

**DOKUZ EYLÜL UNIVERSITY**  
**GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

**INVENTORY AND MODELING OF ATMOSPHERIC  
VOC EMISSIONS FROM MAJOR SOURCES IN  
ALIAĞA, İZMİR**

**by**  
**Sedef ŞİMŞİR**

**November, 2010**  
**İZMİR**

# **INVENTORY AND MODELING OF ATMOSPHERIC VOC EMISSIONS FROM MAJOR SOURCES IN ALIAĞA, İZMİR**

**A Thesis Submitted to the  
Graduate School of Natural and Applied Sciences of Dokuz Eylül University  
In Partial Fulfillment of the Requirements for the Degree of Master of Science  
in Environmental Engineering, Environmental Technology Program**

**by  
Sedef ŞİMŞİR**

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## M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **INVENTORY AND MODELING OF ATMOSPHERIC VOC EMISSIONS FROM MAJOR SOURCES IN ALIAĞA, İZMİR** completed by **SEDEF ŞİMŞİR** under supervision of **PROF. DR. ABDURRAHMAN BAYRAM** 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.

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# INVENTORY AND MODELING OF ATMOSPHERIC VOC EMISSIONS FROM MAJOR SOURCES IN ALIAĞA, İZMİR

## ABSTRACT

The objective of this study was to calculate the amount of NMVOCs coming from industrial facilities in the Aliğa and to estimate their effects in atmosphere under meteorological and topographical conditions of the region. With this aim, at the beginning, the required information of industrial facilities in Aliğa were collected; then NMVOC emissions were calculated by using these information, with the help of emission factors from literature and a software of USEPA, called TANKS. As a result of these calculations, it was approximately found that nine thousand seven hundred tons per year NMVOC emissions had been emitted to atmosphere from industrial facilities in Aliğa. The highest contributions to these emissions were coming from petrochemical, oil refining and liquid fuel storage and loading activities with thirtynine, thirtyfour and nine percentiles respectively. When the results were assessed according to emission types, it could be seen that the highest NMVOC emissions had come mainly from storage tanks (thirtyfour percentile), equipment leaks (twentyeight percentile), liquid loading (twenty percentile), process (seventeen percentile) and combustion (one percentile). As a second step, contributions of calculated emissions to air quality of the study area was estimated by using ISCST-Three dispersion model of USEPA. According to model results the highest pollution concentrations were found around the petrochemical, oil refinery and fuel loading and storage facilities; maximum values were about six hundred micrograms per cubic meter there. A significant NMVOC concentration dispersion could not be seen around the iron and steel plants because of low emission release from facilities.

**Keywords:** Aliğa; emission inventory; industrial facilities; non-methane volatile organic compounds (NMVOCs); TANKS; ISCST-Three.

# İZMİR'İN ALIAĞA İLÇESİ İÇİN TEMEL KİRLETİCİ KAYNAKLARDAN ATILAN ATMOSFERİK UOB EMİSYONLARININ ENVANTERİ VE MODELLEMESİ

## ÖZ

Bu çalışma ile amaçlanan, Aliğa'daki sanayi tesislerinden kaynaklanan uçucu organik bileşiklerin (UOB) miktarını hesaplamak ve bölgenin meteorolojik ve topografik koşulları altında hava kalitesine katkılarını tahmin etmektir. Bu amaçla önce Aliğa'daki sanayi tesislerine ait bilgiler toplanmış; daha sonra bu bilgiler kullanılarak, literatürden emisyon faktörleri ve USEPA'nın TANKS yazılımı yardımı ile UOB emisyonları hesaplanmıştır. Bu hesaplar sonucunda Aliğa'da sanayi tesislerinden yıllık yaklaşık dokuzbinyediyüz ton UOB emisyonunun atmosfere verildiği bulunmuştur. Bu emisyonlara en yüksek katkılar sırasıyla yüzde otuzdokuz, otuzdört ve dokuzluk oranlar ile petrokimya, rafineri ve sıvı akaryakıt depolama ve dolum aktivitelerinden gelmektedir. Sonuçlar emisyon türlerine göre değerlendirildiğinde ise, en yüksek UOB emisyonlarının sırasıyla depolama tanklarından (yüzde otuzdört), bağlantı ekipmanlarından (yüzde yirmisekiz), dolum kollarından (yüzde yirmi), proseslerden (yüzde onyed) ve yanmadan (yüzde bir) kaynaklandığı görülmüştür. İkinci aşama olarak, hesaplanan emisyonların çalışma alanının hava kalitesi üzerindeki etkileri, USEPA'nın ISCST-Üç adlı dağılım modeli kullanılarak tahmin edilmiştir. Model sonuçlarına göre en yüksek kirlilik konsantrasyonları petrokimya, rafineri ve akaryakıt dolum ve depolama faaliyetleri çevresinde bulunmuştur ki oradaki maksimum değerler altıyüz mikrogram bölü metreküp mertebelerindedir. Demir-çelik tesislerinden atılan UOB emisyonları çok düşük seviyelerde olduğundan, buralarda kaydedeğer bir UOB konsantrasyon dağılımı bulunmamıştır.

**Anahtar sözcükler :** Aliğa; emisyon envanteri; sanayi tesisleri; uçucu organik bileşikler (UOB); TANKS; ISCST-Üç.

# CONTENTS

	<b>Page</b>
M.Sc THESIS EXAMINATION RESULT FORM.....	ii
ACKNOWLEDGMENTS .....	iii
ABSTRACT .....	iv
ÖZ .....	v
<b>CHAPTER ONE – INTRODUCTION .....</b>	<b>1</b>
<b>CHAPTER TWO – LITERATURE REVIEW .....</b>	<b>3</b>
2.1 Volatile Organic Compounds (VOCs) .....	3
2.2 Emission Inventories and Preparation Methods .....	5
2.2.1 Using Emission Factors to Estimate Emissions.....	8
2.2.2 Using a Computer Software to Estimate Emissions .....	8
2.2.3 Using an Emission Factor Based Method to Estimate Emissions .....	18
2.3 Dispersion Modeling .....	23
2.4 Previous Studies .....	25
<b>CHAPTER THREE – MATERIALS AND METHODS.....</b>	<b>30</b>
3.1 Study Area .....	30
3.2 Emission Estimations .....	33
3.2.1 Combustion Emissions of an Oil Refinery and a Petrochemical Plant .	35
3.2.2 Emission Estimations Using Emission Factors .....	36
3.2.3 Emission Estimations Using TANKS 4.0 Software .....	38
3.2.4 Emission Estimations Using Liquid Loading Method .....	40
3.3 Dispersion Modeling .....	41

<b>CHAPTER FOUR – RESULTS AND DISCUSSION .....</b>	<b>42</b>
4.1 Results of Emission Inventory .....	42
4.2 Results of Dispersion Modeling .....	49
<b>CHAPTER FIVE – CONCLUSIONS .....</b>	<b>53</b>
<b>REFERENCES.....</b>	<b>55</b>
<b>APPENDICES .....</b>	<b>61</b>



## **CHAPTER ONE**

### **INTRODUCTION**

The hydrocarbon gases and vapours in the air which have a vapour pressure between 0.13 and 101.3 kPa at ambient temperature and pressure are called volatile organic compounds (VOCs) (Derwent, 1995). They are one of the most important air pollutants because of causing undesired ozone formation, promoting the global greenhouse effect and having toxic effects on human health. VOC inventories are useful devices to determine the pollutant concentrations, their sources and effects on earth.

İzmir is one of the most developed cities of Turkey with its industrial activities, besides the commercial, economical, and social facilities. There are several industrial areas in the city which contribute to air quality significantly. Aliğa is one of these areas, even the most important one (Müezzinoğlu et al., 2000), because of having the most important heavy industrial facilities like an oil refinery, a large petrochemical industry, a lot of iron and steel plants, fuel and LPG storage and loading facilities, chemical plants and much more other industrial facilities in its boundaries. Moreover, it is a popular ever-growing area that, much more industries are planned to be established here. So that, air quality management studies are very important and required for this region.

Volatile organic compounds (VOCs) are one of the most important pollutants in Aliğa (Müezzinoğlu et al., 2000), because of being emitted in large quantities mainly from oil refining (crude oil processing), petroleum storage and distribution, solvent usage, chemical processes, metals industries, stationary combustion, landfilled wastes, food manufacture and agriculture (Derwent, 1995; Passant, 1995), and Aliğa has the large part of these industrial sectors.

In the previous years, several studies were carried out to determine the concentration levels of VOCs in Aliğa atmosphere (Eryiğit, 2000; Andiç, 2008; Civan et al., 2008; Doğan et al., 2008; Dumanoglu et al., 2008; Elbir et al., 2008).

However these studies included either a few types of VOCs or a few industrial plants. A detailed study on concentrations of total volatile organic compounds and for the Aliaga region was not achieved by this time. This study was prepared to overcome an important deficiency on emission levels and sources of nonmethane volatile organic compounds (NMVOCs) and their dispersion movements under certain meteorological and topographical conditions in Aliaga region. With this aim, at the beginning, the required information of industrial facilities in Aliaga were collected by the help of the questionnaires and the emissions were calculated. After the emission calculations, the dispersion of emission values were modeled by using the ISCST3 Dispersion Model of United States Environmental Protection Agency (USEPA).

The objectives of this study were;

1. to estimate the NMVOC emissions from industrial facilities in Aliaga industrial region,
2. to investigate the contribution of these emissions to the air quality under the meteorological and topographical conditions of the study area.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 Volatile Organic Compounds (VOCs)**

Pollutants can be categorized into two as primary and secondary pollutants. Primary pollutants are the pollutants that are emitted directly to atmosphere from a source, while secondary pollutants are the pollutants which come out as a result of some atmospheric reactions of primary pollutants (Müezzinoğlu, 2003). The most important secondary pollutant in the literature is ozone and VOCs (volatile organic compounds) is one of the most important primary pollutants which cause ozone formation as a result of several chemical reactions in the atmosphere.

There are various definitions about volatile organic compounds in the literature. The hydrocarbon gases and vapours in the air are generally called volatile organic compounds in a simple definition. Their vapour pressure at ambient temperature and pressure are between 0.13 and 101.3 kPa (Derwent, 1995).

According to EPA, the term volatile organic compounds (VOC) defines any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions (USEPA, 2010c). There are some compounds that have negligible photochemical reactivity. These compounds are mostly chlorofluorocarbons and also in spite of being important organic compounds, methane and ethane are not considered as VOC because of their properties of low reactivity. For this reason, in this study the emissions of only nonmethane volatile organic compounds were considered and this point forward, the term NMVOC was used to define the volatile organic compounds emissions.

NMVOC formation can be investigated in two different categories. The first one has natural origin, which comes from plants, trees, wild animals, natural forest fires and anaerobic processes in bogs and marshes (Derwent, 1995). The second one is

anthropogenic origin, which includes evaporation of petrol vapours from vehicle exhausts, oil refining (crude oil processing), petroleum storage and distribution, solvent usage, chemical plants, metals industries, stationary combustion, landfilled wastes, food manufacture and agriculture (Derwent, 1995; Passant, 1995).

NMVOC emissions from oil refining, petroleum (liquid and gaseous) storage and distribution facilities, steel making facilities, chemical processes, petrochemical activities and some other various industrial facilities and stationary combustion emissions from all of these facilities are mainly considered in this study.

The term NMVOC defines a large number of pollutants, and all effects of all of them can not be explained here in detail. But there are some common effects of these compounds, which can be found in the literature. These common effects can be discussed under five main headings; “stratospheric ozone depletion”, “ground level photochemical ozone formation”, “toxic or carcinogenic human health effects”, “enhancing the global greenhouse effect”, and “accumulation and persistence in the environment” (Derwent, 1995).

Many organic compounds can reach to stratosphere from atmosphere and as a result of photolysis and hydroxyl radical destruction, stratospheric ozone depletion occurs. This is also known as ozone hole formation and is a serious threat for both humans and natural life balances.

In the ground level, organic compounds take part in photochemical ozone formation by reacting with the hydroxyl radical in the lack of the  $\text{NO}_x$  compounds. If there are enough  $\text{NO}_x$  compounds in the ground level, the hydroxyl radical prefers to react with  $\text{NO}_x$ . But if the hydroxyl radical prefers to react with NMVOC as a result of lack of  $\text{NO}_x$ , ozone formation occurs in the atmosphere. This is an undesired case, because ozone has toxic effects in the lower layers of atmosphere (Eryiğit, 2000).

NMVOCs not only effect the humans by ozone formation, but also have dangerous and harmful effects on people. They can cause cancer and genetic

problems besides developmental disorders and problems on reproductive functions (Müezzinoğlu, 2003).

Some organic compounds can accumulate in the troposphere and absorb solar or terrestrial infrared radiation. This causes the greenhouse effect (these organic compounds are called radiatively active gases). But many compounds act as secondary greenhouse gases, that means they cause greenhouse effect indirectly. If a compound reacts to produce ozone in the troposphere or the same compound increases or decreases the tropospheric hydroxyl radical distribution, it can be classified as a secondary greenhouse gas (Derwent, 1995).

## **2.2 Emission Inventories and Preparation Methods**

The term *emission* defines the mass flow rate of a pollutant which is released to atmosphere from an identified pollutant source. EPA describes the same term as the gases and particles which are emitted by various sources (USEPA, 2010b). Based on those definitions, EPA defines the term *emission inventory* as the quantities of pollutants measured over a certain period (USEPA, 2010b). It can also be defined as the list of emission estimates for sources of air pollution in a certain area for a specified time period is called emission inventory (BAAQMD, 2010). They are detailed studies which help to identify the main sources of pollutants such as combustion, industrial processes, product use, agricultural facilities, waste control facilities, natural sources, etc. (EEA, 2009).

Emission inventories are useful and required tools for both scientific researches and decision mechanisms of local authorities about air quality management strategies. Emission maps which show the geographic distribution of emissions, can be plotted as a result of emission inventories and these maps help in case of land use planning (Hutchinson, 1997). Hutchinson (1997) also points out that, “Emission inventories can be used in conjunction with an atmospheric dispersion model to assess trends in air quality”. According to study, it is also possible to evaluate possible

future scenarios for air quality in the study area, by changing the input data of the model study.

The emission data are required for the following purposes (Obermeier, Seier, Friedrich, & Voß, 1992):

- identification of main sources of pollutants
- quantification of the objectives of pollution control
- establishment of a basis for evaluation of optimal emission reduction strategies
- creation of input data for models of transport and chemical transformation of air pollutants.

To sum up, the existing pollution levels in an area (e.g., country, city, town or zone) can be determined by using emission inventories. The potential pollutant levels for the years ahead can be estimated by using various mathematical models or computer softwares using emission data in inventories. Then prevention strategies and techniques can be developed by local authorities in association with the researchers to reduce the emission values and reach the desired air quality levels for health.

The USEPA reported that (USEPA, 1980; USEPA, 1997), there are mainly four stages which can be followed to prepare an emission inventory. The first stage is *planning*. The purpose of the inventory study and the planned end use should be explained at the beginning. After this, the pollutants, emission source categories (i.e., point, area, line sources) and geographical boundaries of the study area should be designated. Then a work plan should be prepared to determine the steps for the creation of the intended inventory. Source category coverage, selection of emission estimation methods and data management and reporting strategies should be included in the work plan. A work plan is very important for an emission inventory study to study systematically and solve the possible problems during the study easily.

The second stage of an emission inventory study is *data collection*. After planning the study, the data collection can be started. At this stage, according to type of the emission source (i.e, point, area, line), questionnaires are prepared and distributed or meetings with the relevant institutions (e.g., industrial plants and governmental institutions) are organized to have the required information clearly. The necessary information are mainly composed of nature of facility, production capacity, raw material and fuel consumption data. Furthermore, if there is a control device in the plant to reduce the emissions, it should also be noted in this stage of the study.

The third stage is composed of the *analysis of data collected* and the *development of emission estimates*. In this stage, the collected data should be arranged and evaluated to use in emission estimations. The emission estimations can be done in three different ways; the source test method, material balance method and emission factors method. In source test method, the process conditions and emission concentrations are reported as a result of direct measurements or monitoring service. In material balance method, the emissions from solvent evaporation are estimated; but to achieve this method, the inputs and outputs must be known for each point of the flow diagram of the process. In emission factors method, some coefficients which were created in different previous studies as a result of source test or material balance methods done previously are used to estimate emissions. In fact, in recent years, emission estimation models (computer softwares) and various calculation methods are also used to determine the emissions from point, area or line sources. In this study, emission factors were mainly used to estimate industrial emissions, and besides them a software, which was produced by USEPA, was also used to estimate emissions.

The fourth and the last stage of generating an emission inventory is *reporting*. In this stage, the results of emission inventory should be expressed clearly with the help of tables and graphics also. Emission inventories are the tools which can be used while making researches on air quality of a region, estimating the possible pollution levels in further years and improving pollution prevention strategies for the region. This means, different people from various institutions can make benefit of the results

of the mentioned inventory, so that it is very important to present the study results clearly.

### ***2.2.1 Using Emission Factors to Estimate Emissions***

One of the most frequently used emission estimation methods is determining emissions using emission factors from literature. Emission factors are the coefficients which are prepared as a conclusion of various emission measurement studies done before, and they define the amount of pollutants given to the atmosphere per an unit of activity by a definite source. A general equation for emission estimation with an emission factor can be seen below (USEPA, 2009).

$$E = A \times EF \times \left(1 - \frac{ER}{100}\right) \quad (2.1)$$

E : emissions

A : activity rate

EF : emission factor

ER : overall emission reduction efficiency (%).

In the literature, there are several reliable emission factor databases which were generated by USEPA (United States Environmental Protection Agency), EEA (European Environment Agency), IPPC (European Commission Integrated Pollution Prevention and Control) and IPCC (Intergovernmental Panel on Climate Change). There are a huge number of emission factors for various situations in these databases and they are updated regularly depending on the developments in technology.

### ***2.2.2 Using a Computer Software to Estimate Emissions***

Storage tanks are one of the most important constituents of NMVOC emissions in industrial plants. Although the tanks, which are used for storage, are sheltered not to exude the contents out, fugitive emissions can be occurred from tanks. This cause a common and important emission problem for industries which have tank farms. So,



The United States (US) Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards (OAQPS) developed a software, called TANKS 4.0, to determine the fugitive emissions arising from tanks. The working principle of this software belongs to the emission factors method (USEPA, 1995c) and it was created to accelerate the emission calculation studies.

According to the software, there are 3 tank types; fixed roof tanks, external floating roof tanks and internal floating roof tanks.

Fixed roof tanks (Figure 2.1) are made up of a cylindrical steel shell and a flat or dome or cone shaped stationary roof. The tank can have a breather (pressure/vacuum) vent or can be freely vented. There can be very small changes in liquid level, temperature or pressure in the tank, and if the system has a breather vent, these changes do not cause the vapor release from the tank. This is an advantage of a tank with a breather vent when compared with a freely vented tank. Fixed roof tanks are also the most economic tank type when compared with the other tank types in the software.

