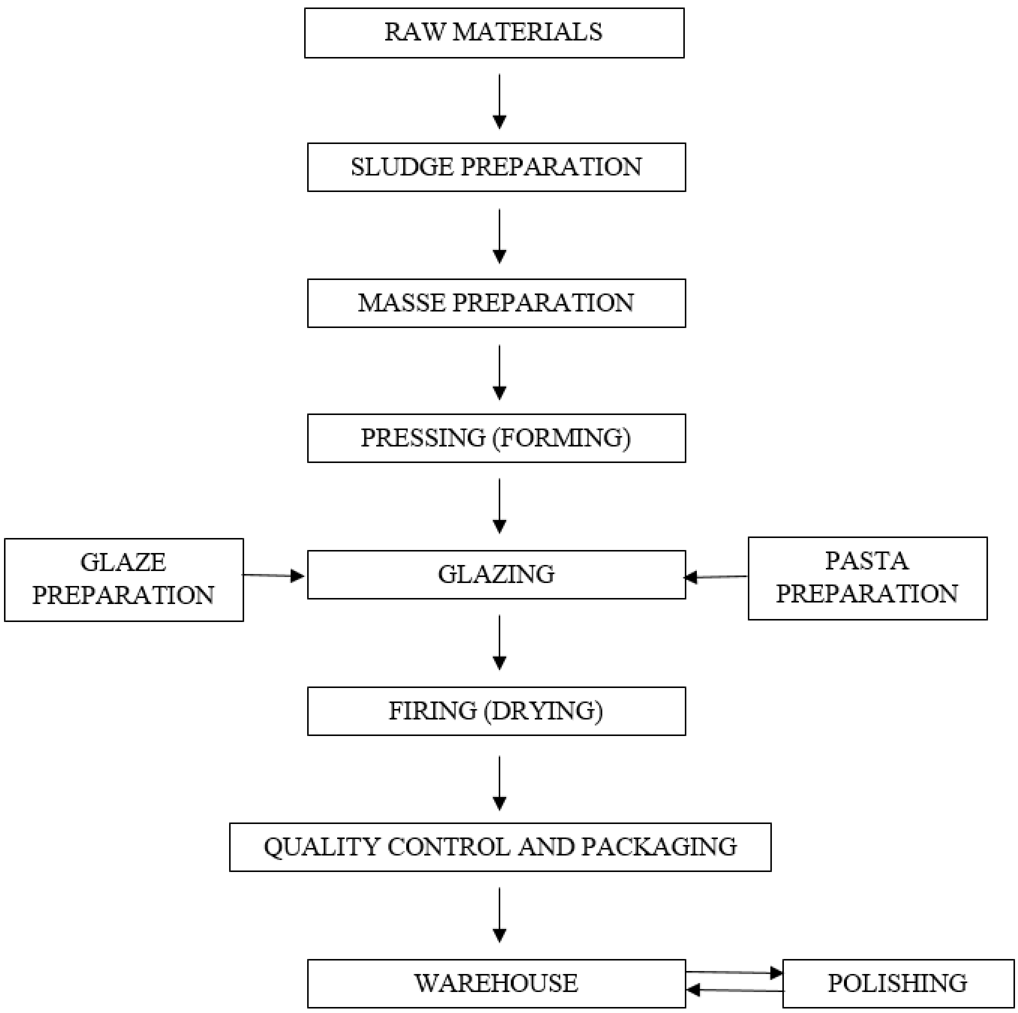

Figure 4.1 Production flow scheme of the pilot plant

4.1.1 Raw Material Preparation

The raw materials used in the facility during production are supplied in the desired grain size after a series of physical and chemical control (percentage of SiO2, Fe2O3, etc.), and stored in the stock area. The raw materials used in the plant are first conveyed to the crushers. Clay, kaolin, pegmatite, and feldspar used in the production are taken from this section and conveyed to the facility with bands. Clay product, which is the most important raw material used during production, has properties (plasticity, cohesion, color, rotate, etc.) that are closely related to tile properties.

Plasticity is an important feature for processing and shaping clays. This feature gives the ability to form clays that have been kneaded with the appropriate amount of water and then to retain the given shape. It does not have plasticity with any liquid other than water.

The main raw materials used during the production are conveyed from the storage areas to the steel silos, each of which has automatic weighing belts under each conveyor belt. The main raw materials (clay, feldspar, etc.) and other substances specified in the preparation recipes (sodium carbonate, sodium silicate, etc.) are filled into the silos above the mill with the help of conveyor belts. Also, raw and baked waste tile pieces that are broken down in the process lines and returned are stocked in this department and reused.

4.1.2 Sludge Preparation

The raw materials are conveyed to the sludge mills by adjusting the computerized automatic scales from the silos which are above the mills (Figure 4.2). The sludge mills consist of a steel cylinder that is covered with different materials (silica bricks, alubite, rubber, etc.) and whose inner surface is rotated about its own axis.

The mills are allowed to spin after the addition of sufficient water (usually 65% dry matter, 35% water) to knead the raw materials. The grinding process in the mills is achieved by mixing the silica spheres by crushing the raw materials during rotation. The grinding process takes approximately 7-8 hours. The slurry obtained at the end of the milling is conveyed to the stock pools when it reaches the appropriate viscosity, sieve analysis, and liter weight. The resulting slurry is conveyed to the sludge drying system.

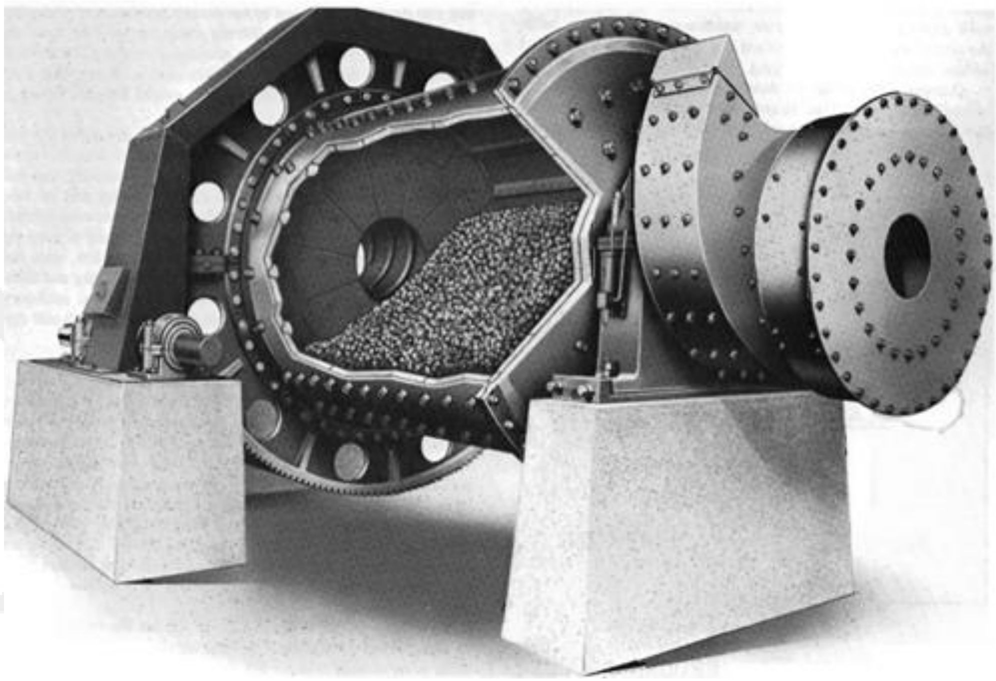

Figure 4.2 The mill, which is used for sludge preparation (911 Metallurgist, n.d.)

4.1.3 Masse (Granule) Preparation

The slurry conveyed to the stock ponds is conveyed to the vertically positioned conical-shaped drying system called the spray drier.

The aqueous slurry, which is allowed to drop free in droplets in the spray dryer, is contacted with hot air at about 600 °C, and the water in the sludge droplets is eVAPOURated to form a moist granule. The obtained moist granules are transported by conveyor belts and stored in granular silos. Types of spray dryers are given in Figure 4.3.

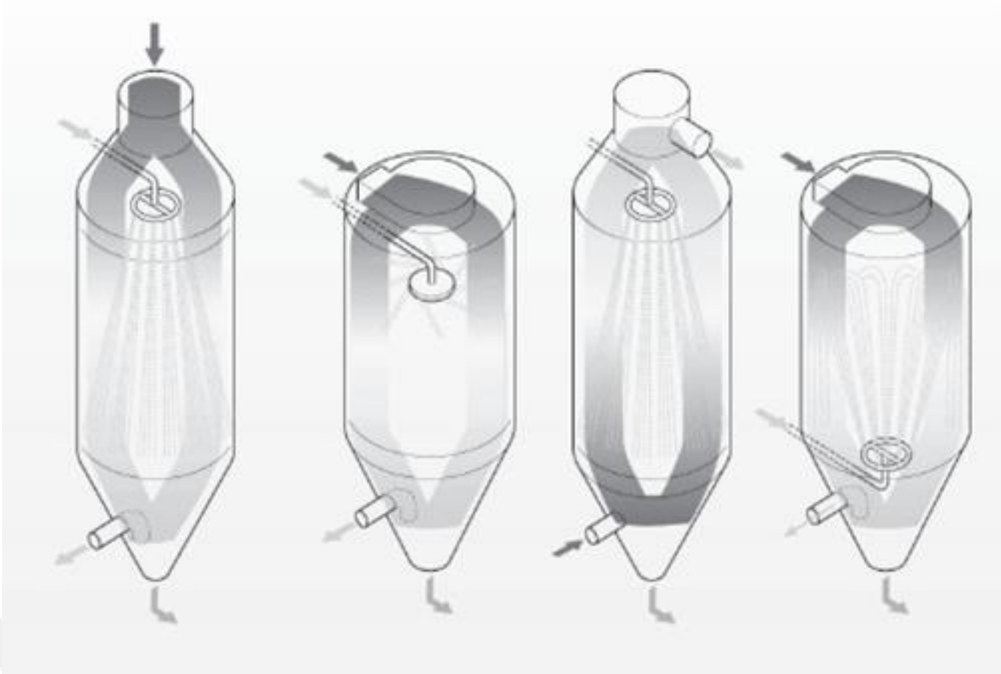

Figure 4.3 Types of spray dryer (SACMI Applied Ceramic Technology, 2002)

4.1.4 Pressing (Forming)

The obtained granule is sieved and conveyed to the press silos to separate the coarse particles that may be present. The granule is mixed with a suitable binder and lubricant material. The tile or ceramic forming process is done by automatic hydraulic presses. In the presses, the upper mold prepared according to the product to be produced is applied to the granular-filled lower mold and raw tile (biscuit) of the desired size is obtained. The granule generally contains 5-8% moisture.

In the presses, the tile forming process is carried out in two pulses, the first blow provides air to escape, the second blow provides full compression and shaping. In dry pressing, homogeneous forming is required, the particle size distribution, moisture surface and binder ratio must always be controlled.

4.1.5 Drying

After forming, the raw tile (biscuit) entering into the dryer is left in contact with the hot air and its moisture content is reduced to 0.5%.

4.1.6 Glazing

After pressing, the raw tiles are passed through drying and the moisture rate is reduced to 0.5%. Desired patterns and other applications (processes) are applied to the tile surface on the bands. The glazed raw tiles are loaded into the stock trolleys by the loading machine at the end of the tape and conveyed to the baking stock lines.

