

**EMISSION OF VOLATILE ORGANIC COMPOUNDS FROM
NATURAL GAS LIQUID TANK VESSEL**

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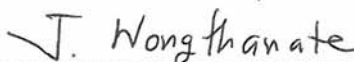
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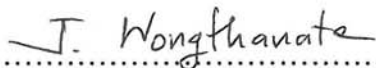
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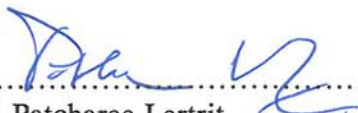
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EMISSION OF VOLATILE ORGANIC COMPOUNDS FROM STORAGE NATURAL GAS LIQUID TANK VESSEL

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ABSTRACT

This study aimed to investigate the relationship between physical factors and the venting volume of volatile organic compounds (VOCs), to find the VOCs compositions, and to estimate the annual emissions of VOCs from natural gas liquids floating and storage tank (FSO) vessel in the Gulf of Thailand. The data of relevant factors were collected from 365 daily reports in 2014. The relationship between venting volume and five factors of wave height, natural gas liquid's Reid Vapor Pressure (RVP), ambient temperature, cargo tank temperature and total condensate onboard were tested by multiple regressions analysis. It was found that the factor related to the venting volume was the total condensate onboard (P value < 0.001). The regression equation was $y = 0.187x$ ($R^2 = 0.048$) which indicated poor relationship between the two variables. This finding was against the research hypothesis which assumed that 5 independent variables were related to dependent variables. It may come from the independent variables in this study were varied too narrow range to find a relationship. Moreover there may be other factors influencing the venting volume from FSO. Thirteen samples of vent gas mixture were collected to analyze gas compositions by using gas chromatography techniques. It was found that the average composition was 55% nitrogen, 7% carbondioxide, 3% oxygen and six VOCs of 2.63% ethane, 14.60% propane, 14.87% butane, 1.96% pentane, 0.26% hexane and 0.17% heptane. Butane (most found of VOCs in this study), Pentane and Hexane have odor, thus they could have adverse effects on the health of the workforce on the FSO. The others VOCs were odorless. To estimate the baseline of the VOCs emission, two calculation methods were applied, the first method used the fraction of each compound in the vent gas mixture and its molecular weight to find its density in the vent gas. It was found that the annual average of VOCs emission was 3,907 tons/year. The second method used was (Pring et al) equation which applied VOCs's emission factor from condensate and total production of VNGL a year. The calculation gave the emission of 10,172.67 tons/year as 2.6 times greater than the first method. The difference may come from the application of different factors. Finally, Screen View model was applied to predict the pollution concentration from both vent stacks in scenarios of average emission and it was found that the maximum emission scenario released 2.29 times VOCs greater than the average emission scenario.

KEY WORDS: EMISSION/ VOCs/ STORAGE TANKS/ VESSEL

113 pages

การปลดปล่อยสารอินทรีย์ระเหยง่ายจากเรือกักเก็บก๊าซธรรมชาติเหลว

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บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อหาความสัมพันธ์ระหว่างปัจจัยทางกายภาพและปริมาณการปลดปล่อยสารอินทรีย์ระเหยง่าย หองศ์ประกอบของสารอินทรีย์ระเหยง่ายและปริมาณสารอินทรีย์ระเหยง่ายที่ปล่อยจากเรือกักเก็บก๊าซธรรมชาติเหลวลำหนึ่งในอ่าวไทย ทำการเก็บข้อมูลปัจจัยต่าง ๆ จากบันทึกผลการตรวจวัดรายวันจำนวน 365 วัน ในปี 2557 ทดสอบความสัมพันธ์ระหว่างปริมาณการปล่อยไอระเหยกับปัจจัยทางกายภาพ 5 ปัจจัยคือ ความสูงของคลื่น ค่าความดันไอของก๊าซธรรมชาติเหลว อุณหภูมิอากาศพื้นผิวเหนือเรือ อุณหภูมิในถังเก็บก๊าซธรรมชาติเหลว และปริมาตรของก๊าซธรรมชาติเหลวที่มีอยู่ในถังเก็บกักในแต่ละวัน ทดสอบโดยใช้สถิติความถดถอยเชิงพหุคูณ (Multiple Regression Analysis) พบว่าปัจจัยที่มีผลต่อการปล่อยไอระเหยคือ ปริมาตรก๊าซธรรมชาติเหลวที่มีอยู่ในถังเก็บกักในแต่ละวัน โดยมีเปอร์เซ็นต์ของความแปรผันเท่ากับ 0.023 (P value <0.001) แสดงว่าตัวแปรมีความสัมพันธ์กันในระดับน้อย ซึ่งขัดแย้งกับสมมติฐานตามทฤษฎีที่คาดว่าตัวแปรต้นทั้ง 5 ตัวแปรมีความสัมพันธ์กับตัวแปรตาม น่าจะมีปัจจัยอื่นนอกเหนือจาก 5 ปัจจัยดังกล่าวเข้ามาเกี่ยวข้องและมีอิทธิพลต่อปริมาณการปล่อยไอระเหยจากเรือกักเก็บก๊าซธรรมชาติเหลวในการศึกษานี้ จากการเก็บตัวอย่างอากาศในถังเก็บก๊าซธรรมชาติเหลว จำนวน 13 ตัวอย่าง ไปวิเคราะห์ด้วยเทคนิค Gas Chromatography พบองค์ประกอบโดยเฉลี่ยดังนี้ โนโครเจน 55% คาร์บอนไดออกไซด์ 7% ออกซิเจน 3% พบสารอินทรีย์ระเหยง่าย 6 ชนิด ได้แก่ Ethane 2.63 % Propane 14.60% Butane 14.87 % Pentane 1.96% Hexane 0.26 % และ Heptane 0.17% โดยที่ Butane (พบมากที่สุดในการศึกษานี้) Pentane และ Hexane เป็นสารก่อกลิ่นที่สามารถสร้างผลกระทบต่อสุขภาพของผู้ที่อยู่บนเรือ ส่วนสารอินทรีย์ระเหยง่ายตัวอื่นเป็นสารไร้กลิ่น สำหรับการหาปริมาณสารอินทรีย์ระเหยง่ายที่ถูกระบายออกสู่บรรยากาศ ใช้วิธีคำนวณ 2 วิธี วิธีแรกใช้สัดส่วนของสารประกอบที่ตรวจพบจากการตรวจวัดและน้ำหนักโมเลกุลของสารประกอบ เพื่อหาความหนาแน่นของสารประกอบเหล่านี้ในอากาศที่ระบายออกไป ผลการคำนวณพบว่าปริมาณการระบายโดยเฉลี่ยเท่ากับ 3,907 ตัน/ปี วิธีที่สองเป็นวิธีของ Pring และคณะ ซึ่งอาศัยค่าสัมประสิทธิ์การปลดปล่อยสารอินทรีย์ระเหยโดยรวมและปริมาณก๊าซธรรมชาติเหลวที่กักเก็บในหนึ่งปี ผลการคำนวณพบว่าปริมาณการระบายเท่ากับ 10,172.67 ตัน/ปี ซึ่งสูงกว่าวิธีแรก 2.6 เท่า ความแตกต่างมาจากวิธีการคำนวณที่ใช้ตัวแปรที่ต่างกัน ขั้นตอนสุดท้ายแบบจำลองคุณภาพอากาศ สกรีนวิว ทำนายความเข้มข้นของมลพิษจากปล่อยระบาย สถานการณ์ของการปล่อยสารประกอบอินทรีย์ระเหยง่ายแบบสูงสุดพบความเข้มข้นของมลพิษสูงกว่า 2.29 เท่า เมื่อเทียบกับสภาวะการทำงานปกติ

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CHAPTER I

INTRODUCTION

1.1 Statement of the problems

Generally, the natural gas sent to onshore is produced from the processes of petroleum production and is kept offshore as the natural gas liquid (NGL). NGL is sent to storage in vessels called Floating Storage and Offtake (FSO), via subsea pipeline. It is accumulate to a desired quantity and prepare for loading operation. The vessel's hull was designed to be more efficient in terms of its operation to support the safe and environmental protection, such as the wall of the FSO is double hull for safety, durable in exchange of environmental protection. The vessels are double hull and so designed as to have a safe operation without any adverse impact on environment during her entire life with proper and timely maintenance. Natural gas liquids

NGLs) are hydrocarbons is same kind of molecules as crude oil and natural gas, composed with carbon and hydrogen which are ethane, propane, butane, isobutane, and pentane (see Table 1.). NGLs used for growing economy sector in every country. NGLs are used as inputs for petrochemical industry, heat, and cooking and vehicle fuel blended substance. Crude oil in high prices has contributed to increase the prices of NGLs (U.S. Energy Information Administration (EIA). [1]

Hydrocarbon oils are mostly a mixture of a wide range of hydrocarbon compounds. The boiling points of these compounds vary between as low as -162 degree Celsius up to and in excess of 400 degree Celsius. The volatility of the oil (hydrocarbon-based liquid) depends on the quantities of the compound with boiling points nearer the lower end of this range of temperature. The vapour pressure of oil is important in respect of the flammability hazard associated with the evolution of gases. It is also a factor in determining how easily a liquid can be pumped.

Table 1.1 NGL Attribute summaries [1]

NGL Attribute Summary				
Natural gas liquid	Chemical formula	Applications	End Use Products	Primary Sectors
Ethane	C ₂ H ₆	Plastic production , Petrochemical feedstock	Plastic bags, plastics anti- freeze, detergent	Industry
Propane	C ₃ H ₈	Residual and commercial heating, cooking fuel, petrochemical feedstock	Home heating ,small stoves and barbeques, LPG	Industry, Resident, Commercial.
Butane	C ₄ H ₁₀	Petrochemical feedstock, Blending with propane or gasoline	Synthetic rubber for tired, LPG, lighter fuel	Industry, Transportation.
Isobutane	C ₄ H ₁₀	Refinery feed stock, Petrochemical feedstock	Alkylate for gasoline , aerosols , refrigerant	Industry
Pentane	C ₅ H ₁₂	Natural gasoline , blowing agent for polystyrene foam	Gasoline, Polystyrene, solvent	Transportation
Pentanes Plus or natural gasoline	Mix of C ₅ H ₁₂ and heavier	Blending with vehicle fuel exported for bitumen production in oil sand	Gasoline, ethanol blends , oil sands production	Transportation

When oil is transferred to a container free of gases, it will immediately begin to vaporize liberating gas into the space above the liquid level. However as more gas is liberated, there is a tendency for the gas to re-dissolve into the liquid. This will

continue until a balance is reached where a certain amount of gas will evenly occupy the space above the liquid.

While the natural gas liquid (NGL) accumulates in Floating Storage and Offtake (FSO), it is necessary to release volatile organic compounds (VOCs) flash emission. The reason is to prevent exploding of the storage tanks and vessel storage tank deformation as the oil is loaded in the tanks of the FSO at the same time the pressure builds up inside the tanks due to the release of the gas from the oil. This is a direct result of temperature variation and movement of the oil. The storage tanks are designed to withstand a certain amount of pressure both on the positive side as well as on the negative side. This makes it necessary to release the pressure inside the tank before it reaches its maximum value and so the gas inside the tanks needs to be vented at regular interval to avoid damage to the FSO. The venting is also a direct result of heating the oil in the tank and at such times the venting is more frequent than normal.

Flashing losses are vapors that are released when liquid with entraining gases experiences a pressure drop. During the transfer of liquid the vapors are released through a vent valve which is set up to close and open automatically. The effect of this release is affects the environment but also has an effect on the health of the personnel on board and on the exposed decks structure of FSO, fully depends on the weather condition, wind speed and direction). Gas tends to form liquid (moisture) again when subjected to atmosphere, this leads to corrosion of the surface which are exposed to it. The problem is smell after being released into the atmosphere, the smell distributes in to the corridors of the main deck of the vessel. The observation found that the VOCs blowout is always on the windward side so the wind blows the smell into an accommodation building which stands in leeward direction. For health and safety reasons all working outside the accommodation building need to pause. Furthermore it was also found the same incident more serious in a day that the wind speeds was less than 5 kilometers per hour (1.4 m/sec). In previous incidents, gas detectors such as micro gas alert clip a photoionization detector (PID) see Figure A8 in Appendix A and Micro fit, a flame ionization detector (FID), see Figure A9 in Appendix A, were used and it found that VOCs concentration in the air on vessel main deck was in the range of 3-50 ppm. This significant level of exposures can lead to serious case of dangerous health. Take benzene for an example, American Conference of Governmental

Industrial Hygienists (ACGIH) limits volatile exposure of benzene at working place called Threshold Limit Value (TLV) to not over 0.5 ppm.[2]

Basically, there are emissions from vent stack because of high pressure accumulated in cargo tanks. Thus, VOCs release to atmosphere, leads to the decreasing pressure releasing more, some vapour from the liquid hydrocarbon less pressure transform liquid to vapor and emits into atmosphere. Some of the heavier compounds in the liquids may become entrained in this gas and will be emitted with them.[3]

The origins of VOCs in the atmosphere come from the chemical industry and petroleum industry. In this study VOCs refer to hydrocarbon. This research studied of factors affecting the release of vapors and analysis of composition of compounds from evaporation is very important. The findings in this study are to provide the proper management, baseline measurement and propose determining vent gas emissions mitigation guidelines conclusions, and recommendations.

The problems from the VOCs emission on the storage tank vessel were gathered from the working experience. It was observed that

- There was strong odor on the main deck in the summer time or monsoon season.
- When odor was sensed, all tasks or activities on the main deck need to stop or be postponed.
- Under the researcher's acknowledge, there was no study conducted the correlation between VOCs emission and physical factors on the main deck.

Additionally, a previous study of Dabdub, et al [4] found that in the future, the problems from ship emissions are becoming a significant source of air pollution in cities near major ports. Recent estimates of global sulfur and nitrogen oxide emissions from international shipping show the emission contain oxides of nitrogen (NO_x) and sulfur (SO_x) are processed by atmospheric chemical and physical mechanisms resulting in the formation of secondary pollutants such as ozone and particulate matter (PM). Although ship emissions currently constitute only a small fraction of total global emissions, they could have important environmental effects on coastal areas near ports with heavy ship traffic as shown in studies for regions in Europe, Asia and

North America. Ship emissions become increasingly important. Moreover Air model was applied to predict VOCs concentration at the study area [4].

1.2 Objectives

This research aims to study VOCs emission from VNGL storage tank vessel in five objectives.

1.2.1 To investigate relevant factors affecting the daily VOCs venting volume of Volatile Natural Gas Liquid in storage tanks vessel.

1.2.2 To examine chemical components of Volatile Natural Gas Liquid in storage tanks vessel.

1.2.3 To estimate the baseline of VOCs emission from storage tanks.

1.2.4 To predict the concentration of the VOCs using Gaussian plume dispersion model

1.2.5 To propose vent gas emissions mitigation guidelines.

1.3 Scope of study

This study is retrospective in one year; 2014 A.D. Emission was measured 365 days of hydrocarbon venting from 14 cargo storage tanks or Cargo Oil Tanks (COT) in Gulf of Thailand. Study of the factors influencing the vapor emissions of ships was undertaken by data collection from daily weather condition report, quantity in cargo tanks. The measurements were made by monitoring the gas flow rates escaping from storage tank vents and sampling the vent gases for chemical compositions. This research focuses on the physical factors that affect emissions.

This research is not allowed to disclose industry name. The purpose of study is to understand the relevant factors that affect the release of VOCs include components that are presented in VNGL and approaches to mitigate VOCs venting and effects on workforce

1.4 Expected outcomes

1.4.1 The findings from this study will improve the knowledge on the factors affecting venting volume from storage tank vessel.

1.4.2 This study can be used as a proof to encourage an improvement of to improve the storage tank's layout in the change of office and accommodation position so as to prevent impact of VOCs venting on workforce

1.4.3 The findings from this study will provide a better understanding for decision making in mitigation of VOCs vent from storage tanks vessel

1.5 Conceptual framework

Under author's working experience, emission of VNGL in storage tank was detected regularly on the main deck. Previously the factors affecting the emissions has never studied or predicted. Hence, the relevant factors base on physical and chemical basis should be studied. The venting volume of VOCs and their concentrations in the air should be acquired. Then, the mitigation guideline on the basis of source, path and receptor will be proposed. The conceptual framework is presented in Figure 1.1

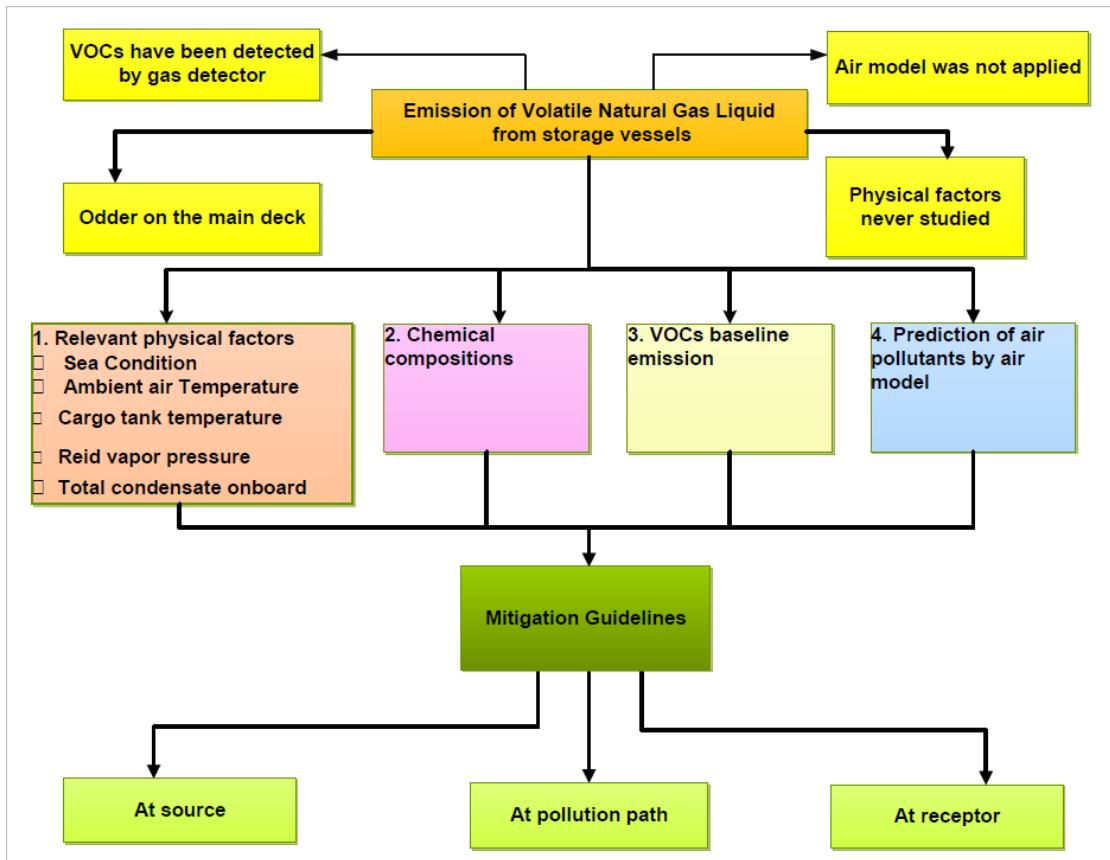


Figure 1.1 Conceptual frameworks.

1.6 Research hypothesis

1.6.1 The vent volume will be affected from sea condition.

1.6.2 The ambient temperature will affect on the VOCs venting volume

1.6.3 The cargo tank temperature will affect on VOCs venting volume on deck.

1.6.4 Variation of VOCs venting volume depends on volume of cargo in the tanks.

1.6.5 VOCs venting volume is related directly to Reid Vapor Pressure (RVP) of ship's cargo.

1.7 Definition of research

1.7.1 Onshore Crude Oil and Natural Gas Production means structure constructed temporarily or permanently to onshore area that houses equipment to drill the hydrocarbon liquid or natural gas from wells head, separation equipment, and storage tanks, used in the production, recovery , extraction, stabilization, separation, treatment of hydrocarbon liquid or gas. This includes natural gas production and petroleum facilities located onshore, or structures connected by a causeway to onshore.

1.7.2 Floating storage and offloading units (FSO) are normally used in the open sea by the offshore oil and gas industry to receive crude oil or condensate from central platform and store it until it can be offloaded onto other oil tankers.

1.7.3 Condensate means hydrocarbon liquid which separated from crude oil or natural gas, it was condenses according to changing of pressure temperature, or both, it remains in liquid form under storage conditions and API gravity between 41 and 60.

1.7.4 API gravity means The American Petroleum Institute (API) gravity which used to measure petroleum liquid in heavy or light and compared to water. API gravity is greater than 10, which mean lighter and floats on water and if less than 10, which mean heavier and sinks.

1.7.5 Crude Oil means hydrocarbon liquid which condition is liquid form in storage conditions and API gravity equal to or less than 40.

1.7.6 Flashing means the emission of hydrocarbons and carbon dioxide from liquid to the air when the liquid increased temperature and pressure or both.

1.7.7 Flash Vapor means the resulting volume of hydrocarbon vapor and carbon dioxide that is evaporated from the liquid when the liquid increased temperature and pressure or both.

1.7.8 Cargo tank emission is to be entirely distinct from the vent stacks of the ship and or other compartments. The location and position of openings on the main deck from which venting vapours shall be minimized the possibility of venting vapours being admitted from enclosed spaces and prevent source of ignition on the main deck .