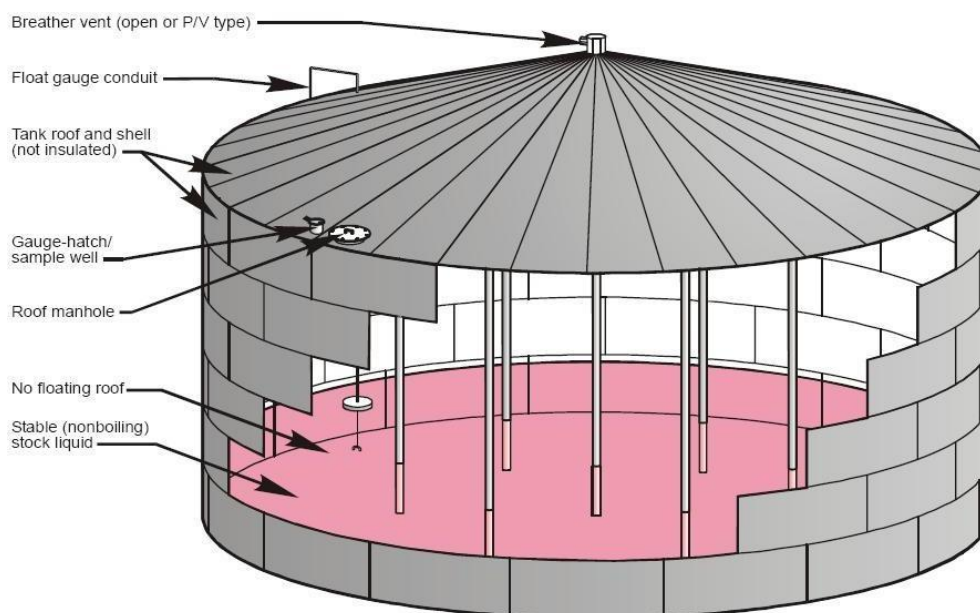


Figure 2.1 Fixed roof tank (USEPA, 1995c)

There are two types of emissions from fixed roof tanks according to the software. They are storage and working losses. When there is a change in temperature and barometric pressure, the vapor in the tank expands or contracts, so that a part of this vapor leaves the tank. This is called *standing storage loss (breathing loss)*. It should be considered that there is not a significant change in liquid level in the tank in case of storage loss. There are also other losses which come into existence during liquid filling and emptying activities and the total of these losses is called *working loss*. There is a liquid level change in the tank in this case, opposite of the storage loss.

Emissions from fixed roof tanks can vary according to vessel capacity, vapor pressure of the stored liquid, utilization rate of the tank and atmospheric conditions at the tank location (USEPA, 1995c).

The total emission value is composed of storage losses and working losses in fixed roof storage tanks and it is calculated in the software as shown below (USEPA, 1995c).

$$L_T = L_S + L_W \quad (2.2)$$

$L_T$  : total losses, lb year<sup>-1</sup>

$L_S$  : standing storage losses, lb year<sup>-1</sup>

$L_W$  : working losses, lb year<sup>-1</sup>

$$L_S = 365 V_V W_V K_E K_S \quad (2.3)$$

$L_S$  : standing storage loss, lb year<sup>-1</sup>

$V_V$  : vapor space volume, ft<sup>3</sup>

$W_V$  : stock vapor density, lb ft<sup>-3</sup>

$K_E$  : vapor space expansion factor, dimensionless

$K_S$  : vented vapor saturation factor, dimensionless

365 : constant, the number of daily events in a year, (year)<sup>-1</sup>

Here,  $V_V$  is the function of the tank diameter and effective height of tank;  $W_V$  is the function of molecular weight of vapor, pressure of vapor at daily average liquid surface temperature.  $K_E$  is the function of vapor temperature, ambient temperature, solar insolation or the function of vapor temperature, vapor pressure, breather vent pressure, atmospheric pressure and average liquid surface temperature; one of these two functions can be selected according to the values of true vapor pressure of the liquid in the tank and the breather vent settings (pressure/vacuum values). Finally,  $K_S$  is the function of vapor pressure at liquid surface temperature and heights of tank and liquid.

$$L_W = 0.0010 M_V P_{VA} Q K_N K_P \quad (2.4)$$

$L_W$  : working loss, lb year<sup>-1</sup>

$M_V$  : vapor molecular weight, lb (lb mole)<sup>-1</sup>

$P_{VA}$  : vapor pressure at daily average liquid surface temperature, psia

$Q$  : annual net throughput, bbl year<sup>-1</sup>

$K_N$  : working loss turnover factor, dimensionless

$K_P$  : working loss product factor, dimensionless

Here,  $K_P$  is a constant that changes according to the liquid type.  $K_N$  is a function of turnovers per year.  $Q$  is the annual net throughput and it is calculated by the multiplication of tank capacity and annual turnover rate.  $P_{VA}$  times  $M_V$  is equal to the multiplication of  $W_V$ , the idle gas constant ( $R$ ) and daily average liquid surface temperature ( $T_{LA}$ ).

Floating roof tanks have two different types; external (Figure 2.2) and internal (Figure 2.3) floating roof tanks. Although their construction mechanisms are substantially same, there are some differences between them. Both of them are made up of a cylindrical steel shell and a floating roof on the liquid content. The floating roof goes up and down according to the change of liquid content level in the tank. The tank system also contains a deck, fittings and rim seal system. The deck is in contact with the tank wall with the rim seal system. The purpose of the floating roof

and the rim seal system is to reduce the evaporative loss of the stored liquid. The difference is the fixed roof above the floating roof which is available in internal floating roof tanks, while the external one has an open-top. Also, the internal floating roof tanks have a lighter floating deck than the external one; this is also another difference (USEPA, 1995c).

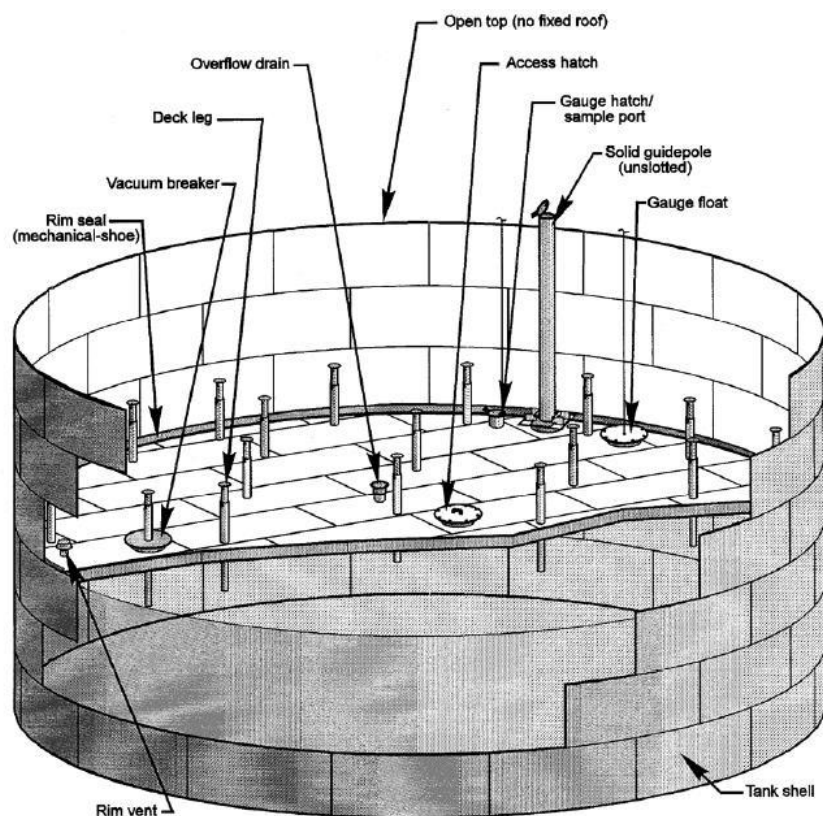


Figure 2.2 External floating roof tank (USEPA, 1995c)

Emissions of external and internal floating roof tanks are composed of withdrawal losses and standing storage losses. When the floating roof goes down depending on the decrease of liquid level in the tank, a part of liquid remains on the inner part of the tank wall (on the upper part) and this liquid remains evaporate. This is called *withdrawal losses*. Rim seal, deck fitting and deck seam losses are the constituents of *standing storage losses*. There is also a little amount of breathing losses which occur during the pressure and temperature changes, that can be considered under the standing storage losses. The total emissions of a floating roof tank are the sum of the

withdrawal and standing storage losses and their calculation equations are described below (USEPA, 1995c).

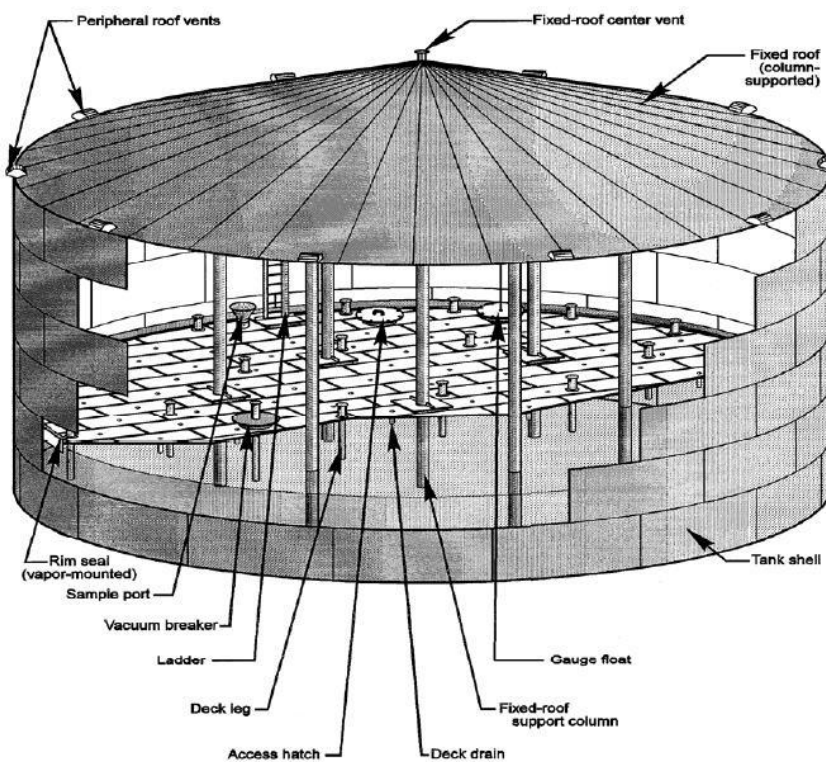


Figure 2.3 Internal floating roof tank (USEPA, 1995c)

Floating roof tank emissions are estimated for two different conditions; the first one is *normal operation* and the second one is *roof landing* situation.

For normal operation;

$$L_T = L_R + L_{WD} + L_F + L_D \quad (2.5)$$

$L_T$  : total loss, lb year<sup>-1</sup>

$L_R$  : rim seal loss, lb year<sup>-1</sup>

$L_{WD}$ : withdrawal loss, lb year<sup>-1</sup>

$L_F$  : deck fitting loss, lb year<sup>-1</sup>

$L_D$  : deck seam loss, lb year<sup>-1</sup>

$L_D$  is considered for bolted internal floating roof tanks only. In the study, all of the internal floating roof tanks are acknowledged as welded. So the emissions are always equal to zero in the study.

$$L_R = (K_{Ra} + K_{Rb} v^n) D P^* M_V K_C \quad (2.6)$$

$L_R$  : rim seal loss, lb year<sup>-1</sup>

$K_{Ra}$  : zero wind speed rim seal loss factor, lb-mole (ft year)<sup>-1</sup>

$K_{Rb}$  : wind speed dependent rim seal loss factor, lb-mole ((mph)<sup>n</sup>ft year)<sup>-1</sup>

$v$  : average ambient wind speed at tank site, mph

$n$  : seal-related wind speed exponent, dimensionless

$P^*$  : vapor pressure function, dimensionless

$D$  : tank diameter, ft

$M_V$  : average vapor molecular weight, lb (lb-mole)<sup>-1</sup>

$K_C$  : product factor depending on the stored liquid type

Here,  $P^*$  is a function of atmospheric pressure and vapor pressure at liquid surface temperature.  $K_{Ra}$ ,  $K_{Rb}$  and  $n$  factors can be taken from a table in which the factors alternate according to the rim-seal system type. Average ambient wind speed ( $v$ ) and tank diameter ( $D$ ) are requested directly by the software to be entered by the user.  $M_V$  is taken from the related table depending on the stored liquid. Finally,  $K_C$  is a constant value which alternates according to the liquid.

$$L_{WD} = \frac{(0.943) Q C_S W_L}{D} \quad (2.7)$$

$L_{WD}$ : withdrawal loss, lb year<sup>-1</sup>

$Q$  : annual throughput, bbl year<sup>-1</sup>

$C_S$  : shell clingage factor, bbl (1,000 ft<sup>2</sup>)<sup>-1</sup>

$W_L$  : average organic liquid density, lb gal<sup>-1</sup>

$D$  : tank diameter, ft

0.943 : constant, 1,000 ft<sup>3</sup> gal bbl<sup>-2</sup>

Here,  $Q$  is the multiplication value of tank capacity and annual turnover rate.  $C_S$  is a factor which can be read from a table, and alternates depending on the stored product (like gasoline or crude oil) and shell condition (light rust, dense rust or gunite lining).  $W_L$  is selected from the related tables according to the stored product and finally  $D$  is entered to the software by the user.

$$L_F = F_F P^* M_V K_C \quad (2.8)$$

$L_F$  : the deck fitting loss, lb year<sup>-1</sup>

$F_F$  : total deck fitting loss factor, lb mole year<sup>-1</sup>

$P^*$  : vapor pressure function, dimensionless

$M_V$  : vapor molecular weight, lb (lb mole)<sup>-1</sup>

$K_C$  : product factor depending on the stored liquid type

Here,  $K_C$ ,  $M_V$  and  $P^*$  are known from the previous equations.  $F_F$  is a new definition and calculated as below;

$$F_F = \left[ (N_{F1} K_{F1}) + (N_{F2} K_{F2}) + \dots + (N_{F_{n_f}} K_{F_{n_f}}) \right] \quad (2.9)$$

$N_{Fi}$  : number of deck fittings of a particular type ( $i = 0,1,2,\dots,n_f$ ), dimensionless

$K_{Fi}$  : deck fitting loss factor for a particular type fitting ( $i = 0,1,2,\dots,n_f$ ), lb mole year<sup>-1</sup>

$n_f$  : total number of different types of fittings, dimensionless

For roof landings;

$$L_{TL} = L_{SL} + L_{FL} \quad (2.10)$$

$L_{TL}$  : total losses during roof landing, lb per landing episode

$L_{SL}$  : standing idle losses during roof landing, lb per landing episode

$L_{FL}$  : filling losses during roof landing, lb per landing episode

When the storage tank is emptied, the roof no more floats on the surface of the liquid and it lands on deck legs. During the drop of liquid and landing on deck legs (with a little liquid in the tank, this is also called liquid heel), a vacuum condition arises. This is a dangerous situation, because of the vacuum the roof can collapse. To avoid the danger, an equilibrium should be created in pressure; so a breather vent must be used. This vent remains open while the roof is landed. The vapor that occurs in this time period goes out of the tank by using this breather vent and is called standing idle loss (Figure 2.4).

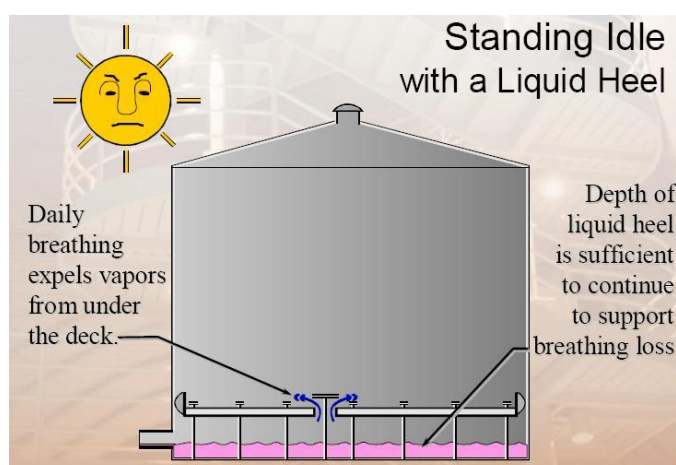


Figure 2.4 Standing idle with a liquid heel in floating tanks (Troxel, 2009).

In external floating roof tanks with a liquid heel, the wind affects the emission releases from the tank. Because the wind causes the liquid vapor to go out of the tank and the liquid produces vapor again to fill the space under the roof (Figure 2.5) (USEPA, 1995c).

$$L_{SLwind} = 0.57 n_d D P^* M_V \quad (2.11)$$

- $L_{SLwind}$  : daily standing idle loss due to wind,  $\text{lb day}^{-1}$   
 $n_d$  : number of days that the tank is standing idle, days  
 $D$  : tank diameter, ft  
 $P^*$  : a vapor pressure function, dimensionless  
 $M_V$  : stock vapor molecular weight,  $\text{lb (lb mole)}^{-1}$



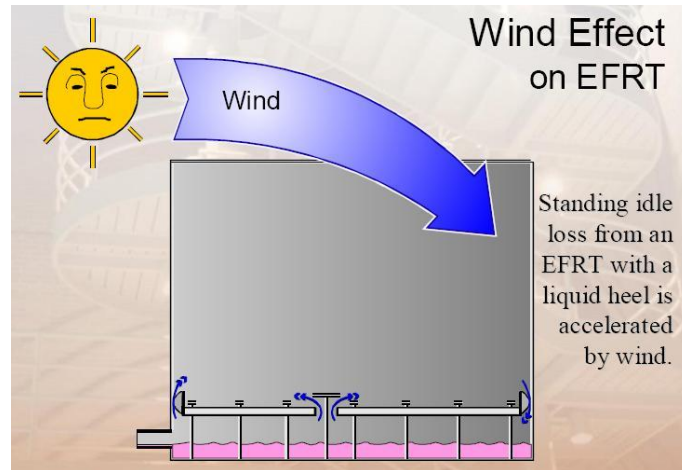


Figure 2.5 Wind effect on external floating roof tanks (Troxel, 2009).

$$L_{FL} = \left( \frac{P V_V}{R T} \right) M_V (C_{sf} S) \quad (2.12)$$

$L_{FL}$  : filling loss during roof landing, lb

$P$  : true vapor pressure of the liquid within the tank, psia

$V_V$  : volume of the vapor space, ft<sup>3</sup>

$R$  : ideal gas constant, 10.731 psia ft<sup>3</sup> (lb mole °R)<sup>-1</sup>

$T$  : average temperature of the vapor and liquid below the floating roof, °R

$M_V$  : stock vapor molecular weight, lb (lb mole)<sup>-1</sup>

$C_{sf}$  : filling saturation correction factor, dimensionless

$S$  : filling saturation factor, dimensionless (0.60 for a full liquid heel; 0.50 for a partial liquid heel)

Here,  $S$  is a dimensionless factor that alternates according to the liquid heel to be full or partial.  $C_{sf}$  is calculated as a function of standing idle losses with and without the wind effect.

A group of data should be entered into the software in four main steps. These are identification, physical characteristics, site selection and tank contents. At the beginning, an identification number should be given for the tank that will be defined, and the definitive notes should be added in the identification step. In physical characteristics step, tank dimensions, shell and roof characteristics and breather vent

settings should be entered. In the other step, the location of the tank must be defined and the meteorological properties of the location should be described into the software. Finally the liquid in the tank should be selected from the list in tank contents step or if it does not exist in the list, it should be defined in the software with its specific characteristics like density, molecular weight, vapor pressure for different temperatures and etc.