4.1.7 Glaze Preparation

It is the part where the printing material to be made on the tile surface is prepared. Glaze; is a supercooled state of a high viscosity liquid. In this section, raw materials (kaolin, marble, feldspar, quartz, etc.) are weighted according to glaze recipes that are filled into the mill. The raw materials used should not contain iron which negatively affects the quality of the glaze. The frit, suspension kaolin, ceramic paint, angop frit, zinc oxide, talc, etc. used in glaze production are taken to the mill in certain proportions and the mill is left to spin after adding water. When the glaze reaches the desired viscosity (fluidity) and liter weight, it is taken into the stock tanks. It is given to service glazing bands with service tanks as required.

4.1.8 Pasta Preparation

The patterns printed on the tile are formed with colored ceramic raw materials based on pastes. The paste is filled into small mills according to its recipe. When it reaches the specified viscosity and liter weight, it is taken to the drums and shipped to the production lines.

4.1.9 Glazing Bands

After pressing, the raw tiles are reduced to 5% by drying and the tiles are ordered in glazing bands. The glazed raw tiles are loaded into the stock trolleys by the loading machine at the end of the belt and transferred to the baking stock lines.

4.1.10 Firing (Drying)

Raw tiles are transported to the furnace entrances by stock trolleys and delivered to the furnace in rows. The firing process takes approximately 30-70 minutes depending on the product type.

Drying in furnaces is computer controlled. After the firing process is completed, the tiles loaded on the stock carts are shipped to the packaging department after quality controls.

4.1.11 Quality Control and Packaging

Baked tiles come to quality separation machines with transport system. The tiles are separated by qualified personnel in terms of surface quality and the tiles matching the specified quality are automatically packed. The tiles are delivered to the warehouse in pallets.

4.1.12 Polishing

Tiles can also be prepared as matt or glossy according to demand. For this purpose, the upper surfaces and edges of matt porcelain tiles are abraded and polished.

4.1.13 Finished Warehouse

All the tiles produced are stocked and controlled for shipment.

4.2 Water Use in the Plant

Water is consumed in the facility for wet grinding, sieve, polishing, sizing, glaze preparation, glazing, cake preparation, sludge preparation, shaping, hand casting unit, pool parts production, washing of sludge mills and personnel drinking and using water.

Approximately 30,000 m^3/month of water is needed for production. Most of the water used eVAPOURates in the dryers and wastewater formation is up to 11.000 m^3/month. The process wastewater is treated and reused in production. 180 m^3/day domestic wastewater is produced as a result of the usage of water consumed by the person other than process water. Domestic wastewater is treated in the wastewater treatment plant and discharged. The current water usage cycle in the facility is given in Figure 4.4.

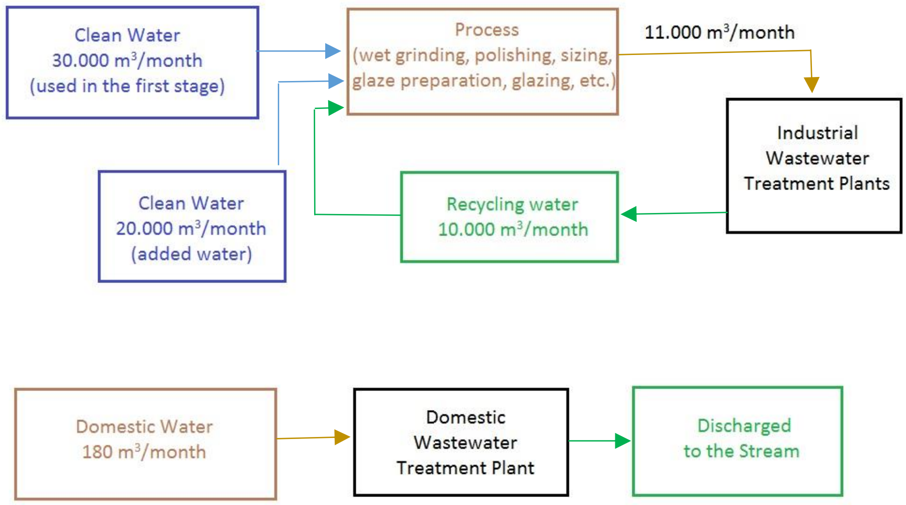

Figure 4.4 Water cycle in the pilot plant in current situation

The capacity of the industrial wastewater treatment plant in the pilot plant is 1,400 m^3/day. In the treatment plant, primary sedimentation, equalization tank, and chemical treatment (rapid mixing, slow mixing, and settling tank) units are used for wastewater treatment. There is a filter press, which is one of the mechanical dewatering equipment, for dewatering the sludge formed during wastewater treatment processes.

4.3 Vapour Production in the Plant

There are 15 spray dryers in three different locations in the pilot plant. Capacities of these dryers are listed below. In brackets, models of dryers are indicated.

- 6 spray dryers in Sector-1 (ATM 52, ATM 40, ATM 36, ATM 18, ATM 15, ATM 15),
- 3 spray dryers in Sector-3 (ATM 36, ATM 18, ATM 18),
- 6 spray dryers in Slime Preparation (ATM 52, ATM 36, ATM 36, ATM 25, ATM8, ATM 6)

Maximum vapour generating capacities of each dryer is given below:

- ATM 52: 5200 L/h
- ATM 40: 4000 L/h
- ATM 36: 3600 L/h
- ATM 18: 1800 L/h
- ATM 15: 1500 L/h
- ATM 8: 800 L/h
- ATM 6: 600 L/h

The resulting steam temperature is in the range of 70-120 °C, with an average of 110 °C.

CHAPTER FIVE
RESULTS AND DISCUSSION

5.1 Determination of the Condensate Reuse Locations and Collection of Condensate

The location and capacities of the condensers to be used were determined according to the vapour generation locations. As indicated in previous section, there are 15 spray dryers in three different locations. The locations of the dryers, in other words vapour production sites, are given on the overall layout of the pilot plant in Figure 5.1.

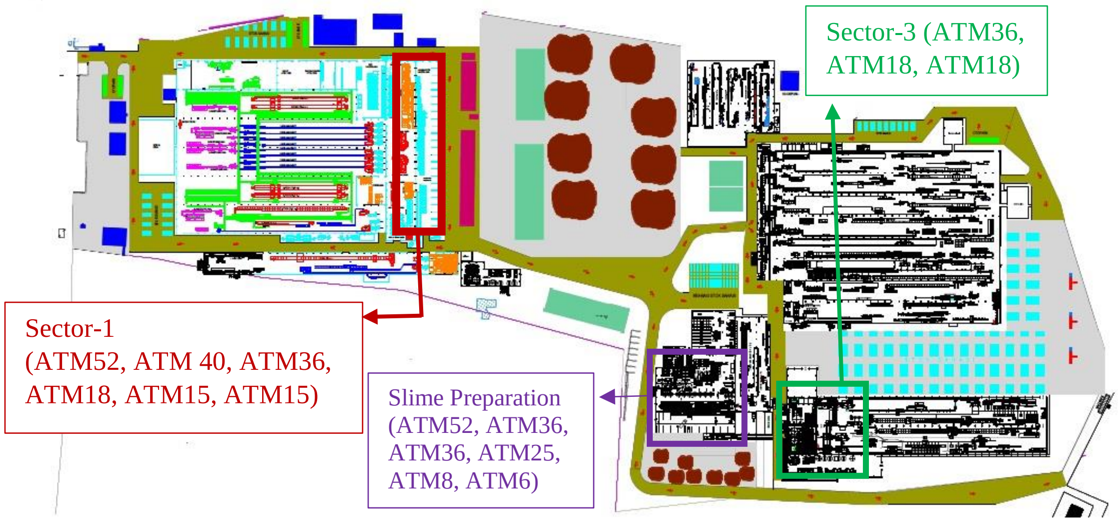

Figure 5.1 VAPOUR production locations in the pilot plant

When 15 spray dryers operate at maximum capacity, a total of 41,100 liters of vapour per hour is generated. When this value is taken into consideration, it has been thought that the use of water-cooled condenser is more accurate. It has been decided to use three condensers according to the vapour formation. The maximum amount of vapour to be generated in each location is given in Table 5.1.

Table 5.1 The maximum amount of vapour to be generated in each location

Location	Type of dryers	Vapour amounts (L/h)
Sector-1	ATM 52	5200
	ATM 40	4000
	ATM 36	3600
	ATM 18	1800
	ATM 15	1500
	ATM 15	1500
	Total (Sector-1)	17600
Sector-3	ATM 36	3600
	ATM 18	1800
	ATM 18	1800
	Total (Sector-3)	7200
Slime Preparation	ATM 52	5200
	ATM 36	3600
	ATM 36	3600
	ATM 25	2500
	ATM 8	800
	ATM 6	600
	Total (Slime Production)	16300
	TOTAL	41100

The selected condenser and its properties are given in Figure 5.2. Considering the condenser capacity, 3, 1, and 2 condensers were selected for Sector 1, Sector 3, and Slime Preparation, respectively.

Steam Condenser / Hot Water	
Steam Temp in/Out	105 C / 95 C
Water Temp In/Out	10 C / 88 C
Exhaust/Water Mass Flow	844 / 8,000 Kg/h
Weight of Unit	300 Kg
Exhaust Pressure Drop	N/A
Energy Recovered	446 KW
Recovered Energy Value	2 x £20K p/a
Heat Exchanger Cost	2 x £10K
Price per KW recovered	£22

Figure 5.2 Selected condenser (Econotherm, n.d.)

When selecting the condenser, it is considered to make heat recovery as well as water recovery from water VAPOUR.

It is stated that the condenser water inlet temperature should be 10 degrees. It was planned to supply the necessary water for the condenser from tap water. It is known that air and water temperature is below normal conditions in the region, where the pilot plant is located. Also, to make the heat transfer easier, the selection of the material forming the condenser is made in such a way that it can conduct heat easily and there are fins inside the condenser, which will create pressurized water and airflow. Therefore, additional energy will not be used for cooling the water. However, in the summer, the efficiency will reduce as the water is used.

It is thought that the membrane condenser is more suitable for the retention of combustion gases and particulate matter contained in the water VAPOUR. However, in addition to the recovery of water VAPOUR, the water cooling system has been chosen to recover heat at the same time. In addition, water-cooled condenser was chosen because it requires less equipment and has less capital cost.

The resulting condensate, which is hot water, can be used for wet grinding or as washing water.

5.2 Calculation of the Water Savings

When the pilot plant is operated at full capacity, the amount of steam produced in the spray dryers is 41,100 L/hour. It is expected to produce 1 part water of 1 part steam after condensation under perfect conditions. However, in reality this value is between 30-60%. This value was accepted as 50% in this study. Considering this assumption, the amount of water to be recovered is calculated as follows:

$$41,100 \text{ L/h} * 50\% = 20,550 \text{ L/h}$$

The calculation was done based on the maximum capacity of the dryers. It was assumed that 70% of the maximum capacity is operated under normal operating conditions. Accordingly, the amount of water to be recovered was found as follows:

$$20,550 \text{ L/h} * 70\% = 14,400 \text{ L/h}$$

As a result, 345 m^3 of water can be recovered per day (approximately 10,500 m^3/month). In this case, the possible new water cycle after water recovery from steam in the plant is given in Figure 5.3.