1.7.9 Reid vapor pressure (RVP) means parameter used to estimation petroleum production evaporative losses or measure of the volatility of condensate. It is defined as the vapor pressure exerted by a liquid form at 37.8 °C (100 °F). This studied applies to condensate.

1.7.10 Vapor Recovery System is equipment constructed to control, treat gaseous emissions, including pipe line, connections, and flow-inducing devices for conducting vapour to a process.

1.7.11 Wave buoy means equipment applies to calculate vertical acceleration by averages of an accelerometer which is mounted on a gravity-stabilized platform that is suspended in a fluid-filled plastic sphere installed at the base of the wave buoy then processed to report the sea conditions.

1.7.12 Environmental Protection Agency (EPA) means agency works to protect human health and the environment of the United States Government

1.7.13 Hazardous Air Pollutants (HAP) means air pollutants or resulted to cause cancer or serious health effects such as birth defects or reproductive effects and adverse environmental consequences.

1.7.14 The International Maritime Dangerous Goods (IMDG) means international code of dangerous goods transportation by sea including such matters as packing, container traffic and segregation of incompatible substances.

1.7.15 International Maritime Organization (IMO) means specialized agency of United Nations with concern in safety, security responsibility of shipping and marine pollution preventing from ships.

CHAPTER II

LITERATURES REVIEW

This chapter presents the literature review on natural gas liquid components and characteristics, structure of storage tank and vessel, VOCs on storage tank problems ship or vessel design with emission characteristics. Guidelines for VOCs management, the effects of VOCs occurred, air pollution models and related researches.

2.1 Natural gas liquid components and characteristics

As regards to petroleum components and natural gas liquids(NGL), condensate is mixture low-density of hydrocarbon liquids which is presented as gaseous compositions of the raw natural gas produced from petroleum industry fields. It condenses out of the raw gas while the temperature reducing to below, the hydrocarbon dew point temperature of the raw gas.

The natural gas condensate is also referred to as condensate, or gas condensate and sometimes natural gasoline according to it contains hydrocarbons within the gasoline boiling range. Raw natural gas can able to one of three types of well.

- Crude oil wells have raw natural gas that produces with the crude oil and associated gas which can exist separate from the crude oil in the underground formation, or dissolved in it. Condensate produced from oil wells is frequently referred to as lease condensate.

- Dry gas wells typically turn out only raw natural gas that does not contain hydrocarbon liquids. Such gas is called non-associated gas. Condensate from dry gas is extracted at central processing platform (CPP)

- Condensate wells produce raw natural gas along with NGL such gas is also called non-associated gas and frequency referred to as wet gas.

There are many condensate sources production and each has its own specific composition of gas condensate. However, gas condensate has a range of specific gravity from 0.5 to 0.8 which composed of hydrocarbons such as propane, butane, pentane and hexane. Natural gas compounds with more carbon atoms (e.g. pentane or blends of butane, pentane and other hydrocarbons with additional carbon atoms) exist as liquids form at ambient temperatures additional condensate able to contain additional impurities for example carbon dioxide, hydrogen sulfide, mercaptans, straight-chain alkanes, cyclohexane, aromatics, and naphthenes [5].

The factor which indicates volatile of non-viscous hydrocarbon liquids is Reid Vapor Pressure (RVP). This is developed by industrially standard the test method to determine vapour pressure of hydrocarbon liquids. The requirements specified procedure from Institute of Petroleum test IP 69. RVP is the vapour pressure obtained within a standardized piece of test equipment for the slowly developed hydrocarbon vapour at 37.8°C (100°F). The procedure test parameters for the determination of this pressure are very important to show and relate to the ratio of a fixed liquid form to a fixed vapour form. The ratio is one part liquid to four parts vapours as a result the pressure reported for this parameter reflects, in generally, the pressure that would be registered when the condensate in cargo oil tank are approximately 20% loaded.

The available technologies on board of condensate tankers for the control of pressure within the cargo oil tank are very important to identify the pressure significance and respect to the develop of hydrocarbon vapours from a condensate liquid phase. Control of the extent of the pressure within a condensate cargo tank vapour system may influence the extent of further condensate vapour evolution. If the pressure within the system is controlled at the saturated vapour pressure of the cargo, then equilibrium pressure between the liquid and vapour phase is gained and no further VOCs will evolve from the cargo oil tank. However, if the vapour pressure in the condensate tank vapour system is reduced to a pressure lower than saturated vapors pressure of the cargo, then VOCs will slowly develop to restore the equilibrium balance of the system.

2.2 Temperature of the crude oil in a cargo tank

The calculation and measurement of temperature on the two differing phases in a cargo oil tank (COT) have differing effects on the size and extent of pressure exerted at any one time in the cargo oil tank. It is necessary to consider the two phases separately with regard to the effect of the temperature. The temperature of the liquid in a COT, the temperature of the liquid phase in a COT will small vary over the period of a voyage unless cargo heating is being undertaken. It is this temperature that determines the saturated vapour pressure that will be exerted by the slowly developing VOCs from the cargo volume and contribute to the total vapour pressure in the COT at any one time. The cooler the liquid phase temperature the lower will be the saturated vapour pressure of the product but should be taken not cooling which lead to promotes wax product.

The temperature of the vapour or gas in COT will change more rapidly and vary during the day and night time .As this phase in the COT contains a mixture of saturated (slowly developed hydrocarbon gases) and unsaturated (Inert gas) gas species the pressure in this space will vary with temperature according to the chemical reaction of the unsaturated gas component to temperature which illustrates the temperature of gas is proportional to the average kinetic energy of molecules and pressure is due to collisions between the wall of the container and the molecules. As a result, during the day time when the gas phase increases, the pressure in the COT will increase so long as there is an inert gas component in the gas phase. The obverse will occur at night time as the gas phase temperature decreases [6].

2.3 Structure of storage tank and vessel

Structure of storage tank and vessel or COT dependent on the products and large quantities of transported. The construction of modern synthetic materials has created growing trade in sophisticated chemicals and these are now being carried in quite large quantities in volume liquid carriers because of they used to be carried in very small quantities and were subject to the suggestions in the International Maritime

Dangerous Goods (IMDG) code. The transportation of oil product cargoes is agreed with first, liquefied gas cargoes and chemical cargoes are considered later.

Petroleum product is carried in volume by specially designed of ship. A large proportion of this economic consists of crude oil transportation, while refined products are also carried in other considerable quantities which are fuel oil, gas oil, diesel oil, kerosene, gasoline and lubricating oils.

The tanker or ship design must take into account the unique trade for which it is intended. A high rate discharging or loading activities is desirable, size of pipelines, pumping capacity and reliability being important in these specifications. The safety factors must be considerate with the provision of a fire protection systems installation and the preparation of cofferdams at the ends of cargo spaces and ventilating pipes of COT.

The cargo oil tank is generally divided into three sections athwart ships by means of two longitudinal bulkheads and into each tank by transverse bulkheads. The maximum length of an oil tank is 20% length of the vessel .There is at least one wash bulkhead if the length of the tank overs 10% length of vessel. The cargo oil tanks are generally numbered from forward, each number having port, center and starboard compartments. Pump rooms installations are located at aft resulting power easily to supply the pumps which generate from the engine room. Ships designed to carry vary grades of oil product cause may be fitted with two pump rooms placed so as to divide the cargo space into three sections. The pipelines system used in a storage tanker is such that great flexibility is possible in the method of discharging or loading and cargo different parcels may completely isolated from one another during subsequently during discharge and loading period . In some cases a small, separate line is used for stripping the last few inches of oil from each COT [6].

Generally, vapor venting from storage tank occurs on three reasons:

- During loading activities.
- During the loaded voyage to the discharge period at port
- During the cargo tanks ballasting at the discharge period at port.

The cargo tanks venting systems are to be entirely distinct from the piping of the ship. The piping preparations and position of openings on the main deck from which release of flammable vapors can occur shall be such as to minimize the

possibility of flammable vapours being released to COT containing a source of ignition. Moreover, collecting in the vicinity of main deck machinery and equipment which lead to constitute an ignition hazard. (From Oil Tanker Design Equipment) [7]

The cargo venting arrangements shall be so operated and designed as to ensure that neither pressure nor vacuum in cargo oil tanks shall exceed design parameters and be such as to provide for:

- The small volumes of vapor flow, air or inert gas mixtures caused by thermal variations in a cargo oil tanks in all cases through vacuum valves or pressure.
- The passage of large volumes of air, vapor and inert gas mixtures during ballasting, cargo loading and discharging period.

The cargo venting arrangements in individual cargo tank may be independent or included with other cargo tanks which incorporated into the inert gas pipe line. Where the piping preparations are combined with other cargo oil tanks, either stop valves or other acceptable means shall be prepared to isolate each cargo oil tanks. Where stop valves are fitted, they shall be provided with locking preparations, which shall be under the management of the responsible ship's officer. The cargo venting arrangements shall be connected to the top of each cargo oil tank and shall be self-draining to the COT under all normal conditions of trim and list of the vessel. Where it may not be possible to prepare self-draining lines, permanent arrangements shall be provided to drain the vent lines to a COT. The cargo venting system shall be provided with devices to protect the passage of flame reverse to the COT. The design, locating and testing of these devices shall comply with the safety requirements, rule or regulations and established by the administration.

Preparation shall be made to safeguard against liquid overflowing in the venting system to a height, which would exceed the design head of cargo oil tanks. This shall be completed by high-level alarms or overflow control systems or other equivalent means, together with gauging equipment, cargo tank filling operating procedures and checklist.

Vacuum valves or pressure may be prepared with a by pass arrangement when they are located in an emission main source or vent stacks. Where such an arrangement is prepared there shall be suitable indicators to show whether the by-pass is open or closed.

Department of Environmental Quality, Oklahoma [8] studied the flashing losses of VOCs emissions occur when a liquid with entrained gases goes from a higher pressure to a lower pressure immediately. As the pressure on the liquid decreases some of the lighter compounds dissolved in the liquid are released or “flashed” and some of the compounds that are liquids at the initial pressure or temperature transform from a liquid into vapor and are also released or “flashed” from the liquid. As these gases are vented, some of the heavier compounds in the liquids may become entrained and emitted in these gases. Flashing losses /VOCs emissions are greater as the pressure drop increases and as the amount of lighter hydrocarbons in the liquid increases. The temperature of the liquids and the storage tank will also influence the amount of flashing losses/VOCs emissions. These flashing losses/ VOCs emissions are then either vented to the atmosphere through the tank’s pressure relief valve, hatch, or other opening, or they may be vented to a capture and/or control system. Flashing losses/VOCs emissions from hydrocarbon storage tanks include emissions of VOCs, Hazardous Air Pollutants (HAP), and toxic air contaminants (TAC). Moreover, there are the other two losses, breathing loss which is normal evaporation of liquid in the tank. Working loss is increase evaporation due to agitation of liquid in the tank.

2.4 Ship or vessel designed to be a storage tanks

Natural gas liquid (NGLs) is stored in a ship as seen in Figure 2.1 below. The stored is transferred from the central processing platform (CPP) to the shore.



Figure 2.1 Store liquefied natural gas which transferred from the central processing platform (CPP) [9]



Figure 2.2 The venting stack in study area

The tank vent system outlets (see Figure 2.2) are installed at a safe distance from the other working areas where workforce who are not related with cargo work may be presented, to ensure that toxic vapours or HAP are diluted to a

acceptable range of concentration before they can expose such an area. The acceptable distances specified depend on the severity of the toxic vapours concentration. In all cases the principles explained in the IMO Codes will have been met by the ship's requirement. What need is wind directions awareness additional concern for fixed storage vessel.

International Code for the Construction and Equipment of Ships Carrying Annex 4 studied results [10] comparison with study area, cargo venting system is not aware of the wind direction to the accommodation and the venting stack height should fit within 4 meters of raise walk ways and not less than 6 meters. The accommodation is recommended to stand away from the vent stack at least 10 meters without concern on the impact of wind blow from the vent to the accommodation. Because normal standards especially consider sailing ship and do not considerate at fix location like storage tanker see in Figure 2.3, the structure of the ship and the emission of VOCs in the direction to the accommodation see in Figure 2.4 which located below wind.

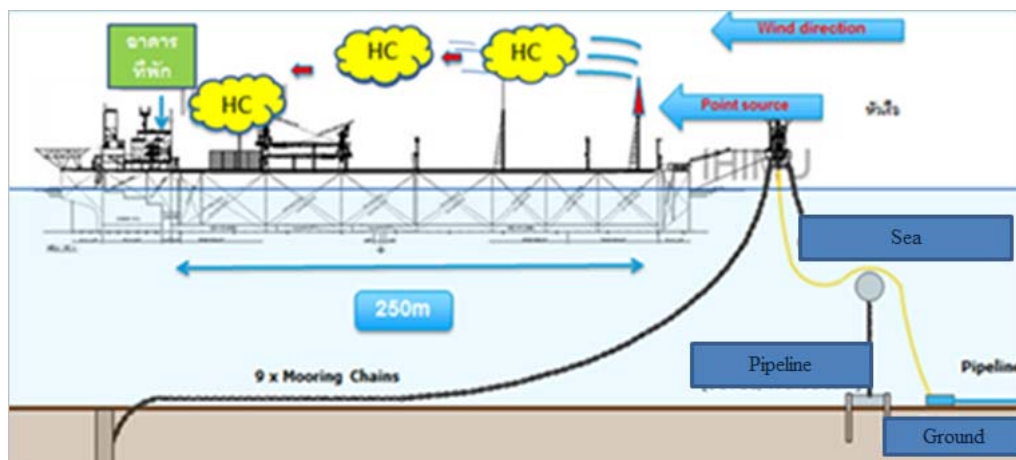


Figure 2.3 Structure of ship and the emission of VOCs in the direction of wind



Figure 2.4 Ship accommodation of study area

2.5 Guidelines for VOCs management

VOCs are air pollutants which act as a precursor to the formation of Tropospheric Ozone and commonly termed smog. Therefore, to control an air pollutants emission, there are four criteria that effect to the extent and rate of evolution of gaseous VOCs from oils product and its subsequent emit to atmosphere following

- The crude oil's volatility or vapor pressure.
- The liquid and gas phase temperature of the crude oil tank.
- The control pressure setting or the vapor phase within the cargo oil tank.
- The volume or size of the vapor phase within the cargo oil tank.

Criteria are defined and briefly described below together with any interaction between the criteria for general operational circumstances. In 1990s certain Administrations required petroleum industry to reduce emissions of VOCs and this led to the development and installation of vapour recovery unit (VRU) on board shuttle tankers. Different opinions were developed for the purpose of decreasing the releases of VOCs. The primary efficiency requirement was set to 78%. The systems can recover VOCs in all operational phases.

For ships that have been installed with vapour recovery unit, the VOCs emissions will be managed when the recovery plant is in normal operation. The VOCs

recovery unit efficiency as well as any operational limitations related to, e.g., applicability for different cargo handling modes (transit, loading, crude oil washing), maximum allowable vapour pressures or loading rates, are to be specified in management plan of VOCs. [6]

2.5.1 Vapour recovery systems (Condensation systems)

The concept is similar to that of re-liquefaction plants on LPG carriers, i.e. condensation of VOCs released from cargo tanks. In the system, the VOCs pass through a knock out containment before it is liquefied and pressurized in a two stage process. The resulting liquefied gas is kept in a containment under pressure and could either be offloaded to other ship, or be used as in house fuel (possibly including methane and ethane) for generators, boilers, or engines subject to strict safety requirements. It is also variable that the stored gas could be applied as an alternative to inert gas subject to the administration's acceptance. [6]

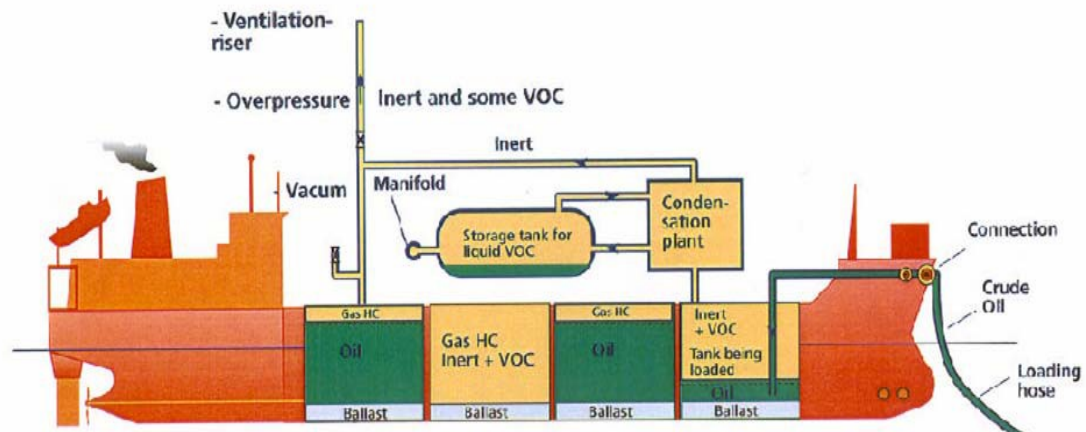


Figure 2.5 Vapour Recovery Systems (Condensation Systems) [6]

The Comparison of the Vapors Recovery Systems (condensation systems) between advantages and disadvantages of condensation systems from writer experience can be shown as below.

Advantages

- Low primary cost.
- Simple procedure to operate.
- Low operating cost in case of nitrogen is not applied.

Disadvantages

- Expensive cost from nitrogen if not applied for another functions.
- Complicated to maintenance.
- Workforce and complicated for nitrogen managing

The structure of the ship and the emission as Figure 2.5 is similar to the research's ships which not have Vapors recovery Unit or VRU , if VRU installed, the effects of VOCs not occurred but its will manage by condensation plant which benefits are both direct impact on natural environment and the working environment has also been improved. The efficiency of the condensation systems will decrease emission VOCs emissions are reduced by nearly 100%. [11]

2.5.2 Vapour recovery systems (Absorption systems)

The concept is based on the absorption of VOCs in a counter current flow of vapours in an absorber containment which is fed into the bottom of the containment, with the side stream of condensate or crude oil acting as the absorption medium. The oil containing the absorbed VOCs is then passed from the lower of the containment back to the piping line where it is mixed with the main crude oil loading pumps and compressors are used to pressurize the oil and gas. Unabsorbed gases are relieved to the venting stack to increase the recovery efficiency [6].

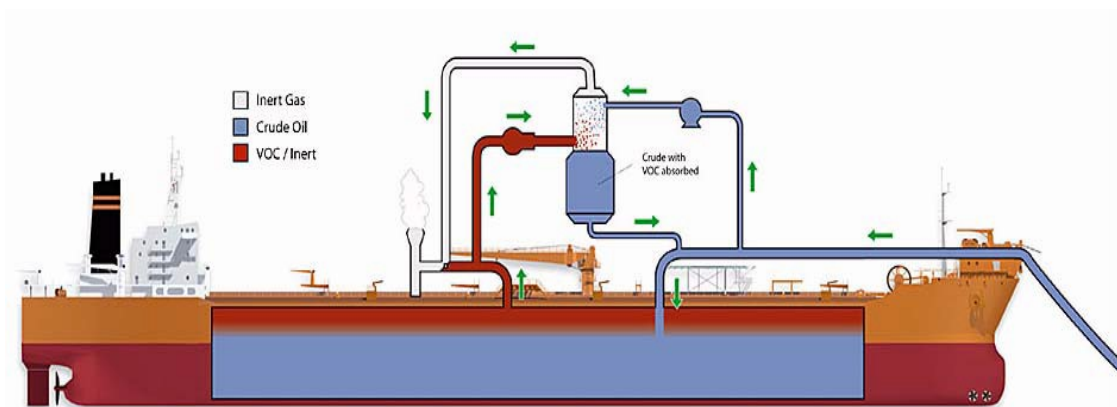


Figure 2.6 Vapour Recovery Systems (Absorption System) [6]

The advantages and disadvantages of vapour recovery by absorption system from written experience are as follows:

Advantages

- Simple procedure to operate.
- Low pressure decrease through system
- Insensitive to varying gas flow rates.
- Insensitive to dirty vapor streams.
- Insensitive to varying vapor concentrations.
- High humidity operation.
- High/low temperature not significantly affected.
- Low primary cost
- Lowest continue operating cost.
- Economic value from the recovered VOCs yield benefit.
- Absorbent media does not require to be replaced,
- Absorbent media not consumed.
- Compression or blowers not required

Disadvantages

- Cost effective and low vapor concentrations.
- Sometime it may require high amount of electricity for regeneration if fuel reboiler is not applied. Diesel consumption for generated electricity and waste management.

The main propose for an adsorption system as shown in Figure 2.6 is to separate fractions of hydrocarbons from inert gas. Several technologies are commercially available and adsorption system is used on shuttle tankers transporting oil from the field, and on floating storage and offloading units (FSO). The hydrocarbons will then be recycled back to the oil with help from the adsorption plant. Absorption Systems efficiency reduced VOCs emissions are approximately 80 %.(VOCs recovery systems n.d.) [11].

2.5.3 Vapour recovery systems (Absorption carbon vacuum - regenerated adsorption)

The hydrocarbon vapours are filtered through active carbon, which adsorbs the hydrocarbons after that the carbon is regenerated for restore its adsorbing

capacity and adsorb hydrocarbons in the next cycle. The vacuum pump decrease the pressure in the carbon bed until reached the level where the hydrocarbons are desorbed from the carbon. The extracted, very highly concentrated vapours then pass into the absorber, where the hydrocarbon vapours is absorbed in a stream of crude oil taken from and returned to the cargo oil tanks.