### 2.2.3 Using an Emission Factor Based Method to Estimate Emissions

Petroleum and petrochemical liquid loading facilities are also an important source of volatile organic compound emissions to the atmosphere. These emissions from loading facilities are called *loading losses*. Loading losses can occur at three stages. While the liquid in the tank is being emptied, it evaporates at the same time; this is the first type of emission. There are always liquid residues in the tank after a liquid is being emptied, and in spite of being empty, an evaporation occurs in the tank; this is the second type emission. Finally, while the new liquid is being loaded within the tank, the third type of evaporation occurs. These three type of evaporations constitute the total loading losses.

There are two types of loading methods; *splash loading* and *submerged loading*. In splash loading (Figure 2.6), a pipe is swung into the tank and the liquid is loaded into the tank from above. A liquid turbulence comes into existence while the liquid is loaded and a vapor-liquid contact occurs in this type of loading; vapor generation and losses are relatively higher.

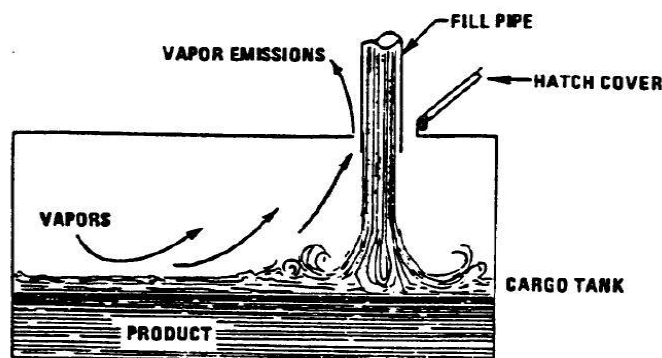


Figure 2.6 Splash loading method (USEPA, 1995d)

In submerged loading, there are two methods; *submerged fill pipe* (Figure 2.7) and *bottom loading* (Figure 2.8). The pipe is swung into the tank from above again in submerged fill pipe method, but it's different from splash loading because the end of loading pipe is almost at the bottom of the tank and after a short while it is submerged by the liquid. In bottom loading method, there is a fixed pipe under the tank and the liquid is loaded from that pipe. Both submerged loading methods cause less emissions than splash loading method.

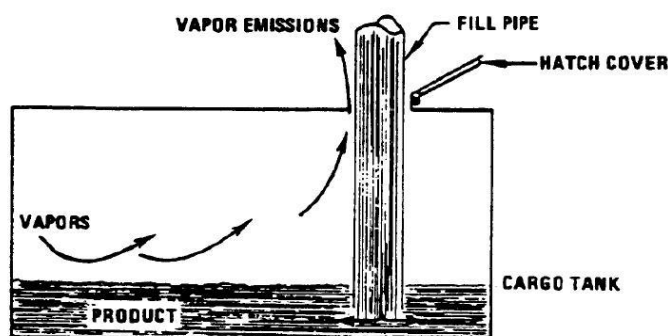


Figure 2.7 Submerged fill pipe method (USEPA, 1995d)

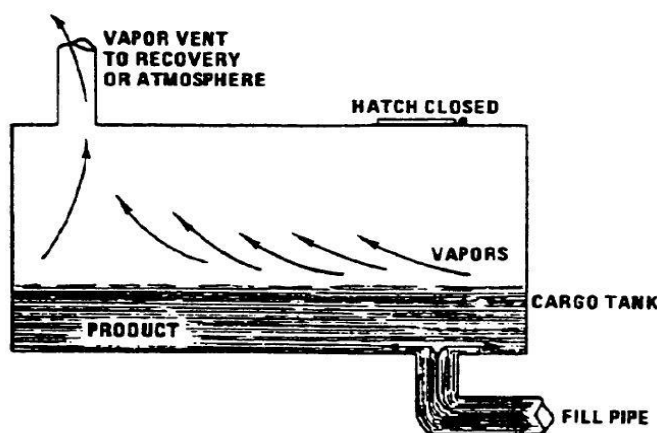


Figure 2.8 Bottom loading method (USEPA, 1995d)

Emissions from liquid loading facilities can be estimated as explained below by the reference of USEPA (1995d).

$$L_L = 12.46 \frac{S P M}{T} \quad (2.13)$$

$L_L$  : loading loss, pounds per 1000 gallons ( $\text{lb } (10^3 \text{ gal})^{-1}$ ) of liquid loaded

S : a saturation factor

P : true vapor pressure of liquid loaded, psia

M : molecular weight of vapors, lb (lb mole)<sup>-1</sup>

T : temperature of bulk liquid loaded, °R

Here, T should be known. M and P can be selected from Table 2.1 and Table 2.2 and S should be selected from Table 2.3.

For marine vessels, for products other than gasoline and crude oil, the saturation factor (S) can be selected from Table 2.2. If there is a marine loading of gasoline, emission factors from Table 2.4 should be used to estimate the NMVOC emissions. If the product is crude oil, equations 2.14 and 2.15, and Table 2.5 should be used.

Table 2.1 Properties of selected petrochemicals.

Petrochemical Name	Molecular Weight lb (lb mole) <sup>-1</sup>	Liquid Density lb (gal) <sup>-1</sup>	Vapor Pressure psi
Acrylonitrile	53.06	6.8	5.2
Benzene	78.11	7.4	4.2
Paraxylene	106.20	7.2	6.2
Monoethylene glycol	62.07	9.3	5.2
Diethylene glycol	106.12	9.3	5.2
Ortoxylene	106.20	7.2	6.2
Vinyl chloride	62.5	7.7	5.2
Hexane	86.2	5.9	5.2
Heptane	100.20	5.9	5.2
Acetic Acid	60.05	8.8	9.6
Propylene	42.08	4.4	5.2
Butadiene	54.70	5.1	5.2
Toluene	92.14	7.3	4.2
Ethylene	28.05	4.7	3.4
Ammonia	17.03	5.7	3.4

Table 2.2 Properties of selected petroleum liquids (USEPA, 1995c)

Petroleum Liquid	Vapor Molecular Weight At 60°F, $M_V$ lb (lb mole) <sup>-1</sup>	Liquid Density At 60°F, $W_L$ lb (gal) <sup>-1</sup>	True Vapor Pressure, $P_{VA}$ (psi)						
			40°F	50°F	60°F	70°F	80°F	90°F	100°F
Crude oil RVP 5	50	7.1	1.8	2.3	2.8	3.4	4.0	4.8	5.7
Distillate fuel oil No. 2	130	7.1	0.0031	0.0045	0.0065	0.0090	0.012	0.016	0.022
Gasoline RVP 7	68	5.6	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Gasoline RVP 7.8	68	5.6	2.5929	3.2079	3.9363	4.793	5.7937	6.9552	8.2952
Gasoline RVP 8.3	68	5.6	2.7888	3.444	4.2188	5.1284	6.1891	7.4184	8.8344
Gasoline RVP 10	66	5.6	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasoline RVP 11.5	65	5.6	4.087	4.9997	6.069	7.3132	8.7519	10.4053	12.2949
Gasoline RVP 13	62	5.6	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gasoline RVP 13.5	62	5.6	4.932	6.0054	7.2573	8.7076	10.3774	12.2888	14.4646
Gasoline RVP 15.0	60	5.6	5.5802	6.774	8.1621	9.7656	11.6067	13.7085	16.0948
Jet kerosene	130	7.0	0.0041	0.0060	0.0085	0.011	0.015	0.021	0.029
Jet naphtha (JP-4)	80	6.4	0.8	1.0	1.3	1.6	1.9	2.4	2.7
Residual oil No. 6	190	7.9	0.00002	0.00003	0.00004	0.00006	0.00009	0.00013	0.00019

Table 2.3 Saturation (S) factors for calculating petroleum liquid loading losses (USEPA, 1995d)

Cargo Carrier	Mode of Operation	S Factor
Tank trucks and rail tank cars	Submerged loading of a clean cargo tank	0.50
	Submerged loading: dedicated normal service	0.60
	Submerged loading: dedicated vapor balance service	1.00
	Splash loading of a clean cargo tank	1.45
	Splash loading: dedicated normal service	1.45
	Splash loading: dedicated vapor balance service	1.00
Marine vessels*	Submerged loading: ships	0.2
	Submerged loading: barges	0.5

\*For products other than gasoline and crude oil. For marine loading of gasoline, factors from Table 2.4 should be used. For marine loading of crude oil, Equations 2.14, 2.15 and Table 2.5 should be used.

$$C_L = C_A + C_G \quad (2.14)$$

$C_L$  : total loading loss, lb (10<sup>3</sup> gal)<sup>-1</sup> of crude oil loaded

$C_A$  : arrival emission factor, contributed by vapors in the empty tank compartment before loading, lb (10<sup>3</sup> gal)<sup>-1</sup> loaded

$C_G$  : generated emission factor, contributed by evaporation during loading, lb (10<sup>3</sup> gal)<sup>-1</sup> loaded

$$C_G = 1.84(0.44 P - 0.42) \frac{M G}{T} \quad (2.15)$$

$C_G$  : generated emission factor, contributed by evaporation during loading, lb/10<sup>3</sup> gal loaded

$P$  : true vapor pressure of loaded crude oil, psia

$M$  : molecular weight of vapors, lb (lb mole)<sup>-1</sup>

$G$  : vapor growth factor = 1.02 (dimensionless)

$T$  : vapor temperature, °R, (°F + 460)

$C_A$  and  $C_G$  factors are for total organic carbons. NMVOC factor can be calculated by multiplication of  $C_A$  and  $C_G$  factors with 0.85 (USEPA, 1995d).

Table 2.4 Volatile organic compound (VOC) emission factors for gasoline loading operations at marine terminals (USEPA, 1995d)

Vessel Tank Condition	Previous Cargo	Ships/Ocean Barges		Barges	
		mg l <sup>-1</sup> Transferred	lb (10 <sup>3</sup> gal) <sup>-1</sup> Transferred	mg l <sup>-1</sup> Transferred	lb (10 <sup>3</sup> gal) <sup>-1</sup> Transferred
Uncleaned	Volatile	315	2.6	465	3.9
Ballasted	Volatile	205	1.7	-	-
Cleaned	Volatile	180	1.5	-	-
Gas-freed	Volatile	85	0.7	-	-
Any condition	Nonvolatile	85	0.7	-	-
Gas-freed	Any Condition	-	-	245	2.0
Typical overall situation	Any Condition	215	1.8	410	3.4

Table 2.5 Average arrival emission factors (C<sub>A</sub>), for crude oil loading emission equation (USEPA, 1995d)

Ship/Ocean Barge Tank Condition	Previous Cargo	Arrival Emission Factor, lb (10 <sup>3</sup> gal) <sup>-1</sup>
Uncleaned	Volatile	0.86
Ballasted	Volatile	0.46
Cleaned or gas-freed	Volatile	0.33
Any condition	Nonvolatile	0.33

### 2.3 Dispersion Modeling

Creating an emission inventory is the first step of an air quality assessment. The emission inventory can give an idea about the amount of a pollutant; but its dispersion with meteorological conditions on air, corresponding pollutant concentrations and effects on air quality can be estimated by using special dispersion models. Activating a mathematical simulation which is used to simulate the behaviour of air pollutants in the ambient atmosphere under certain meteorological conditions is defined as *dispersion modeling*. The dispersion models achieve the estimation of downwind concentrations of air pollutants emitted from various sources (e.g., industrial, domestic or traffic based). There are many special computer programs, achieving dispersion modeling (i.e., BLP, CALINE3, CDM2, ISCST3,

MPTER, PTPLU, etc.) created by various organizations. In this study the Industrial Source Complex Short Term Model (ISCST3) of USEPA was used to estimate the dispersion of industrial based NMVOCs on Aliğa; because it was a widely-used program in similar previous studies.

Modeling is a cheap and easy way to comment on air quality of an area when compared with air quality monitoring activities. Monitoring activities require special and long periods of time, special devices and money correspondingly. But modeling can be realized any time in anywhere in which a computer exists.

Dispersion modeling is an easy way of estimating the concentrations of a pollutant under various meteorological and geographical conditions. The most widely used models are based on Gaussian distribution (Godish, 1997). ISCST3 is also a steady-state Gaussian plume model that can be used to estimate pollutant concentrations from various sources (e.g., stacks, storage tanks, liquid loading pipelines and pipeline equipments in this study) of an industrial facility. The model calculates the concentrations according to the following equation of Gaussian distribution given below with equation number 2.16 (Cooper, & Alley, 1994; USEPA, 1995b). The coordinate systems, used in Eq. 2.16, are applied as shown in Figure 2.9.

$$C_{(x,y,z,h)} = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left\{ \exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right] \right\} \quad (2.16)$$

$C$  : steady-state concentration at a point (x,y,z),  $\mu\text{g m}^{-3}$

$Q$  : emissions rate,  $\mu\text{g s}^{-1}$

$\sigma_y, \sigma_z$  : horizontal and vertical spread parameters, m (the functions of distance, x, and atmospheric stability)

$u$  : average wind speed at stack height, ( $\text{m s}^{-1}$ )

$y$  : horizontal distance from plume centerline, m

$z$  : vertical distance from ground level, m

$H$  : effective stack height (the sum of physical stack height and plume rise), m



The assumptions about Eq. 2.16 are given below;

- the turbulence is the same for anywhere,
- $\sigma_y$  and  $\sigma_z$  are the functions of distance,  $x$ ,
- the wind speed and wind direction are constant at the plume layer,
- the plume dispersion is a Gaussian distribution.  $\sigma_y$  and  $\sigma_z$  are the standard, deviation values of plume concentration distribution in lateral and vertical directions,
- the total reflection occurs in the ground surface; a storage in this surface or a reaction with this surface are not possible.

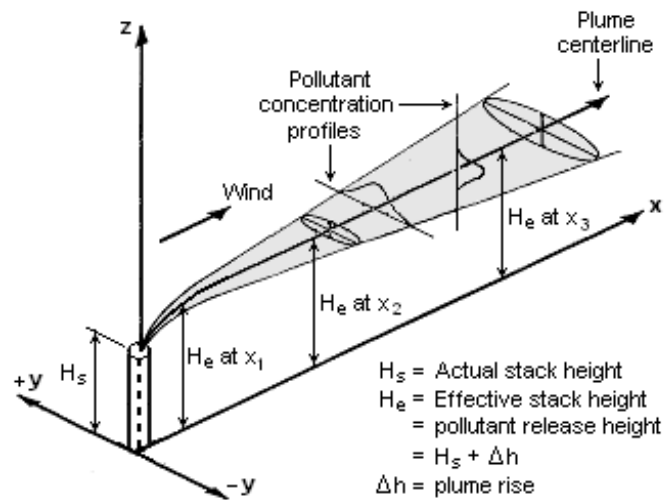


Figure 2.9 Coordinate systems for Gaussian plume model.

## 2.4 Previous Studies

Emission inventories have been prepared for different areas all over the world for many years. Elbir (1997) treated the emission inventories for different scales of important organizations and project teams those had been carried out till the year 1997 in his study. Generation methods, similarities and differences of different emission inventories were investigated by exploring the important inventories of OECD-MAP, CEC-CORINAIR, ECE-EMEP and much more in this study. Elbir mentioned a local scale emission inventory study in his work. The aim of that study

which was achieved by Muezzinoğlu, Elbir, Bayram, & Seyfioğlu (1997), was to identify the major air pollution sources and emission levels of Izmir for the year 1996. In the study, emissions from industrial facilities, domestic heating and traffic were considered. The emissions were estimated by the use of emission factors together with the fuel consumption values for each source. The emission factors were taken from Corinair and USEPA's databases. At the end of the study, it was found that, in Turkey, 9% of SO<sub>x</sub>, 6% of NO<sub>x</sub>, 3.5% of NMVOC and 3.5% of CO emissions were originated from Izmir. When these values were evaluated according to only industrial pollution, 30% of SO<sub>x</sub>, 18% of NO<sub>x</sub> and 52% of CO were originated from Izmir. It was specified in the study results that, this was because of the use of poor quality fuels and inappropriate technology use in industrial facilities. According to the study, industries were the main pollutant sector for SO<sub>x</sub> and NMVOC, while for NO<sub>x</sub> and CO traffic was the main pollutant sector in İzmir in 1996.

The same project group (Muezzinoğlu et al., 2000) created a regional emission inventory for the Aegean Region in Turkey then, as a follow up study. In that study, the same approach was used to estimate industrial, domestic and traffic emissions; the fuel consumptions and emission factors were used together for seven cities in the region. At the end of the study, İzmir was found to have the highest emissions for both industrial and domestic heating sectors. Specialized result for Aliğa in that study was 10,645 tons year<sup>-1</sup> NMVOC emissions.

In 2004, again Elbir & Muezzinoğlu (2004) published an article which reports the emission values of İzmir, for the year 2000; coming from point (industrial), line (vehicular) and area (domestic) sources. In that article, it was specified that SO<sub>2</sub> was the major pollutant with 84,271 ton year<sup>-1</sup> total emission value in Izmir and the most pollutant sector for this pollutant was the industry with 74,443 ton year<sup>-1</sup>. For PM, the most polluting sector was domestic heating with 14,697 ton year<sup>-1</sup> and for NO<sub>x</sub>, the most polluting sector was the traffic with 29,711 ton year<sup>-1</sup>. According to the study results, the petroleum refinery and the petrochemical industry were found as the largest sources of air pollution.

When looked at national scale, the study of Ağaçayak (2007) can be viewed. In this study, an emission inventory was prepared for Turkey by considering the emissions coming from mobile sources, small combustion processes, large combustion plants and the most important industrial processes. Study results showed that, İstanbul, Ankara and İzmir had the highest pollution levels. NO<sub>x</sub> was the most emitted pollutant from mobile sources. PM<sub>10</sub> emissions came from industrial combustion processes and cement production at first. Power plants were the main contributors of SO<sub>2</sub> emissions with a percentage of 67% of all pollutant sectors.

Another country based emission inventory was prepared for Thailand by Pham, Manomaiphiboon, & Vongmahadlek (2008). In this study, emissions from power plants and industrial facilities were estimated using fuel consumptions. In the inventory, the examined pollutants were nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), ammonia (NH<sub>3</sub>), organic carbon (OC) and black carbon (BC). Emissions were calculated by the multiplication of activity rates (i.e., fuel consumption values) and emission factors. The emission factors were selected from different sources; from USEPA, IPPC, and different previous studies of other scientists. At the end of the study, the total annual NMVOC emissions of power plants due to fuel consumption were found as  $6.1 \times 10^3$  tons. For industrial facilities this number was found as  $33.4 \times 10^3$  tons NMVOC emissions (due to fuel consumption), and  $76.0 \times 10^3$  tons NMVOC emissions due to industrial processes. It was reported that the Central and Eastern regions of the country emitted the 70%-80% of the national emissions from industrial facilities and the largest emissions came from Food and Beverage, Chemical and Non-Metal industries. Large NMVOC emissions were seen in Food and Beverage industry and large CO emissions were seen in Paper industry. Petroleum facilities also emitted large amount of NMVOC, i.e., it was approximately equal to half of NMVOC emissions from total industrial processes.