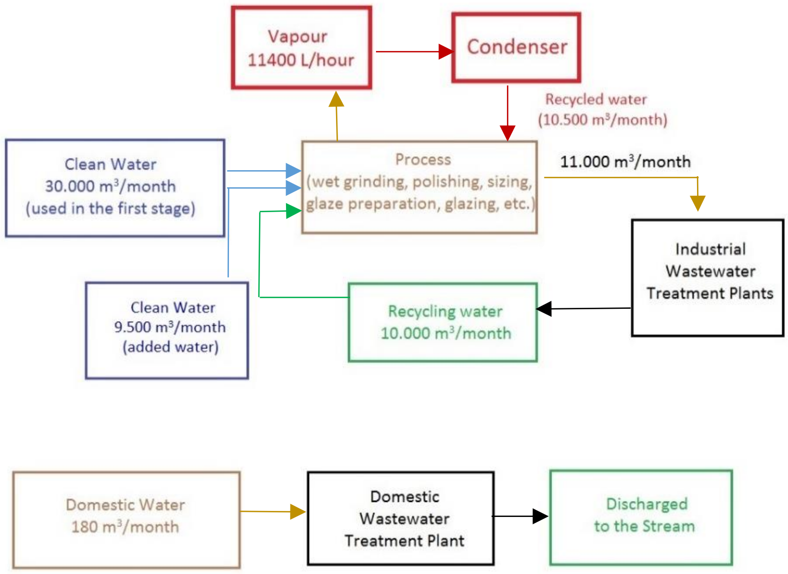

Figure 5.3 Water cycle after vapour reuse

35% more profit in the consumption of fresh water in the plant will be achieved by reusing the condensed vapour, which is released to the atmosphere in the current situation. A total of 68.3% fresh water saving will be obtained with the reuse of treated wastewater, which is the current application in the plant. Fresh water consumption will be reduced from 30,000 m^3/month to 9,500 m^3/month with vapour condensate and treated wastewater reuse applications.

5.3 Evaluation of the Environmental Impacts of Reuse of Condensate

The main objective of the study is to reduce water use in the pilot plant and to make recommendations for more environmentally friendly production (Fuel&Energy Abstracts, 2009). In this context, water recovery from waste vapour was evaluated with appropriate condenser selection. To evaluate the environmental impacts of condensate reuse, life cycle assessment (LCA) approach was applied. Environmental impacts were determined for both the absence and presence of vapour reuse. The cradle to grave principle, which belongs to ISO 14040, is the guideline for the assessment of Ica in case studies (Yuguda et al., 2019).

5.3.1 LCA Approach

Life-cycle assessment is a method that enables products to be assessed throughout their lives. During the life cycle process, negative environmental impacts are evaluated and identified.

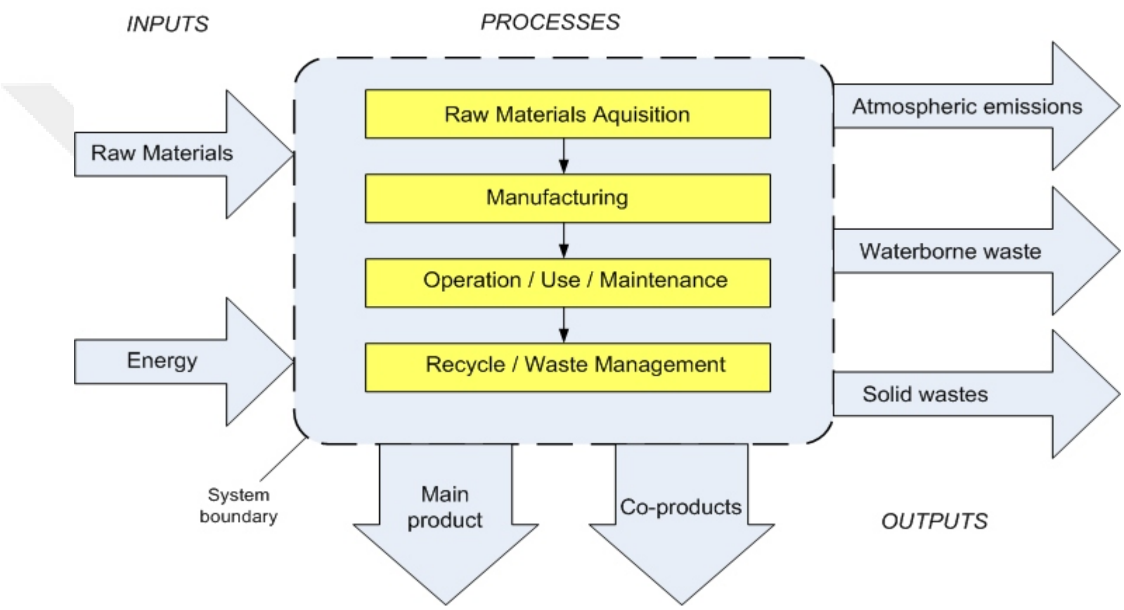

Figure 5.4 The main stages and typical inflows and outflows considered in lifecycle assessment (Guinee et al., 2011).

LCA helps decision makers choose the product, process or technology that has the least environmental impact but LCA implementation can be resource and time intensive (Pennstate, 2006).

When conducting an LCA study, its boundary is determined by the subject and the work we have determined (ISO 14040, 2006).

5.3.2 LCA Application

5.3.2.1 Aim and Scope of the Study

The aim of the LCA study is to determine the environmental benefits of the condensate reuse. For this aim, environmental effects were determined for both for the presence (Scenario-1) and absence (Scenario-2) of condensate reuse.

5.3.2.2 Functional Unit

Functional unit was selected to be m^2 of production of ceramic tile production. All input and output data was determined considering the functional unit.

5.3.2.3 System Boundaries

LCA analyses was only carried out for the production phase. Therefore, system boundaries were determined by using “gate to gate” approach. LCA study process plan is given in Figure 5.5.

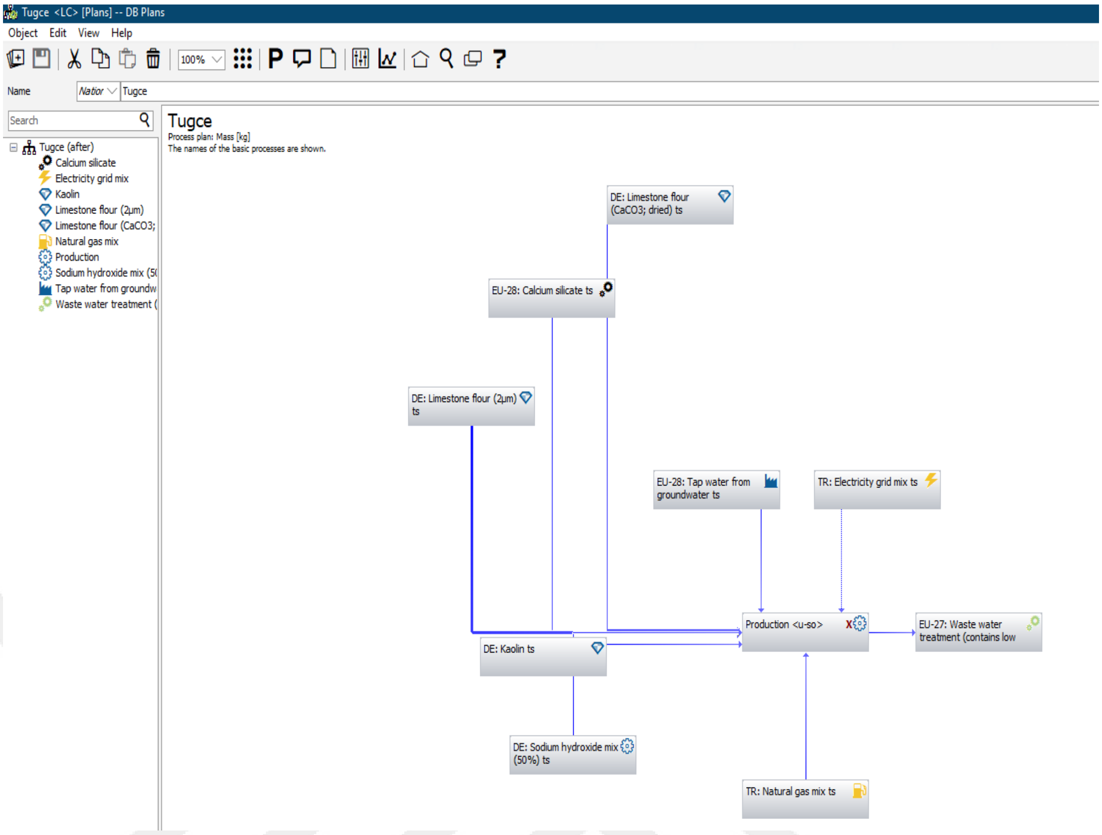

Figure 5.5 LCA study process plan

5.3.2.4 GaBi Software and Data Set

LCA analyses were carried out by using GaBi 9.1 software. The needed data for the software was obtained from the literature, pilot plant and Eco-invent database, which are integrated into the GaBi 9.1. Used data set is given in Table 5.1.

Table 5.2 Inventory data for ceramic production (Scenario-1)

INPUT (Scenario-1)			
Material		Consumption	unit/ton product
Clay		20,678 ton/month	0.85
Kaolinite		8,236 ton/month	0.33
Calcium calcite		2,580 ton/month	0.10
Feldspar		3,853 ton/month	0.15
Sodium silicate		775 ton/year	0.0026
Sodium carbonate		517 ton/year	0.0017
Sodium tripoly phosphate		181 ton/year	0.0006
Sodium hydroxide		775 ton/year	0.0026
Polyacrylate		1,033 ton/year	0.0034
Humate		1,033 ton/year	0.0034
Electricity		6,690,313 kWh/month	269
Natural gas		4,746,168 m^3/month	189
Water		32,640 m^3/month	1.317
OUTPUT			
Emissions	CO	32.3 mg/Nm^3	0.0013
	NO_2	55.8 mg/Nm^3	0.0022
	NO	26.4 mg/Nm^3	0.0011
	SO_2	3.4 mg/Nm^3	0.0001
	Dust	8.4 mg/Nm^3	0.0001
Wastewater		180 m^3/month	0.008

Table 5.3 Inventory data for ceramic production (Scenario-2)

INPUT (Scenario-2)			
Material		Consumption	unit/ton product
Clay		20,678 ton/month	0.85
Kaolinite		8,236 ton/month	0.33
Calcium calcite		2,580 ton/month	0.10
Feldspar		3,853 ton/month	0.15
Sodium silicate		775 ton/year	0.0026
Sodium carbonate		517 ton/year	0.0017
Sodium tripoly phosphate		181 ton/year	0.0006
Sodium hydroxide		775 ton/year	0.0026
Polyacrylate		1,033 ton/year	0.0034
Humate		1,033 ton/year	0.0034
Electricity		6,690,313 kWh/month	269
Natural gas		4,548,623 m^3/month	181
Water		17,136 m^3/month	0.69
OUTPUT			
Emissions	CO	32.3 mg/Nm^3	0.0013
	NO_2	55.8 mg/Nm^3	0.0022
	NO	26.4 mg/Nm^3	0.0011
	SO_2	3.4 mg/Nm^3	0.0001
	Dust	8.4 mg/Nm^3	0.0001
Wastewater		180 m^3/month	0.008

5.3.3 LCA Results

5.3.3.1 Global Warming Potential

The global warming potential (GWP) shows the greenhouse potential of an emission and it is is calculated in carbon dioxide equivalents (CO_2-Eq.). The different contributors to the GWP of the ceramic production process are shown in Figure 5.6. 424 kg CO_2-eq of total GWP was calculated for producing 1.0 m^2 of ceramic tile production. 38.9% of GWP arises from electricity consumption, while 25.2% of GWP arises from the kaolinite usage. GWP values indicate dependents that are the opposite of production efficiency (Liang et al., 2013).