Although carbon bed adsorption systems are normally sensitive to high hydrocarbons level concentrations in the VOCs inlet stream, the VOCs feed stream first passes through an inlet absorber where some hydrocarbon vapours are removed by absorption systems. The recovered VOCs stream may be reabsorbed in the beginning source in the same inlet absorber as can be seen from Figure 2.7 and drawing see Figure 2.8.



Figure 2.7 Vapor Recovery Systems. (Absorption Carbon Vacuum-Regenerated Adsorption) [6]

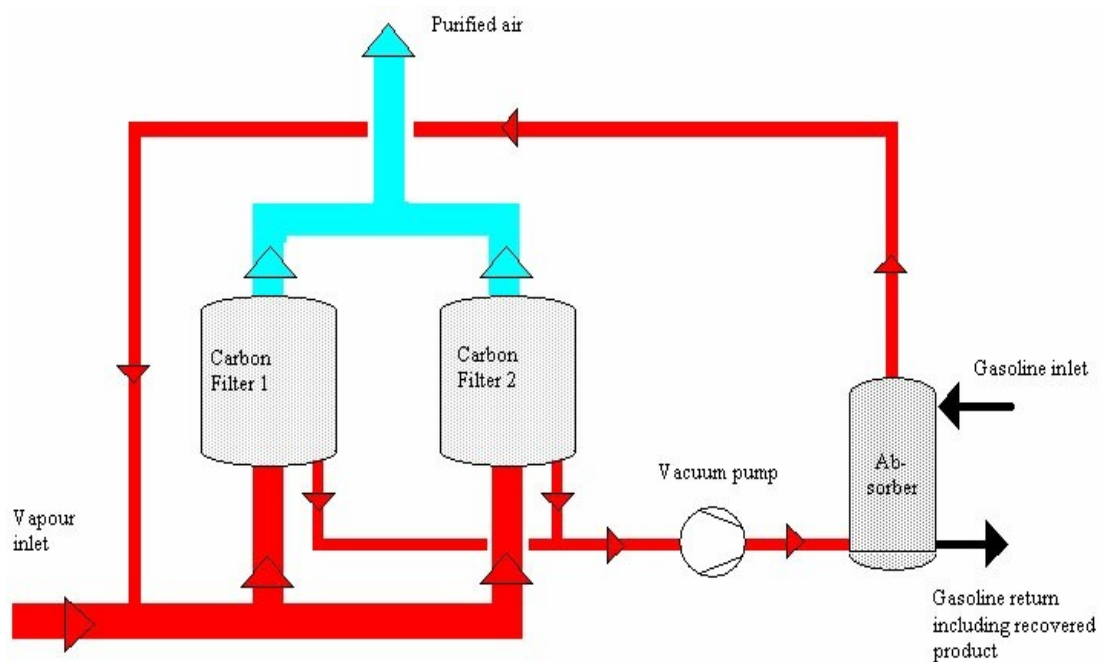


Figure 2.8 Vapor Recovery Systems drawing (Absorption Carbon Vacuum-Regenerated Adsorption) [6]

The useful technology of absorption carbon vacuum has been used for more over 2 decades in many countries such as Denmark, Russian and Norway at Navion Europa field where is very good result of high efficiencies of 92 to 97 percent emission control the advantages are below [12]. Moreover, from the writer experience, the benefits of absorption carbon vacuum can be said as below.

- Can be located or installed in a hazardous area.
- Save from ignition source.
- Operate in any marine loading conditioning
- No environment pollutants or waste.
- Not requirement supplemental fuel
- Requires only space for installation area.

2.5.4 Active VOCs recovery: offshore loading, Norwegian continental shelf

Industry case studies of achieve VOCs recovery: offshore loading, Norwegian Continental Shelf. There were eighteen operations (both active and passive) operating under the VOCs industry cooperative (VOCIC) to reduce nm VOCs

emissions. Some VOCIC tankers use active VOCs recovery units to achieve non-methane volatile organic compounds (NMVOC) reductions [11]. Table 2.1 below concludes the reductions achieved by each shuttle tanker.

Table 2.1 NMVOC reductions by Norwegian shuttle tankers using active VOCs recovery systems [11]

Ship	Loaded volume (millSm ³)	Number of loads	System (design reduction efficacy)	Achieved regularity	NMVOC reduction (tonne)
Grena	3,667	27	Condensation (100%)	97%	3,346
Karen Knutsen	4,408	33	Absorption (80%)	100%	4,469
Navion Anglia	1,235	11	Absorption (80%)	96%	826
Navion Brittanica	2,094	17	Condensation (100%)	95%	2,025
Navion Hispania	3,555	28	Condensation (100%)	99%	3,910
Navion Oceania	4,081	33	Absorption (80%)	93%	3,601
Navion Scandia	3,292	28	Condensation (100%)	86%	3,127
Stena Alexita	2,,285	25	Condensation (100%)	75%	2,024
Stena Natalita	1,137	21	Condensation (100%)	95%	935

2.5.5 Passive VOCs recovery offshore loading, Norwegian continental shelf

In 2011, eighteen operations (both passive and active) were operating under VOCs industry cooperative to decrease NMVOC emissions. The cost of nm

VOCs reductions for VOCIC facilities was approximately 200 million NOK (Norway Krone) .Of this total cost, about 125 million NOK was for capital investment while the remaining 75 million NOK was for net operating costs. Typical unit abatement cost for vapor balancing on tankers and loading operations is estimated at 40–300 ECU per tonne VOCs. Some VOCIC shuttle tankers use passive VOCs recovery systems to achieve NMVOC reductions. Table 2.2 concludes the reductions achieved by each ship. [11]

Table 2.2 NMVOC reductions by Norwegian shuttle tankers using passive VOCs recovery systems [11]

Ship	Loaded volume (millSm³)	Number of loads	System (design reduction efficiency)	Achieved regularity	NM VOC reduction (tonne)
Amundsen Spirit	2,208	25	KVOC (50%) ^[1]	100%	962
Betty Knutsen	25	1	KVOC (50%) ^[1]	100%	16
Bodil Knutsen	2,336	17	KVOC (50%) ^[1]	100%	1,361
Elisabeth Knutsen	3,439	28	KVOC (50%) ^[1]	100%	2,157
Hanne Knutsen	397	3	KVOC (50%) ^[1]	100%	184
Nansen Spirit	1,890	22	KVOC (50%) ^[1]	100%	767
Navion Norvegia	2,604	20	KVOC (50%) ^[1]	100%	1,810
Peary Spirit	326	3	KVOC (50%) ^[1]	100%	181
Sallie Knutsen	3,871	31	KVOC (50%) ^[1]	100%	2,108

Table 2.2 NMVOC reductions by Norwegian shuttle tankers using passive VOCs recovery systems (cont.) [11]

Ship	Loaded volume (millSm ³)	Number of loads	System (design reduction efficiency)	Achieved regularity	NM VOC reduction (tonne)
Siri Knutsen	53	2	KVOC (50%) ^[1]	100%	34
Vigdis Knutsen	508	4	KVOC (50%) ^[1]	100%	493

Remark KVOCs increased by diameter extension of drop line system developed by Knutsen OAS.

2.6 Effects of VOCs

VOCs are released during the production of oil and natural gas which can cause breathing problems, especially children, or person who have existing respiratory problems such as asthmatic attack. The effects of VOCs are presented in two issues on health and environmental effects.

2.6.1 Health effects

VOCs are hazardous air pollutants which can have effects on human health by inducing to respiratory disease, and some VOCs are toxic or mutagenic to reproduction and harmful to the embryo of human including environmental effects. High concentration levels of VOCs exposure may cause eye, nose and throat irritation, loss of coordination, headaches, nausea, liver and kidney damaged, and central nervous system (CNS) effects. Some VOCs can cause cancer in animal and some are suspected or known to cause cancer in humans. The ability of VOCs to cause health effects varies greatly from those that are highly toxic, to those with no known health effect. As with other pollutants, the extent and nature of the health effect will depend on many factors including high level of exposure, concentration and length of time exposed. Eye, skin, respiratory tract irritation, dizziness, headaches, visual disorders,

and memory impairment are among the immediate symptoms that some people have experienced soon after exposure to VOCs. At present, not much information is known about what health effects occur from VOCs usually found in homes. Many organic compounds are known to cause cancer in animals, some are suspected of causing, or are known to cause, cancer in humans [13].

Natural gas production or oil released toluene benzene, ethylbenzene, and xylenes (BTEX) as well as n-hexane. The adverse effects of these air pollutants are as follows [14].

1) Benzene

- Skin, eyes, and upper respiratory tract irritation.
- Skin may blister
- Long term exposure to benzene may cause blood disorders, developmental disorders, reproductive and cancer.

2) Toluene

- Long term exposure to toluene may cause nervous system (CNS) effects, dizziness, headaches, difficulty with sleep, birth defects. skin, eyes, and respiratory tract irritation

3) Ethylbenzene

- Short term exposure may cause eye and throat irritation, chest discomfort, and dizziness.
- Long term exposure may cause blood disorders.

4) Xylenes

- Short term exposure to high concentration or high level of mixed xylenes may cause the nose, throat irritation, mild transient eye irritation, neurological effects, nausea, vomiting and gastric irritation.
- Long term exposure to high concentration of xylene may affect the nervous system.

5) n-Hexane

- Short term exposure can cause giddiness, slight nausea, dizziness, and a headache.
- Long term exposure can cause numbness in extremities, blurred vision, headaches, muscular weakness, and fatigue.

A previous study on the measurement of concentration response between human sensory reactions and exposure to VOCs was found that odor was perceived approximately 3 mg/m^3 . The air quality was reported to be unpleasant only at concentrations above 8 mg/m^3 with the need for additional ventilation to remove of sources becoming evident. Moreover the irritation of the mucous membranes was statistically significant only at concentrations of 8 mg/m^3 or higher for an exposure time in 50 minutes. In a controlled chamber study the reactions of 21 healthy persons were compared with a group of 14 persons suffering from the sick building syndrome (SBS subjects) when exposed to 25 mg/m^3 of the same specific mixture of VOCs. A tendency to a stronger response was seen among the SBS subjects. Physiological measures indicated exposure related reduction of lung function among the SBS persons. Both groups had an increased number of polymorpho-nuclear leukocytes in tear fluid as a result of exposure. This was not seen in nasal secretions. Additionally found after neurobehavioral tests to characterize the possible effects of the same specific mixture of VOCs as above in young healthy men. Most subjects showed adverse subjective reactions at 25 mg/m^3 , general discomfort (defined as irritation of the eyes, nose and throat) as well as symptom questionnaire responses on odour intensity, air quality, eye and throat irritation, headache and drowsiness and mood scale measures of fatigue and confusion all differed in predicted directions between clean air and VOCs exposure conditions [15].

2.6.2 Environmental effects of volatile organic compounds

Transportations for petroleum products could present unobservable hazards to people and environment and VOCs should be considered extremely. During both transportation and loading of hydrocarbon there is a venting of hydrocarbon vapours from cargo oil tanks through the vent stacks. These hydrocarbon vapours commonly denominated VOCs effect to formation of ground level ozone and is a low level pollutant that over time oxidizes to carbon dioxide thus becoming a greenhouse gas that cause damage to natural resources, vital environmental, economic importance and harmful to human health as seen in Figure 2.9. The major problem of the VOCs emissions comes from offshore shuttle tankers loading activity.

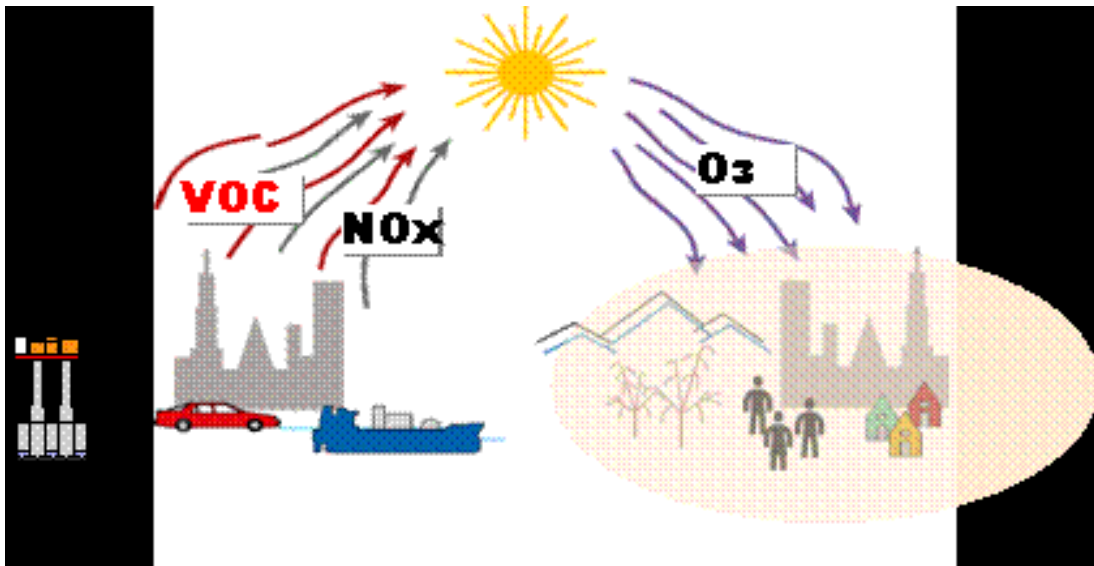


Figure 2.9 Formation of Ground -level Ozone [16]

Generally, Volatile Organic Compounds (VOCs) are found in everything from paints and finishes to underarm deodorant and freshly baked bread which are major concern by Environmental Protection Agency (EPA) and air quality boards across the USA and Europe. Hazardous Air Pollutants (HAPs) and VOCs have been found to be a major contributing factor to the production of ozone and public health hazard concern common about the air pollutants.

Control of Ozone is a difficult because it is not emitted into the air, but actually formed in the atmosphere through a photochemical reaction. It is in this process that VOCs play a significant role. VOCs in the air react with oxides of nitrogen in the presence of sunlight to form ozone. Ozone in the stratosphere is part of what is commonly referred to as the 'ozone layer'. Ozone in the ozone layer is helpful because it helps to block the sun's ultraviolet radiation.

Unfortunately, most VOCs produce ozone, which inhabits the troposphere. Troposphere or ground level ozone is a harmful, photochemical oxidant that significantly contributes to the formation of smog. Troposphere ozone is regularly measured as an indicator of smog levels in the atmosphere.

2.7 Measurement and analytical methods for VOCs

In an indoor air quality investigation, European Commissions Joint Research Center [15] selected the method for measurement and analysis of VOCs as follows.

2.7.1 Direct instruments reading for VOCs

These instruments are used in gas chromatography to detect individual compounds after separation can also be applied to provide information on a given mixture without a prior separation step. VOC detectors that can be applied for this purpose are, such as the flame ionizations detector (FID) and the photoionization detector (PID). A further direct reading instrument for VOCs is the photo acoustic sensor (PAS)

In the flame ionizations detector (FID), an organic compound is burned in a hydrogen flame giving increase to ions which are attracted to a collector electrode. The resulting electric current is amplified and recorded. The intensity of the signal depends primarily on the number of carbon atoms of the molecule, but to some extent it is also influenced by the character or structure of the chemical. Therefore, the same amount of molecules of two different VOCs with the same number of carbon atoms can give increase to two different signals. The FID is very stable. It is the most common detector used for VOCs because it detects high concentration of VOCs. In the photoionization detector (PID), the energy from the UV lamp is sufficient to ionize most VOCs and VOCs are ionized by UV radiation such as some chlorinated compounds are not ionized. The PID is more sensitive to reading than the FID by about an order of magnitude. However, the FID may be more stable than the PID and again, the response can only be viewed as an indicator of Total Volatile Organic Compounds (TVOC).

Direct reading instruments are generally calibrated with one single compound, e.g. a hydrocarbon such as toluene or n-hexane. Consequently, the signal obtained from a mixture of VOCs is always expressed in terms of concentration equivalents of this compound regardless of the composition of the mixture.

Direct reading instruments are easy to apply. They are provided a real-time signal and portable which makes the detector possible to detect rapid concentration

changes and apply to measure the other organic compounds, especially to very volatile organic compounds (VOCs). As the direct reading instruments are calibrated with only one compound, the signal shows total compounds of the mixture as an equivalent of the sample. The output signal gives no information about the qualitative composition of the mixture.

2.7.2 Method for separation VOCs

A previous study, the information resulted from direct reading instruments are inadequate because details are required on individual organic compounds. To fulfil this require, the chemical mixture has to be separated into its constituents. Most VOCs analyses of indoor air are carried out using sampling on a sorbent and subsequent separation by gas chromatography (GC). However, if special attention is paid to specific classes of VOCs, analytical techniques other than GC may be used. As an example, aldehydes are frequently determined using high-performance liquid chromatography following derivatisation with 2,4-dinitrophenyl hydrazine. The number of GC procedures used to analyses VOCs in indoor air is large and no single procedure can be recommended as the only possible. Indoor air analysis analytical procedures compilation for examples, GC procedures including short term and long term sampling are given. In the following sections, information is given on the general steps that are needed in separation procedures, and on the different ways used to generate the TVOC value from the results of the analysis [15].

The comparison of the analytical methods the study above has measure VOCs by gas flow meter which can measure the volume of daily emission. GC interpreted the components and air model applied to predict the VOCs approximately on the main deck of the ship.

2.8 Consideration of emissions from natural gas and oil activities

A previous study of Picard [17] which informs the emission factors in average are developed and published by industry associations and environmental agencies. Good practice guidance and uncertainty management in National

Greenhouse Gas inventories Fugitive emissions provided that statistical values which may be expected to provide reasonable results when applied to a large population of applicable sources (e.g., for national emission or regional inventories). They are not intended for application to individual or small numbers of sources. The reliability of an emission factor in a given application depends on the quality of the factor, the specific pollutants of interest, and the type of source. Emission factors are continually being updated to include additional measurement results and to reflect development and penetration of new control technologies as well as impacts of increasing performance standards and regulatory control requirements. Accordingly, regular reviews should be conducted to ensure that the best available factors are being used, and the references for the chosen values should be clearly documented. Since emission factors are developed and published by environmental agencies and industry associations, it then becomes necessary to develop inventory estimates in consultation with these organizations. The selected emission factors must be valid for the given application and be expressed on the same basis as the activity data. In some cases, it may be appropriate to apply speciation profiles and factors to account for the amount of time a source is active and for specific control measures being used. The following are additional considerations to be taken into account in choosing emission factors.

The conclusions, to assess the applicability of the selected factors for the target application to ensure similar or comparable source behavior and characteristics are important.

In the absence of better data, it may sometimes be necessary to apply factors reported for other regions, that mean in every location have different factors. However, tests should ultimately be performed to verify the validity of these selections. Where measurements are performed to develop new emission factors only recognized or proven test procedures should be applied. The methodology and quality control (QC), quality assurance (QA) procedures should be documented and the sampled sources should be representative of typical variations in the overall source population. Uncertainties and limitations of the results should be also assessed. If all the necessary historical data are present for the base year, emission estimates should be made using the good practice approach described .Where some historical data are missing it should still be possible to use source-specific measurements made under the

good-practice regime, and back-casting techniques to establish an acceptable relationship between emissions and activity data in the base year. While establishing baseline emission levels is meaningful and important at a regional or national level, it is often a misleading indicator at the company level due to frequent mergers, divestitures and acquisitions in many areas. This may be an issue where national inventories are developed based on a rollup of company-level inventories, and some extrapolations or interpolations are required.

2.9 Air quality impacts from ship emissions

The study of the emissions of Dabdub and Irvine [5] on a ship in California of South Coast Air Basin provides that the emission would have been significantly increasing in next 10 to 40 years because of growing international commerce and growing activities of shipping. Furthermore, 2020 forecasted ship emissions by consideration some factors such as fuel quality, engine size and vessel numbers by using the UCI-CIT model to simulate. The result is presented on Table 2.3, which means that VOCs emission would have been produced continuously.

Table 2.3 Daily domain-wide emissions of VOCs

Year	Without ship emission (tons/day)	With ship emission (tons/day)	Emission from ships (tons/day)	Ship emissions as percentage of total basin-wide emission (%)
2002	580.0	582.9	2.9	0.5
2020	662.4	671.2	8.8	1.3

According to the International Maritime Organization (International Maritime Organization, 2000), found 80% of shipping transportation occurs in the Northern Hemisphere of which 75% occurs within 400 kms from coast. The study conducted by Dabdub and Irvine [5] shows the speciation of VOCs emissions in Table 2.4. Therefore, these emissions it is necessary to understand of atmospheric impacts, especially on air in quality regional. The emissions from such shipping transportations

undergo atmospheric transport and may reflect coastal air quality. Over past two of environmental rule and regulation decades led to the reduction of emissions sources from land based. Finally, the consideration of emission factors becomes increasingly important and is challenging study [5].