In another study, Srivastava & Majumdar (2010) prepared an inventory of evaporative non-methane hydrocarbons for four metro cities (Delhi, Mumbai, Chennai and Kolkata) in India for the time period of April 2003 to March 2004. The

evaporative emissions from activities of dry cleaning, architectural surface coating, automobile refinishing, newspaper printing, petrol loading, petrol refuelling, computer printers, commercial consumer product, graphic art applications, and also emissions from transit losses and fuel evaporation losses from vehicles during different conditions were considered in the study. Various emission factors were accepted for these activities by making assumptions in line with related information taken from the relevant institutions. Finally, it was found that, evaporative emissions existed highest to lowest in Delhi, Chennai, Mumbai and Kolkata respectively. The total evaporative emissions of hydrocarbons were calculated as  $3.7683 \text{ Gg year}^{-1}$  at these four metros. The highest emission values in these cities were from vehicular activities; with a value of approximately 96% of the total evaporative emissions. Also surface coating, consumer products, graphic art printing, petrol refuelling, loading/unloading and dry cleaning activities were the major responsible of these emissions.

When the literature is examined, a detailed emission inventory of total NMVOCs for Aliğa can not be found; although there are several measurement studies of different organic compounds for the town. The first study about NMVOC concentrations in Aliğa (Eryiğit, 2000) includes the measurements of benzene, toluene, xylenes with gas chromatography, using the sampling method of activated carbon adsorption, and formaldehyde with two different colorimetric methods. The results were found as  $101\text{-}180 \mu\text{g m}^{-3}$  for formaldehyde while  $0.8\text{-}35.5$ ,  $0.4\text{-}100.7$ ,  $7.3\text{-}25.6$ ,  $5.6\text{-}97.1$  and  $5.6\text{-}28.8 \mu\text{g m}^{-3}$  were detected for benzene, toluene, p-xylene, m-xylene and o-xylene respectively. The second study (Andiç, 2008) is a passive sampling study of twenty-three different volatile organic carbons. Four of them, called BTEX (i.e., benzene, toluene, ethyl benzene and xylene) were also examined in detail because of having harmful effects on human health. As a result, it was found that styrene, 2-methylhexane and toluene were respectively the most abundant compounds in Aliğa and the highest NMVOC concentrations were detected around the refinery and petrochemical industry. In other studies (Civan et al., 2008; Doğan et al., 2008; Dumanoğlu et al., 2008) passive and active sampling methods were applied to determine the NMVOC concentrations in Aliğa. These studies indicate

that, highway traffic and domestic heating are effective on NMVOC pollution, but the highest concentrations come from industrial facilities in the region, and mainly from refinery and petrochemical industry. From this point of view, Elbir and colleagues (2008) examined the NMVOC emissions from storage tanks and liquid loading facilities of petroleum refinery in Aliğa. The NMVOC emissions from storage tanks were found as 85 tons year<sup>-1</sup>, while the emissions from liquid loading were 1,162 tons year<sup>-1</sup>. In the study, NMVOC concentrations were measured also near five different tanks and the values changed between 229 to 3577  $\mu\text{g m}^{-3}$ .

## **CHAPTER THREE**

### **MATERIALS AND METHODS**

#### **3.1 Study Area**

Aliğa is a town of İzmir which is located in the northern part of the city with its surface area of 412.5 km<sup>2</sup>. It is surrounded by Manisa on the East, Bergama and Dikili on the North, Menemen on the South and Foça on the Southwest directions. The West border is Aegean Sea. There are Dumanlı and Yunt (~1000 m) Mountains around the town. Güzelhisar is the only watercourse within the town boundaries with an average flowrate about 3.71 m<sup>3</sup> s<sup>-1</sup> (Aliğa Municipality, 2009). There is also a dam on this brook, called Güzelhisar Dam, which was constructed by Petkim Petrochemical Company and managed by DSİ (General Directorate of State Hydraulic Works) to supply the water demand of Petkim and other industrial plants in the zone besides drinking and other usage demands. The dam has a volume capacity of 158 million m<sup>3</sup>.

The dominant climate type is the mild Mediterranean climate in Aliğa. This means that winters are mild and rainy, and the summers are hot and arid. In winter, northerly winds are dominant in the town but in summer, the breeze comes from West and refreshes the environment. The average temperature in Aliğa in winter is about 10°C and the coldest month is January while the average temperature is between 24 – 27 °C in summer. The dominant vegetation is compatible with the climate type; so it has very few forests but lots of maquis shrublands.

Aliğa has a human population of 63,503 according to 2009 population census (TUİK, 2010). 51,108 people of this value live in the centre of the town and 12,395 people live in the surrounding villages (TUİK, 2010). The ratio of men population to women is approximately 1.02 in the town (TUİK, 2010).

Aliğa is one of the most developed towns of İzmir in terms of industrial facilities. The first industrialisation activities started at seventies with establishments

of the refinery and the petrochemical industry. Several liquified gas filling and storage facilities, arc furnaces and rolling industries were established later. In the town, private sector investments are established in eighties, and especially in the second half of the nineties, they became accelerated. Today, there are a lot of iron and steel industries, gas and liquid fuel filling, storage and sale facilities, ship breaking facilities, paper and fertiliser industries, rolling mills and other various industries in Aliğa besides the refinery and the petrochemical industry (Figure 3.1). There are also 3 power plants, using natural gas, which have installed powers of 250 MW, 180 MW and 1532 MW (Aliğa Municipality, 2009) in the town.

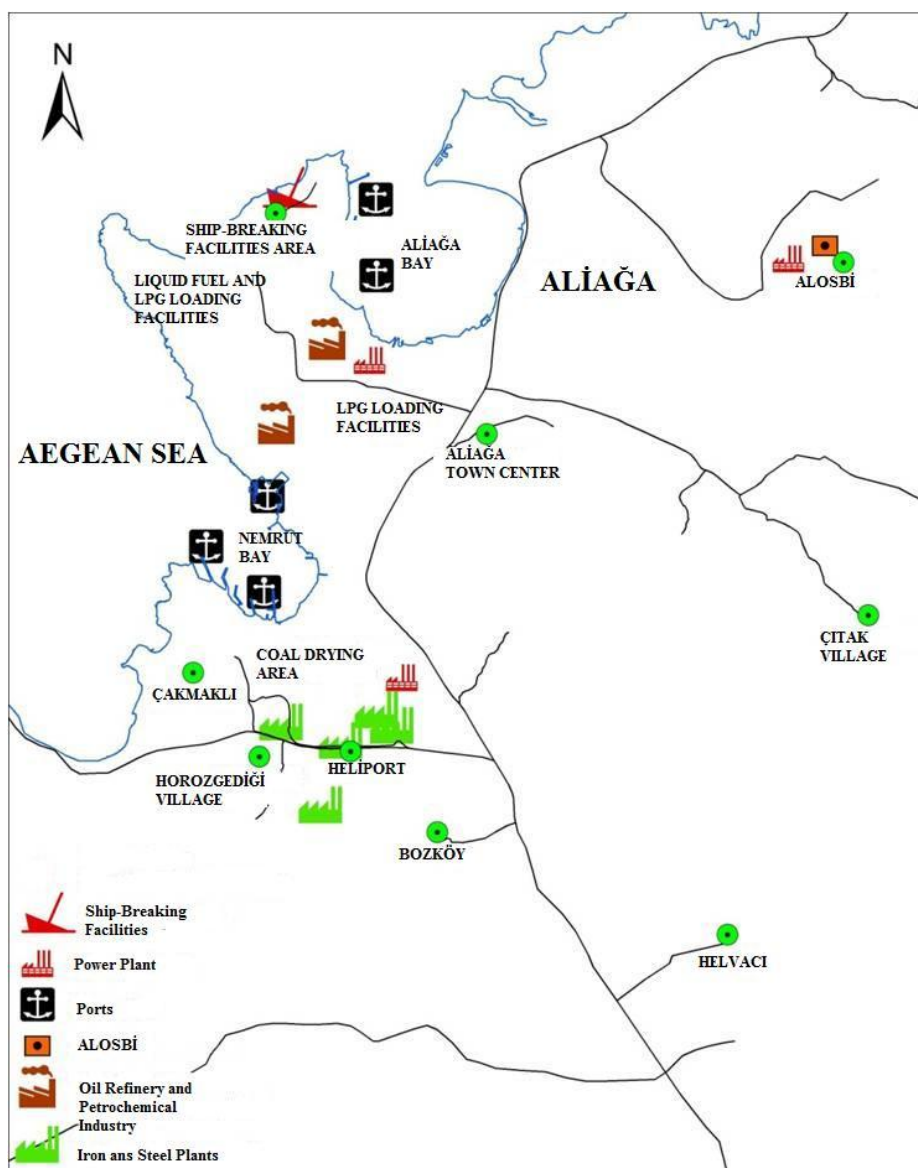


Figure 3.1 Study area and the industries in Aliğa town.

In Aliaga, there are 15 iron and steel plants; 10 of them have only rolling mills, and the others have both steel mills and rolling mills. In steel mills, the scrap iron is melted in electric arc furnaces with the help of carbon electrodes and NMVOC emissions come out during this process. In rolling mills, hot rolling technology is used to produce billets and various steel profiles from steel ingots. The ingots are heated in reheating furnaces and then passed through the cylinders. The lubricating oil between the cylinders become evaporated while the steel ingots are passing and this cause NMVOC emissions during the process.

There is an important oil refinery in Aliaga which was established in 1972 and now have a crude oil processing capacity of 11 million tons per year. The main NMVOC sources in the refinery are storage, product loading and handling facilities, fugitive emissions from pipeline equipment (e.g., valves, flanges, etc.) and flare systems.

Aliaga is an inviting place for liquid fuel loading and LPG loading facilities because of the refinery in the region. There are 5 liquid fuel loading and 7 LPG loading plants in the town. Liquid fuel loading plants emit NMVOC from storage tanks, liquid loading activities and leaks from equipment like valves, flanges and etc. Also, LPG loading facilities cause NMVOC emissions from equipment leaks and bottle painting; but there is not any emissions from storage tanks, because of being pressurized and not having breathers.

The petrochemical industry is also an important NMVOC emissions source in the region. The volatile organic emissions come from almost every product's manufacture (i.e, aromatics, ethylene, propylene, polyethylene, polypropylene, terephthalic acid, acrylonitrile, vinyl chloride monomer and ethylene dichloride).

There are also 5 plants in the region which emit NMVOC emissions in remarkable levels as a result of chemical processes. They work generally about paint or other chemicals manufacture.



In addition, there is a solvent reclamation plant in the region. A reclamation plant have several steps, which causes volatile organics, like solvent storage and condensation. Also fugitive emissions from loading and spillage are available. Additively, equipment leaks are available in spite of not having a special emission factor in the literature.

There are also 8 coal screening plants in Aliaga. In 4 of them, coal drying which is one of the processes that causes NMVOC emissions, is applied besides the breaking and screening processes.

Besides these plants, there are also other various industrial activities in Aliaga like ship breaking, mineral oil, paper production, etc. which are also considered in the study. It was assumed that, there was no evaporation in mineral oil facilities because of using heavy oils, so there were no NMVOC emissions. Emission factors for ship breaking facilities could not be found in the literature, so this industry type was neglected in the study. The literature (EEA, 2009; IPPC, 2009; USEPA, 2009) points out that paper industries had the considerable VOC emissions from pulp production. But the paper factory in Aliaga does not produce pulp, they buy the pulp from an other company; so these emissions were neglected in the study. The NMVOC emissions from printing units were also neglected in the study.

### **3.2 Emission Estimations**

Eight different industrial sectors were mainly considered as NMVOC sources in the town. These were oil refinery, petrochemical, chemical, iron and steel, liquid fuel storage and loading, LPG storage and loading, coal drying, and electricity production sectors. Besides these, there were also other various facilities in Aliaga like ship breaking, mineral oil, paper, and etc. production subjects which were also considered in the study. They were counted under “others” title as a ninth sector in the study.

NMVOC emissions were calculated in five different classes. These were emissions from process, combustion, storage tanks, liquid loading facilities and

equipment leaks (Table 3.2). Process emissions referred to NMVOC emissions those came into being during the main process of the facility. As an example those could be the NMVOC emissions while the scrap iron was melted in the arc furnace in iron and steel industries. Combustion emissions referred to the emissions from boilers in plants. There was an exception for electricity production plants that their emissions were considered as process emissions although they came from combustion; because it was the main process of these plants. On the other hand, combustion emissions referred to the emissions from small boilers generally for heating. Both of these emissions (i.e., process and combustion) originated from almost every plant. But emissions from storage tanks, liquid loading and equipment leaks came only from oil refinery, petrochemical industry, liquid fuel storage and loading facilities and a few chemical plants. LPG storage and loading facilities had only equipment leak emissions besides the bottle painting emissions. There was not a different emission class for bottle painting emissions; they were considered as process emissions for LPG storage and loading facilities in this study.

In the study, process, combustion and equipment leak emissions were calculated by using emission factors from the literature (EEA, 2009; IPPC, 2009; USEPA, 2009). Emissions from storage tanks were calculated by using a software, called TANKS 4.0, which was produced by USEPA and liquid loading emissions were calculated by using a special method (USEPA, 1995d) from USEPA again (Table 3.1).

Table 3.1 Methods used in emission estimations.

	Emission Factors Method	Computer Software (TANKS 4.0)	Emission Factors Based Liquid Loading Method
Process Emissions	X		
Combustion Emissions	X		
Storage Tanks Emissions		X	
Liquid Loading Emissions			X
Equipment Leaks Emissions	X		

Table 3.2 Classification of emissions according to industrial sectors.

Sectors	Sources of Emissions				
	Process	Combustion	Storage Tanks	Liquid Loading	Equipment Leaks
Chemical Processes	X	X			
Coal Drying	X				
Electricity Production	X				
Iron and Steel Production	X				
Liquid Fuel Storage and Loading		X	X	X	X
LPG Storage and Loading	X				X
Petrochemical Production		X	X	X	X
Oil Refinery		X	X	X	X
Other		X			

### ***3.2.1 Combustion Emissions of an Oil Refinery and a Petrochemical Plant***

There were 2 major plants in Aliğa; an oil refinery and a petrochemical plant which promoted the town to be an important industrial zone. Both of them had large amount of working capacities with a vast number of process flows. Upon their requests, stack emissions coming from combustion activities in the facilities were measured by Air Pollution Laboratory staff of Dokuz Eylül University Environmental Engineering Department in the past. The emission measurement methods, used in those studies, based on the Turkish standard called TS EN 13649 (TSE, 2003). According to this standard, the sample was taken from the stack by using a sorbent tube which had activated carbon as an adsorbent in itself. Then in the laboratory, the sample was desorbed and analyzed in the gas chromatograph. Both studies were very detailed and reliable studies; so that their emission results were considered as combustion emissions of those industries instead of new calculations in this study.

### 3.2.2 Emission Estimations Using Emission Factors

In the study, related documents of IPPC (European Commission Integrated Pollution Prevention and Control), USEPA (United States Environmental Protection Agency), EEA (European Environment Agency) and IPCC (Intergovernmental Panel on Climate Change) were examined. The emission factors were taken mainly from EEA EMEP/Corinair and USEPA AP-42 databases and Industrial Air Pollution Control Turkish Regulation.

Emission factors were used in the study to estimate emissions from process, combustion and pipeline equipment leaks. All of these factors, used in the study, were tabled below in Tables 3.3 to 3.8.

Table 3.3 Process emission factors for the industries in Aliğa.

Industrial Sector	Process Name	NMVOE Emission Factor	Source
Iron and Steel Production	Electric Arc Furnace	0.046 kg ton <sup>-1</sup> steel produced	EEA, 2009
	Hot Rolling Mills	0.007 kg ton <sup>-1</sup> steel produced	EEA, 2009
Coal Drying	Coal Drying	0.196 kg ton <sup>-1</sup> coal	USEPA, 2009
Chemistry	Paint, ink production	11.00 kg ton <sup>-1</sup> product	EEA, 2009
	Chemicals production	10.00 kg ton <sup>-1</sup> product	EEA, 2009
Solvent Reclamation	Storage tank vent	0.010 kg ton <sup>-1</sup> reclaimed solvent	EEA, 2009
	Condenser vent	1.650 kg ton <sup>-1</sup> reclaimed solvent	EEA, 2009
	Fugitives-spillage	0.100 kg ton <sup>-1</sup> reclaimed solvent	EEA, 2009
	Fugitives-loading	0.360 kg ton <sup>-1</sup> reclaimed solvent	EEA, 2009
Electricity and Heat Production	Gas turbines	0.001 kg GJ <sup>-1</sup> natural gas	EEA, 2009
	Reciprocating engines	0.046 kg GJ <sup>-1</sup> natural gas	EEA, 2009
Painting Applications	Industrial paint application	400 kg ton <sup>-1</sup> paint applied	EEA, 2009

Table 3.4 Combustion emission factors for the industries in Aliaga (EEA, 2009).

Fuel Name	NMVOC Emission Factor
Coal	88.80 g GJ <sup>-1</sup>
Fuel Oil	10.00 g GJ <sup>-1</sup>
Diesel	10.00 g GJ <sup>-1</sup>
LPG	10.00 g GJ <sup>-1</sup>
Natural Gas	2.50 g GJ <sup>-1</sup>

Table 3.5 Some properties of fuel types used in the study (USEPA, 2009).

Fuel Name	Heating Value (kcal m <sup>-3</sup> ) *	Density (ton m <sup>-3</sup> )
Coal	3,990,000	-
Fuel Oil	9,120,000	0.944
Diesel	9,120,000	0.845
LPG	6,250,000	0.550
Natural Gas	9,350	-

\*Unit of coal heating value is kcal ton<sup>-1</sup>, the other fuels' are kcal m<sup>-3</sup>.

Table 3.6 Equipment leak emission factors for refinery and liquid fuel loading facilities (USEPA, 1996; SKHKKY, 2009).

Equipment Type	Service	Emission Factor (kg (hour source) <sup>-1</sup> )
Valves	Gas	0.02680
	Light Liquid	0.01090
	Heavy Liquid	0.00023
Pump Seals	Light Liquid	0.11400
	Heavy Liquid	0.02100
Compressor Seals	Gas	0.63600
Pressure Relief Valves	Gas	0.16000
Connectors	All	0.00025
Open-Ended Lines	All	0.00230
Sampling Connections	All	0.01500

Table 3.7 Equipment leak emission factors for LPG loading facilities (USEPA, 1996; SKHKKY, 2009).

Equipment Type	Emission Factor (kg (hour source) <sup>-1</sup> )
Valves	0.00560
Safety Valves	0.10400
Open-Ended Lines	0.00170
Connectors	0.00083

Table 3.8 Equipment leak emission factors for petrochemical industry (USEPA, 1996; SKHKKY, 2009).

Equipment Type	Service	Emission Factor (kg (hour source) <sup>-1</sup> )
Valves	Gas	0.00597
	Light Liquid	0.00403
	Heavy Liquid	0.00023
Pump Seals	Light Liquid	0.01990
	Heavy Liquid	0.00862
Compressor Seals	Gas	0.22800
Pressure Relief Valves	Gas	0.10400
Connectors	All	0.00183
Open-Ended Lines	All	0.00170
Sampling Connections	All	0.01500

### 3.2.3 Emission Estimations Using TANKS 4.0 Software

In this study, Version 4.0 of TANKS Software (TANKS 4.0) was used to calculate the NMVOC emissions for tank farms and single tanks of liquid fuel storage and loading facilities, petrochemical industry and oil refinery. The software is installed from TANKS Software Web Site (USEPA, 2010a) and the working principle is studied from both the User's Manual of the software and "Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources" (AP-42), Section 7.1, Organic Liquid Storage Tanks (USEPA, 1995c).