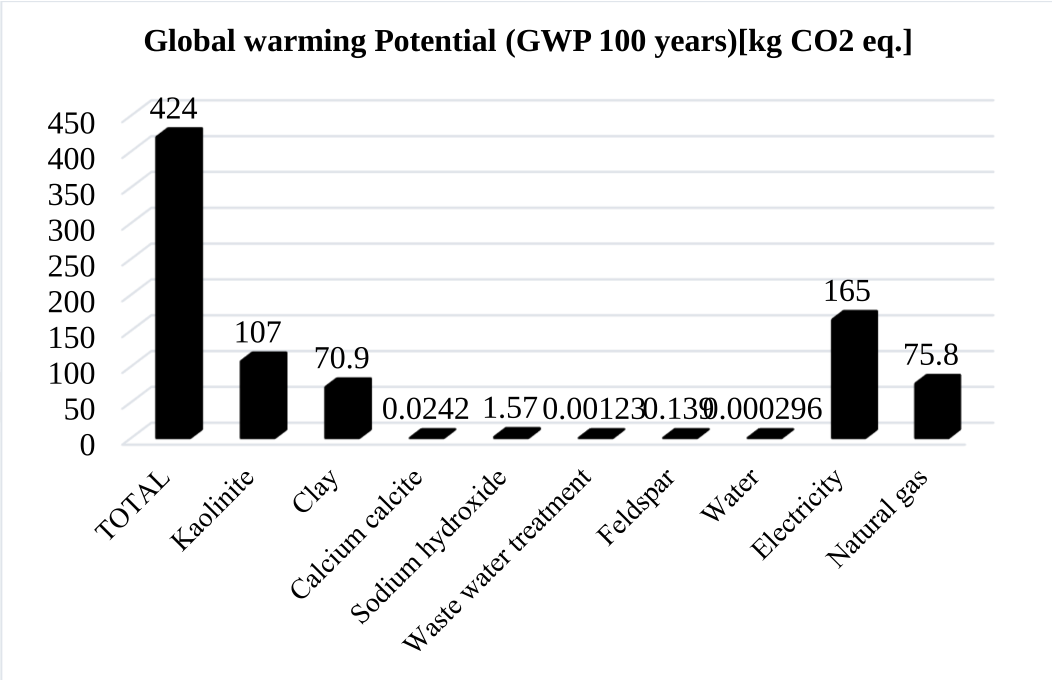

Figure 5.6 GWP for 1.0 m^2 of ceramic tile production (Scenario-1)

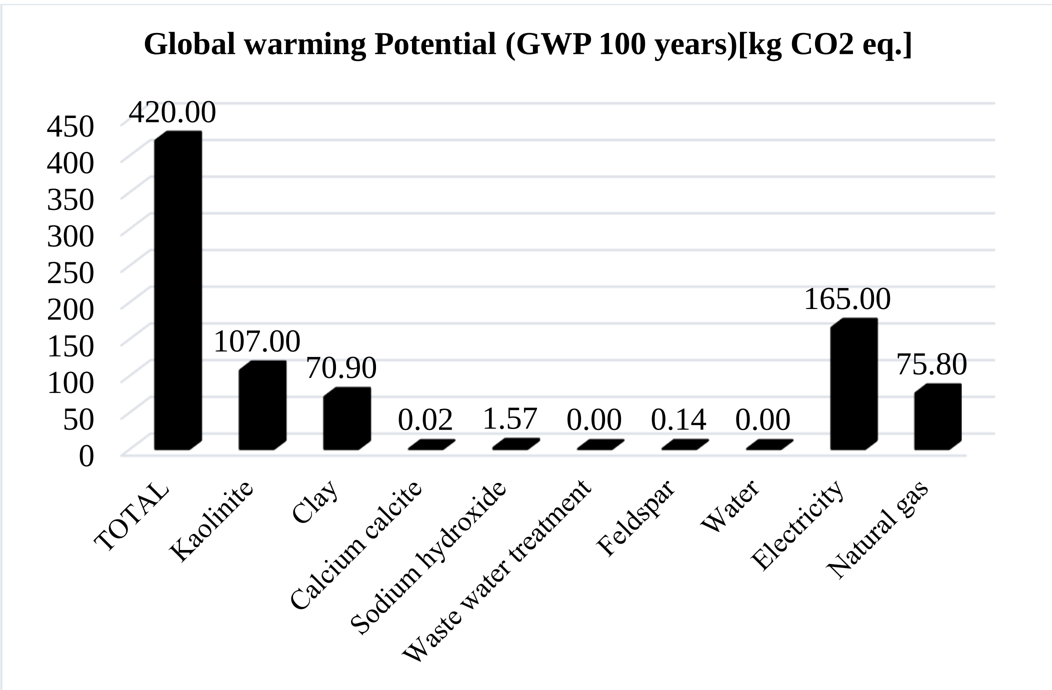

Figure 5.7 GWP for 1.0 m2 of ceramic tile production (Scenario-2)

After the recovery of water and heat, it was observed that the GWP value decreased. In addition, there was no change in electricity consumption and kaolinite usage values.

A little bit benefit in GWP was achieved with condensate and heat recovery.

5.3.3.2 Acidification Potential

The acidification potential (AP) results from an increased concentration of hydrogen ions, which are built and released by certain substances. The acidification potential is given in sulphur dioxide equivalents (SO_2-Eq.). The different contributors to the AP of the ceramic production process are shown in Figure 5.8. 2.36 kg SO_2-eq of total AP was calculated for producing 1.0 m^2 of ceramic tile production. 85.2% of AP arises from electricity consumption.

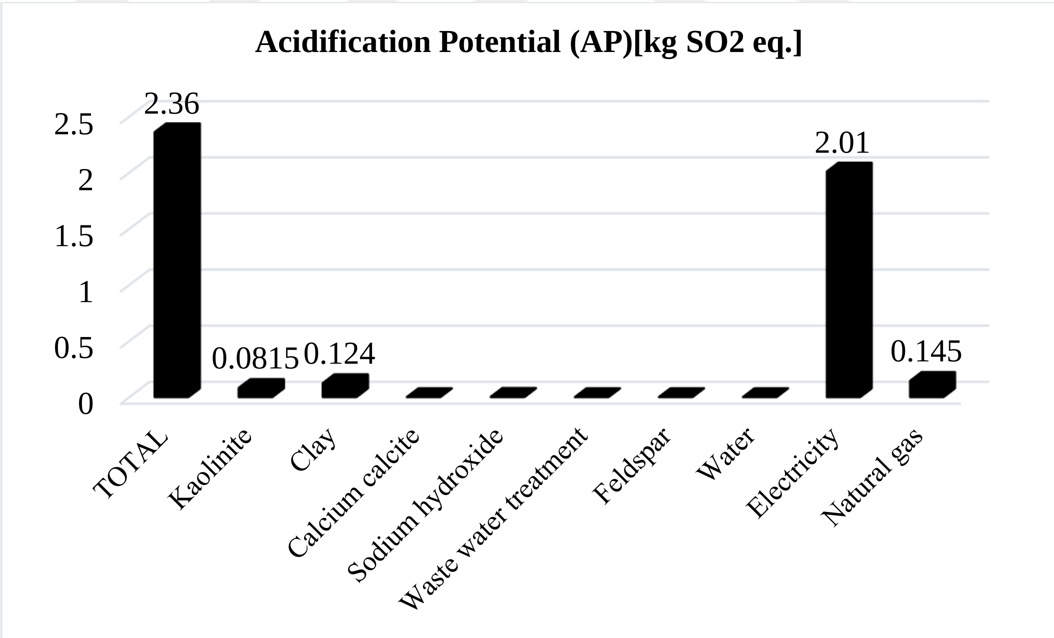

Figure 5.8 AP for 1.0 m^2 of ceramic tile production (Scenario-1)

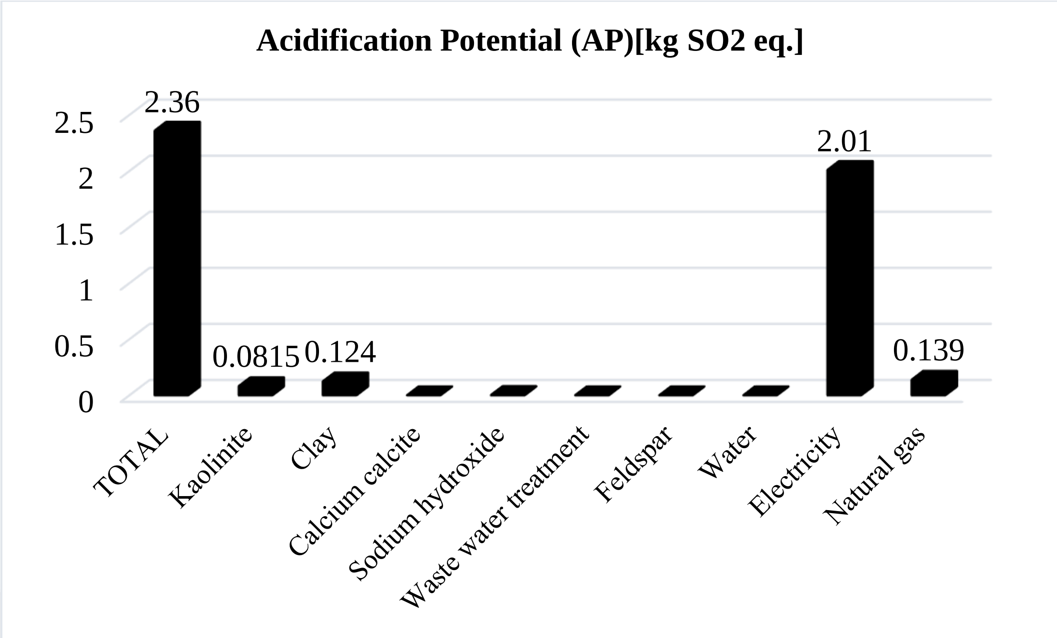

Figure 5.9 AP for 1.0 m2 of ceramic tile production (Scenario-2)

5.3.3.3 Eutrophication Potential

Eutrophication is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial. The result in water is an accelerated algae growth, which in turn, prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. The eutrophication potential (EP) is calculated in phosphate eq. (PO4-Eq.). The different contributors to the EP of the ceramic production process are shown in Figure 5.10. 0.122 kg PO_4-eq of total EP was calculated for producing 1.0 m^2 of ceramic tile production. 55.4%, 18.4%, and 12.7% of EP arises from electricity consumption, clay and kaolinite usage, respectively.