Table 2.4 The fraction of VOCs emission [5]

VOCs	Fraction
Methane	0.116
Ethane	0.028
Ethylene	0.287
Propylene	0.173
Acetylene	0.113
1-Butene	0.134
1,3-Butdiene	0.070
Benzene	0.079

According to this research, the fraction of VOCs emissions from cargos will be compared with VOCs emission stated on Table 2.4

2.10 Evaporation loss from storage tanks

Stricklin [18] studied the product loss in the crude oil industry. Evaporation is a natural phenomenon describing when a liquid turns into a gas. A liquid will tend to evaporate depending on its vapor pressure. A liquid vapor pressure is dependent on the composition and surface temperature of the liquid. Evaporation losses should be minimized to help maximize company revenue, meet regulatory requirements, and reduce greenhouse gas emissions.

The local governments and United States Environmental Protection Agency (USEPA) are implementing stricter regulations on volatile organic compounds (VOCs) and greenhouse gas (GHG) emissions which result from storage tank

evaporation. The accurate quantification of evaporative losses from storage tanks is imperative given the impact to the economic and the environment. [18].

Crude oil and condensate are multi-component liquids made up of a wide range of hydrocarbons that have different volatilities. In addition, the composition of crude oil and condensate will be different for each well. Therefore, evaluating the evaporative losses from crude oil and condensate is challenging because the composition of the liquid mixture must be known and no two storage tanks carry the same liquid mixture. Crude oil and condensates are typically classified by their density, which is measured by API gravity. Crude oil and condensate with a low density or high API gravity typically consist of smaller hydrocarbons and have higher vapor pressures, and hence are more volatile. High API gravity crude oil or condensate is primarily composed of hydrocarbons with fewer carbon atoms than 20 atoms. Heavy crude oil has a low API gravity and low vapor pressure, and hence is less volatile. Heavy crude oils are primarily composed of more 40 atoms. For any crude oil or condensate mixture its composition determines its API gravity, which in turn is a good indicator of its volatility or tendency to evaporate. The evaporation rate of crude oil and condensate is logarithmic over time because the more volatile components evaporate first at high rates followed by the less volatile components. The lighter molecules evaporate first leaving the heavier molecules behind causing a reduction in the rate of evaporation with time, typical of a logarithmic trend.

Evaporation in crude oil and condensate storage tanks leads to lost saleable product, air pollution, and Greenhouse gas emissions. Storage tanks store produced crude oil and condensate at near-atmospheric pressure. Produced gas or oil from the wellhead typically passes through at least a separator and sometimes a heater-treater depending on the quality of the gas/oil. The separated liquids from the separator and heater-treater are dumped to storage tanks. Once the liquids have settled in the storage tank, gases from evaporation are contained in the tank until the pressure in the tank exceeds the set point on the tank vents. Evaporative losses occur primarily in two ways: standing losses and working losses. The total evaporative loss from any storage tank is the working losses and the sum of the standing losses.

Standing losses result from the thermal expansion and contraction of the tank and vapor mixture from the daily heating cycle. As the temperature increases

during the day, the air-vapor mixture expands and increases the pressure in the tank. If the pressure in tank exceeds the set points on the tank vents, vapor is vented from the tank resulting in evaporative losses. Standing losses occurs without any change in liquid level in the tank. The standing losses are a function of the following:

- Liquid height.
- Liquid surface temperature.

Moreover, standing losses could be predicted roughly via calculation following API MPMS chapter 19.1. [18] and depends significantly directly on below factors.

- Tank shell height.
- Tank diameter.
- Roof outage and volume contained under a cone roof or dome roof.
- Vapor pressure.

Working losses result from the change in liquid level in the tank. When the liquid level increases, the vapor in the tank is compressed increasing the pressure in the tank. If the pressure in the tank exceeds the set point on the tank vents, vapor is vented from the tank resulting in evaporative losses. Working losses are a function of the following:

- Vapor density.
- Liquid surface temperature.
- Liquid height.

Additionally, working losses can be explained by the same standard, API MPMS chapter 19.1, [18] which content and varies directly on factors such as:

- Stock turnover rate.
- Annual throughput.
- Tank diameter.
- Vapor pressure.

Rudd and Hill [19] studied VOCs emission factors from a ship. They found that emissions of VOCs during loading and unloading depends on many factors, take percentage of loading for a good example as shown in Figure 2.10, and other important factors which are directly proportional to VOCs emission loss as follows the list

- Temperature.
- Loading rate.
- Turbulence in the vapors space.
- Sea conditions or wave height

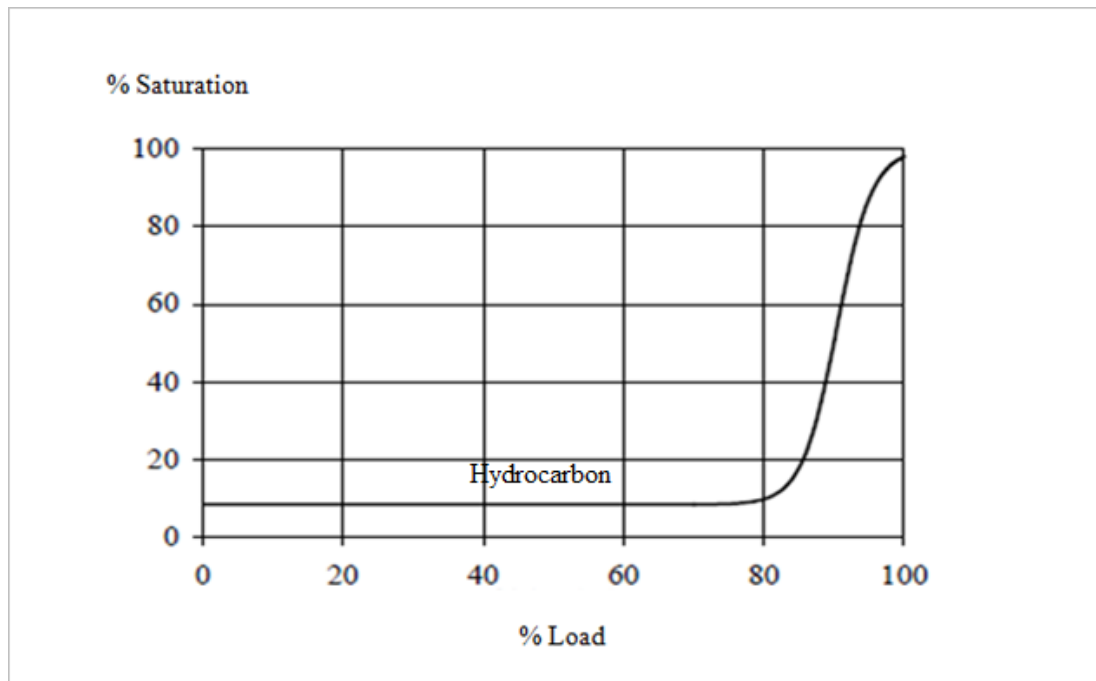


Figure 2.10 Hydrocarbon in vent gas as a function of percentage loaded [19]

Some relevant factors are similar to this research and according to working experience, the amount of the emissions of volatile natural gas liquid may depend on the following

- Ambient temperature.
- Cargo temperature.
- Turbulence weather.
- Percentage of condensate in cargo.
- RVP characteristic of products.

Because the emissions of the gas and condensate effect on the environment, mitigation for ship design should be considerate scrupulously in the future.

2.11 Methodology to estimate emissions from storage tanks

Pring et al [20] studied environment quality regarding emission estimates from upstream petroleum activities in Texas, with over 90,000 gas wells, 150,000 oil wells and equipment operated such as pump, compressor, heater and storage tank. One of the emissions, which are similar to this research, is VOCs emitted from storage tanks. Pring et al figured out that the majority of VOCs emission source was storage tank for condensate, with being 55% of total volume approximately. VOCs emission could be calculated by this below equation.

$$E = TOP * EF * \frac{1}{2,000} \quad (\text{Equation 2.1})$$

Where

E = VOCs emission [tons/year].

TOP = Total production of condensate [BBL/year].

EF = Emission factor [VOCs emission from condensate is 33.3].

The study in VOCs emission from cargo will be calculated by above equation and the result will be compared with recorded data.

2.12 Emissions from natural gas production in the Barnett Shale area

The condensate in storage tanks of Barnett Shale are generally 10,000 to 20,000 gallons. Condensate is continuously collected and transported by truck to refineries for incorporation by liquid fuels form, At product wells, tanks are used to store product on-site before it transported to the refiners. The hydrocarbon liquid known as condensate can evaporate hydrocarbons vapors and be vent to the atmosphere through tanks venting pipe which direct distribute to ozone and particulate matter smog, are called toxic chemicals, and induce of climate change. The oil and gas exploration and production diagram in normal operation, Armendariz [21] is shown in Figure 2.11.

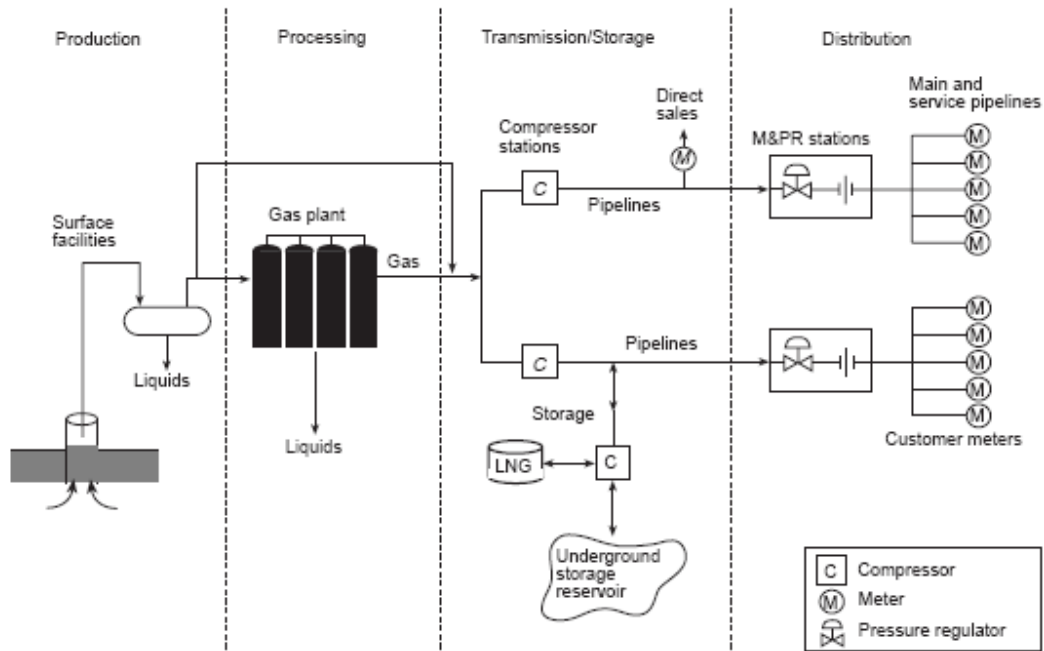


Figure 2.11 Process flow diagrams in the natural gas industry from wells to customers [21]

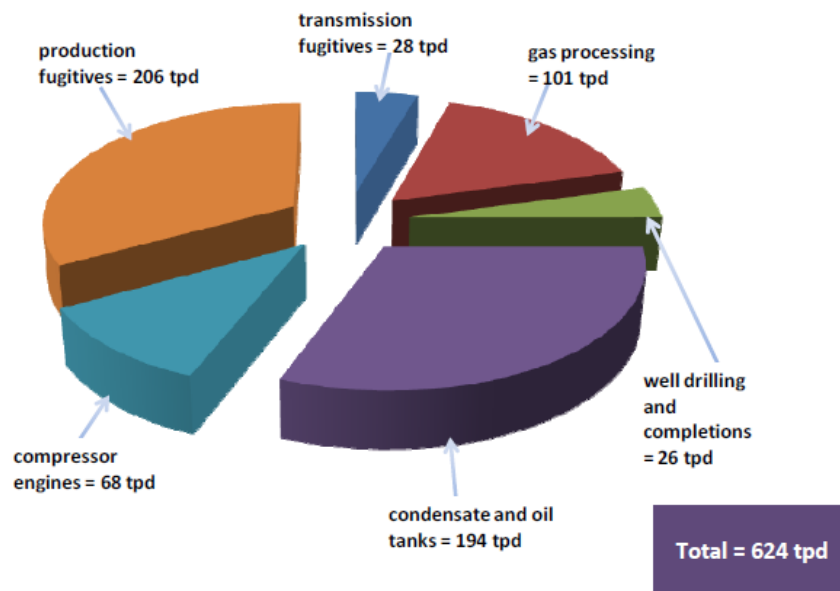


Figure 2.12 Emissions sources from Barnett Shale in 2009. [21]

The study were estimate emissions of volatile organic compounds from Barnett Shale oil and gas production such as hazardous air pollutants, nitrogen oxides,

carbon dioxide , nitrous oxide, and methane. Emission estimates were made in years 2007 and 2009 calendar year as can be seen in Figure 2.12 and Table 2.5.

In conclusion, condensate emissions VOCs from oil tanks are shown were 124 tpd in 2007 and it is expected to rise to 194 tpd in 2009. Hazardous air pollutant emissions were also substantial from the oil tanks, with 2007 emissions of 9.5 tpd and 2009 emissions of 14.9 tpd. Greenhouse gas emissions from the tanks are near entirely from methane (CH₄), include a small contribution from carbondioxide (CO₂). In 2007 carbon dioxide equivalent tons, greenhouse gas emissions were 308 tpd which will rise to 483 tpd in 2009. Emissions of VOCs were expected from all sources of the Barnett Shale, but the highest was come from condensate tank vents and VOCs fugitive emissions which contain with VOCs compounds significant in quantities.

Table 2.5 Comparison of air pollutants from Barnett Shale Tanks between 2007 and 2009

Barnett Shale Tanks	Year	
	2007 (tpd)	2009 (tpd)
VOCs	124	194
HAPs	9.5	14.9
CH ₄	15	23
CO ₂	308	483

How to reduce emission is very important for resulting in important air quality benefits. Some of VOCs emissions reductions would also result in increased production of condensate and natural gas, increasing an economic benefit for efforts to reduce VOCs emissions.

Firstly, an enclosed flare is generally used to be pollution control devices because of high efficiency (approximately 90%), with simple principle of combustion. The amount of the VOCs, HAPs and methane content is sent to the flare and there are flames which cannot visible from outside and air added to provide oxygen. These leads to combustion and the pollutant emissions are destroyed. Take Barnett Shale field for instance, the visible emission reduction of 15 tpd of hazardous air pollutants, 190 tpd of VOCs, and 22 tpd of methane.

Even though enclosed flares is impossible to install in vessel storage tank according to safety concern for tank explosive, this is not allowing for tanker operation.

Secondary, Vapor Recovery Units (VRU) can be high efficient systems to separating vapors, capturing gases produced from oil or condensate storage tanks. Vapors and Gases from the storage tanks are directed to the inlet part of a compressor, and reverse back into liquid form by increases the pressure of the mixture to the point that many of the moderate and higher molecular weight (MW) compounds. The methane (CH_4) and other light vapours are directed to the inlet part of the well site production compressors to join the main pipe of natural gas being produced. In this way, at the gas well VRU use increases the total of production and leading to increase in gas available for metering and revenue production which is benefit. Moreover, the production in liquid form is directed back into the liquid phase in the condensate storage tank, increasing condensate production and the potential income. VRU are found to have control efficiencies over 98%.

In conclusions, Oil and gas production has expanded rapidly over the last 10 years .Not only the benefits are more production and finance, but also global air quality that is responsibility of the company. In this report examined emissions of smog forming compounds, air toxic compounds, and greenhouse gases from point sources such as, compressor engines, oil and condensate tanks. It was found that significant emission reductions could also be achieved by use VRU from oil and condensate storage tanks, which could control VOCs emissions approximately 190 tpd. Efforts to control condensate storage tanks emissions would easily pay for themselves in a matter of months and start generating revenue to producers because of the high value of the condensate and gas that would be separated and captured instead of emitted to the atmosphere.

This study informs the increasing trend of VOCs and from oil and gas industry. The relevant factors are from quantity of the products and to support environment stewardship and financial benefit in the future there will be plan for Vapor recovery units (VRU) but enclosed flares Impossible to install in vessel storage tank according to safety concern for tank explosive. This is not allowing for tanker operation [21]. Comparison between enclosed flares and vapor recovery were shown

in Table 2.6 and Table 2.7, this is very important to study factors for emission, quantity of emission and mitigation to improve environment stewardship.

Table 2.6 Comparison between enclosed flares and vapor recovery units.

Methods	Advantages	Disadvantages
Enclosed Flares	1.Safety 2.Reduce greenhouse gas emission	1.Production loss
Vapor Recovery Units	1.Economic benefit	2. High maintenance cost

Table 2.7 Comparison between two methods and possible installation at cargo.

Methods	Reasons
Enclosed Flares	Enclosed flares impossible to install in vessel storages tank according to safety concern for tank explosive
Vapor Recovery Units	Support environment stewardship and financial benefit in the future there will be plan

2.13 Air pollution models

Air quality modeling is applied to ambient effects prediction of one or more sources of air pollution. Algorithms and equations showing atmospheric processes are incorporated into various dispersion models. The Algorithms and equations applied in the models are based on both known empirical data and atmospheric processes. Air quality modeling is useful in properly designing and configuring sources of pollution to minimize ambient effects [22].

The most commonly applied air quality models for regulatory applications generally fall into two categories, photochemical grid models and dispersion models. Photochemical grid models are typically used in regulatory or policy assessments to simulate the impacts from all sources by estimating pollutant concentrations and deposition of both inert and chemically reactive pollutants over large spatial scales. Dispersion models are typically used in the permitting process to estimate the

concentration of pollutants at specified ground level receptors surrounding an emissions source. This guidance document addresses dispersion modeling as a regulatory tool.

Owing to the intrinsic uncertainty of air quality modeling, a modeled prediction alone does not necessarily indicate a real-world pollution condition. However, a modeled prediction of an exceedance of a standard or guideline may indicate the possibility of potential real-world air quality violations. The impacts of new sources that have not been constructed can only be determined through air quality modeling. Moreover, monitoring data normally are not sufficient as the sole basis for demonstrating the adequacy of emission limits for existing sources because of the limitations in the spatial and temporal coverage. Therefore, air quality models have become a critical analytical tool in air quality assessments. In particular, they are widely used as a basis to modify allowable emission rates, stack parameters, operating conditions, or to require state implementation plan review for criteria pollutants.

Purpose of an Air Quality Modeling Analysis may also be required to:

- Determine whether air quality monitoring is required and appropriately locate air quality and/or meteorological monitors
- Determine if, for any pollutant, a concentration will exist that may pose a threat to public health or welfare or unreasonably interfere with the enjoyment of life or property (e.g. odor), and/or
- Perform a human health or ecological risk assessment.

2.14 Case study using Gaussian air pollution modeling

Air quality modeling is a technical method that uses computer simulation and statistics knowledge to predict the concentration profile of pollutant emission in ambient atmosphere. Generally, more and more mathematical models are based on Gaussian model especially in steady state system. The general Gaussian can be shown as equation 2.2 below.

$$c(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \left(\exp\left(\frac{-(z-h)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+h)^2}{2\sigma_z^2}\right) \right)$$

(Equation 2.2)

Analytically integrated and results the well-known Gaussian plume distribution [23]

Where

c	=	concentration at a given position (g/m ³)
Q	=	the source term (g/s)
x	=	the downwind (m)
y	=	the crosswind (m)
z	=	the vertical direction (m)
u	=	the wind speed at the height of the release (m/s)
σ_y, σ_z	=	deviations describe the crosswind and vertical (m)

The researchers studied a method for estimating landfill methane emission and found that the methane emission from the landfill in Florida [24] was estimated by solving the Gaussian dispersion equation as Figure 2.13. After being run by air model, emission of methane concentration was compared to methane concentration from measurements. As can be seen from Figure 2.14, the graph provides that the linear correlation between the modeled and the measured VOCs concentrations had a slope of 1.36, with R² being 0.89. In the other words, there was a slight tendency toward over prediction and very good relationship between the modeled and the measured VOCs concentrations



Figure 2.13 Methane emissions from the landfill in Florida [24].

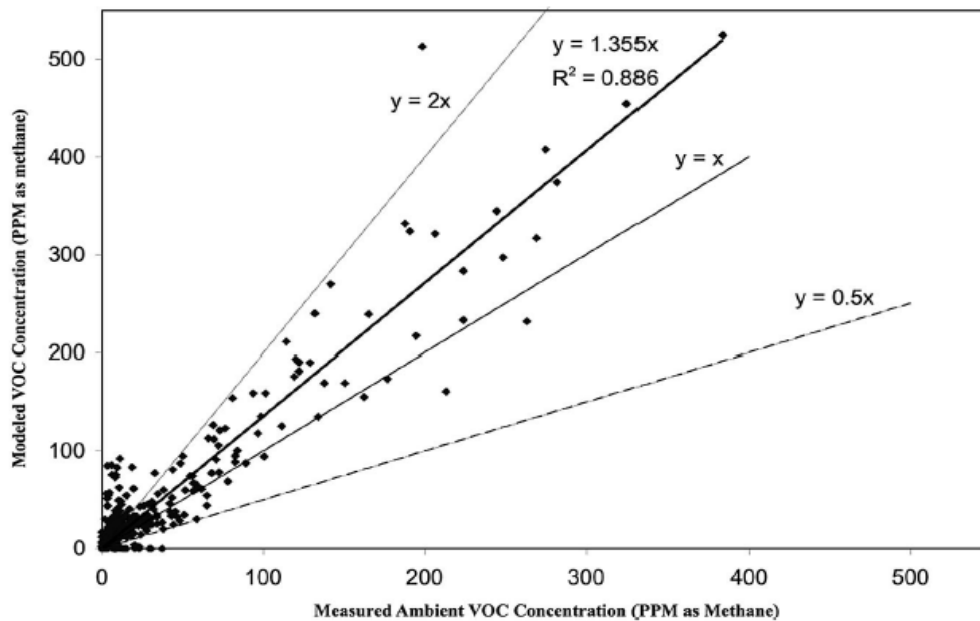


Figure 2.14 Scatterplot of modeled versus measured VOCs concentrations at the landfill [24].