The meteorological data of Aliğa which were obtained from Turkish Meteorological Data Archive System (TÜMAS, 2010) were presented in Table 3.9. These data were required to run TANKS 4.0 and calculate the emissions from storage tanks. Table 3.10 showed the same data converted to the units used in the software. Other required data like dimensions, shell and roof characteristics and breather vent settings of the tank, and the properties of the tank liquid were obtained from questionnaires for mentioned plants. Default values of the software were used instead of the missing data.

The NMVOC emissions from storage tanks were estimated for an annual period using the software. The results were in lbs year<sup>-1</sup> unit; then converted to tons year<sup>-1</sup>.

Table 3.9 Meteorological parameters of Aliğa according to the months of year 2009. (TÜMAS, 2010)

Months	Average monthly temperature (°C)	Minimum monthly temperature (°C)	Maximum monthly temperatures (°C)	Average wind speed (m s <sup>-1</sup> )	Average pressure (mBar)	Solar Insolation Value* (hour day <sup>-1</sup> )
January	9.2	3.0	14.9	3.3	1013.4	4.2
February	9.0	4.3	16.8	3.7	1008.3	3.8
March	10.7	5.6	17.9	2.9	1010.1	6.0
April	14.7	11.0	17.8	2.4	1010.9	7.4
May	19.9	15.5	24.0	2.7	1011.3	11.3
June	24.7	19.7	28.4	3.2	1008.3	12.7
July	27.3	25.2	29.5	3.5	1006.6	12.8
August	26.2	23.2	28.6	3.9	1007.8	12.2
September	21.8	18.5	25.4	2.9	1010.8	9.1
October	19.7	13.5	23.4	2.8	1010.9	7.2
November	13.8	9.2	18.9	2.5	1014.1	6.3
December	12.2	6.5	17.8	3.2	1008.6	2.6

\*These values belong to Dikili station, because DMİ (Turkish State Meteorological Service) does not measure this parameter in Aliğa station.

Table 3.10 Meteorological parameters of Aliğa according to the months of year 2009 in British unit system.

Months	Average monthly temperature (F)	Minimum monthly temperature (F)	Maximum monthly temperatures (F)	Average wind speed (mph)	Average pressure (psi)	Solar Insolation Value* (Btu (ft <sup>2</sup> day) <sup>-1</sup> )
January	48.6	37.4	58.8	7.4	14.7	1332.3
February	48.2	39.7	62.2	8.3	14.6	1205.4
March	51.3	42.1	64.2	6.5	14.7	1903.3
April	58.5	51.8	64.0	5.4	14.7	2347.3
May	67.8	59.9	75.2	6.0	14.7	3584.5
June	76.5	67.5	83.1	7.2	14.6	4028.6
July	81.1	77.4	85.1	7.8	14.6	4060.3
August	79.2	73.8	83.5	8.7	14.6	3869.9
September	71.2	65.3	77.7	6.5	14.7	2886.6
October	67.5	56.3	74.1	6.3	14.7	2283.9
November	56.8	48.6	66.0	5.6	14.7	1998.4
December	54.0	43.7	64.0	7.2	14.6	824.7

\* These values belong to Dikili station, because DMI (Turkish State Meteorological Service) does not measure this parameter in Aliğa station.

### ***3.2.4 Emission Estimations Using Liquid Loading Method***

The emission calculation method in the document of “Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, (AP-42), Section 5.2, Transportation and Marketing of Petroleum Liquids (USEPA, 1995d)” was used in the study to estimate the NMVOC emissions from liquid loading facilities of oil refinery, petrochemical industry and liquid fuel storage and loading plants. The information about amounts of loaded liquids and the types of loading were obtained from questionnaires for some plants; and the others were taken from previous studies achieved by Dokuz Eylül University Environmental Engineering Department.



### 3.3 Dispersion Modeling

The second part of this study contained the dispersion modeling of the emissions calculated in this study. One of the objectives of this study was to investigate the contribution of the calculated emissions to the air quality under the meteorological and topographical conditions of the study area. With this objective, the Industrial Source Complex Short Term Model (ISCST3) of USEPA was used to estimate the dispersion of industrial based VOCs on Aliğa in this study. The required input data were obtained from questionnaires again. The geographical coordinates of the plants and the lengths of area source borders were identified by using Google Earth and previous studies of DEÜ Environmental Engineering Department. The topographical data were prepared from a digital map of Aliğa town. As the meteorological data for the model, data of Aliğa Horozgediği meteorological station which had been used before in previous studies of DEÜ, was used.

The model was run for an area of 30 km x 30 km with a spatial resolution of 1 km. The hourly emissions were estimated for a whole year.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 Results of Emission Inventory

At the beginning of the study, several lists from different corporations (i.e. Aliğa Municipality, İzmir Provincial Environmental Directorate and Chamber of Commerce of Aliğa) which included the industrial facilities in Aliğa were compared. Some facilities in the town, not emitting NMVOC emissions according to literature (Derwent, 1995; Passant, 1995) were ignored in the study. The required information of others were obtained by using questionnaires. Some missing information of the considered facilities after having the questionnaires back, were estimated by comparing the related information of similar plants. Besides this, for a few plants no information could be obtained; these plants were also ignored in the study.

The number of considered facilities was 50 in this study. Their calculated NMVOC emissions were given in Table 4.1 without specifying the names of the companies. As a result of calculations, the value of total NMVOC emissions from industrial facilities in Aliğa was 9,700 tons year<sup>-1</sup>. In a previous study (Müezzinoğlu et al., 2000) NMVOC emissions were found as 10,650 tons year<sup>-1</sup> in Aliğa from 18 industrial plants. When that study was achieved, industrial plants in Aliğa were using heavy fossil fuels instead of natural gas; so that the value is greater than our value, although the considered plant number is higher in our study.

According to Table 4.1, the highest value of NMVOC which come from only one plant was 3,741.41 tons year<sup>-1</sup> from Petrochemical Plant. Second highest value belonged to Oil Refinery with 3,254.34 tons year<sup>-1</sup>, and the third one is Chemical Plant-1 with 540.44 tons year<sup>-1</sup>. Similarly, the lowest value belongs to Other Plant-8 with 4.4E-5 tons year<sup>-1</sup>. This plant has a very small boiler and no emissions from process, so that the emission values are so small.

Table 4.1 Calculated NMVOC emissions of industrial facilities in Aliaga.

<b>Plant Name</b>	<b>NMVOC Emissions (tons year<sup>-1</sup>)</b>
Chemical-1	540.44
Chemical-2	0.59
Chemical-3	23.07
Chemical-4	63.06
Chemical-5	141.40
Coal drying-1	1.88
Coal drying-2	16.93
Coal drying-3	7.84
Coal drying-4	36.29
Iron and Steel-1	1.40
Iron and Steel-2	1.63
Iron and Steel-3	0.12
Iron and Steel-4	34.61
Iron and Steel-5	1.27
Iron and Steel-6	95.37
Iron and Steel-7	1.75
Iron and Steel-8	117.73
Iron and Steel-9	67.24
Iron and Steel-10	1.16
Iron and Steel-11	0.65
Iron and Steel-12	2.23
Iron and Steel-13	1.97
Iron and Steel-14	34.94
Iron and Steel-15	0.51
Liquid loading-1	184.27
Liquid loading-2	79.01
Liquid loading-3	85.49
Liquid loading-4	355.30
Liquid loading-5	217.28
LPG loading-1	4.26
LPG loading-2	102.59
LPG loading-3	18.56
LPG loading-4	79.58
LPG loading-5	33.21

Table 4.1 Calculated NMVOC emissions of industrial facilities in Aliaga (continue).

Plant Name	NMVOC Emissions (tons year <sup>-1</sup> )
LPG loading-6	49.55
LPG loading-7	21.55
Oil Refinery	3,254.34
Petrochemical	3,741.41
Power plant-1	126.29
Power plant-2	5.61
Power plant-3	86.59
Other-1	0.09
Other-2	3.28
Other-3	0.11
Other-4	0.21
Other-5	0.03
Other-6	0.02
Other-7	14.08
Other-8	4.4E-5
Other-9	1.14
<b>TOTAL</b>	<b>9,657.91</b>

The results can be assessed by distributing the emissions according to industrial sectors as shown in Figure 4.1. According to this chart, the highest NMVOC emissions come from petrochemical industry with 39% (3,741.41 tons year<sup>-1</sup>). Oil refinery follows it with a percentage of 34% (3,254.34 tons year<sup>-1</sup>). The third highest value belongs to the liquid fuel storage and loading sector with 9% (921.34 tons year<sup>-1</sup>) and plants with chemical processes followed them with 8% (768.56 tons year<sup>-1</sup>). Others had very small percentiles compared with these four sectors (Figure 4.1).

As mentioned in Chapter 3, there is a solvent reclamation plant in Aliaga. But its NMVOC emissions were too small to be categorized separately so that it was added to “other” sector.

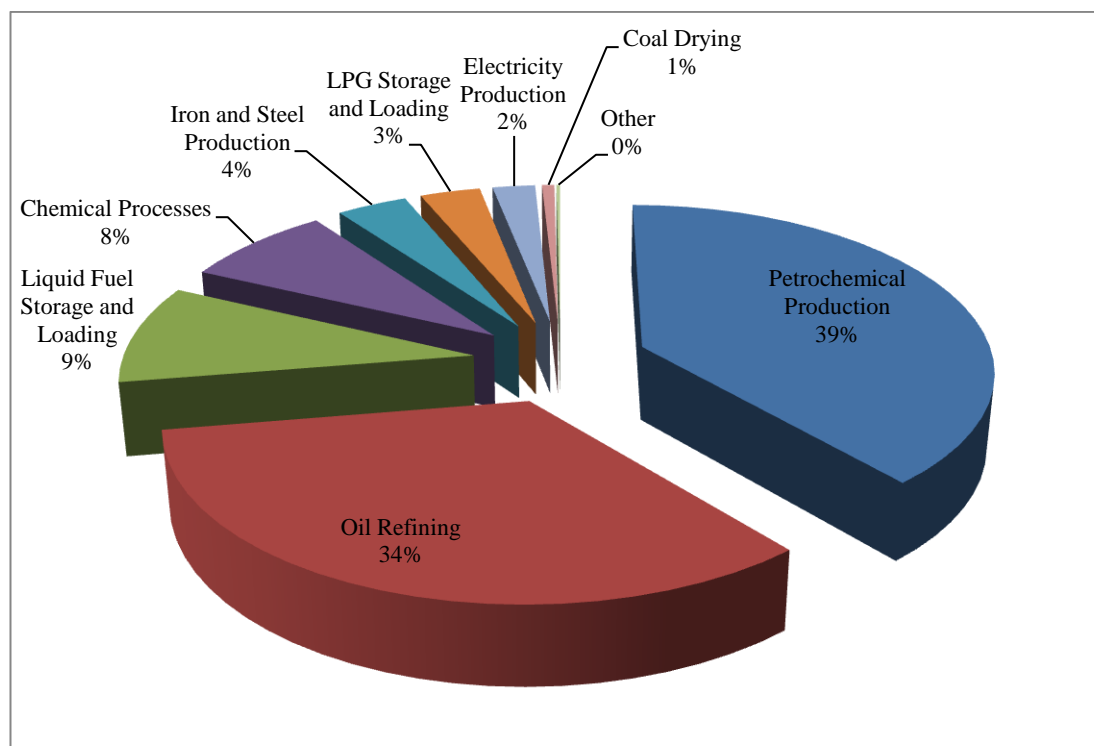


Figure 4.1 Percentage distribution of NMVOC emissions according to different industrial sectors in Aliaga.

During the calculations, NMVOC emissions were divided into 5 parts according to their sources. These were emissions from process, combustion, storage tanks, liquid loading and equipment leaks. At the end of the calculations, storage tanks were found to be the most important NMVOC emitters with  $3,250 \text{ tons year}^{-1}$ . Equipment leaks ( $2,750 \text{ tons year}^{-1}$ ), liquid loading ( $1,925 \text{ tons year}^{-1}$ ), process ( $1,650 \text{ tons year}^{-1}$ ) and combustion ( $95 \text{ tons year}^{-1}$ ) emissions followed storage tanks respectively (Figure 4.2).

The main contributor of storage tanks emissions was the petrochemical industry with  $2,600 \text{ tons year}^{-1}$  and oil refinery followed it with  $350 \text{ tons year}^{-1}$  (Figure 4.3). There was a big difference between these two large industries, because organic chemicals released much more VOC than the petroleum distillates according to the TANKS Software. The main storage liquids were organic liquids in petrochemical industry, while in refinery they were petroleum distillates. So, the emissions from storage tanks were higher in petrochemical industry than the oil refinery.

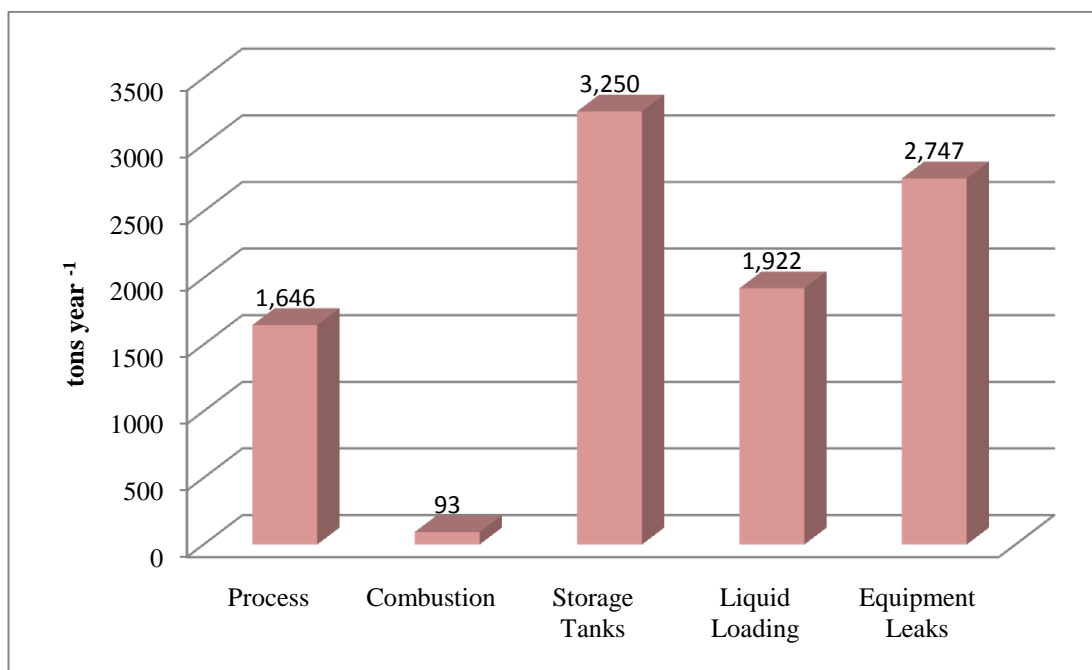


Figure 4.2 Distribution of NMVOC emissions in tons year<sup>-1</sup>, according to pollution sources considered in the study.

When the equipment leaks emissions, which was the second highest category, was examined, the oil refinery was the main contributor with 2,000 tons/year that equalled to 70 percentile (Figure 4.4). Petrochemical industry followed it with 700 tons/year. The difference was because of the high equipment (i.e, valves, flanges and etc.) numbers in oil refinery.

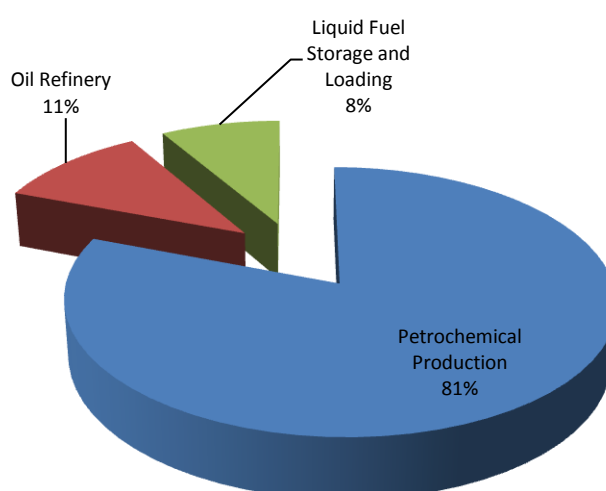


Figure 4.3 Distribution of storage tanks emissions

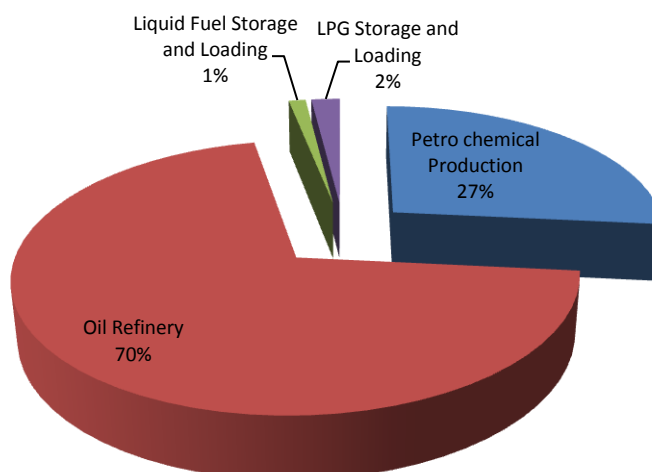


Figure 4.4 Distribution of equipment leaks emissions

The third highest emission class was liquid loading with an approximate total value of 2,000 tons year<sup>-1</sup>. 51 percent of this value belonged to oil refinery; 32 percent belonged to liquid fuel loading and storage facilities, and the remainder came from petrochemical industry (Figure 4.5). The sequence was directly proportional to loaded liquid volumes.

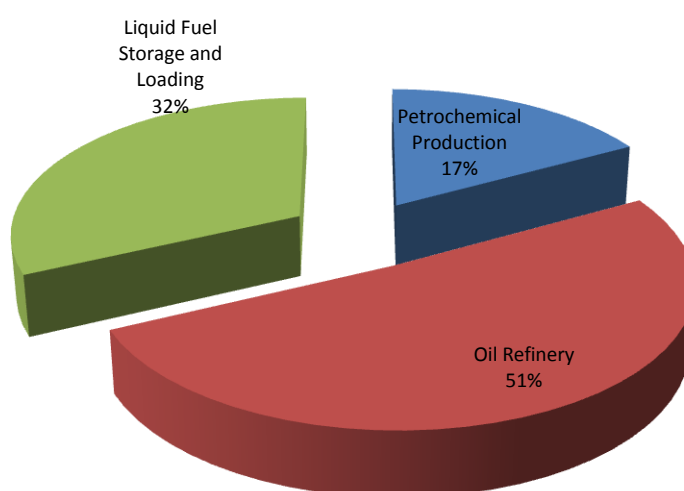


Figure 4.5 Distribution of liquid loading emissions

An emission map (Figure 4.6) was also created with the estimated emissions by using a geographical information system (GIS) software, called ArcGIS. In that map, the total emissions were presented in a spatial resolution of 250 m. According to Figure 4.6, the maximum emissions per grids were seen in a few points in ALOSBI, but mainly in the peninsula of oil refinery, petrochemical industry and fuel loading facilities. The maximum value per a grid was 541 tons year<sup>-1</sup>.