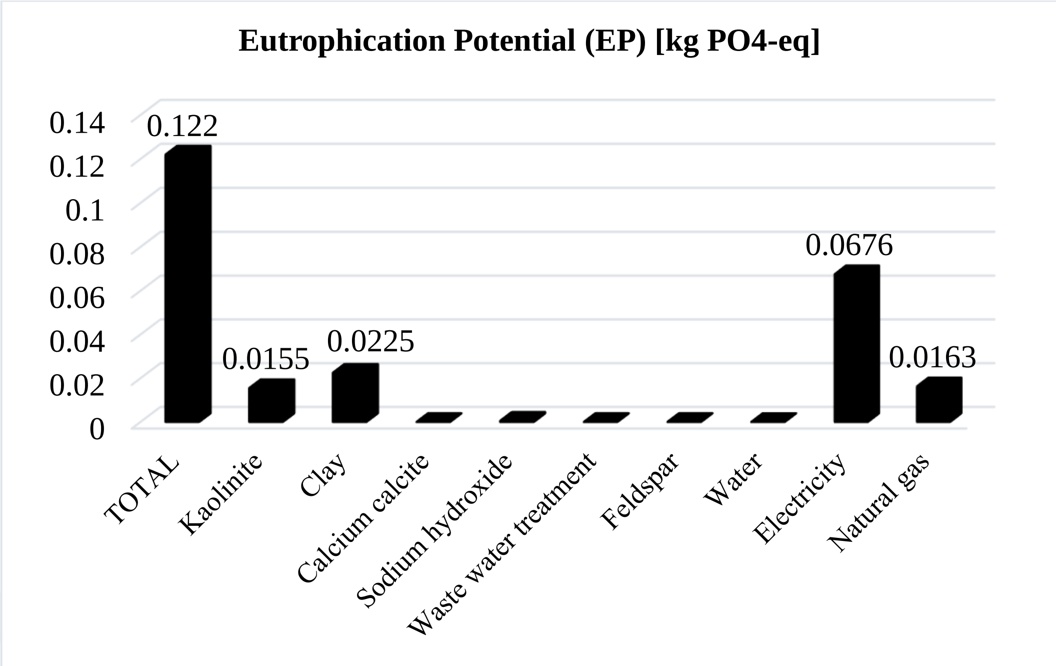

Figure 5.10 EP for 1.0 m^2 of ceramic tile production (Scenario-1)

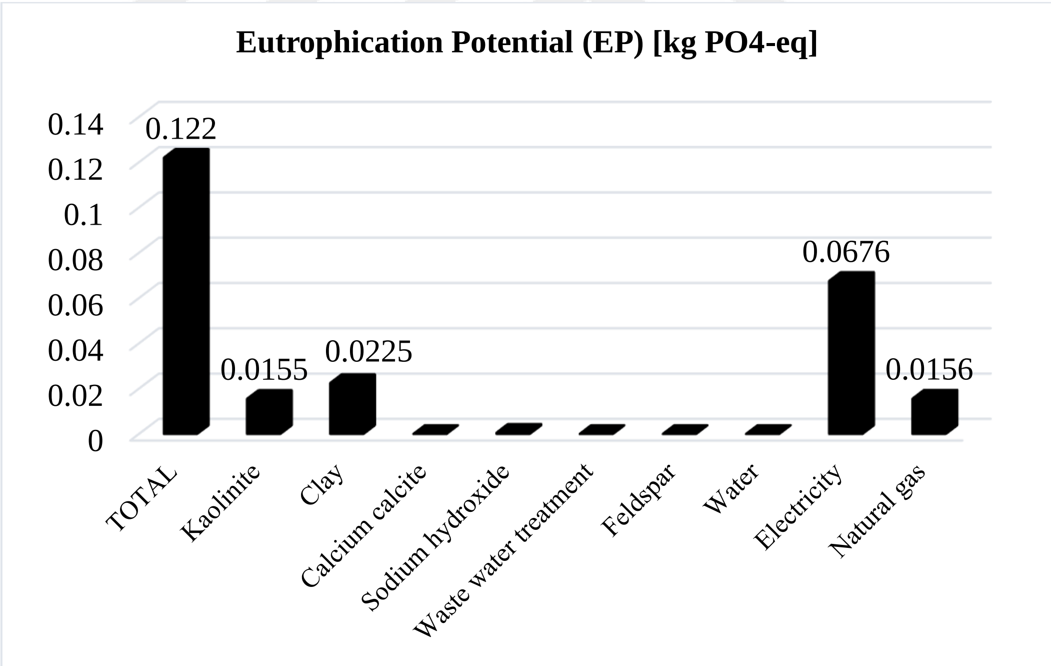

Figure 5.11 EP for 1.0 m2 of ceramic tile production (Scenario-2)

5.3.3.4 Ozone Layer Depletion Potential

Anthropogenic emissions deplete ozone, which is essential for life on earth. chlorofluorocarbons (CFCs) and the nitrogen oxides (NOX) have a depleting effect on the ozone. The ozone layer depletion potential (ODP) is calculated in trichlorofluoromethane eq. (R-11 or CFC-11). The different contributors to the ODP of the ceramic production process are shown in Figure 5.12. 3.95×10^{-12} kg R11-eq of total ODP was calculated for producing 1.0 m^2 of ceramic tile production. 72.4% of ODP arises from clay consumption.

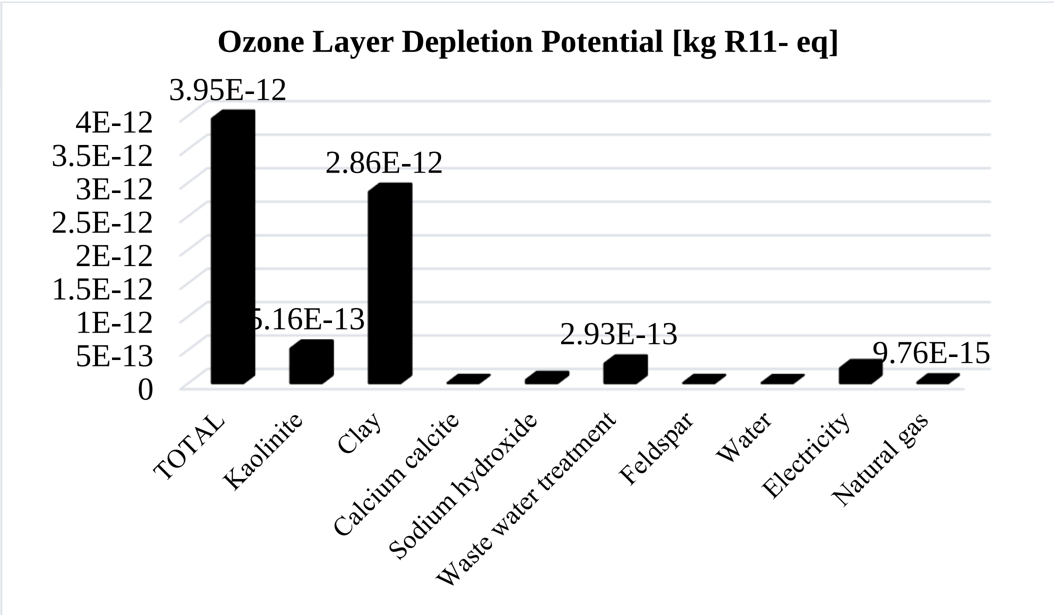

Figure 5.12 ODP for 1.0 m^2 of ceramic tile production (Scenario-1)

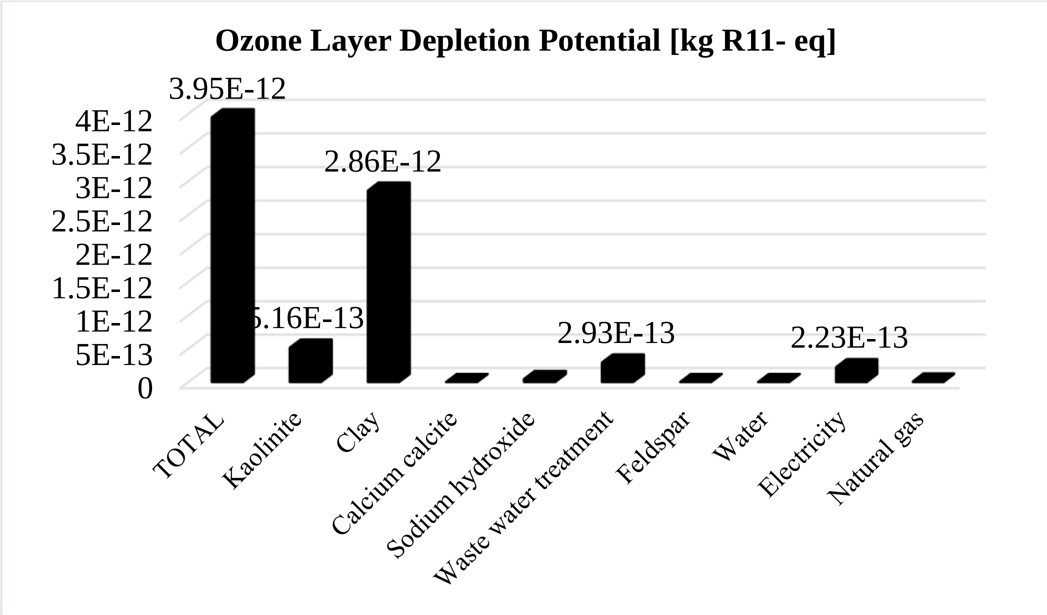

Figure 5.13 ODP for 1.0 m2 of ceramic tile production (Scenario-2)

5.3.3.5 Abiotic Depletion Potential

The abiotic depletion potential is split into two sub-categories, elements and fossil. Abiotic depletion potential (ADP)-elements covers an evaluation of the availability of natural elements like minerals and ores, including uranium ore. The reference substance for the characterisation factors is antimony (kg Sb-eq). The different contributors to the ADP-elements of the ceramic production process are shown in Figure 5.14. 9.04×10^{-5} kg Sb-eq of total ADP-elements was calculated for producing 1.0 m^2 of ceramic tile production. 32.1% and 24.2% of ADP-elements arises from clay and natural gas consumption, respectively.

The second sub-category is abiotic depletion potential (fossil), which includes the fossil energy carriers (crude oil, natural gas, coal resources). Abiotic depletion potential (ADP)-fossil is calculated in MJ. The different contributors to the ADP-fossil of the ceramic production process are shown in Figure 5.16. 11200 MJ of total ADP-fossil was calculated for producing 1.0 m^2 of ceramic tile production. 61.6% and 17.6% of ADP-fossil arises from natural gas and electricity consumption, respectively.