Furthermore, another cause studies regarding Gaussian air model there had been the development of air model for industrial point such as power plant and refinery in Paris. However, this study will use Gaussian air model to forecast the concentration of VOCs emission because it is wild and basic simulation program.

To sum up briefly, it is obviously clear that Gaussian air model could well forecast VOCs emission, with slight deviation. Although it can be use wildly in emission of many substances, not only is Gaussian air model sensitive but also other models. The VOCs emission of writer study will be predicted by Gaussian air model because it is picked to a lot of researches.

2.15 Dispersion Model Screen View

Screening models were applied as a primary tool to conservatively estimate the impact due to emissions from a given source, and confirm or mitigate a requirement for further detailed dispersion modelling. Such models typically use pre-defined meteorological parameters, negating the need for initial purchase of local meteorological data.

The screening assessments in this research demonstrated in worst case scenario data inputs to ensure that the model outputs are conservative and provide a sound basis for deciding whether or not further detailed modelling is required for the purposes of estimating the overall impact. In this research applied Screen View Version 3.5.0 [25] which is interface for the U.S. EPA, user friendly, saving resources and researcher time.

CHAPTER III

RESEARCH METHODOLOGY

This study used numerous methods. The data were taken from daily emission report and weather forecast in year 2014.

3.1 Study area

This study was undertaken on a storage tanks vessel in the Gulf of Thailand. Some relevant factors such as sea condition and ambient air temperature were obtained from meteorological station in Gulf of Thailand.

3.2 Sample selection

Data for this study were daily basis taken from observations and records in year 2014 (see in Table 1 Appendix C)

3.3 Material and method

Based on Rudd and Hill study is [19] and author's experience, the venting volume of VNGL depends on the following factors

- Ambient air temperature.
- Cargo temperature.
- Sea condition or wave height.
- Percentage of condensate in cargo.
- RVP characteristic of products.

However a previous research suggests that there are influences of static factors on VOCs venting such as diameter of tanks and storage pressure which are

designed due to the concern of safety tank structure and expense. These static factors were, then, out of interest in this research. The factors in concern s come from five factors as mentioned above, which were collected at 6.00 am as daily report.

3.3.1 Physical factors affecting the VOCs venting.

3.3.1.1 Sea condition was observed as wave height which was measured by Fugro Norway Wave Buoys (see Figure A10 in Appendix A) to measure wave height or sea condition by direction and period. The highest 33 waves out of 100 waves were daily averaged from 7 wave buoys. Direction was calculated by instrument assembling dominate of direction at that time keeping. Then the data were classified with The Douglas sea scale (international sea and swell scale) (see Table 1 in Appendix B) which using for describing the swell of the sea daily averaged and recorded. Wave height is classified into ten classes as following

Calm (Glassy)	: No wave
Calm (rippled)	: 0-0.1 meter, daily averaged=0.05 meter
Smooth	: 0.10–0.50 meter, daily averaged=0.300 meter
Slight	: 0.50–1.25 meter, daily averaged=0.875 meter
Moderate	: 1.25–2.50 meter, daily averaged=1.875 meters
Rough	: 2.50–4.00 meter, daily averaged =3.25 meters
Very rough	: 4.00–6.00 meter daily averaged =5 meters
High	: 6.00–9.00 meter daily averaged =7.5 meters
Very high	: 9.00–14.00 meter daily averaged =12.5 meters
Phenomenal	: >14 meters

3.3.1.2 Temperature of cargo tank was measured by PT100 sensor which was fixed probe and the Kongsberg GL-300 (see Figure A1 and Figure A2 in Appendix A) which was installed in cargo tanks. The temperature sensor was delivered in the tailored lengths according to tank heights. The connection box and signal converter were designed for installation of up to 3 sensors in each. The measuring data were monitored at the control room and recorded.

3.3.1.3 Venting volume were measured by GF868 Ultrasonic Flare Gas Flow meter (see Figure A3 in Appendix A) manufactured by GE Measurement & Control USA, venting volume daily emission were monitored and recorded. The meter operates reliably even under unsteady flow, pulsating pressure, varying composition and temperature, harsh environments and the wide flow ranges typical of flare systems. Flow velocity measurable range from 0.1 to 275 ft/s (0.03 to 85 m/s) standard bi-directionally in pipe or stack sizes up to 120 in (3m) in diameter. Extended performance range configuration is available to 395 ft/s (120 m/s) velocity and interpreted to control room for monitor, averaged and recorded.

3.3.1.4 RVP was measured by Holler Bomb Test (see Figure A11 in Appendix A) manufactured by Koehler instrument USA. VNGL sample was put into the stainless steel cylinder in the lower portion, after the lower chamber was filled with condensate, it was connected to the upper chamber. The RVP bomb sitting in the Koehler circulating water bath at 100 °F. It held approximately 20 gallons of 100 °F water agitated by a propeller driven by the motor on the upper right. After the assembled vapor pressure apparatus was immersed in the bath for 5 minutes, tap the pressure gauge lightly and record the reading. The apparatus was withdrawn from the bath, inverted shaken, shake it vigorously and immediately place back in the bath. At intervals of about 10 minutes, It was repeated and a gauge observation of at least five times until the last two gauge readings become constant. These operations required 60 to 90 minutes. The final gauge pressure was read to the nearest 0.05 psig. For gauges with intermediate graduations of 0.1 psig and to the nearest 0.1 psig for gauges with graduation of 0.2 to 0.5 psig. The optimum RVP of Petroleum Liquid was usually in range 7.4-16.09 on the properties of production [26]

3.3.1.5 Ambient Temperature was measured by PT100 sensors by Fugo Survey computation systems (see Figure A5 in Appendix A) manufactured by SMA Solar Technology Germany. The sensor enables measurements in a 4 wires system measurement range of the ambient temperature sensor was between -30 °C and +80 °C. Turn the sensor to the sun. Sensor box for further processing of the ambient data and display in computer for monitor, averaged and recorded.

3.3.1.6 Total cargo onboard was measured by PT100 sensor which was fixed probe and the Kongsberg GL-300 to verified cargo high level, ullage, temperature and send data to TSB supercargo program in the computer which calculated compartment capacity, then the total cargo onboard converted to volume in percentage, volume cubic meter and total Bbls onboard.

3.3.2 Chemical component

Chemical component was measured gas chromatography (standard method for analysis of natural gas). The machine name is Agilent 7890B GC manufactured by Agilent Technologies USA, to find out the percentage components. The thirteen venting samples were tested by company's laboratory in March 2014 (see Figure A7 in Appendix A)

3.3.2.1 This procedure gave the composition of natural gas in the range $C_1 - C_9$ including nitrogen and carbon dioxide. The method has been adapted from Agilent GC 7890-0171 by using a combination of capillary/packed column and thermal conductivity/flame ionization detectors. The analysis can be accomplished in a 19 minutes run time with two chromatogram output.

3.3.2.2 A preheated sample of natural gas was injected simultaneously through two gas switching valves and carried by helium gas into a gas chromatograph (Agilent 7890A). It was equipped with split/split fewer inlets, Thermal Conductivity Detector (TCD) and a Flame Ionization Detector (FID). The sample was injected through a 6-port gas switching valve flows via a splitter injector into a capillary column. The other sample was injected through a 10-port gas switching valve flows directly into porous polymer packed columns and a 6-port gas valve into a molecular sieve column then hydrocarbon (C_3 to C_9) were separated by the PONA capillary column and detected by FID.

3.3.2.3 The chromatograph was connected to a computer which controlled all GC parameter set points, data collection, and data manipulation reporting.

3.3.3 VOCs vent volume baseline from storage

3.3.3.1 Using GF868 Ultrasonic Flare Gas Flow meter to measure the VOCs daily vent volume which operate in reliably even under unsteady flow rate , varying composition, temperature, and pulsating pressure, harsh environments and the wide flow ranges typical of flare systems. Flow velocity was measured from 0.1 to 275 ft/s or 0.03 to 85 m/s standard bi-directionally in pipe or vent stack sizes up to 3meters in diameter. Performance range configuration was available extended to 395 ft/s (120 m/s) velocity. There are no orifices moving parts or to wear or clog. The GF868 flow measurement was independent of the gas properties. The venting volume can be seen on monitor in control room.

3.3.3.2 Calculation of the VOCs venting volume for 1 year, called baseline by each chemical component and the emission's chemical component was compared with the case study of ship emissions in the previous studies. The result of them is provided in tons/year. A procedure to estimate VOCs fraction in tons/year area is shown in Table 3.1

Table 3.1 Design Table for emission calculation

Fraction	Averaged percent (%V/V)	Density (kg/m³)	Emission (Ton/Day)
Methane	V1	D1	E1
Ethane	V2	D2	E2
Propane	V3	D3	E3
Butane	V4	D4	E4
Pentane	V5	D5	E5
Hexane	V6	D6	E6
Heptane	V7	D7	E7
Total			tons/day
Total			tons/years

Where:

V1 = Averaged percent of Methane (%v/v)

V2 = Averaged percent of Ethane (%v/v)

V3 = Averaged percent of Propane (%v/v)

V4 = Averaged percent of Butane (%v/v)

V5 = Averaged percent of Pentane (%v/v)

V6 = Averaged percent of Hexane (%v/v)

V7 = Averaged percent of Heptane (%v/v)

D1 = Density of Methane (g/m^3)

D2 = Density of Ethane (g/m^3)

D3 = Density of Propane (g/m^3)

D4 = Density of Butane (g/m^3)

D5 = Density of Pentane (g/m^3)

D6 = Density of Hexane (g/m^3)

D7 = Density of Heptane (g/m^3)

E 1 = Emission of Methane (ton/day)

E2 = Emission of Ethane (ton/day)

E3 = Emission of Propane (ton/day)

E4 = Emission of Butane (ton/day)

E5 = Emission of Pentane (ton/day)

E6 = Emission of Hexane (ton/day)

E7 = Emission of Heptane (ton/day)

F = Averaged vent volume (SCF)

The emission of VOCs was calculated by equations as follow

Density (kg/m^3) applied by equation 3.1

$$D = \frac{\text{Molecular weight} \times 1 \text{ atm}}{(8.206 \times 10^{-5}) / \text{Averaged venting temperature (K)} / 1000} \quad (\text{Equation 3.1})$$

$$E = \frac{\text{Averaged daily venting volume (SCF)} \times \text{Density of each fraction (kg/m}^3\text{)} \times \text{fraction}}{35.315 \times 1000} \quad (\text{Equation 3.2})$$

Where

- 35.315 was changing cubic foot to cubic meter.
- (8.206×10^{-5}) was gas constant

3.3.3.3 Estimate emission using equation proposed by Pring et al, [20] as follow

$$E = \frac{\text{TOP} \times \text{EF} \times 1}{2,000} \quad (\text{Equation 3.3})$$

Where

- E = VOCs emission [tons/year]
- TOP = Total condensate production of study area [BBL/year]
- EF = Emission factor [VOCs emission from condensate is 33.3]
- 2,000 = the conversion factor from pounds to tons of emissions

3.3.3.4 The results obtain from equation 3.2 and equation 3.3 were compared

3.3.4 Prediction VOCs concentration

In this research Screen View Version 3.5.0[25]. was applied which is the U.S. EPA interface screening model and user friendly quality Screen View Version 3.5.0 can remove the need for more complicated modeling and time saving

Steps for computer installation

- Self-extracting installation file downloaded to a temporary folder in the computer.
- Obtain an activation code by submit user registration. Within 24 hours. an activation code will be send via e-mail.
- Open self-extracting installation file to install Screen View on to the computer.

- Start-up Screen View.
- Enter activation code which received via e-mail and press OK bottom.
- Start using Screen View.

In order to find the output ,under normal and worse case operations, emission rate on gram per day transfer in to gram per second based on average an maximum basis ,The input data were required as following

- Emission rate in gram per second.
- The vent stacks both high in meters and inside diameter (m) from ship drawing.
- Stack gas exit flow rate yearly average m^3/s applied equation3.4 below

$$\text{Venting volume (m}^3\text{)} \tag{Equation3.4}$$

(24hours x 60minutes x 60seconds)

- Stack gas exit maximum flow rate m^3 /s verified from maximum venting volume and calculated by equation3.4
- Stack gas exit temperature from control room monitor (averaged)
- Averaged ambient air temperature.
- Building height from ship drawing.
- Minimum horizontal building diameter (m) from ship drawing
- Maximum horizontal building diameter (m) from ship drawing
- Receptor height above ground 1.65 meters.

Input required data in screen view in normal operation day scenario by use averaged g/s and worst case scenario in maximum g/s scenarios. As table below

Table 3.2 Scenario1: At normal operation emission from vent stack A. located 150 meters from accommodation or living area and 50 meters from working area.

Distance	Methane	Ethane	Propane	Butane	Pentane	Hexane
R1						
R2						

Table 3.3 Scenario2: At normal operation emission from vent stack B. located 200 meters from accommodation or living area and 100 meters from working area.

Distance	Methane	Ethane	Propane	Butane	Pentane	Hexane
R3						
R4						

Table 3.4 Scenario3: At worst case operation emission from vent stack A located 150 meters from accommodation or living area and 50 meters from working area.

Distance	Methane	Ethane	Propane	Butane	Pentane	Hexane
R1						
R2						

Table 3.5 Scenario4: At worst case operation emission from vent stack B located 200 meters from accommodation or living area and 100 meters from working area.

Distance	Methane	Ethane	Propane	Butane	Pentane	Hexane
R3						
R4						

Where

- R1 was distance from stack A 50 meters (mid ship) or working area
- R2 was distance from stack A 50 meters(accommodation for living)
- R3 distance from stack B 100 meters (mid ship) or working area.
- R4 distance from stack B 200 meters (accommodation for living)

Note: R1-R4 was the most working area and living area

Screen View data input instructions were following

3.3.4.1 Open the program in computer and input the data in the boxes as show in Figure 3.1 click next step bottom.

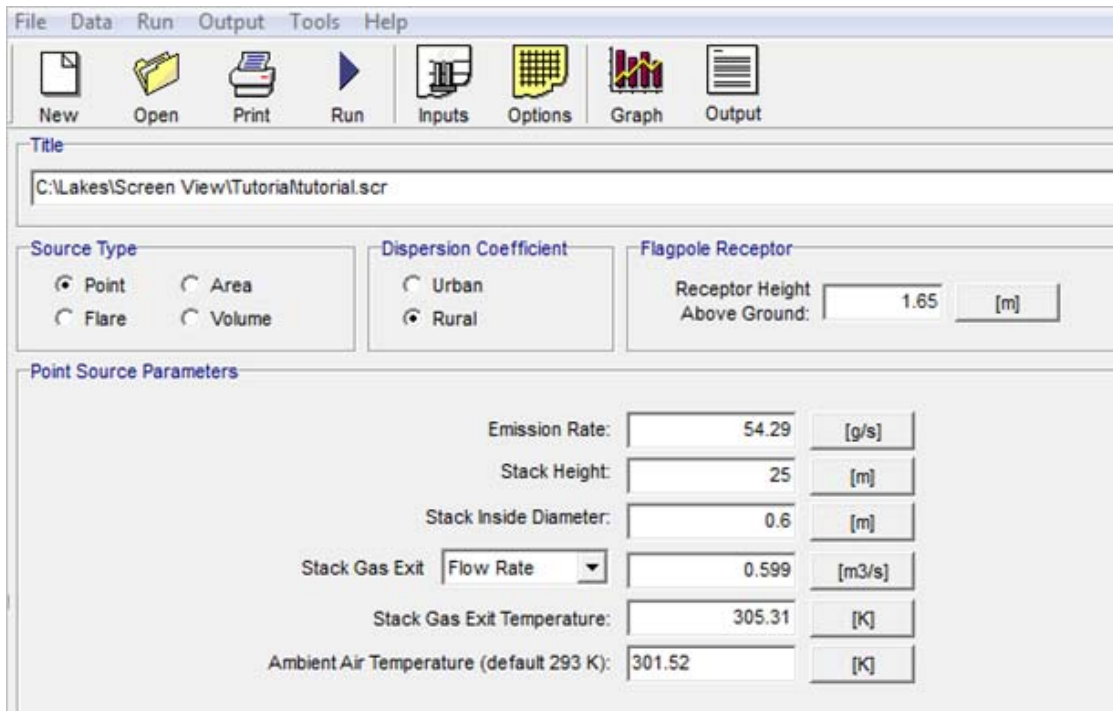


Figure 3.1 Screen view data input

3.3.4.2 Input the data of discrete distance as project required as show in Figure3.2 then click next step bottom.

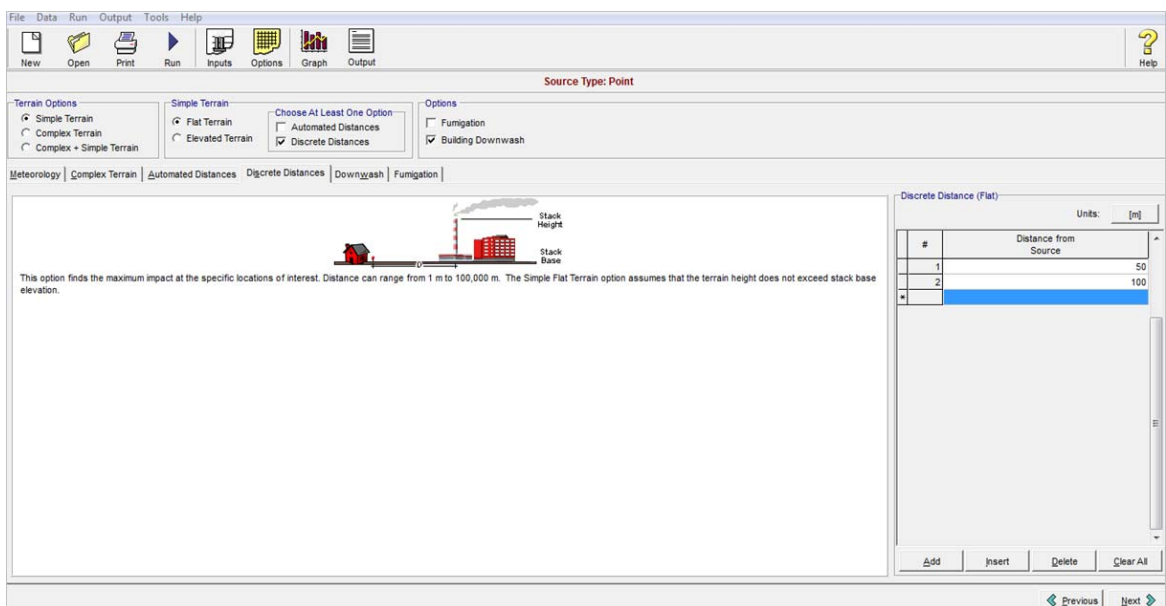


Figure3.2 Screen view selecting discrete distances

3.3.4.3 Input the data of building down wash as project required as shown in Figure

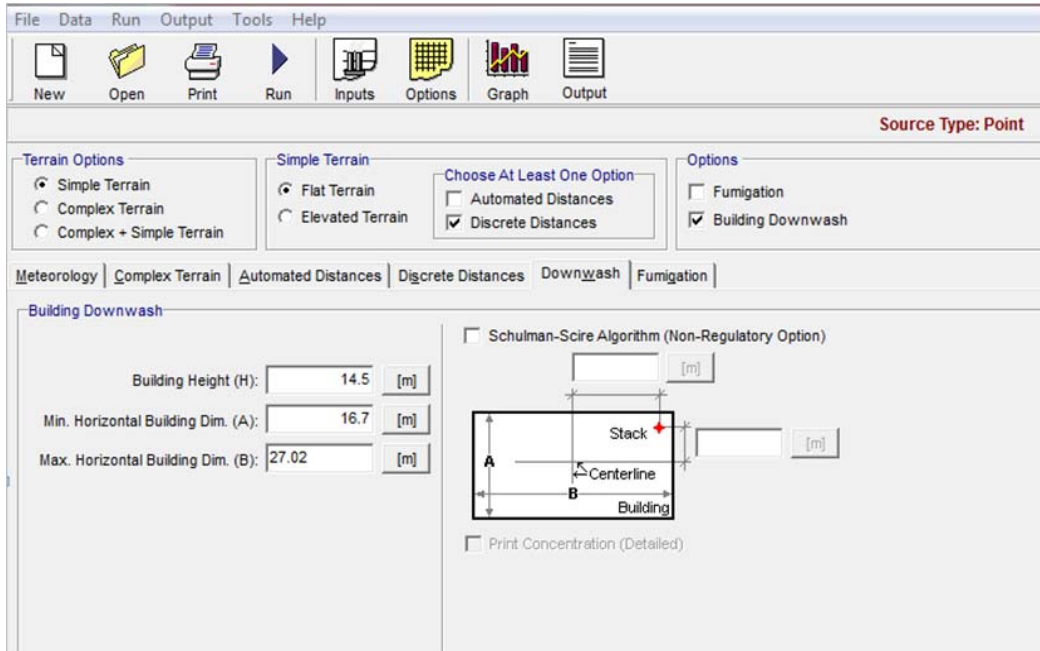


Figure 3.3 Building down wash data input

3.3.4.4 Press next step and the project status completely shown then click run bottom as shown in Figure 3.4 below

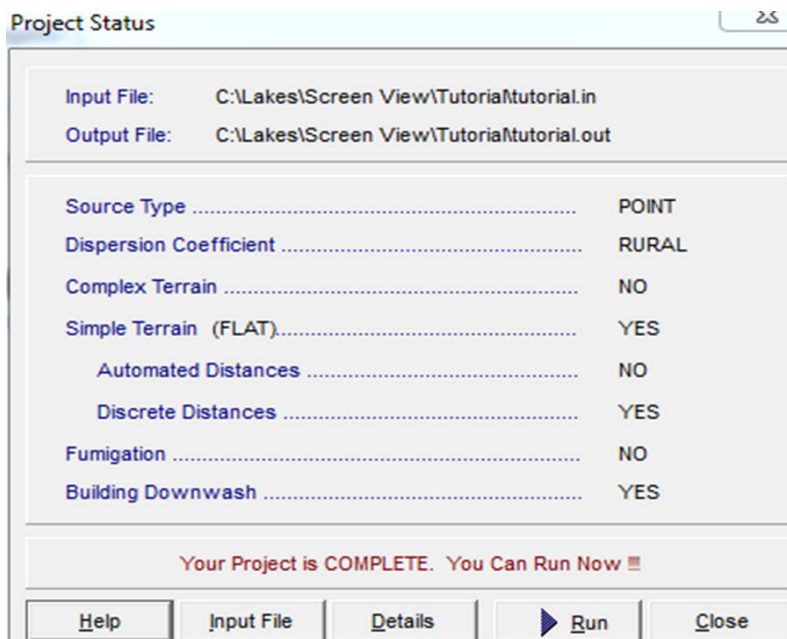


Figure 3.4 Project completed picture

3.3.4.5 The input data and resulted were displayed as Figure 3.5 and Figure 3.6

```

07/15/15
08:42:04
*** SCREEN3 MODEL RUN ***
*** VERSION DATED 96043 ***

C:\Lakes\Screen View\Tutorial\tutorial.scr

SIMPLE TERRAIN INPUTS:
SOURCE TYPE           =          POINT
EMISSION RATE (G/S)  =          54.2900
STACK HEIGHT (M)     =          25.0000
STR INSIDE DIAM (M)  =           0.6000
STR EXIT VELOCITY (M/S)=          2.1185
STR GAS EXIT TEMP (K) =          305.3100
AMBIENT AIR TEMP (K) =          301.5200
RECEPTOR HEIGHT (M) =           1.6500
URBAN/RURAL OPTION   =           RURAL
BUILDING HEIGHT (M)  =          14.5000
MIN HORIZ BLDG DIM (M) =          16.7000
MAX HORIZ BLDG DIM (M) =          27.0200

THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS
ENTERED.

STACK EXIT VELOCITY WAS CALCULATED FROM
VOLUME FLOW RATE = 0.59899998 (M**3/S)
    
```