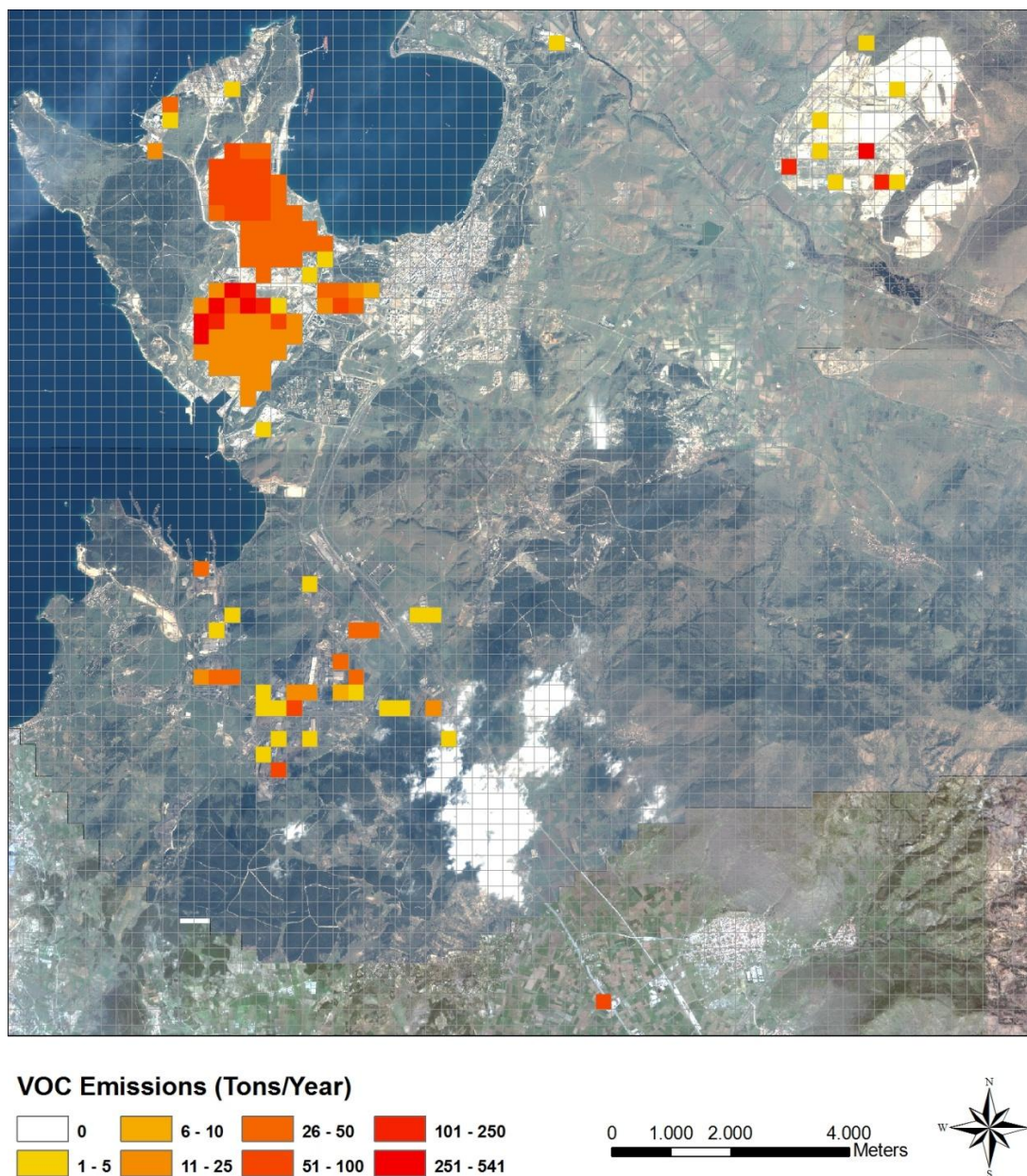


Figure 4.6 Map of estimated emissions coming from grids of 250 m to 250 m.



## 4.2 Results of Dispersion Modeling

As the second part of the study, after the calculations, the emission values were put into the ISCST3 Model, and under the certain meteorological and topographical conditions, the dispersion of the emissions in the atmosphere, and the effects on air quality of Aliaga were estimated.

When the data were evaluated in annual period, the highest concentration was found as  $859.7 \mu\text{g m}^{-3}$  in the X, Y coordinates of (495000, 4292000) and according to the Figure 4.7, the maximum concentrations were around that point, as a result of the presence of oil refinery, petrochemical industry, liquid and LPG fuel storage and loading facilities there. The smaller polluted area, on the right side of the map, pointed at Aliaga Organized Industrial Site (ALOSBI). There were several important chemical processes which were available there. The NMVOC concentrations there were also significant and about  $200 \mu\text{g m}^{-3}$ .

When the national regulation (SKHKKY, 2009) was examined, two different types of limit values could be seen; those were short-term limit values (KVS) and long-term limit values (UVS). There short-term limit values referred to the hourly and daily values, while long-term limit values referred to the annual values. When the SKHKKY (2009) was examined, there were two important UVS values for NMVOC concentrations in our study. One of them was the value of  $500 \mu\text{g m}^{-3}$  which was determined for the inside area of oil refineries, petrochemical industries and fuel storage facilities; and the other one was the value of  $90 \mu\text{g m}^{-3}$  which indicated the NMVOC concentrations in the influence area of the same industrial sectors.

When Figure 4.7 was evaluated according to SKHKKY, it could be seen that the limit value of  $500 \mu\text{g m}^{-3}$  was exceeded in some areas. When the influence area was considered as a 2 km distance from the plants, the concentration values were again exceeded the limit value of  $90 \mu\text{g m}^{-3}$ . There, the values were about  $200 \mu\text{g m}^{-3}$  according to the Figure 4.7.

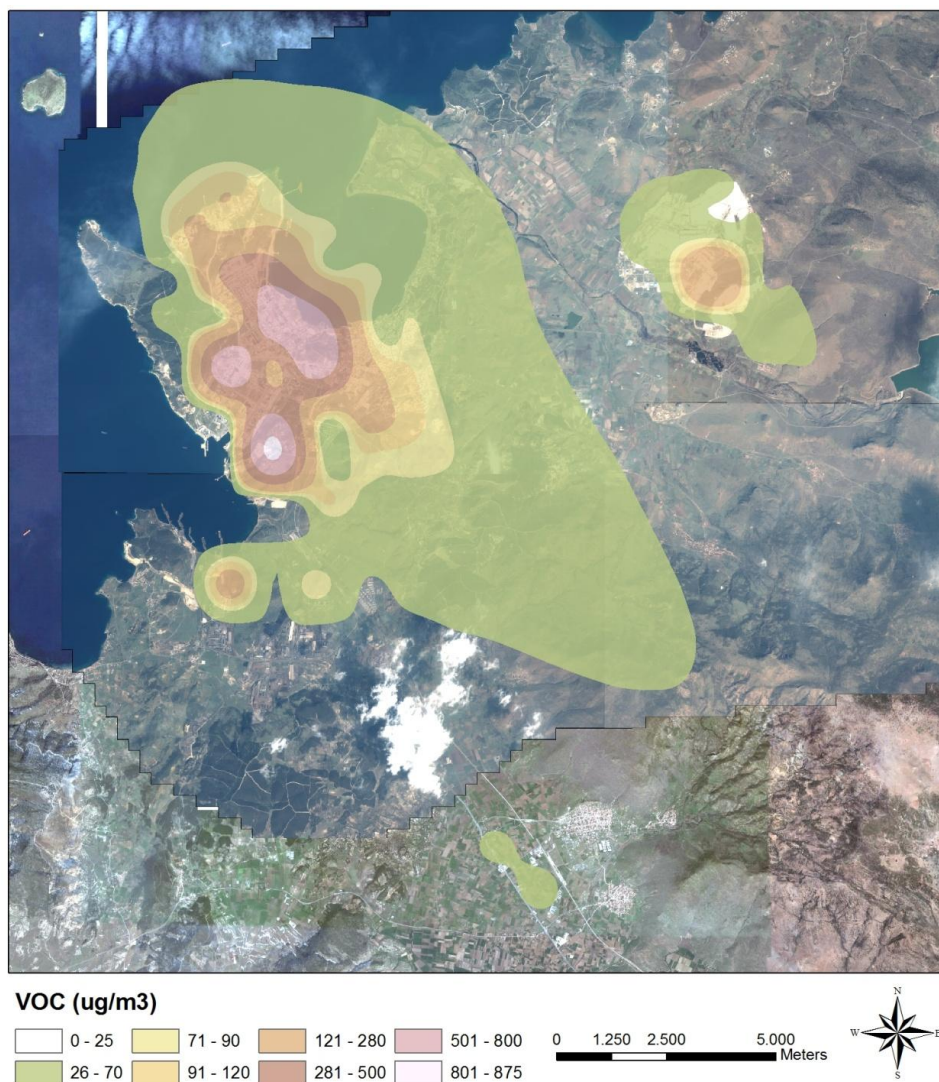


Figure 4.7 Map of model results, annual average NMVOC concentrations in Aliaga atmosphere.

In Figure 4.8, the emissions and their dispersions could be seen. The emissions of the refinery and petrochemical industry were the highest, so the concentrations were very high in that peninsula. The dominant wind directions were southeast and eastsoutheast (Figure 4.9); so a large part of emissions dispersed in those directions. But also there were winds in north directions, so a smaller part of emissions also dispersed in those directions. For ALOSBI also the same comments could be made. In the same figure, it could also be seen that there were emissions from iron and steel plants. But their emissions were in low values compared with the emissions in the peninsula; so their dispersion concentrations were about  $10\text{-}20\ \mu\text{g}\cdot\text{m}^{-3}$ ; so they could not be seen on the figure.

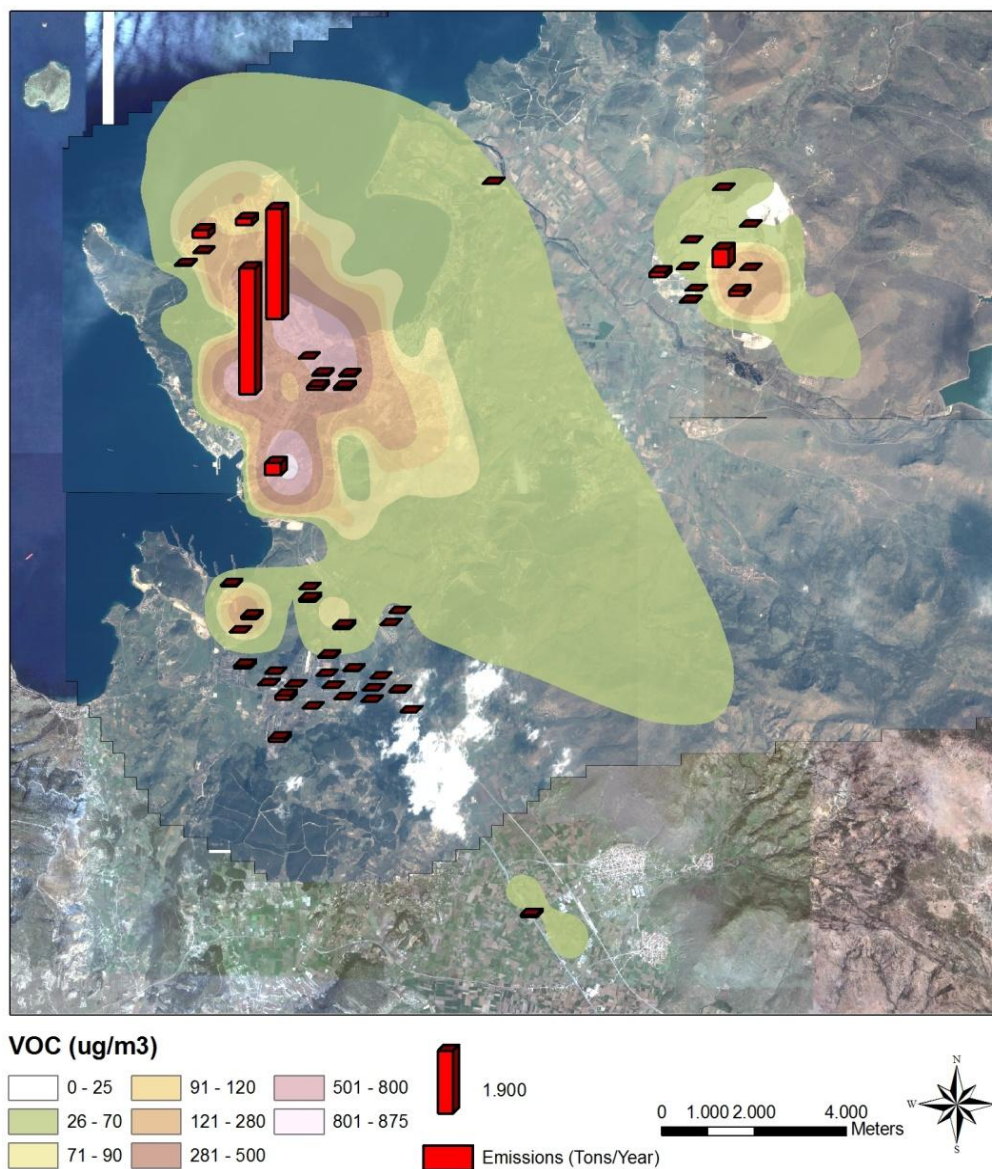


Figure 4.8 Emissions and their dispersions in the study area

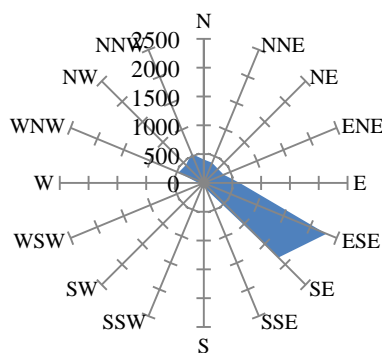


Figure 4.9 Wind rose of Horozgediği meteorological data

In an ongoing study, passive sampling measurements were achieved to determine the NMVOC emissions in a similar study area in Aliğa (DEÜ, 2010). When those results (Figure 4.10) were compared with Figure 4.6, it could be seen that the highest NMVOC concentrations were measured around the petrochemical industry and oil refinery as they were found in our study, as a result of modeling study. The concentration values in both studies were found similar. That means the emission calculations and modeling studies in our study were reliable.

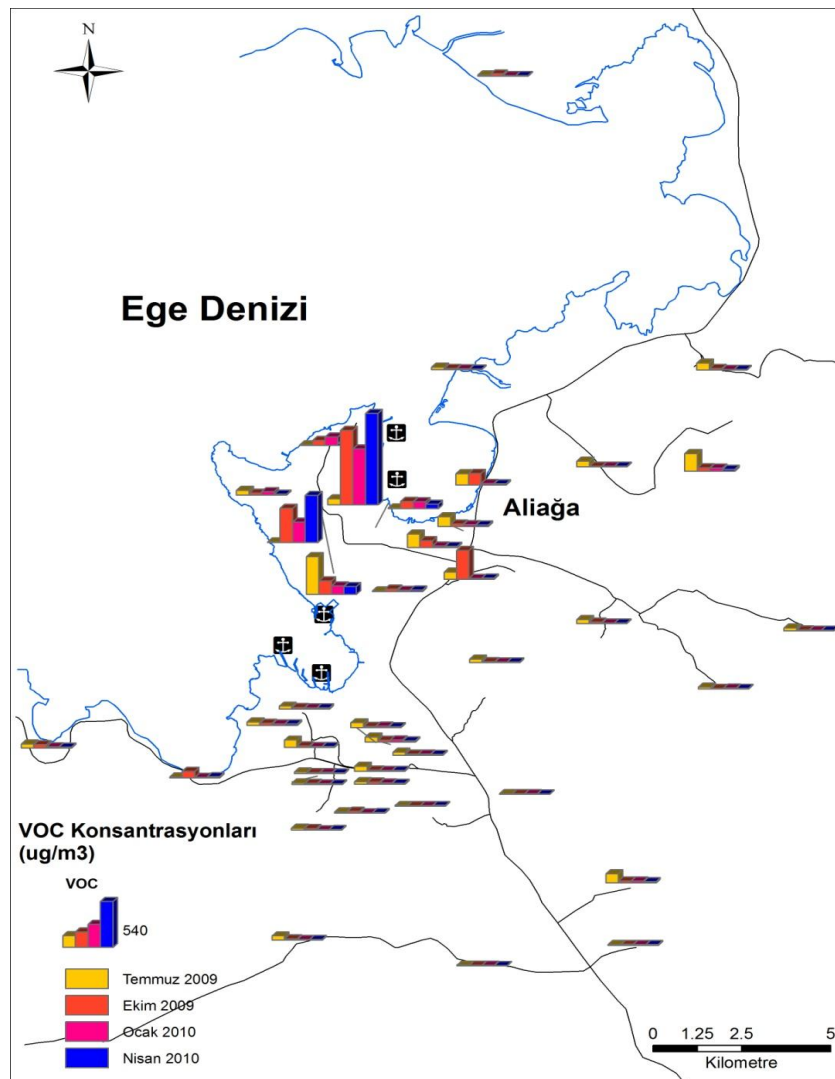


Figure 4.10 Results of passive sampling measurements of an ongoing study (DEÜ, 2010)

## CHAPTER FIVE

### CONCLUSIONS

This was an emission inventory preparation study for nonmethane volatile organic compounds (NMVOCs) which were emitted from industrial facilities in Aliaga. With this scope, three calculation methods (i.e., emission factors, TANKS software and petroleum products loading method of USEPA) were used to calculate NMVOC emissions from various types of industrial facilities. After the generation of the inventory, a simple dispersion modeling study was also achieved by using ISCST3 model of USEPA.

In the study area there were 50 industrial plants which emitted NMVOC emissions in significant amounts. These plants were grouped under 9 industrial sectors; chemical processes, coal drying, electricity production, liquid fuel storage and loading, iron and steel production, LPG storage and loading, petrochemical production, oil refinery and others.

The total NMVOC emissions from this 50 plants were calculated as 9,700 tons year<sup>-1</sup>. The highest NMVOC emissions were coming from petrochemical production, oil refining and liquid fuel storage and loading sectors. The model results also pointed that conclusion by exceeding the limits in national regulation around those industrial facilities. Petrochemical production and oil refining industries generated 73% of total NMVOC emissions together with their emissions from stacks, storage tanks, liquid loading facilities and equipment leaks.

The highest NMVOC emissions were coming from storage tanks with a value above 3,000 tons year<sup>-1</sup>. The main sectors in charge were petrochemical production and oil refining here. Then the equipment leaks and liquid loading emissions followed them respectively with emission values approximately 2,750 and 2,000 tons year<sup>-1</sup>. Fuel storage and loading sectors (i.e., both liquid and gaseous fuels) contributed to these emissions besides the petrochemical and oil refining industries.

In the study the emission factors were selected with an assumption that the industries did not have any emission control systems; so that the real emission values could be lower than the calculated values.

According to ISCST3 model results, the highest pollution concentrations occurred around the petrochemical and oil refining facilities. The liquid and gaseous fuel storage and loading facilities were also around that area. Also the facilities which had chemical processes like various chemicals and paints production, located in the organized industrial region (ALOSBI), contributed negative impact on air quality. The effects of iron and steel plants were so small compared with the other sectors that their concentrations were not seen in the dispersion map.