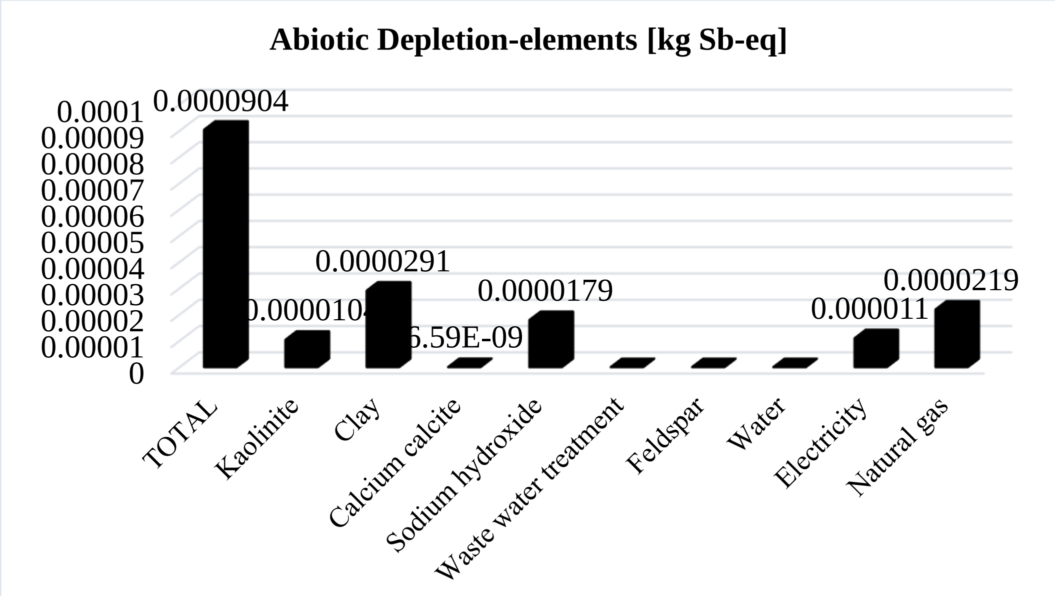

Figure 5.14 ADP-elements for 1.0 m^2 of ceramic tile production (Scenario-1)

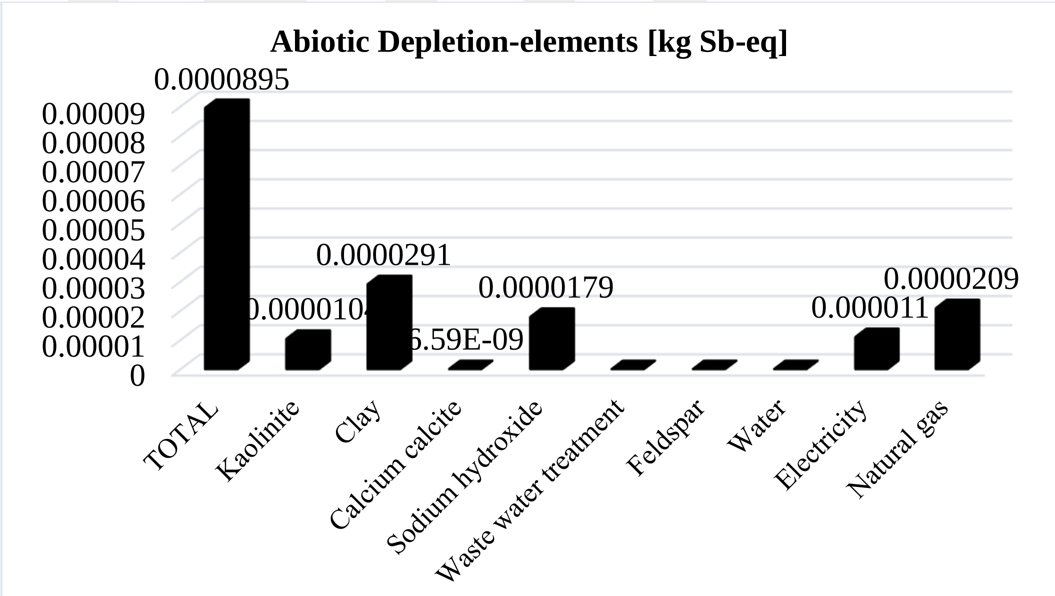

Figure 5.15 ADP-elements for 1.0 m2 of ceramic tile production (Scenario-2)

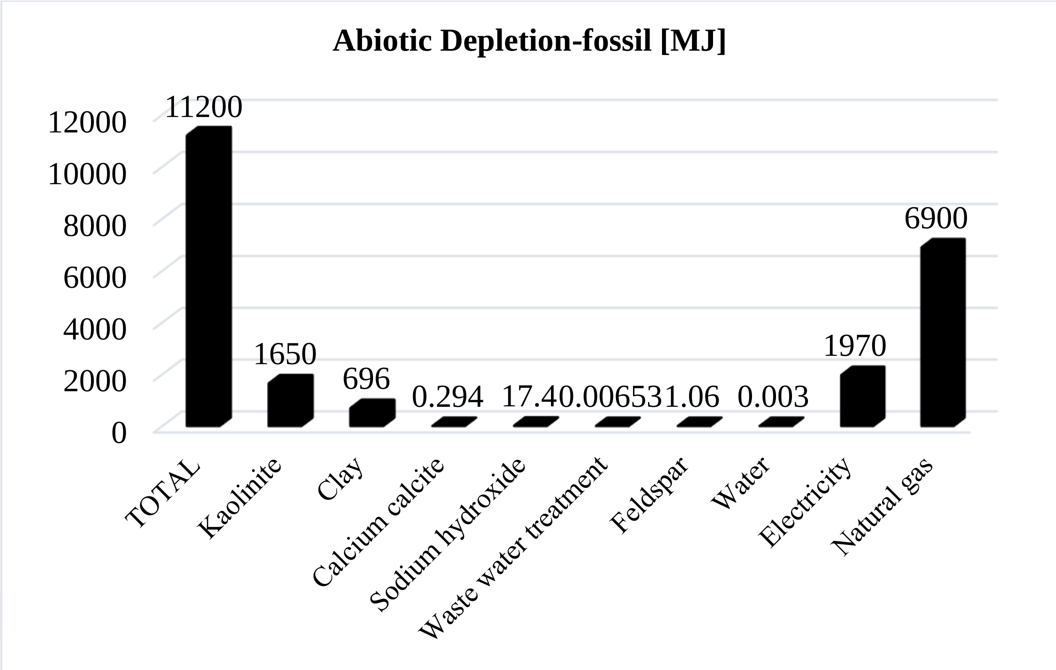

Figure 5.16 ADP-fossil for 1.0 m^2 of ceramic tile production (Scenario-1)

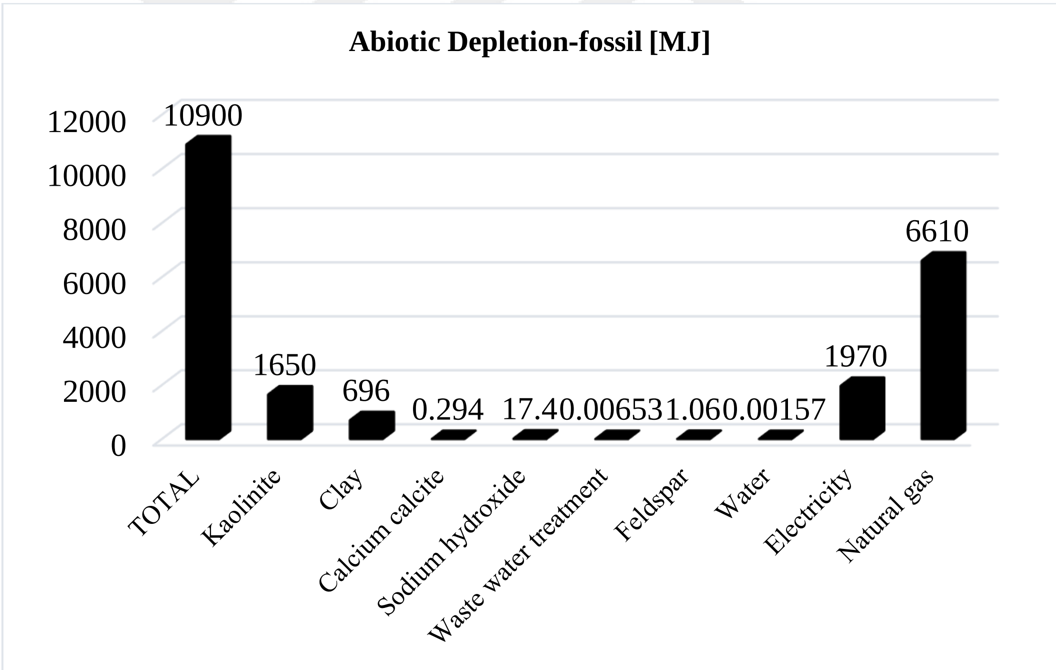

Figure 5.17 ADP-fossil for 1.0 m2 of ceramic tile production (Scenario-2)

5.3.3.6 Photochemical Ozone Creation Potential

Despite playing a protective role in the stratosphere, ozone at ground level is classified as a damaging trace gas. Photochemical ozone production in the troposphere, also known as summer smog, is suspected to damage vegetation and material. High concentrations of ozone are toxic to humans. The photochemical ozone creation potential (POCP) is often referred to in ethylene-equivalents (kg C_2H_4-Eq). The different contributors to the POCP of the ceramic production process are shown in Figure 5.18 0.14 kg C_2H_4-eq of total POCP was calculated for producing 1.0 m^2 of ceramic tile production. 66.3% and 20.6% of POCP arises from electricity and natural gas consumption, respectively.

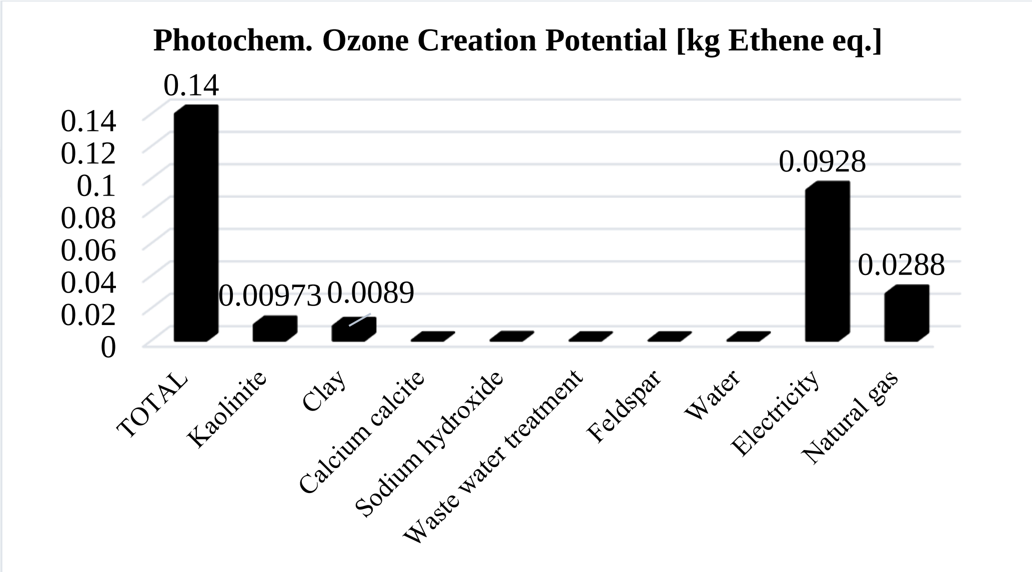

Figure 5.18 POCP for 1.0 m^2 of ceramic tile production (Scenario-1)

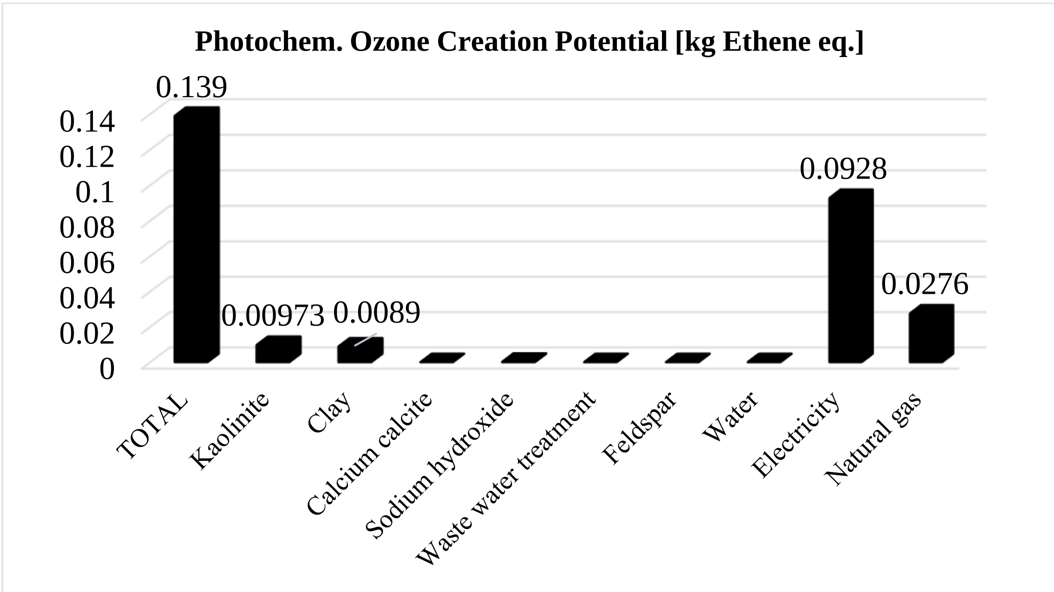

Figure 5.19 POCP for 1.0 m2 of ceramic tile production (Scenario-2)

5.3.3.7 Toxicity Potential

The toxicity potential (TP) is split into four sub-categories, human, freshwater, marine, and terrestic. The different contributors to the TP of the ceramic production process for all sub-categories are shown in Figure 5.20-5.27.