Figure 3.5 Project data input information

```

*** SCREEN DISCRETE DISTANCES ***
*****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR
FOLLOWING DISTANCES ***

      DIST      CONC          U10M   USTK   MIX HT   PLUME   SIGMA
SIGMA
      (M)      (UG/M**3)   STAB  (M/S)  (M/S)    (M)    HT (M)   Y (M)
Z (M)  DWASH
-----
      50.  0.1301E+05    6    1.5    2.5 10000.0  26.72   2.25
10.61   HS
      100. 0.1708E+05    4    1.0    1.1  320.0   28.32   8.26
13.97   HS
    
```

Figure 3.6 Project data result

3.3.4.6 Summaries problem identifications and advice mitigations covering 3 main ways namely source, pollution path and receptor and compare with mitigation guidelines from IMO on development of VOCs management plan.

3.4 Data analysis

3.4.1 Investigation of factors which affect to VOCs emission by using simple linear regression to verify each factor. The pair data of each relevant factor(x) and VOCs venting(y) were: (y_1, x_1) , (y_2, x_2) , ..., (y_5, x_5) to estimate value of the parameter, applied in linear regression, as shown in equation 3.5

$$y = b_0 + b_1x \quad (\text{Equation 3.5})$$

Where

- b_0 is a constant,
- b_1 is the regression coefficient,
- x is the value of the independent variable,
- and y is the predicted value of the dependent

R Square values of the simple linear regression explain the degree of relationship between Y and X.

Moreover multiple regression was also analysis applied to identify the relationship between all independent and dependent variables. Hence, one can describe and compare the relationship of each independent variable. Any variables that influence significantly change the equation showing the relationship between the dependent variable (Y) and the independent variable (X) of the population to see $\square \square$
 $\square \square_1 X \square \square \square_1 X_1 \square \square_2 X_2 \square \dots \square \square_k X_k \square \square$ explain changes in the value of the variable part and the coefficient value. Statistics were calculated by the sample. The analysis is the coefficient was calculated to have an estimated combined flow squared minimum.

Multiple linear regression of the population.

$$Y = \square \square \square_1 X_1 \square \square_2 X_2 \square \dots + \square_k X_k \square \square \varepsilon \quad (\text{Equation 3.6})$$

Multiple regression analysis of samples.

$$Y = a + b_1x_1 + b_2x_2 + \dots + b_kx_k \quad (\text{Equation 3.7})$$

Where

- X was the independent variables or factors affecting the emission of venting volume.
- Y was the dependent variable or volume being released each day.
- K was the number of independent variables That is, the five factors
- a was constants value
- b was regression coefficient of each factors

3.4.2 Thirteen samples of 2014 VNGL were sent to company's laboratory, chemical components of Volatile Natural Gas Liquid were analyzed by Gas Chromatography.

3.4.3 Base line of VOCs area studied emission from storage tanks calculated by use each emission's chemical components resulted from gas chromatography from 2014 A.D. summarized result providing in tons/year equation VOCs fraction estimate ton per year as shown in Table 3.1 Design table prepared for calculation compared resulted with previous researched (Pring et al,) as shown in equation3.3

$$E = TOP * EF * \frac{1}{2000} \quad (\text{Equation3.3})$$

Where

- E = VOCs emission [tons/year].
 TOP = Total production of condensate [BBL/year].
 EF = Emission factor [VOCs emission from condensate is 33.3].

3.4.4 Concentrations of VOCs in each component predicted by Air Dispersion Model, screen view applied in normal operation day (averaged g/s) and worst case scenario (maximum g/s) scenario. The output data were exhibited in average and maximum concentrations and converted to ppm.

CHAPTER IV

RESULTS AND DISCUSSIONS

This chapter presents the analysis and interpretation of data which were drawn from the observation in year 2014 in relation to the research objectives. The data were collected and processed following methods in chapter three. The objectives were accomplished. The findings are demonstrate the potential problems and recommend the mitigation guidelines based on best practice.

4.1 Factors affecting the daily venting volume

4.1.1 Sea Condition or wave height

In this research, sea condition was determined in term of wave height. Sea Condition in gulf of Thailand fall into three types which were smooth, slight and moderate sea conditions as shown in Figure 4.1. The data of daily venting were averaged and given the result of 182,825.16 Standard Cubic Feet (SCF)

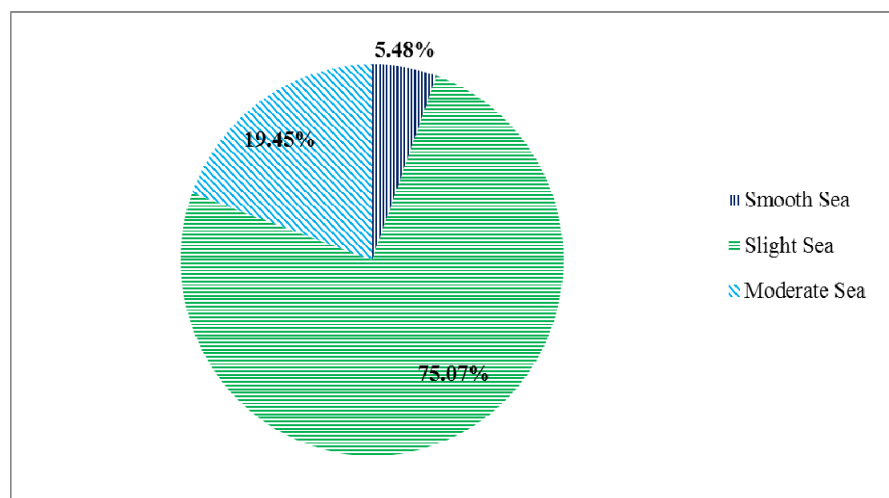


Figure 4.1 Sea conditions in the Gulf of Thailand

It was found that 5.48% of wave height was in type of smooth sea condition which the wave height was 0.3 meter in average. The volume of venting during smooth sea condition was 200,359.65 (SCF) which greater than averaged venting volume (182,825.16 SCF).

Slight sea condition was 75.07 %, the most found of sea condition. The averaged venting volume was 175, 202.73 SCF which close to the average daily venting volume because quantities in this type of sea condition was large number.

Moderate sea condition was 19.45 % of all types of sea condition. The venting volume during this condition was 207,302 SCF which was greater than averaged venting volume. Figure 4.2 illustrates that high venting volume occurred during smooth sea condition and moderate sea condition, while low venting volume occurred during the slight condition. It points that the venting volume depends on several factors other than sea condition or wave height.

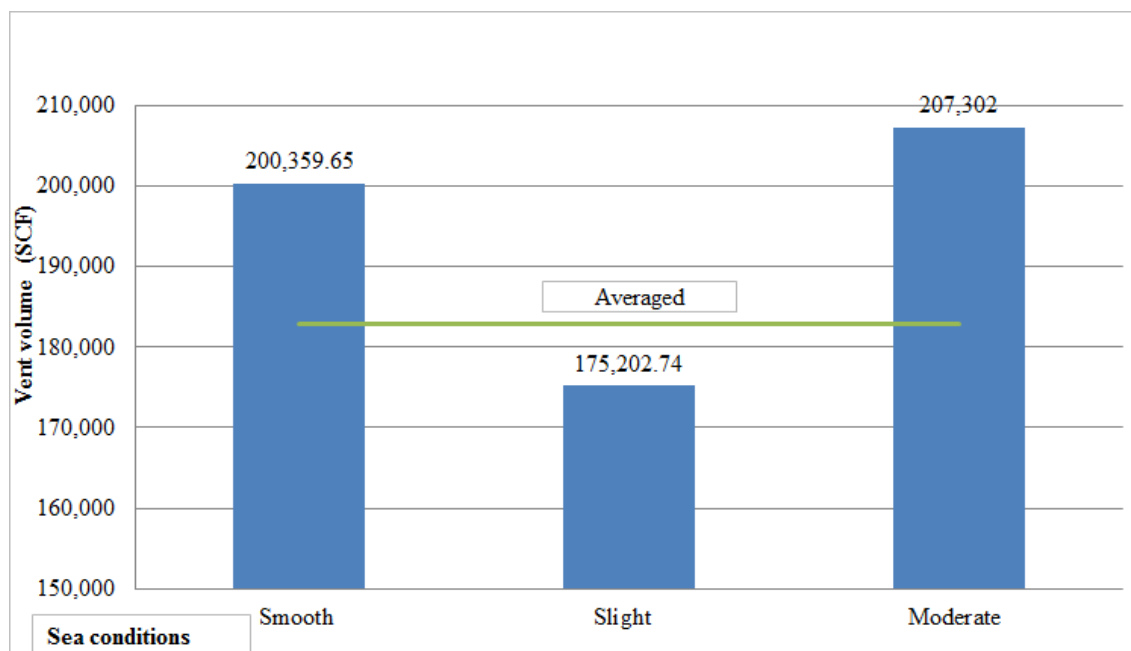


Figure 4.2 Venting volume under sea conditions in year 2014.

To prove the relationship between the daily wave height and the daily venting volume, the simple linear regression was applied and given $R = 0.085$ and $P\text{-value} = 0.107$. It means the wave height was not related to the venting volume which

against the research hypothesis that that the variation of sea condition will affect the venting volume.

4.1.2 Reid Vapor Pressure (RVP)

The variation of RVP in this research was found in a narrow range of 12-15.2 psia which was divided into seven classes as shown in Figure 4.3

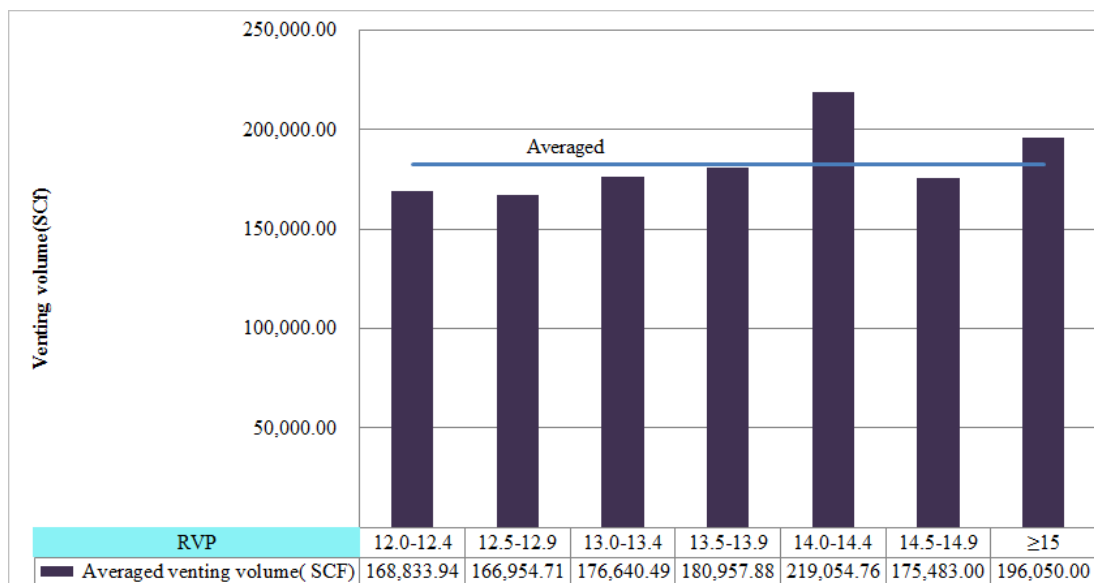


Figure 4.3 Venting volume under the variation of Reid Vapor Pressure (RVP)

Figure 4.3 illustrate the maximum venting volume of 219,054.76 SCF at RVP 14.0-14.4 psia and the minimum venting volume of 166,954.71 SCF at RVP 12.5-12.9 psia.

A previous study conducted by Rudd and Hill [19] found that gasolines and temperature affect the volume of emission (see Figure 4.4). The finding in this study, hence, did not agree with Rudd and Hill's study. Statistical analysis gave P-value of 0.107 and regression coefficient (R) of 0.084 which mean changes in the RVP is not associated with changes in the venting volume. This finding did not agree with the research hypothesis

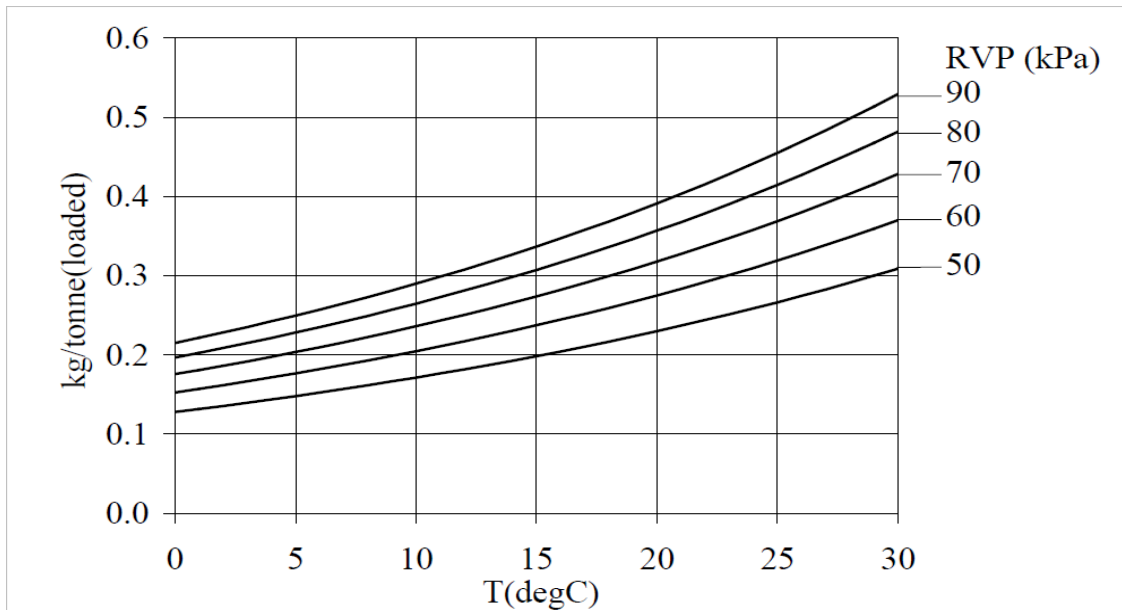


Figure 4.4 Emission factor for gasoline loading affected from RVP and temperature [19]

4.1.3 Ambient temperature

Ambient temperature in this research was found in a narrow range of 25-32 °C which was explained in seven ranges. It seems that the ambient temperature did not affect venting volume.

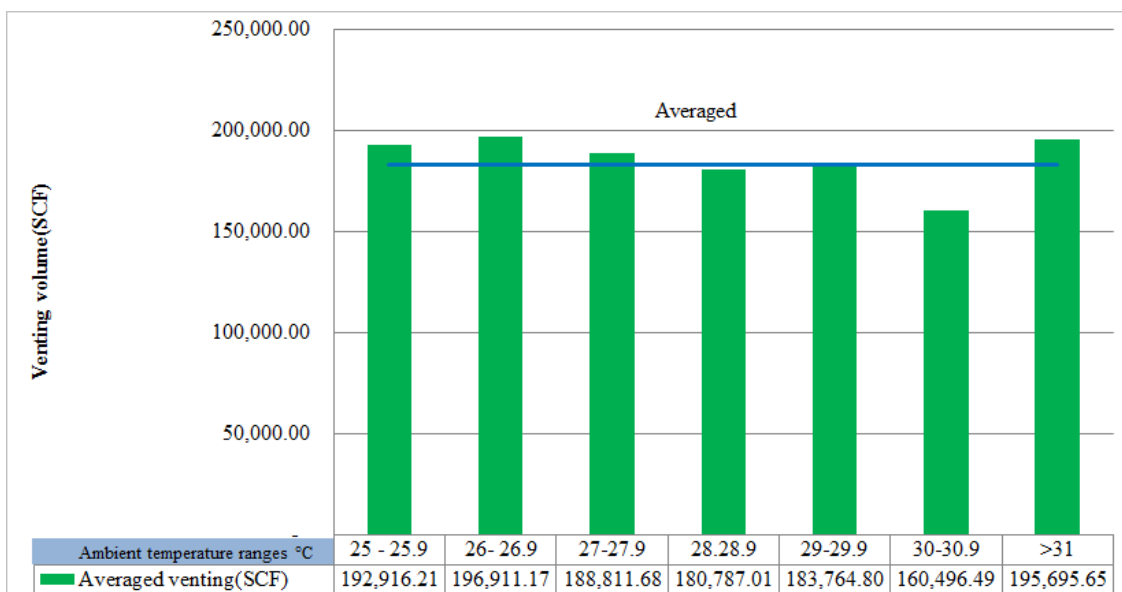


Figure 4.5 Effects of ambient temperature on venting volume.

Figure 4.5 illustrates that when ambient temperature was over 31°C, the venting volume averaged was 195,695.64 SCF which was more than the averaged venting volume (182,825.16 SCF). When the ambient temperature was in range of 30-30.9 °C, the venting volume was 160,496.49 SCF which was lower than averaged daily venting because at the temperature 30-30.9 °C, the volume of condensate onboard was only 585,596.37 Bbls which was less than annual averaged 610,971.05 Bbls.

However a previous study (see Figure 4.4) concluded that ambient temperature gave an effect on venting volume. The finding in this research then is different from that previous research.

From linear simple regression analysis, was -0.044 and P-value was 0.403 which means the variation of ambient temperature had no effect on venting volume. This finding is against the research hypotheses which assume that ambient temperature is associated with venting volume.

4.1.4 Cargo tank temperature

Cargo tank temperature in this research was found in a narrow range of 26.2-30.0°C. The averaged cargo tank temperature was 28.45°C.