For possible further studies, the advices which are given below can be considered.

- The emissions coming from ship breaking activities can be added.
- The recent process and emission information of industries can be available in governmental agencies.
- National emission factors for various industrial processes for “controlled” situations can be created.
- A more comprehensive inventory can be prepared to see the change of emissions in shorter time periods (e.g., monthly or seasonal changes in emissions).

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**APPENDIX-A**  
**The questionnaires used in the study**

**ALIAĞA ÇEVRE DURUM TESPİTİ PROJESİ**  
**SANAYİCİ ANKETİ**  
*ENVIRONMENTAL ASSESSMENT PROJECT OF ALIAĞA*  
*INDUSTRIALIST QUESTIONNAIRE*

**1. Genel Bilgiler/General Information**

TESİS ADI / *PLANT NAME* : .....

FAALİYET TÜRÜ/SEKTÖRÜ / *TYPE OF ACTIVITY* : .....

ADRES / *ADDRESS* : .....

TESİSİN COĞRAFİ KOORDİNATLARI / *GEOGRAPHICAL COORDINATES OF THE PLANT(m)* : .....

SORUMLU KİŞİ / *CONTACT PERSON* : .....

E-Posta / *E-mail* : .....

TELEFON / *TELEPHONE* : .....

FAX / *TELEFAX* : .....

**2. Üretim Bilgileri / Production Information**

TESİSİN KURULUŞ TARİHİ / *ESTABLISHMENT DATE OF PLANT* : .....

TESİSİN ÜRETİM TÜRÜ / *PRODUCTION TYPE OF PLANT* : .....

KURULUŞ KAPASİTESİ / *ESTABLISHED CAPACITY* : .....

ÜRETİMDE KULLANILAN TEKNOLOJİ / *PRODUCTION TECHNOLOGY* : .....

MEVCUT ÇALIŞMA KAPASİTESİ / *WORKING CAPACITY* : .....

TESİSİN ÇALIŞMA SÜRELERİ / *WORKING PERIODS*

Günlük (saat/gün) / *Daily (hour/day)* : .....

Haftalık (gün/hafta) / *Weekly (day/week)* : .....

Yıllık (gün/yıl) / *Annual (day/year)* : .....

**TESİSTE ÇALIŞAN PERSONEL SAYISI / PERSONNEL NUMBER OF THE PLANT**Vardiyasız personel sayısı / *Number of shiftless personnel* :1.vardiya / *1.shift* ..... saatlerinde / *hours* ..... kişi / *person*2.vardiya / *2.shift* ..... saatlerinde / *hours* ..... kişi / *person*3.vardiya / *3.shift* ..... saatlerinde / *hours* ..... kişi / *person***ÜRETİM MİKTARLARI / AMOUNTS OF PRODUCTION**

Ürün tipi / <i>Type of Product</i>	Üretim miktarı / <i>Production Amount</i>

**KULLANILAN HAMMADDELER VE TÜKETİM MİKTARLARI /  
RAW MATERIALS AND CONSUMPTION AMOUNTS**

Hammadde / <i>Raw Material</i>	Tüketim miktarı / <i>Consumption Amount</i>

**KULLANILAN ENERJİ MİKTARLARI / ENERGY CONSUMPTIONS**

Tesiste Kullanılan Elektrik Enerjisi Miktarı / <i>Electrical Energy Consumption of Plant</i>			
Günlük / Daily	Aylık / Monthly	Yıllık / Annual	Birim ürün başına / Per unit product

**PROSES AKIM ŞEMASI / PROCESS FLOW DIAGRAM**(lütfen tesisin proses akım şemasını ankete ekleyiniz/ *please attach the process flow diagram of the plant to the questionnaire*)

**Tesisin “Sanayi Kaynaklı Hava Kirliliğinin Kontrolü Yönetmeliği” ile ilgili Bilgileri / Information About “Industrial Based Air Pollution Control Regulation”**

Yönetmelik kapsamında “İzne Tabi Tesis” ise Yönetmelik Ek-8 listesindeki yeri / Location in the list of Appendix-8 of the regulation, if the plant “subjects to permission” according to the regulation : .....

Tesisin yönetmelikte yer alan Ek-5 listesindeki yeri/yerleri / Location of the plant in the list of Appendix-5 of the regulation: .....

Emisyon İzni varsa tarihi / The date of Emission Permission if it is available: .....

**KULLANILAN YAKMA TESİSİNE AİT BİLGİLER / INFORMATION ABOUT COMBUSTION SYSTEM**

Yakma Tesisi No / Combust. System No	Yakma tesisi tipi / Type of Comb. System	Yakıt türü / Fuel type	Yakma Tesisi Gücü / Power of Comb. System			Günlük Yakıt tüketimi / Daily Fuel Consumption		Çalışma süresi (saat/gün) Working period (hour/day)
			Isıl güç / Heating power MW	Kcal/saat (Kcal/hour)	Buhar ton/saat Vapor tons/hour	Miktar / Amount	Birim / Unit	
1								
2								
3								
4								
5								

Yakma tesisi tipleri / Types of combustion system:

1: Kalorifer / Central heating; 2: Buhar kazanı / Steam boiler; 3: Kızgın yağ kazanı / Hot oil boiler, 4: Kojenerasyon / Cogeneration

Yakıt türleri / Types of fuel:

1: Kömür / Coal; 2: Fuel oil / Fuel oil; 3: Motorin / Diesel; 4: LPG / LPG ; 5: Doğal gaz / Natural gas; 6: Pirina / Olive pomace; 7: Diğer / Other

Not: Varsa yakıt analiz belgesini ankete ekleyebilirsiniz.

Note: If it is available, you can attach your certificate of fuel analysis to the questionnaire.



**BACA ÖZELLİKLERİ / STACK PROPERTIES**

Baca No / Stack No	Baca yüksekliği / Stack height (m)	Baca çıkışı iç çapı / Stack outlet inner diameter (m)	Atık Gaz debisi (Nm <sup>3</sup> /saat) Waste gas flow (Nm <sup>3</sup> /hour)	Gaz çıkış sıcaklığı / Gas exit temp. (°C)	Kontrol teknolojisi (varsa) / Control technology (if available)	Bacanın Bağlı Olduğu kazan no yada proses / Boiler or process name of the stack
1						
2						
3						
4						
5						
6						
7						

Baca gazları için kullanılan kontrol teknolojisi / Available control technology for stack gases:

- 1: Siklon / Cyclone      2: Islak tutucu / Wet collector      3: Torba filtre / Bag filter  
4: Elektrostatik filtre / Electrostatic filter

**EMİSYONLARLA İLGİLİ BİLGİLER / INFORMATION ABOUT EMISSIONS**

Baca No / Stack No	Emisyonların kütleli debileri (kg/saat) / Mass flows of emissions (kg/hour)					
	CO	SO <sub>2</sub>	NOx	Toz / Particulate Matter	VOC	Diğer / Other
1						
2						
3						
4						
5						
6						
7						

Not: Daha fazla sayıda bacanız varsa ekleme yapabilirsiniz.

Note: You can attach if there are more stacks.

**DEPOLAMA TANKLARI ANKETİ**  
**STORAGE TANKS QUESTIONNAIRE**

**Tesis Adı / Plant Name :**

**1. Tesisteki Depolama Tanklarına Ait Bilgiler / Information About Storage Tanks in the Plant**

Tesisteki Tank Sayısı / Number of Tanks in the Plant :

Tank Adı / Tank Name					
Ürün Adı / Liquid Name					
Tank Tipi (Sabit tavanlı(ST)/Yüzer Tavanlı(YT)) Tank Type (Fixed roof(ST)/Floating Roof(YT))					
ST için Çatı Tipi (Konik(1)/Kubbe(2)) Roof type for ST (Cone(1)/Dome(2))					
YT için Tank İnşası (Kaynaklı(1)/Perçinli(2)) Tank Constrct. for YT (Welded(1)/Riveted(2))					
YT için Sızdırmazlık Sistemi (Tek/Çift) Rim-seal system for YT (Single/Double)					
Tank Kapasitesi / Tank Capacity (m <sup>3</sup> )					
Tank Çapı / Tank Diameter (m)					
Tank Yüksekliği / Tank Height (m)					
Ort. Sıvı Yüksekliği / Aver. Liquid Height (m)					
Maks. Sıvı Yüksekliği / Max. Liquid Height (m)					
Dış Cephe Boya (Beyaz(B)/Gri(G)) Ext. Shell Paint (White(B)/Grey(G))					
Dış Cephe Bakım Durumu (İyi(İ)/Korozyon(K)) Ext. Shell Condition (Good(I)/Poor(K))					
Basınç – Vakum Ayarı (Ventili) (psig) Pressure-Vacuum Settings (Breather Vent) (psig)					
Yıllık Doldur-Boşalt Sayısı Turnovers per year					
Tankın Bulunduğu Yer / Location of the tank (Toprak altı(TA)/Toprak üstü(TÜ)) / (Underground(TA)/Ground level(TÜ))					
Tank Isıtılıyor mu? (Evet(E)/Hayır(H)) Is tank heated? (Yes(E)/No(H))					

## 2. Dolum Kolları İle İlgili Bilgiler / *Information About Liquid Loading*

Tesis içinde KARA DOLUM yapılıyorsa / *In case of LAND LOADING in the facility;*

Dolum Yapılan Ürün Adı / <i>Liquid Name</i>					
Yıllık Dolum Miktarı (litre) <i>Annual Loading Amount (liter)</i>					
Dolum Türü Sıvı içine daldırma-Altan doldurma(1) / Yukarıdan Dökme(2) <i>Loading Type</i> <i>Submerged-Bottom Loading(1) /</i> <i>Splash Loading(2)</i>					

Tesis içinde LİMANLARDA dolum yapılıyorsa / *In case of loading in MARINE*

*TERMINALS in the facility;*

Dolum Yapılan Ürün Adı / <i>Liquid Name</i>					
Yıllık Dolum Miktarı (litre) <i>Annual Loading Amount (liter)</i>					
Taşıt Türü (Gemi(G)/Mavna(M)) <i>Vehicle Type (Ship(G)/Barge(M))</i>					

### 3. Ürün İletim Hatları ile İlgili Bilgiler / *Information About Liquid Pipelines*

Bağlantı Elemanı Çeşidi / <i>Equipment Type</i>	Ürün Tipi / <i>Product Type</i>	Bağlantı Elemanı Sayısı / <i>Number of Equipments</i>
Vana / <i>Valves</i>	Gaz / <i>Gas</i>	
	Hafif Sıvı / <i>Light Liquid</i>	
	Ağır Sıvı / <i>Heavy Liquid</i>	
Pompa Sızdırmazlık Elemanı / <i>Pump Seals</i>	Hafif Sıvı / <i>Light Liquid</i>	
	Ağır Sıvı / <i>Heavy Liquid</i>	
Kompresör Sızdırmazlık Elemanı / <i>Compressor Seals</i>	Gaz / <i>Gas</i>	
Basınç Kontrol Vanası / <i>Pressure Relief Valves</i>	Gaz / <i>Gas</i>	
Flanş / <i>Connectors</i>	Tümü / <i>All</i>	
Açık Uçlu Hat / <i>Open-Ended Lines</i>	Tümü / <i>All</i>	
Numune Alma Çıkışı / <i>Sampling Connections</i>	Tümü / <i>All</i>	

Not: Hafif Sıvı, 68 F sıcaklıkta 0,044 psia'dan daha büyük buhar basıncına sahip olan sıvıları tanımlamaktadır. Aynı sıcaklıkta 0,044 psia veya daha küçük buhar basıncına sahip olan sıvılar ise Ağır Sıvılar olarak kabul edilmektedirler.

Note: *Light Liquid* defines the liquids which have a vapor pressure greater than 0.044 psia at 68 °F. The liquids having an 0.044 psia or smaller vapor pressure at the same temperature are accepted as *Heavy Liquids*.

**APPENDIX-B**  
**TANKS Model Outputs**

**1. OUTPUTS FOR LIQUID LOADING-1 PLANT**

**TANKS 4.0.9d**  
**Emissions Report - Brief Format**  
**Total Emissions Summaries - All Tanks in Report**

**Emissions Report for: Annual**

Tank Identification		Losses (lbs)
119/0001	Vertical Fixed Roof Tank ,	32.211,75
119/0002	Vertical Fixed Roof Tank ,	4,57
119/0003	Vertical Fixed Roof Tank ,	27,62
119/0004	Vertical Fixed Roof Tank ,	0,58
119/0005	Vertical Fixed Roof Tank ,	60,34
119/0006	Vertical Fixed Roof Tank ,	34.702,00
<b>Total Emissions for all Tanks:</b>		<b>67.006,85</b>

**2. OUTPUTS FOR CHEMICAL-3 PLANT**

**TANKS 4.0.9d**  
**Emissions Report - Brief Format**  
**Total Emissions Summaries - All Tanks in Report**

**Emissions Report for: Annual**

Tank Identification		Losses (lbs)
159/0001	Vertical Fixed Roof Tank ,	1,070.37
159/0002	Vertical Fixed Roof Tank ,	5,698.34
159/0003	Vertical Fixed Roof Tank ,	1,212.01
159/0004	Vertical Fixed Roof Tank ,	275.16
159/0005	Vertical Fixed Roof Tank ,	5,933.41
159/0006	Vertical Fixed Roof Tank ,	1,057.30
159/0007	Vertical Fixed Roof Tank ,	3,456.42
159/0008	Vertical Fixed Roof Tank ,	2,733.59
159/0009	Vertical Fixed Roof Tank ,	1,096.21
159/0010	Vertical Fixed Roof Tank ,	275.16
159/0011	Vertical Fixed Roof Tank ,	273.09
159/0012	Vertical Fixed Roof Tank ,	1,212.01
Total Emissions for all Tanks:		24,293.06

### 3. OUTPUTS FOR LIQUID LOADING-3 PLANT

TANKS 4.0.9d  
Emissions Report - Brief Format  
Total Emissions Summaries - All Tanks in Report

#### Emissions Report for: Annual

Tank Identification		Losses (lbs)
122/0001	Internal Floating Roof Tank ,	15,62
122/0002	Internal Floating Roof Tank ,	59,67
122/0003	Internal Floating Roof Tank ,	4.363,20
122/0004	Vertical Fixed Roof Tank ,	467,35
122/0005	Vertical Fixed Roof Tank ,	467,35
122/0006	Vertical Fixed Roof Tank ,	467,35
122/0007	Internal Floating Roof Tank ,	4.363,20
122/0008	Vertical Fixed Roof Tank ,	467,35
122/0009	Vertical Fixed Roof Tank ,	467,35
122/0010	Vertical Fixed Roof Tank ,	31.028,41
122/0011	Vertical Fixed Roof Tank ,	51,56
122/0012	Vertical Fixed Roof Tank ,	122,05
122/0013	Internal Floating Roof Tank ,	72,32
122/0014	Internal Floating Roof Tank ,	3.107,00
122/0015	Internal Floating Roof Tank ,	87,78
122/0016	Internal Floating Roof Tank ,	11,55



122/0017	Internal Floating Roof Tank	,	11,55
122/0018	Vertical Fixed Roof Tank	,	74,95
122/0019	Vertical Fixed Roof Tank	,	0,07
122/0020	Vertical Fixed Roof Tank	,	232,71
122/0021	Vertical Fixed Roof Tank	,	232,71
122/0022	Vertical Fixed Roof Tank	,	232,71
122/0023	Vertical Fixed Roof Tank	,	156,30
122/0024	Vertical Fixed Roof Tank	,	156,30
122/0025	Vertical Fixed Roof Tank	,	73,08
122/0026	Vertical Fixed Roof Tank	,	73,08
Total Emissions for all Tanks:			46.862,60

#### 4. OUTPUTS FOR PETROCHEMICAL PLANT

TANKS 4.0.9d  
Emissions Report - Brief Format  
Total Emissions Summaries - All Tanks in Report

#### Emissions Report for: Annual

Tank Identification			Losses (lbs)
151/0001	Horizontal Tank	,	0,02
151/0002	Vertical Fixed Roof Tank	,	0,05
151/0003	Vertical Fixed Roof Tank	,	0,01

151/0004	Vertical Fixed Roof Tank	,	1.395.588,55
151/0005	Vertical Fixed Roof Tank	,	0,01
151/0007	Vertical Fixed Roof Tank	,	0,01
151/0008	Vertical Fixed Roof Tank	,	1,54
151/0009	Vertical Fixed Roof Tank	,	16.181,88
151/0010	Vertical Fixed Roof Tank	,	16.181,88
151/0011	Vertical Fixed Roof Tank	,	16.181,88
151/0012	Vertical Fixed Roof Tank	,	16.181,88
151/0013	Vertical Fixed Roof Tank	,	277.685,50
151/0014	Vertical Fixed Roof Tank	,	277.685,50
151/0015	Vertical Fixed Roof Tank	,	8.327,48
151/0016	Vertical Fixed Roof Tank	,	8.327,48
151/0017	Vertical Fixed Roof Tank	,	805,16
151/0018	Vertical Fixed Roof Tank	,	805,16
151/0019	Vertical Fixed Roof Tank	,	16.181,88
151/0020	Vertical Fixed Roof Tank	,	16.181,88
151/0021	Vertical Fixed Roof Tank	,	16.181,88
151/0022	Vertical Fixed Roof Tank	,	16.181,88
151/0023	Vertical Fixed Roof Tank	,	302.216,04
151/0024	Vertical Fixed Roof Tank	,	302.216,04
151/0025	Vertical Fixed Roof Tank	,	302.216,04
151/0026	Vertical Fixed Roof Tank	,	113.872,83
151/0027	Vertical Fixed Roof Tank	,	113.872,83
151/0028	Vertical Fixed Roof Tank	,	17,56
151/0029	Vertical Fixed Roof Tank	,	46,58
151/0030	Vertical Fixed Roof Tank	,	42,99

151/0031	Vertical Fixed Roof Tank	,	7.480,63
151/0032	Vertical Fixed Roof Tank	,	46,58
151/0033	Vertical Fixed Roof Tank	,	6.782,75
151/0034	Vertical Fixed Roof Tank	,	6.819,80
151/0035	Vertical Fixed Roof Tank	,	2.514,40
151/0036	Vertical Fixed Roof Tank	,	1.261,06
151/0037	Horizontal Tank	,	5.249,19
151/0038	Vertical Fixed Roof Tank	,	10.941,23
151/0039	Vertical Fixed Roof Tank	,	10.941,23
151/0040	Vertical Fixed Roof Tank	,	13,08
151/0041	Vertical Fixed Roof Tank	,	46,50
151/0042	Vertical Fixed Roof Tank	,	0,03
151/0043	Vertical Fixed Roof Tank	,	1.588,12
151/0044	Vertical Fixed Roof Tank	,	2.998,98
151/0045	Vertical Fixed Roof Tank	,	0,00
151/0046	External Floating Roof Tank	,	61.463,20
151/0047	Vertical Fixed Roof Tank	,	312,78
151/0048	Vertical Fixed Roof Tank	,	2.998,98
151/0049	Vertical Fixed Roof Tank	,	9.688,00
151/0050	Vertical Fixed Roof Tank	,	50.512,75
151/0051	Vertical Fixed Roof Tank	,	6,85
151/0052	Vertical Fixed Roof Tank	,	6,85
151/0053	Vertical Fixed Roof Tank	,	4,61
151/0054	Vertical Fixed Roof Tank	,	120.906,11
151/0055	Vertical Fixed Roof Tank	,	139,71
151/0056	Vertical Fixed Roof Tank	,	644,01