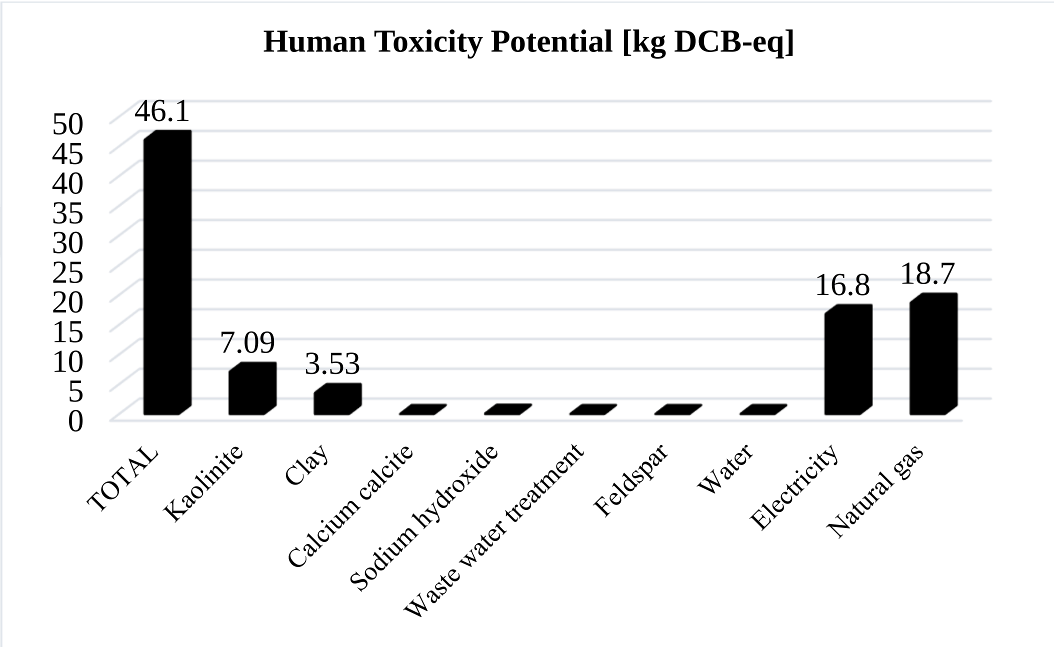

Figure 5.20 HTP for 1.0 m^2 of ceramic tile production (Scenario-1)

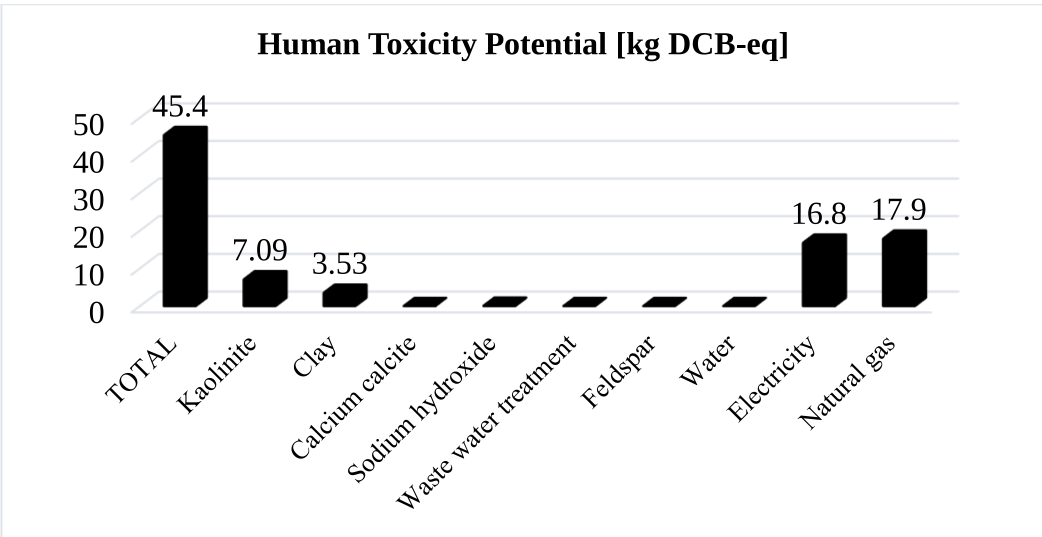

Figure 5.21 HTP for 1.0 m2 of ceramic tile production (Scenario-2)

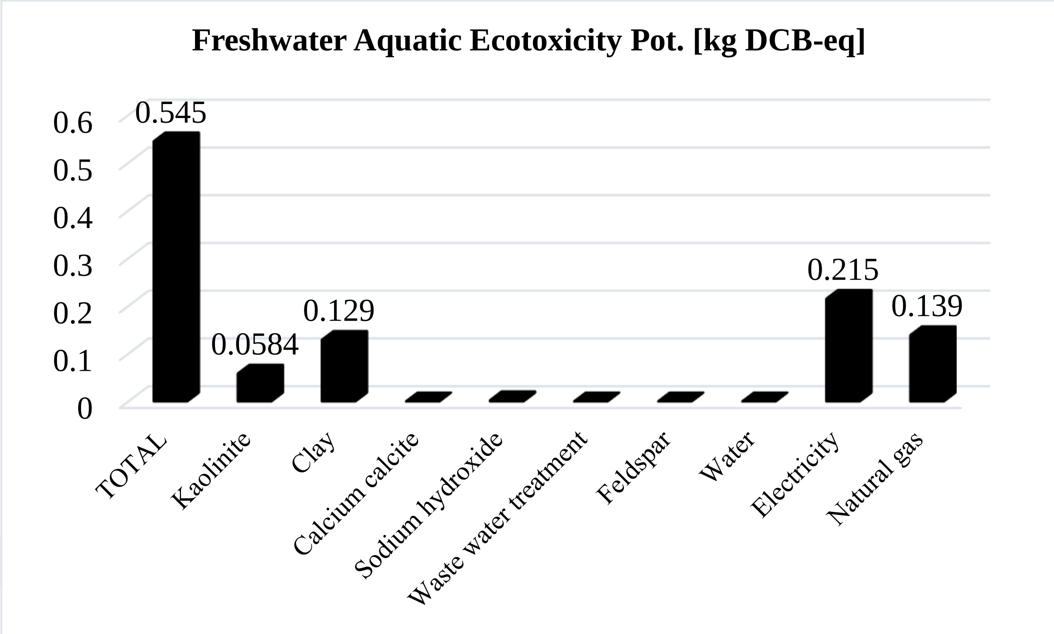

Figure 5.22 FAEP for 1.0 m^2 of ceramic tile production (Scenario-1)

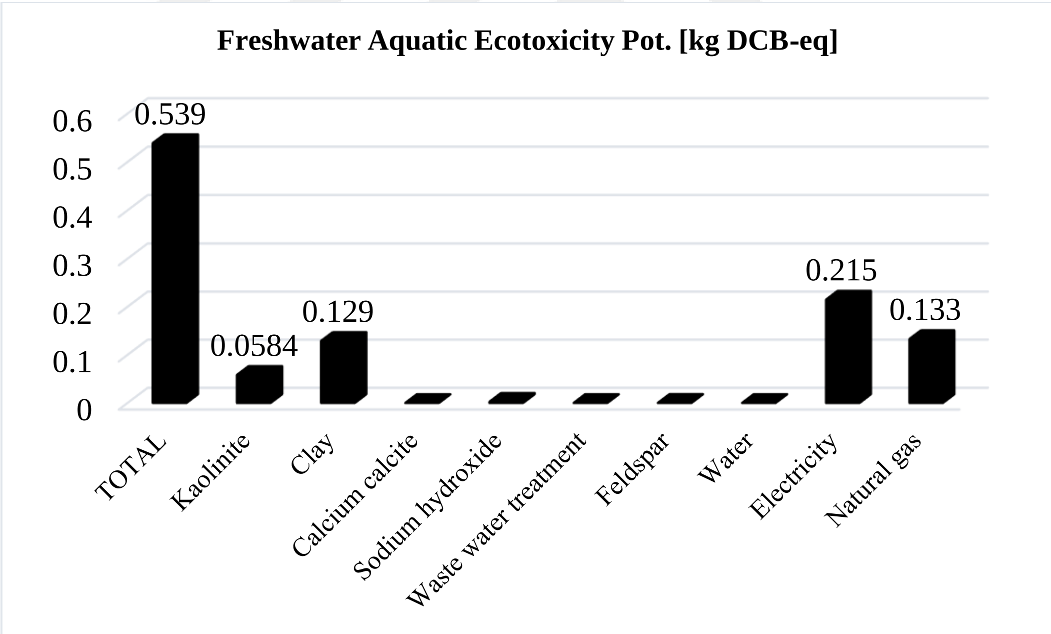

Figure 5.23 FAEP for 1.0 m2 of ceramic tile production (Scenario-2)