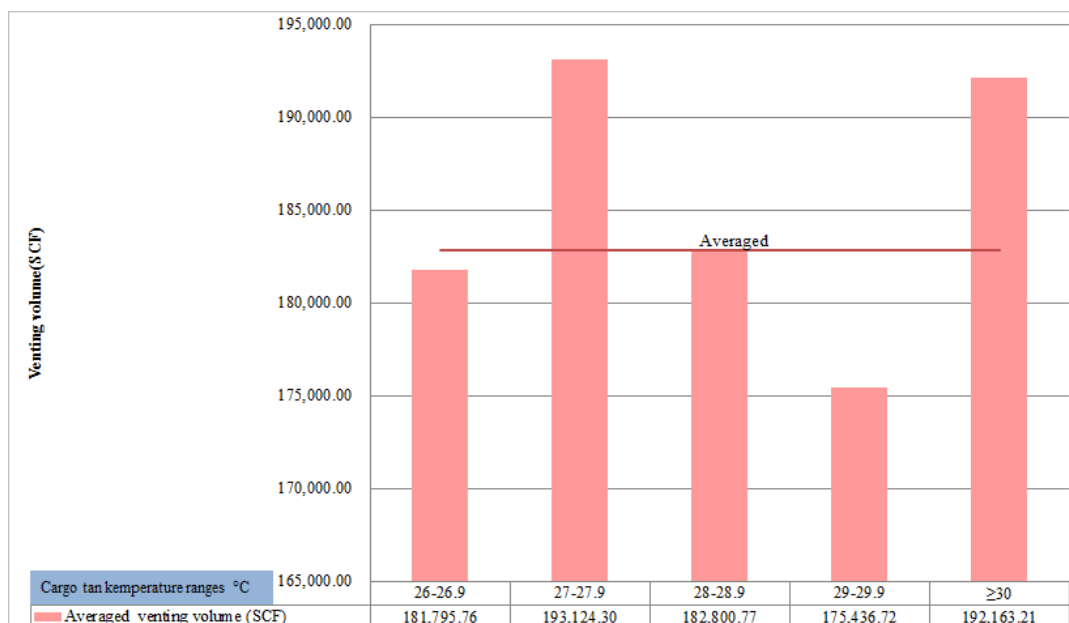


Figure 4.6 The venting volume affected from cargo tank temperature

Figure 4.6 illustrates that when cargo tank temperature $\geq 30^{\circ}\text{C}$ the averaged venting volume was 192,163.2143 SCF which was more than the averaged daily venting volume (182,825.16 SCF) however when the tank temperature was in a range of 29-29.9 $^{\circ}\text{C}$, the averaged venting volume was 175,436.72 SCF which was lower than averaged venting volume because the number of condensate onboard was 596,048.28 Bbls which was less than annual average 610,971.05 Bbls.

From linear simple regression analysis, was -0.045 and P-value was 0.391 which mean cargo tank temperature was not associated with venting volume. This finding is against the research hypothesis which assume that this finding is against the research hypothesis which assume that variation of cargo tank temperature will have an effect on venting volume

4.1.5 Total condensate onboard

Total condensate onboard in this research was found in a range of 386,674 -850,085 Bbls. The averaged daily total condensate onboard was 610,971.0548 barrels (Bbls). It seems that this factor affects to venting volume as seen in Figures 4.7

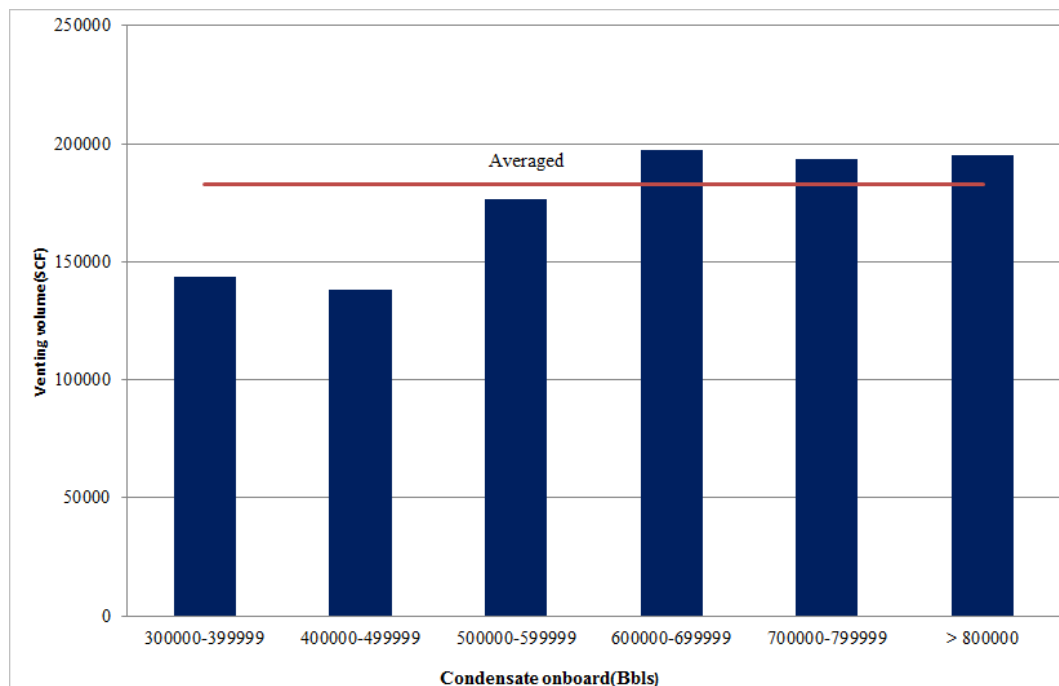


Figure 4.7 Effect of condensate onboard on venting volume

The data of daily total condensate onboard and daily venting volume were analysed by simple linear regression. It was found that R was 0.193 and P-value was <0.001 which means the cargo tank temperature was influential to venting volume. This evidence proves the research hypothesis that venting volume depends on volume of cargo in the tanks.

4.1.6 Multiple Regression Analysis

According to the venting volume affected from outlier input data caused from closed vent stacks, the data from normal operating days were selected for multiple regression analysis. When the multiple regression analysis was applied, it was found that the factor affecting the release of venting volume is total condensate onboard, where P-value < 0.05 which indicates that this relationship is statistically significant. However, when the regression equation was executed as shown in equation 4.1, it was found that adjusted R square = 0.023 (see Appendix D table 1) which means the influence of total condensate in storage tank applies to forecasting the venting volume as shown below

$$Y (\text{Venting volume}) = 118,980.788 + 0.096x (\text{Total condensate}) \quad (\text{Equation 4.1})$$

Where

- x is the total condensate onboard which affects the emission of venting volume (Bbls)
- y is venting volume (SCF)

However, factors affecting the venting volume may not concern only total condensate onboard as found in this research, other factors such as ambient temperature, sea condition or wave height, RVP, and cargo tank temperature were also used for predicting the venting volume which is to be applied in future research.

4.2 Chemical components of Volatile Natural Gas Liquid

The thirteen samples of venting gas were analyzed by GC in a laboratory. The results were shown in the Table 4.1

Table 4.1 Chemical components from 13 samples of venting gas

Unit: percent

Date	NO ₂	CO ₂	O ₂	Methane	Ethane	Propane	Butane	Pentane	Hexane	Heptane	Hydro carbon	Non-Hydro carbon
16-Mar-14	78.63	11.27	4.54	0.00	0.25	1.68	2.45	0.78	0.22	0.18	5.56	94.44
17-Mar-14	75.41	10.71	4.36	0.00	0.45	2.90	4.23	1.34	0.35	0.25	9.52	90.48
20-Mar-14	58.82	8.31	2.61	0.00	1.60	10.92	14.31	2.95	0.31	0.17	30.26	69.74
20-Mar-14	72.82	10.60	3.64	0.00	0.60	3.87	5.75	1.84	0.50	0.38	12.94	87.06
16-Mar-14	78.63	11.27	4.54	0.00	0.25	1.68	2.45	0.78	0.22	0.18	5.56	94.44
17-Mar-14	38.19	4.00	1.77	0.00	4.49	25.99	23.66	1.71	0.10	0.09	56.04	43.96
18-Mar-14	37.88	4.10	1.67	0.00	5.35	25.22	23.36	2.17	0.14	0.11	56.35	43.65
19-Mar-14	30.87	2.75	1.31	0.00	7.10	31.06	25.42	1.34	0.07	0.08	65.07	34.93
17-Mar-14	38.19	4.00	1.77	0.00	4.49	25.99	23.66	1.71	0.10	0.09	56.04	43.96
20-Mar-14	59.65	8.58	3.92	0.00	1.63	8.62	14.35	2.75	0.35	0.15	27.85	72.15
21-Mar-14	68.77	10.24	2.94	0.00	0.81	5.74	8.19	2.46	0.52	0.33	18.05	81.95
22-Mar-14	61.77	8.95	2.71	0.00	1.37	9.10	12.44	3.04	0.39	0.23	26.57	73.43
23-Mar-14	53.73	7.48	2.48	0.00	2.51	14.66	16.67	2.13	0.20	0.14	36.31	63.69
24-Mar-14	39.77	4.29	1.71	0.00	4.39	27.30	21.22	1.19	0.06	0.07	54.23	45.77
Averaged	55.34	7.45	2.72	0.00	2.63	14.60	14.87	1.96	0.26	0.17	34.49	65.51

The averaged components of VNGL as shown in Figure 4.8 compose of 34.49% of hydrocarbons and 65.51% of non-hydrocarbons (55.34% N₂, 7.45% CO₂ and 2.27% O₂). Nitrogen and carbondioxide were produced into the condensate tanks by inert gas generator for using as a topping and prevent explosion. The spontaneous oxygen mixed in the tank have monitored also but it should not over than 8% so as to maintain a safe atmosphere within a ship's cargo tanks [27]

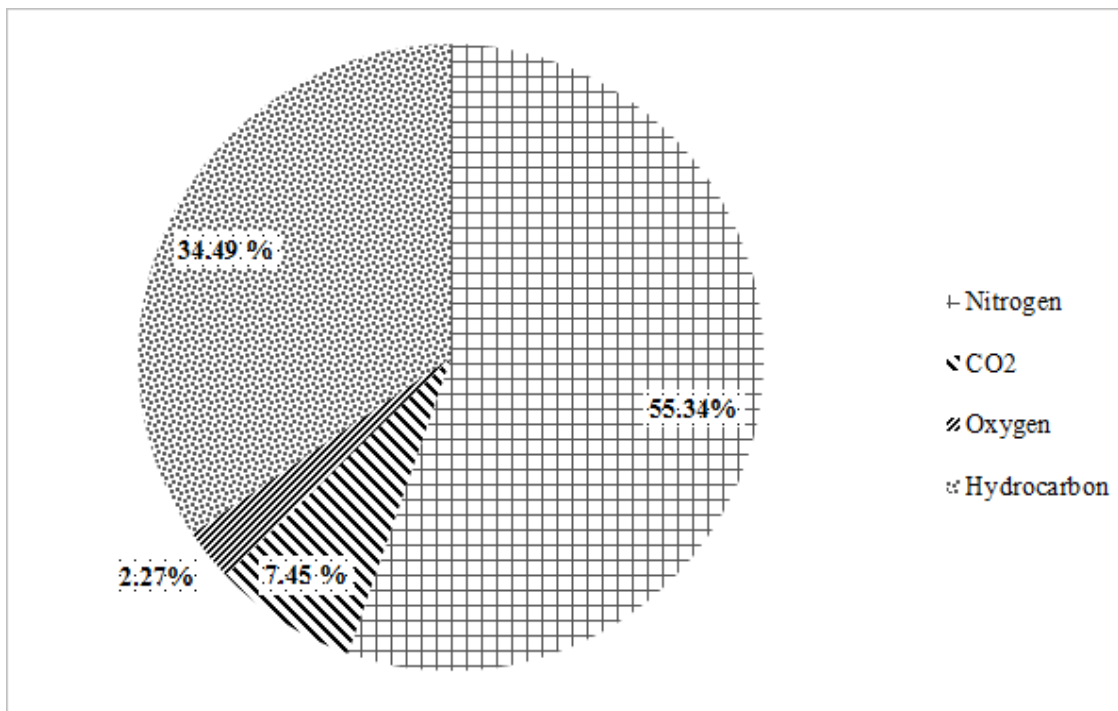


Figure 4.8 hydrocarbon and non-hydrocarbon composition

After gas composition was known as seen in Figure 4.8, the 34.49 % hydrocarbon was further separated to VOCs composition. It is clearly showed that Propane and Butane are dominated in VOCs composition as shown in Figure 4.9 below:

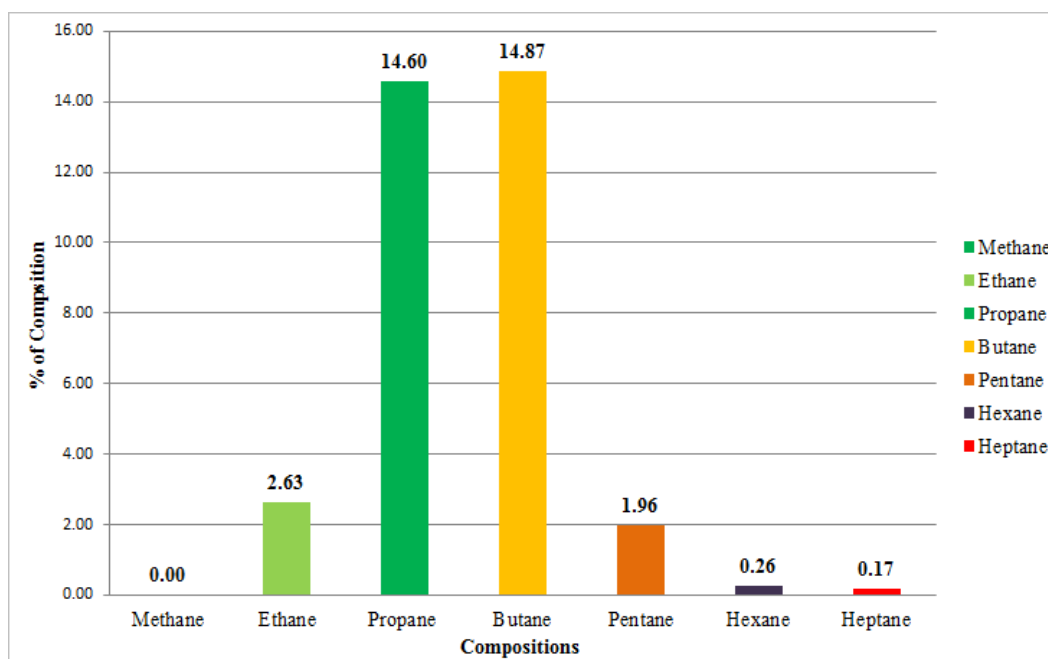


Figure 4.9 VOCs compositions emitted from VNGL

Natural gas liquids (NGLs) composed with carbon and hydrogen such as ethane, butane, propane, isobutane, hexane, and pentane as mentioned with theory in NGL Attribute summaries [1]. The comparison of VOCs in study area with Gurevich, et al [28] and EP Energy [29] were shown in Table 4.1. In the study area, the original condensate was sent to storage tanks, methane was separated by Central Processing Platform (CPP) and condensate was stabilized and sent to storage. It was found that percentage of VOCs from VNGL were different. The reasons may come from the petroleum business process need, variation from geographic location, geologic formation, temperature and pressure.

Table 4.2 Composition in natural gas liquid found in study area and others

Unit: percentage

Composition	Symbol	Study area	Krasnodar region	EP Energy
Methane	CH ₄	0	-	70-90
Ethane	C ₂ H ₆	7.63861	-	1-60
Propane	C ₃ H ₈	42.32125	0.100	20-60
Butane	C ₄ H ₁₀	43.0996	0.335	0-20
Pentane	C ₅ H ₁₂	5.696061	1.857	5-25
Hexane	C ₆ H ₁₄	0.744904	3.691	2-13
Heptane	C ₇ H ₁₆	0.499576	4.829	1-10

The concentration of each composition has compared with OSHA, ACGIH and NIOSH, from Centers for Disease Control and Prevention standard of exposure [30] and New Jersey Department of Health Hazardous Substance Fact Sheet [31] including their properties as shown in Table 4.3

Table 4.3 VNGL properties Standards and exposure controls for personal protection [31] [32]

Composition	MW	Appearance	Odor	Occupational Exposure Limits TWA 8hrs			IDLH LC ₅₀	Unit
				OSHA	ACGIH	NIOSH		
Methane[30]	16	Colorless	Odorless	1000	1000	1000	5000	ppm
Ethane[30]	30	Clear colorless	Odorless	1000	1000	1000	LC ₅₀ = 658	ppm
Propane[30]	44	Colorless	Odorless	1,000	1000	1,000(10hrs)	2,100	ppm
Butane[31]	58	Colorless	Gasoline like odor	1000	1000	800(10hrs)	N.D. [32]	ppm
Pentane[30]	72	Colorless	Gasoline like odor	1,000	600	120(10hrs)	1500	ppm

Table 4.3 VNLG properties Standards and exposure controls for personal protection [31] [32] (cont.)

Composition	MW	Appearance	Odor	Occupational Exposure Limits			IDLH LC ₅₀	Unit
				TWA 8hrs				
				OSHA	ACGIH	NIOSH		
Hexane[31]	86	Colorless	Gasoline like odor	50	50	50	5,000	ppm
Heptane[31]	100	Clear colorless	Odorless	500	400	85	750*	ppm

Note * mean immediately dangerous to life

4.3 Baseline of VOCs emission from storage tanks

Thirteen venting samples were sent to a company's laboratory to examine the chemical components. They were analyzed by Gas Chromatography. The averaged compositions of VOCs were shown in Table 4.4. Butane (14.87%) and propane (14.60%) were main components of VOCs.

Table 4.4 Chemical components

Chemical components	Percent
Methane	0
Ethane	2.63
Propane	14.6
Butane	14.87
Pentane	1.96
Hexane	0.26
Heptane	0.17
Other	65.509

Baseline VOCs emission calculated by use components, molecular weight, daily venting averaged (182,825.16 SCF) and density. The resulted emission ton/day by equations 3.2. The results were shown in the Table 4.5

Table 4.5 Baseline emission calculates from study area.

Type of Hydrocarbon	Components	Percent	Molecular weight	Density (kg/m ³)	Emission (tons/day)	Unit
Methane	0	0	16	0.6468	-	
Ethane	0.076386101	7.63861	30	1.2128	0.48	
Propane	0.423212454	42.32125	44	1.7787	3.90	
Butane	0.43099603	43.0996	58	2.3447	5.23	
Pentane	0.056960614	5.696061	72	2.9106	0.86	
Hexane	0.007449039	0.744904	86	3.4766	0.13	
Heptane	0.004995763	0.499576	100	4.0425	0.10	
Total	1	100				%
					10.705	tons/day
					3,907	tons/year
Cargo Tank Temperature Averaged	28.45					Celcius
Temperature Degree K	301.45					Kelvin
Pressure	1					atm
Daily venting Averaged	182,825					SCF/Day

The result as shown in Table 4.5 was baseline emission calculates from study area which saves time and resources. It was found emission was 10.705 tons/day or 3,907 tons/year.

The result was compared resulted with previous research (Pring et al, 2010) which used equation 4.2. In this study, the averaged daily total production of 610,971.0548 Bbls was kept standing still in tank for the whole year. Thus, the total production of condensate in a year for applying in Pring’s equation was 610,971.0548 Bbls. It was used to calculate the emission in year 2014 by equation 4.2 as the following

$$E = \frac{610,971.0548 \times 33.3 \times 1}{2,000} = 10,172.668 \text{ tons/year. (Equation 4.2)}$$

The calculation’s result from equation 4.2 was compared to the emission shown in Table 4.1. It was found that the emission obtained from Pring et al (2010)

study is greater than this study about 2.6 times. The difference may come from the following reason

- Different method calculated application.
- Previous studied area was tank farm and no movement of VNGL.
- Source of production which make different qualification.
- Different weather condition.
- Composition will vary with geographic location, geologic formation, temperature and pressure.

It was suggested that the emission estimate should be selected calculation method by VNGL compositions because the data of actual composition were collect from study area and accuracy reason.

From the Table 4.5, it would be created the equation from this study which saves time and resources, the calculation as shown in equation 4.3 below

$$E = \frac{\text{Annual averaged emission (SCF)} \times (f_1d_1 + f_2d_2 + \dots f_nd_n) \times 365\text{days}}{35.315 \times 1000} \tag{Equation4.3}$$

Where

- 35.315 is changing cubic foot to cubic meter.
- fi is present fraction ith
- di is density of fraction ith

However the baseline emission was verified by use daily emission for calculation, it was found 3,719.99 ton per year which has accuracy than table 4.5 and equation 4.3 by use equation 4.4 below:

$$E = \frac{\sum A_j \times (f_1d_1 + f_2d_2 + \dots f_nd_n)}{35.315 \times 1000} \tag{Equation4.4}$$

Where

- Aj is daily venting volume,

j are day1, day2...day365

f_i is present fraction i th

d_i is density of fraction i th

35.315 is changing cubic foot to cubic meter.

4.4 Prediction of VOCs concentration

4.4.1. Screen View data gathering

Screen View model was applied to predict the pollution concentration from both vent stacks and verify the intensity for the receptors. The model required input the data as the following.

- Emission rate in gram per second (g/s) at the average and the maximum

The method and results are shown in Table 4.6 below:

Table 4.6 Method to gain averaged emission and maximum emissions

Calculation table								
Composition	Methane	Ethane	Propane	Butane	Pentane	Hexane	Heptane	Total
Composition each	0	0.076386101	0.423212454	0.43099603	0.056960614	0.007449039	0.004995763	1
Density	0.6468	1.2128	1.7787	2.1021	2.9106	3.4766	4.0425	
Average (g/d)	0	479,601.24	3,897,067.30	4,690,330.05	858,289.79	134,070.03	104,551.09	10.16
Average (g/s)	0	5.55	45.10	54.29	9.93	1.55	1.21	3,719.99
Max g/d	0	1,099,368.60	8,933,074.20	10,751,435.14	1,967,419.55	307,322.78	239,657.82	
Maxg/s	0	12.72	103.39	124.44	22.77	3.56	2.77	

- Both vent stacks 25 meters high and inside diameter 0.15 meter.
- Stack gas exit temperature was 89.9 °F observed available in control room.
- Annual averaged of ambient air temperature was 83.08 °F
- Building height was 14.5 meters available from ship drawing.
- Minimum Horizontal building diameter was 16.7 meters available from ship drawing.
- Maximum Horizontal building diameter was 27.02 meters available from ship drawing.