151/0057	Vertical Fixed Roof Tank	,	1.127,55
151/0058	Vertical Fixed Roof Tank	,	867,45
151/0059	Vertical Fixed Roof Tank	,	0,88
151/0060	Vertical Fixed Roof Tank	,	112.429,44
151/0061	Vertical Fixed Roof Tank	,	112.429,44
151/0062	Vertical Fixed Roof Tank	,	1,58
151/0063	Vertical Fixed Roof Tank	,	1.930,75
151/0064	Vertical Fixed Roof Tank	,	1.629,23
151/0065	Vertical Fixed Roof Tank	,	1.585,93
151/0069	Vertical Fixed Roof Tank	,	22,62
151/0070	Vertical Fixed Roof Tank	,	0,06
151/0071	Vertical Fixed Roof Tank	,	32,18
151/0072	External Floating Roof Tank	,	7.394,98
151/0073	Vertical Fixed Roof Tank	,	15,52
151/0074	External Floating Roof Tank	,	7.394,98
151/0075	Vertical Fixed Roof Tank	,	15,52
151/0076	Vertical Fixed Roof Tank	,	4.937,41
151/0077	Vertical Fixed Roof Tank	,	1,75
151/0078	Vertical Fixed Roof Tank	,	1,75
151/0079	Vertical Fixed Roof Tank	,	3,62
151/0080	Vertical Fixed Roof Tank	,	137.618,07
151/0081	Vertical Fixed Roof Tank	,	137.618,07
151/0082	Vertical Fixed Roof Tank	,	1,00
151/0083	External Floating Roof Tank	,	29.920,45
151/0084	External Floating Roof Tank	,	29.920,45
151/0085	Vertical Fixed Roof Tank	,	75.093,15

151/0086	Vertical Fixed Roof Tank	,	75.093,15
151/0087	Vertical Fixed Roof Tank	,	57,71
151/0088	External Floating Roof Tank	,	16.709,61
151/0089	Vertical Fixed Roof Tank	,	65,77
151/0090	External Floating Roof Tank	,	16.709,61
151/0091	Vertical Fixed Roof Tank	,	65,77
151/0092	External Floating Roof Tank	,	16.709,61
151/0093	External Floating Roof Tank	,	16.709,61
151/0094	Vertical Fixed Roof Tank	,	18.911,32
151/0095	Vertical Fixed Roof Tank	,	6,75
151/0096	Vertical Fixed Roof Tank	,	6,75
151/0097	Vertical Fixed Roof Tank	,	8.829,79
151/0098	Vertical Fixed Roof Tank	,	2.442,61
151/0099	Vertical Fixed Roof Tank	,	3.856,03
151/0100	Vertical Fixed Roof Tank	,	5.330,81
151/0101	Vertical Fixed Roof Tank	,	19.446,69
151/0102	Vertical Fixed Roof Tank	,	19.446,69
151/0103	Vertical Fixed Roof Tank	,	19.446,69
151/0104	Vertical Fixed Roof Tank	,	7.202,76
151/0105	Vertical Fixed Roof Tank	,	7.202,76
151/0106	Vertical Fixed Roof Tank	,	0,26
151/0107	Vertical Fixed Roof Tank	,	2,25
151/0108	Vertical Fixed Roof Tank	,	2,25
151/0109	Vertical Fixed Roof Tank	,	515,35
151/0110	Vertical Fixed Roof Tank	,	0,01
151/0111	Vertical Fixed Roof Tank	,	0,04

151/0112	Vertical Fixed Roof Tank	,	1.689,60
151/0113	Vertical Fixed Roof Tank	,	0,00
151/0114	Vertical Fixed Roof Tank	,	0,79
151/0115	External Floating Roof Tank	,	6.651,57
151/0116	External Floating Roof Tank	,	6.651,57
151/0117	Vertical Fixed Roof Tank	,	175.933,95
151/0118	Vertical Fixed Roof Tank	,	175.933,95
151/0119	Vertical Fixed Roof Tank	,	153.695,95
151/0120	Vertical Fixed Roof Tank	,	153.695,95
151/0121	Vertical Fixed Roof Tank	,	7.518,83
151/0122	Vertical Fixed Roof Tank	,	7.518,83
151/0123	Vertical Fixed Roof Tank	,	20.040,47
151/0124	Vertical Fixed Roof Tank	,	20.040,47
151/0125	External Floating Roof Tank	,	7.749,15
151/0126	External Floating Roof Tank	,	7.749,15
151/0127	Vertical Fixed Roof Tank	,	202.867,93
151/0128	Vertical Fixed Roof Tank	,	202.867,93
151/0129	Vertical Fixed Roof Tank	,	676,81
151/0130	Vertical Fixed Roof Tank	,	676,81
151/0131	Vertical Fixed Roof Tank	,	9.547,38
151/0132	Vertical Fixed Roof Tank	,	9.547,38
151/0133	Vertical Fixed Roof Tank	,	516,52
151/0134	Vertical Fixed Roof Tank	,	516,52
151/0135	Vertical Fixed Roof Tank	,	1.217,16
151/0136	Vertical Fixed Roof Tank	,	1.217,16
151/0137	Vertical Fixed Roof Tank	,	64.992,99

151/0138	Vertical Fixed Roof Tank	,	64.992,99
151/0139	Vertical Fixed Roof Tank	,	8.879,40
Total Emissions for all Tanks:			5.766.701,51

## 5. OUTPUTS FOR LIQUID LOADING-4 PLANT

### TANKS 4.0.9d Emissions Report - Brief Format Total Emissions Summaries - All Tanks in Report

#### Emissions Report for: Annual

Tank Identification			Losses (lbs)
140/0001	Vertical Fixed Roof Tank	,	173,60
140/0002	Vertical Fixed Roof Tank	,	71.440,49
140/0003	Vertical Fixed Roof Tank	,	57.700,80
140/0004	Vertical Fixed Roof Tank	,	148,72
140/0005	Vertical Fixed Roof Tank	,	1.006,38
140/0006	Vertical Fixed Roof Tank	,	1.006,38
140/0007	Vertical Fixed Roof Tank	,	1.178,99
140/0008	Vertical Fixed Roof Tank	,	931,52
140/0009	Vertical Fixed Roof Tank	,	931,52

140/0010	Vertical Fixed Roof Tank	,	1.061,92
140/0011	Vertical Fixed Roof Tank	,	183.393,08
140/0012	Vertical Fixed Roof Tank	,	543,35
140/0013	Vertical Fixed Roof Tank	,	613,73
140/0014	Vertical Fixed Roof Tank	,	1.083,16
140/0015	Vertical Fixed Roof Tank	,	34.415,65
140/0016	Vertical Fixed Roof Tank	,	160,61
140/0017	Vertical Fixed Roof Tank	,	39.141,81
140/0018	Vertical Fixed Roof Tank	,	343,60
140/0019	Vertical Fixed Roof Tank	,	405,46
140/0020	Vertical Fixed Roof Tank	,	186,89
140/0021	Vertical Fixed Roof Tank	,	2.043,91
140/0022	Vertical Fixed Roof Tank	,	1.478,69
140/0023	Vertical Fixed Roof Tank	,	1.478,69
140/0024	Vertical Fixed Roof Tank	,	50,76
Total Emissions for all Tanks:			400.919,71



**6. OUTPUTS FOR LIQUID LOADING-5 PLANT**

**TANKS 4.0.9d**  
**Emissions Report - Brief Format**  
**Total Emissions Summaries - All Tanks in Report**

**Emissions Report for: Annual**

Tank Identification		Losses (lbs)
121/0001	Internal Floating Roof Tank ,	9.644,18
121/0002	Internal Floating Roof Tank ,	50,72
121/0003	Internal Floating Roof Tank ,	7.305,23
121/0004	Internal Floating Roof Tank ,	88,13
121/0005	Vertical Fixed Roof Tank ,	4.041,02
121/0006	Internal Floating Roof Tank ,	39,74
121/0007	Vertical Fixed Roof Tank ,	2.617,56
121/0008	Internal Floating Roof Tank ,	146,98
121/0009	Vertical Fixed Roof Tank ,	887,78
121/0010	Internal Floating Roof Tank ,	5.684,82
121/0011	Internal Floating Roof Tank ,	5.684,82
121/0012	Internal Floating Roof Tank ,	4.229,98
121/0013	Internal Floating Roof Tank ,	4.273,06
121/0014	Internal Floating Roof Tank ,	26,53
121/0015	Internal Floating Roof Tank ,	114,87
121/0016	Vertical Fixed Roof Tank ,	13.460,21

121/0017	Vertical Fixed Roof Tank	,	27,96
121/0018	Vertical Fixed Roof Tank	,	31,90
121/0019	Vertical Fixed Roof Tank	,	33,71
121/0020	Vertical Fixed Roof Tank	,	26,82
121/0021	Vertical Fixed Roof Tank	,	31,90
Total Emissions for all Tanks:			58.447,92

## 7. OUTPUTS FOR OIL REFINERY

### TANKS 4.0.9d Emissions Report - Brief Format Total Emissions Summaries - All Tanks in Report

#### Emissions Report for: Annual

Tank Identification			Losses (lbs)
124 / 0001	Vertical Fixed Roof Tank	,	0,14
124 / 0002	Vertical Fixed Roof Tank	,	0,21
124 / 0003	Vertical Fixed Roof Tank	,	43,47
124 / 0004	Vertical Fixed Roof Tank	,	4,87
124 / 0005	Vertical Fixed Roof Tank	,	673,19
124 / 0006	Vertical Fixed Roof Tank	,	298,70
124 / 0007	Vertical Fixed Roof Tank	,	76,46
124 / 0008	Vertical Fixed Roof Tank	,	2.053,57
124 / 0009	Vertical Fixed Roof Tank	,	1.825,09

124 / 0010	Vertical Fixed Roof Tank	,	0,01
124 / 0011	Vertical Fixed Roof Tank	,	4,82
124 / 0012	Vertical Fixed Roof Tank	,	4,83
124 / 0013	Vertical Fixed Roof Tank	,	155,80
124 / 0014	Vertical Fixed Roof Tank	,	8.102,33
124 / 0015	Vertical Fixed Roof Tank	,	134,46
124 / 0016	Vertical Fixed Roof Tank	,	1,49
124 / 0017	Vertical Fixed Roof Tank	,	3,43
124 / 0018	Vertical Fixed Roof Tank	,	357,96
124 / 0019	Vertical Fixed Roof Tank	,	358,03
124 / 0020	Vertical Fixed Roof Tank	,	358,10
124 / 0021	Vertical Fixed Roof Tank	,	357,90
124 / 0022	Vertical Fixed Roof Tank	,	358,10
124 / 0023	Vertical Fixed Roof Tank	,	360,15
124 / 0024	Vertical Fixed Roof Tank	,	367,17
124 / 0025	Vertical Fixed Roof Tank	,	360,29
124 / 0026	Vertical Fixed Roof Tank	,	259,19
124 / 0027	Vertical Fixed Roof Tank	,	259,19
124 / 0028	Vertical Fixed Roof Tank	,	361,91
124 / 0029	Vertical Fixed Roof Tank	,	246,75
124 / 0030	Vertical Fixed Roof Tank	,	90,41
124 / 0031	Vertical Fixed Roof Tank	,	197,57
124 / 0032	Vertical Fixed Roof Tank	,	175,69
124 / 0033	Vertical Fixed Roof Tank	,	175,21
124 / 0034	Vertical Fixed Roof Tank	,	175,21
124 / 0035	Vertical Fixed Roof Tank	,	175,04

124 / 0036	Vertical Fixed Roof Tank	,	175,04
124 / 0037	Vertical Fixed Roof Tank	,	175,43
124 / 0038	Vertical Fixed Roof Tank	,	175,16
124 / 0039	Vertical Fixed Roof Tank	,	357,76
124 / 0040	Vertical Fixed Roof Tank	,	360,87
124 / 0041	Vertical Fixed Roof Tank	,	1,44
124 / 0042	Vertical Fixed Roof Tank	,	38,36
124 / 0043	Vertical Fixed Roof Tank	,	38,82
124 / 0044	Vertical Fixed Roof Tank	,	201,25
124 / 0045	Vertical Fixed Roof Tank	,	201,32
124 / 0046	Vertical Fixed Roof Tank	,	321,32
124 / 0047	Vertical Fixed Roof Tank	,	321,22
124 / 0048	Vertical Fixed Roof Tank	,	580,00
124 / 0049	Vertical Fixed Roof Tank	,	648,79
124 / 0050	Vertical Fixed Roof Tank	,	534,15
124 / 0051	Vertical Fixed Roof Tank	,	534,15
124 / 0052	Vertical Fixed Roof Tank	,	223.590,20
124 / 0053	Vertical Fixed Roof Tank	,	447,13
124 / 0054	Vertical Fixed Roof Tank	,	509,37
124 / 0055	Vertical Fixed Roof Tank	,	283,02
124 / 0056	Vertical Fixed Roof Tank	,	319,19
124 / 0057	Vertical Fixed Roof Tank	,	169,68
124 / 0058	Vertical Fixed Roof Tank	,	187,08
124 / 0059	Vertical Fixed Roof Tank	,	154,77
124 / 0060	Vertical Fixed Roof Tank	,	6,89
124 / 0061	Vertical Fixed Roof Tank	,	6,89

124 / 0062	Vertical Fixed Roof Tank	,	6,89
124 / 0063	Vertical Fixed Roof Tank	,	6,89
124 / 0064	Vertical Fixed Roof Tank	,	2,68
124 / 0065	Vertical Fixed Roof Tank	,	2,68
124 / 0066	External Floating Roof Tank	,	10.908,86
124 / 0067	External Floating Roof Tank	,	8.181,07
124 / 0068	External Floating Roof Tank	,	7.147,98
124 / 0069	External Floating Roof Tank	,	10.911,09
124 / 0070	External Floating Roof Tank	,	10.910,25
124 / 0071	External Floating Roof Tank	,	7.148,47
124 / 0072	External Floating Roof Tank	,	12.271,41
124 / 0073	External Floating Roof Tank	,	6.058,39
124 / 0074	External Floating Roof Tank	,	6.058,48
124 / 0075	External Floating Roof Tank	,	6.058,39
124 / 0076	Vertical Fixed Roof Tank	,	0,30
124 / 0077	Vertical Fixed Roof Tank	,	0,31
124 / 0078	Vertical Fixed Roof Tank	,	0,52
124 / 0079	External Floating Roof Tank	,	15.990,23
124 / 0080	External Floating Roof Tank	,	5.067,71
124 / 0081	External Floating Roof Tank	,	5.067,01
124 / 0082	External Floating Roof Tank	,	5.213,62
124 / 0083	External Floating Roof Tank	,	5.214,10
124 / 0084	Vertical Fixed Roof Tank	,	1.339,03
124 / 0085	Vertical Fixed Roof Tank	,	1.341,27
124 / 0086	Vertical Fixed Roof Tank	,	1.087,26
124 / 0087	External Floating Roof Tank	,	10.429,26

124 / 0088	External Floating Roof Tank	,	6.021,63
124 / 0089	External Floating Roof Tank	,	10.381,18
124 / 0090	External Floating Roof Tank	,	19.878,97
124 / 0091	External Floating Roof Tank	,	19.876,94
124 / 0092	External Floating Roof Tank	,	19.878,97
124 / 0093	External Floating Roof Tank	,	19.878,97
124 / 0094	External Floating Roof Tank	,	19.876,94
124 / 0095	External Floating Roof Tank	,	19.873,57
124 / 0096	External Floating Roof Tank	,	20.077,39
124 / 0097	External Floating Roof Tank	,	20.071,31
124 / 0100	Vertical Fixed Roof Tank	,	3.197,47
124 / 0101	Vertical Fixed Roof Tank	,	3.194,87
124 / 0102	External Floating Roof Tank	,	117,02
124 / 0103	External Floating Roof Tank	,	117,02
124 / 0104	Vertical Fixed Roof Tank	,	3.257,09
124 / 0105	External Floating Roof Tank	,	32.039,74
124 / 0106	External Floating Roof Tank	,	284,31
124 / 0107	External Floating Roof Tank	,	317,03
124 / 0108	External Floating Roof Tank	,	32.039,74
124 / 0109	Vertical Fixed Roof Tank	,	3.244,72
124 / 0110	Vertical Fixed Roof Tank	,	3.241,54
124 / 0111	Vertical Fixed Roof Tank	,	2.896,71
124 / 0112	Vertical Fixed Roof Tank	,	2.899,69
124 / 0113	Vertical Fixed Roof Tank	,	3.194,83
124 / 0114	Vertical Fixed Roof Tank	,	2.968,20
124 / 0115	Vertical Fixed Roof Tank	,	3.217,50

124 / 0116	Vertical Fixed Roof Tank	,	11.853,86
124 / 0117	Internal Floating Roof Tank	,	317,92
124 / 0118	Internal Floating Roof Tank	,	267,27
124 / 0119	Vertical Fixed Roof Tank	,	11.450,55
124 / 0120	Vertical Fixed Roof Tank	,	11.450,55
124 / 0121	Vertical Fixed Roof Tank	,	31,21
124 / 0122	Vertical Fixed Roof Tank	,	31,24
124 / 0123	Vertical Fixed Roof Tank	,	31,17
124 / 0124	Vertical Fixed Roof Tank	,	2.175,32
124 / 0125	Vertical Fixed Roof Tank	,	2.282,26
124 / 0126	Vertical Fixed Roof Tank	,	74,66
124 / 0127	Vertical Fixed Roof Tank	,	74,65
124 / 0128	Vertical Fixed Roof Tank	,	38,42
124 / 0129	Vertical Fixed Roof Tank	,	74,62
124 / 0130	Vertical Fixed Roof Tank	,	17.626,38
124 / 0131	Vertical Fixed Roof Tank	,	17.569,46
124 / 0132	Vertical Fixed Roof Tank	,	27.025,09
124 / 0133	Vertical Fixed Roof Tank	,	16,65
124 / 0134	Vertical Fixed Roof Tank	,	16,65
124 / 0135	Vertical Fixed Roof Tank	,	66,44
124 / 0136	Vertical Fixed Roof Tank	,	1.228,82
124 / 0137	Vertical Fixed Roof Tank	,	502,31
124 / 0138	Vertical Fixed Roof Tank	,	66,07
124 / 0139	Vertical Fixed Roof Tank	,	4,61
124 / 0140	Vertical Fixed Roof Tank	,	4,61
124 / 0141	Vertical Fixed Roof Tank	,	770,79

124 / 0142	Vertical Fixed Roof Tank	,	770,79
124 / 0143	Vertical Fixed Roof Tank	,	179,61
124 / 0144	Vertical Fixed Roof Tank	,	3,49
124 / 0145	Vertical Fixed Roof Tank	,	3,46
124 / 0146	Vertical Fixed Roof Tank	,	13,28
124 / 0150	Internal Floating Roof Tank	,	3.314,00
124 / 0151	Internal Floating Roof Tank	,	3.240,91
124 / 0152	Vertical Fixed Roof Tank	,	1.020,18
124 / 0153	Vertical Fixed Roof Tank	,	790,33
Total Emissions for all Tanks:			771.571,21