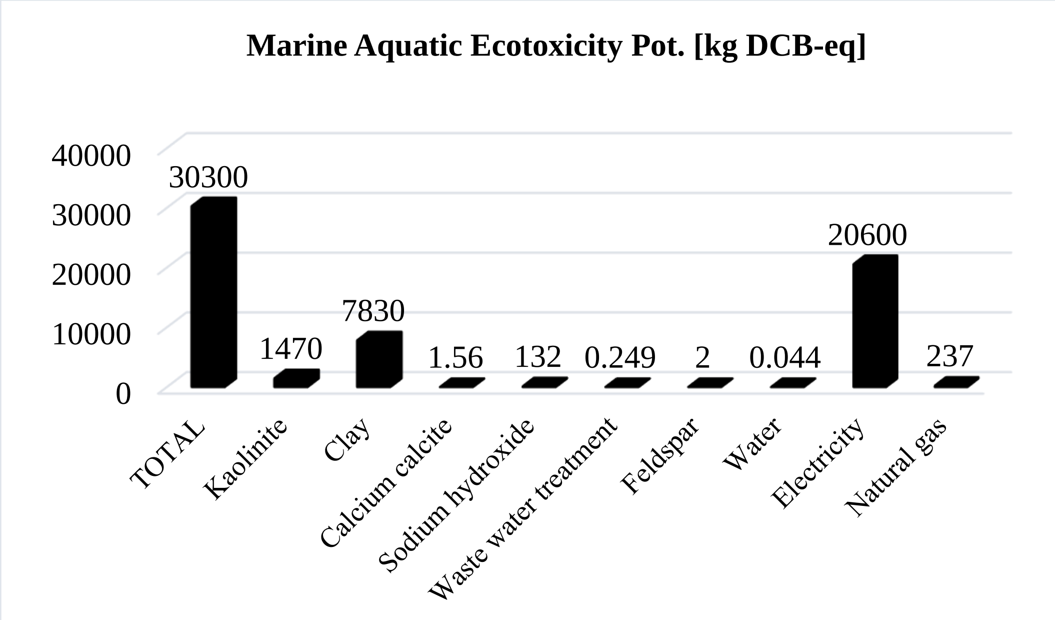

Figure 5.24 MAEP for 1.0 m^2 of ceramic tile production (Scenario-1)

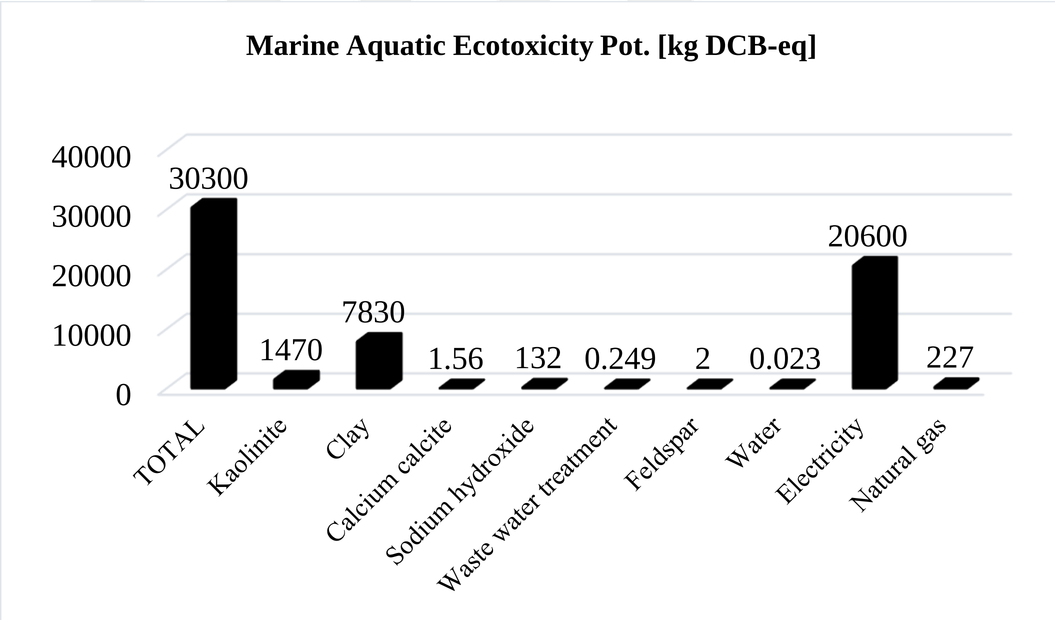

Figure 5.25 MAEP for 1.0 m2 of ceramic tile production (Scenario-2)

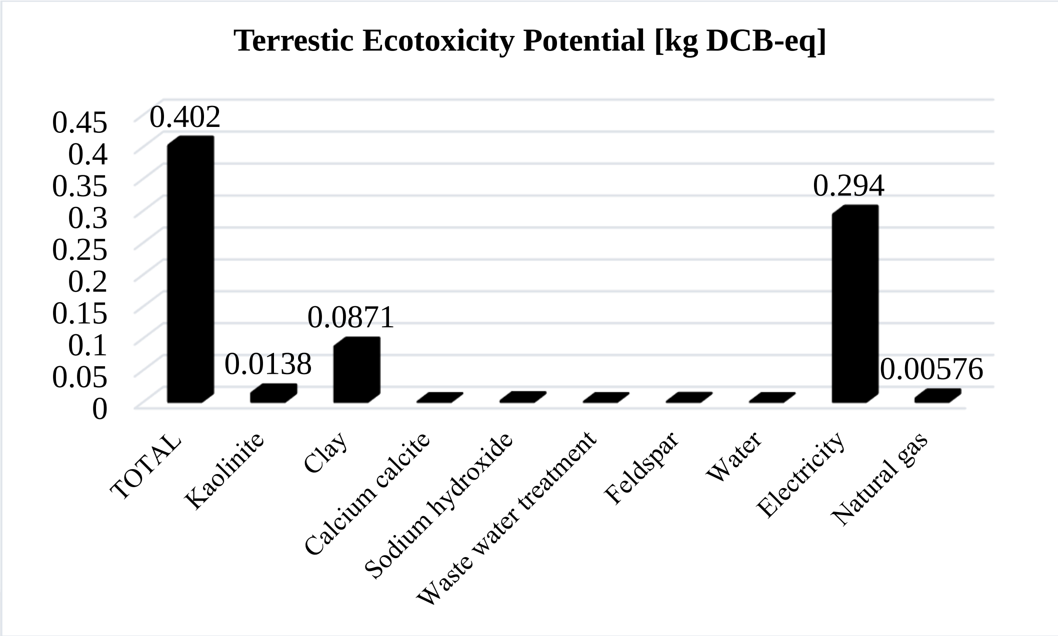

Figure 5.26 TETP for 1.0 m^2 of ceramic tile production (Scenario-1)

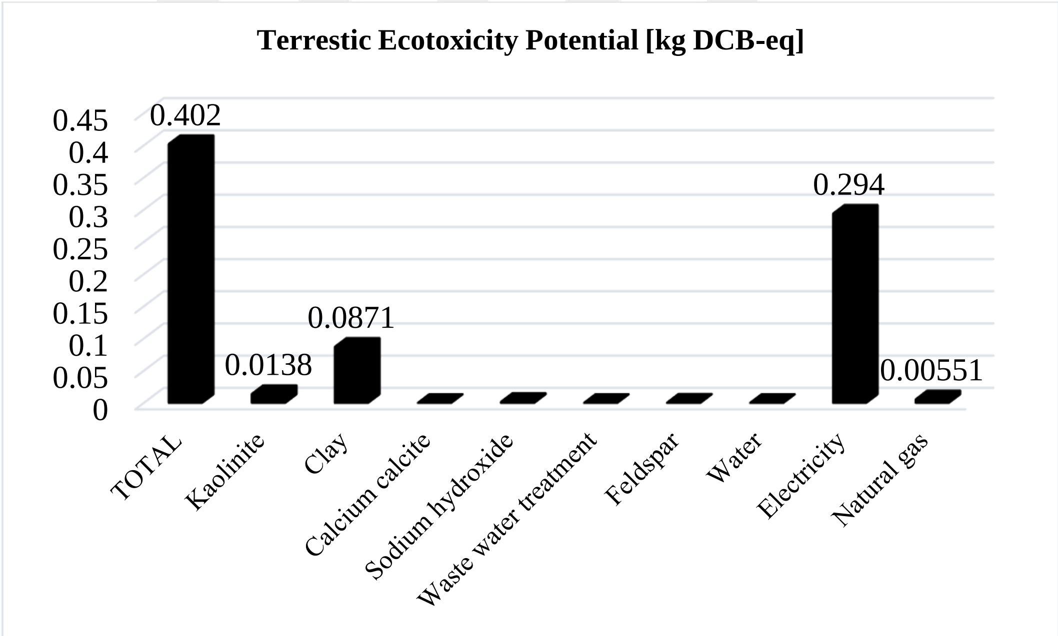

Figure 5.27 TETP for 1.0 m^2 of ceramic tile production (Scenario-2)

5.4 Cost Calculations

No major environmental gains have been achieved as a result of the recovery application. When total effects were taken into consideration, reductions in effects such as GWP, Abiotic Depletion -Elements, Abiotic Depletion -Fossil, Photochemical Ozone Creation Potential, Human Toxicity Potential and Freshwater Aquatic Ecotoxicity Potential were determined. However, it is envisaged to save 10,500 lt/month with the recovery of water VAPOUR. With the recovery of waste heat, it is expected to save 1,926,720 m^3 of natural gas per month.

When the calculation is made considering the natural gas and water unit prices, the following data are encountered.

Water unit price: 11.33 TL/m^3 (for enterprises, 09.2019)
Natural gas unit price: 1.59 TL/m^3 (for enterprises, 09.2019)

Saved costs are;

10.5 (m^3/month) * 11.33 (TL/m^3)= 118,965.00 TL/month
1,926,720.00 (m^3/month) * 1.59 (TL/m^3) = 3,063,484.8 TL/month

When the cost analysis is considered, it is seen that the heat recovery is saved more. However, the importance of water should not be forgotten and it should be recovered.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Within the scope of this thesis, the reusability of this released steam after condensation was investigated. For this purpose, a ceramic tile production plant was selected as a pilot plant. Water recovery from steam, which is produced during the ceramic tile production, by condensation and use of recovered water in the production were investigated. In addition, the environmental impacts of the pilot plant in the existing conditions and in the case of water recovery from steam were determined by life cycle analysis approach.

The most appropriate condenser selection and cost analysis were performed for water recovery. In order to recover the waste heat in addition to water condensation, water cooled type condenser has been selected.

As a result of the calculation, it was found that a total of 6 condensers could save 10.5 m^3/month of water and 1,926,720.00 m^3/month of natural gas. When the average unit prices of natural gas and water are considered, it was predicted that savings can be achieved by recovering natural gas by 3,063,484.8 TL and by recovering water by 118,965.00 TL.

When the environmental impacts of the plant were analyzed with LCA approach, it is seen that the most important impacts are originated from resources and emissions to fresh water. It was observed that a little bit lower environmental effects may be achieved with water recovery from steam. GWP effect decreased from 424 kg CO_2-eq to 420 kg CO_2-eq, ADP-Elements effect decreased from 0.0000904 kg Sb-eq to 0.0000895 kg Sb-eq, ADP-Fossil effect decreased from 11,200 MJ to 10,900 MJ, POCP effect decreased from 0.14 kg Ethene-eq to 0.139 kg Ethene-eq, HTP effect decreased from 46.1 kg DCB-eq to 45.4 kg DCB-eq and FAETP effect decreased from

0.545 kg DCB-eq to 0,539 kg DCB-eq, with the water recovery from steam and reuse it in the production.

6.2 Recommendations

Steam is produced in different industrial facilities and most of them are discharged to the atmosphere. However, the fresh water sources are very limited and in near future, there will be serious water shortage problem in our country. In order to manage the existing fresh water sources, water reuse applications must be widespread. Within this context, water recovery from steam should be evaluated where it is possible.

As a result of the researches, water-cooled type condenser was chosen for the pilot plant. Membrane condenser is also suitable for the recovery of water condensate. Studies on the applicability of the membrane condenser can be made in future researches.

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