- Receptor height above ground 1.65 meters. The average height of workforce in study area
- Annual average of stack gas exit flow rate was 0.599 m³ per second

Where

- R1 50 meters distance from stack A to working area.
- R2 150 meters distance from stack A to living area.
- R3 100 meters distance from stack B to working area.
- R4 200 meters distance from stack B to living area.

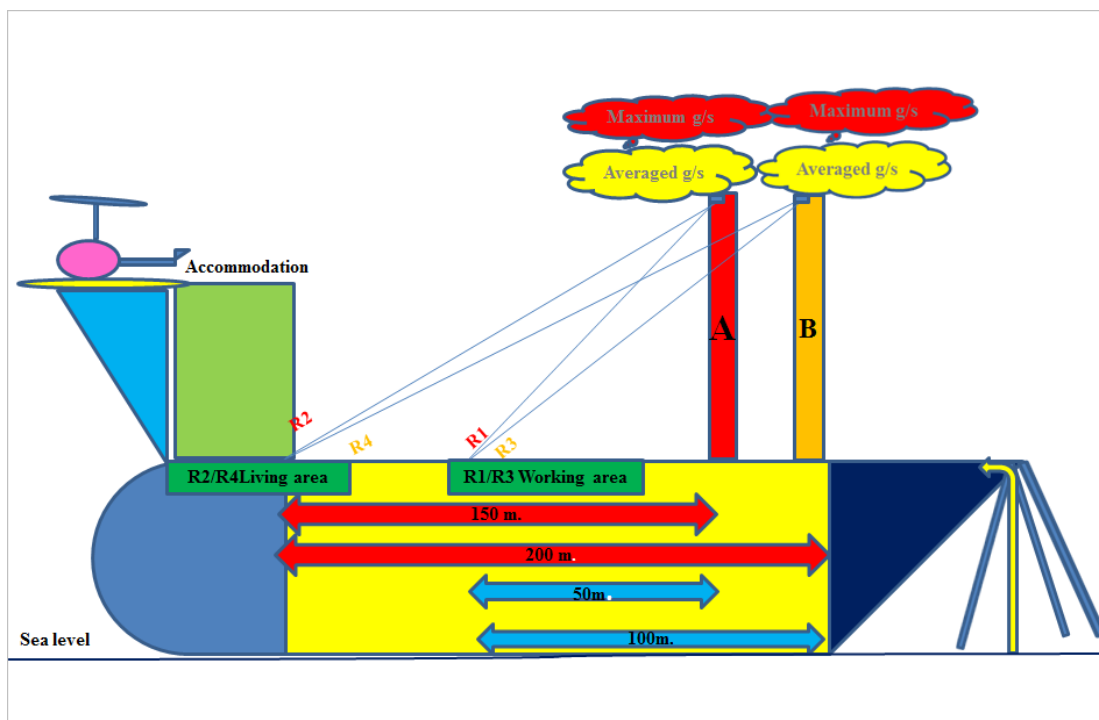


Figure 4.10 Storage tank layout show the working area and living area

The screen view selected point source and dispersant coefficient with rural, simple terrain and discrete distances. The distance from accommodation of vent stack A and B were 150 meters and 200 meters as shown in Figure 4.10. The emission rate were averaged and maximum in g/s of VNLG composition input to screen view to investigate the air pollutants at R1, R2, R3 and R4. The results of air pollutants output data as shown in Table 4.6.

4.4.2 Screen view application

After screen view was applied to predict the air pollutants in scenarios of emission, the results were shown in the Table 4.7 below

Tables 4.7 The finding of air pollutants in the study area

Compounds	Unit	At working area				At accommodation area			
		Stack A		Stack B		Stack A		Stack B	
		Average	Max	Average	Max	Average	Max	Average	Max
Butane (MW58)	$\mu\text{g}/\text{m}^3$	19,830	45,450	25,490	58,420	25,490	58,420	22,530	51,640
	ppm	8.36	19.16	10.75	24.63	10.75	24.63	9.50	21.77
Ethane (MW30)	$\mu\text{g}/\text{m}^3$	2009	4,647	2,606	5,972	2,583	5974	2,303	5,279
	ppm	1.63	3.79	2.12	4.87	2.10	4.87	1.87	4.30
Heptane (MW100)	$\mu\text{g}/\text{m}^3$	441.9	1,012	561.1	1,301	561.1	1,301	502.1	1,150
	ppm	0.10	0.24	0.13	0.3	0.13	0.3	0.12	0.27
Hexane (MW86)	$\mu\text{g}/\text{m}^3$	566.1	1,297	727.8	1,667	727.8	1,667	643.2	1,473
	ppm	0.16	0.36	0.20	0.47	0.20	0.47	0.18	0.41
Pentane (MW72)	$\mu\text{g}/\text{m}^3$	3,627	8,316	4,662	10,690	4,662	10,690	4,121	9,449
	ppm	1.23	2.82	1.58	3.63	1.58	3.63	1.40	3.20
Propane (MW44)	$\mu\text{g}/\text{m}^3$	16,480	37,760	21,180	48,550	21,180	48,550	18,720	42,910
	ppm	9.15	20.98	11.77	20.97	11.77	20.97	10.40	23.84
Total $\mu\text{g}/\text{m}^3$		42,954	98,482	55,227	126,600	55,204	126,602	48,819	111,901
Total ppm		20.63	47.35	26.55	54.87	26.53	54.87	23.47	53.79

Note convert $\mu\text{g}/\text{m}^3$ to ppm by equation 4.3 as following

$$\text{ppm} = \frac{(\mu\text{g}/\text{m}^3 / 1,000) \times 24.45}{\text{Molecular weight (MW)}} \quad (\text{Equations 4.5})$$

Where 24.45 = molar volume of air in liters at NTP conditions (25°C and 760 torr).

4.4.2.1 Average emission in normal daily operation

- Scenario1: At normal operation. The vent stack A. located 150 meters from accommodation (R2) or living area and 50 meters from working area (R1), applies averaged emission. It was found the air pollutants concentration at accommodation greater than working area which dominated with propane and butane.

- Scenario2: At normal operation. The vent stack B. located 200 meters distance from accommodation (R4) and 100 meters from working area (R3), applies averaged emission calculation. It was found the air pollutants concentration at the working area greater concentration more than or living area

The scenario1 and scenario 2 observed the air pollutants occurred in both scenarios which mean the receptor should be aware, especially in case of the emission of VOCs were vent from both stack, Personal protective equipment and personal gas detector should be in place while working to monitor of air pollutants in real time.

4.4.2.2 Maximum emission in worst case operation

- Scenario3: At worst case operation. The vent stack A located 150 meters from accommodation (R2) and 50 meters from working area (R1), applies maximum emission

- Scenario4: At worst case operation. The vent stack B located 200 meters distance from accommodation (R4) and 50 meters from working area (R3), applies maximum emission

Scenario3 and scenario 4 observed the air pollutants occurred in the study area in both scenarios. The concentration was greater than scenario1 and scenario 2 2.29 times. Which mean the receptor or worker should be aware more to use the personal protective equipment and personal gas detector should be in place while working to monitor of air pollutants in real time.

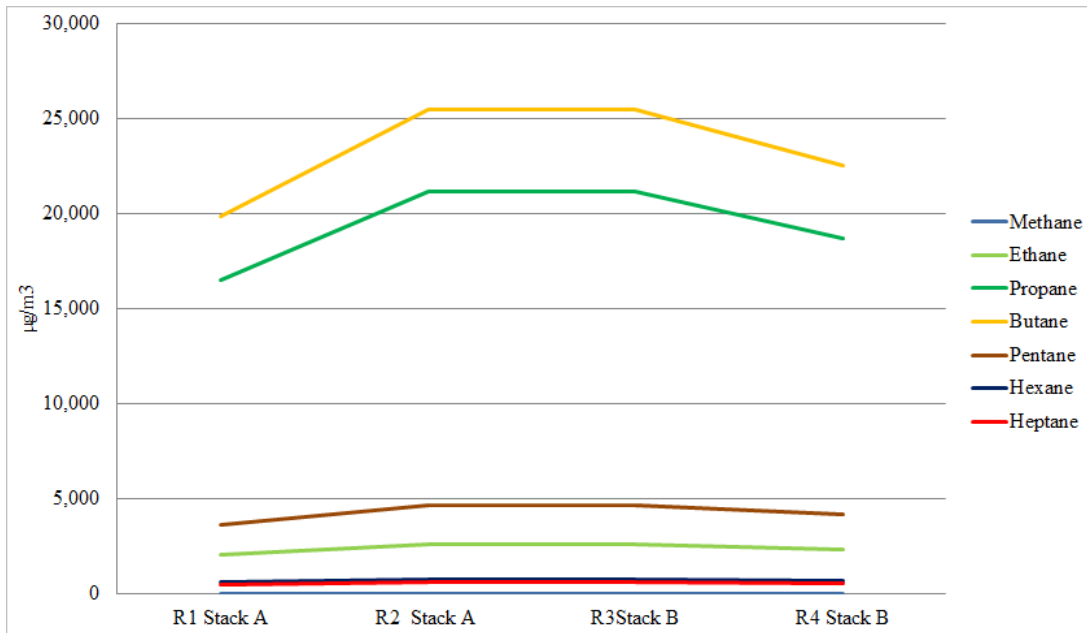


Figure 4.11 Air pollutants concentration at study area in normal operation day

It was found the relation of concentration from vent stack A, air pollutants concentrations of living area(R2) was greater than working area(R1), while vent stack B found air pollutants concentrations at working area(R3) was greater than living area(R4) as shown in Figure 4.11.

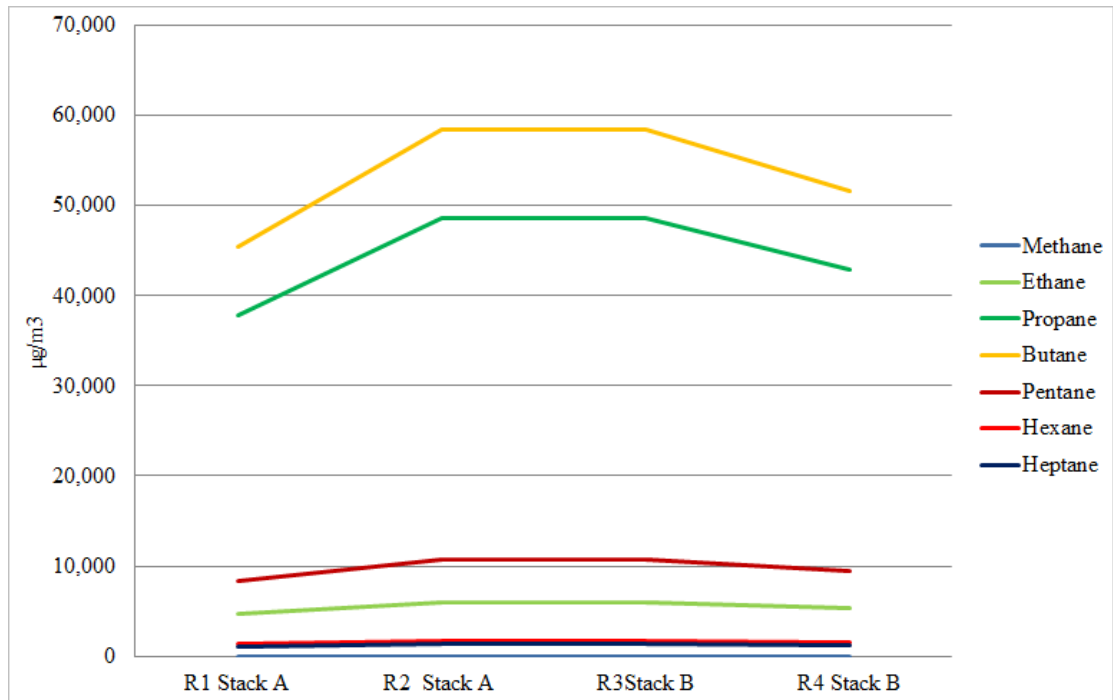


Figure 4.12 Air pollutants concentration at study area in worst case scenario

From the graph above, it was found the relation of concentration from vent stack A, concentration of the point living area(R2) was greater than working area(R1), while the vent stack B found the concentrations of the substance working area(R3) greater than living area (R4) but substance concentration was greater than studied in normal operation day scenario as shown in Figure 4.12.

Prediction from screen view found the area concentration in $\mu\text{g}/\text{m}^3$ then converted concentrations to ppm which situation will occurred or not from no venting process, wind direction, dilution in the air and the predictions derived will obviously be highly affected by the quality of the input data, as well as the inherent difficulty in obtaining accurate predictions under conditions of very low wind speeds or unstable atmospheric conditions, A previous study of Pemberton, Maurice Thyer and Ledin [33] applied the mathematical modelling of a release from a vent with a Computational Fluid Dynamics (CFD) model for ignition hazard area and found the density of the VOCs was greatly influences in low wind speeds where vent plumes may fall or be pulled to FSO deck level as show in Figure 4.13.

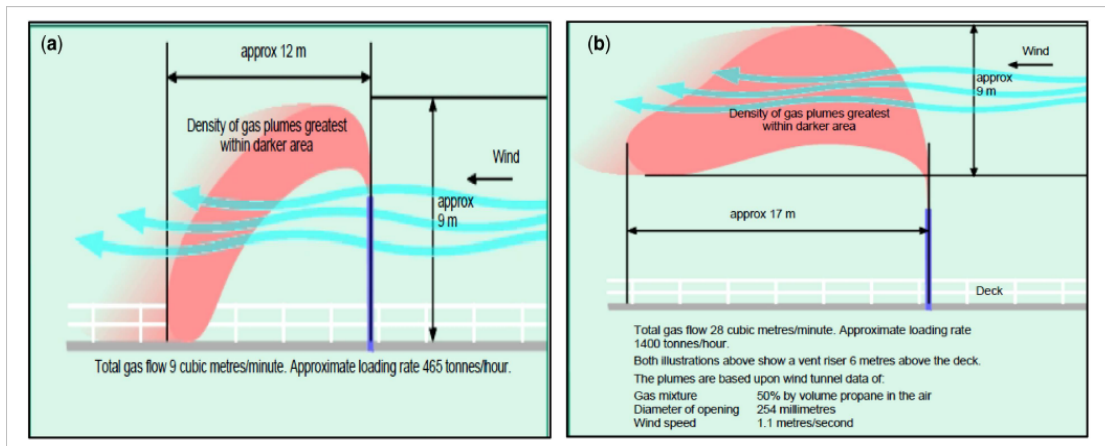


Figure 4.13 Behaviors of vented hydrocarbon plumes [33]

However the real time monitor at the working area suggest preforming according to safety reason to Time Weight Averaged (TWA) to prevent the workforce over exposure. In case of portable gas detectors found the VOCs from area sampling, personal protective equipment such as face shield, respiratory protection, gloves and protective clothing may be appropriate during work or stop work authority and job postpone. The severity was come from vent stack A. in maximum emission at the accommodation and vent stack B at the working area. The compositions health hazard can be occur in case of the worker exposure as following

- Butane: It may cause frostbite at skin and eyes when contact with liquid form of butane. In case of exposure to high concentration can cause drowsiness, and lack of oxygen, headache. It has not been researched for ability to cancer cause and reproductive hazard. Long term health effect can occur in sometime. [32]
- Ethane: Exposure can cause headache, nausea, vomiting and high level can cause lack of oxygen. It has not been researched for ability to cancer cause and reproductive hazard. Long term health effect can occur in sometime. [32]
- Heptane: Exposure can affect the nervous system, headache, lightheadedness, dizziness, lack of coordination and loss of consciousness and it has not been researched for ability to cancer cause and reproductive hazard. Long term health effect can occur in sometime. [32]
- Hexane: Contact with skin may cause irritated or burn affect the nervous system, headache, lightheadedness, dizziness, lack of coordination and loss of

consciousness High level can cause coma and death and it has not been researched for ability to cancer cause and reproductive hazard. Long term health effect can occur in sometime. [32]

- Pentane: Routes of exposure may from inhalation, skin or eye contact. The symptoms may cause eyes, skin, nose irritation dermatitis, drowsiness and in animals test can be necrosis. [31].

- Propane: Routes of exposure may from inhalation, skin or eye contact. The symptoms was confusion, dizziness, excitation, asphyxia and liquid form may cause frostbite [31].

The best from this practices and additional recommendations research to prevent the exposed VOCs are following

- Do not eat and drink at the working area or outside accommodation
- Contaminated clothes should be change , laundered promptly and inform to the laundry man
- Eye was station provided or portable eye wash station stand by in working area including shower station should be provide
- In case of contact, immediately wash or remove.
- If person unconscious, remove from the exposure area

4.5 Summarize problem and mitigation guidelines.

Table 4.8 shows the summaries problems and mitigations covering source, pollution path and receptor and propose mitigation guidelines from IMO [6] and additional measures on development of VOCs management plan.

Table 4.8 Problems and mitigation guidelines

Source	Problem	IMO mitigation guidelines	Mitigation guidelines recommendation for study area
At path	1. VOCs emission	<ul style="list-style-type: none"> • Vapour recovery unit to reduce emissions of VOCs which can recover VOCs in all operational phases. 	<ul style="list-style-type: none"> • Improve opportunity to install VRU, but study for economics, engineering design and risk assessment required. <p><u>Additional mitigation</u></p> <ul style="list-style-type: none"> • The venting stack must be situated downwind to accommodation • Review the design of pollution path in case of apply the ship using by engineer • Air model should be applied before design, to study the prognosis in normal operation and worst case scenario. • Air model should be applied during both operation of normal operation scenario and worst case scenario • Personnel safety hazards related to exposure to VOCs vapour. <p><u>Additional mitigation</u></p> <ul style="list-style-type: none"> • Occupational health program to apply with all personal onboard working.

Table 4.8 Problems and mitigation guidelines (cont)

Source	Problem	IMO mitigation guidelines	Mitigation guidelines recommendation for study area
At receptors	2. Workers have risk to air pollutants exposure.	<ul style="list-style-type: none"> • Training programme is to be conducted for the persons intended to assume overall charge of the VOCs management on board each ship. The programme is to include that Volatile Organic compounds (VOCs) may be toxic, and when they evaporate into the air they can react with Nitrogen Oxides (NO_x) in sunlight and split apart oxygen molecules in air and thereby form ground-level ozone, commonly referred to as smog. The layer of brown haze it produces is not just an eyesore, but also is a source of serious illnesses. Ozone is extremely 	<ul style="list-style-type: none"> - For example pre-posttest urine after tank entry. - Personal protective equipment must in good condition. Best practice inspection program conduct every 3 months. - Work force must be train in Hazmat course and refresh every 3 years • Intensive monitoring of vapor while maximum emission could be predicted, such as high volume of condensate onboard, high RVP and sea condition swell and encourage employee to use stop work procedure immediately when found abnormal condition. • Qualified gas tester training course

Table 4.18 Problems and mitigation guidelines (cont.)

Source	Problem	IMO mitigation guidelines	Mitigation guidelines recommendation for study area
At receptors		<p>- irritating to the airways and the lungs, causing serious damage to the delicate cells lining the airways. It contributes to decreased lung function, increased respiratory symptoms and illnesses.</p> <ul style="list-style-type: none"> • Completed a training programme in VOC management as specified in the VOC management plan 	

Remark: The RVP and temperature were conflicted the result; however it was safety concern and experienced for the mitigation which provide by following

1. At path, high RVP may increase tank pressure leading to increase venting volume in theory, from this studied RVP

IMO mitigation guidelines

- When venting to decrease tank pressure is required, the decrease in the pressure in the storage tanks should be as small as possible to maintain the tank pressure as high as possible.

- Inert gas topping up procedures.

- After completion of the controlled release, monitor the tank pressure required in order to check the final pressure obtained within the Vapour and Inert Gas system.

Mitigation guidelines recommendation for study area

- Follow IMO
- Use of vapour return manifold and pipelines when shore facilities are available
- Central processing platform condensate stabilizer process should send products' RVP not over 12 psia which is contract of operation.

2. At path, Temperature affected to vent volume by theory from this studied RVP conflicted the result.

IMO mitigation guidelines

Tanker has the double hulled construction of a void or ballast space located between the cargo tank and the outer hull. This causes the temperature of the liquid cargo to remain closer to the temperature of the cargo upon loading for a longer period due to the so called "Thermos Effect" or heat loss insulation created by the void or empty ballast space.

Mitigation guidelines recommendation for study area

- Use sea water for cooling VNGL In case when VNGL's temperature in tank is higher than ambient temperature. It should be best practice by theory to use sea water for cooling.
- It should be concern in ship stability, Strong throttle and shear force will be given against the vessel including the use of an electric pump for the water into the tank, waste energy, diesel consumption ,economics, knowledge and understanding of others further risk.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This chapter presents the conclusion and recommendations from investigation relationship between physical factors, VOCs compositions, and baseline calculations to estimated annual emissions and VOCs concentrations in the air as following five objectives

- To investigate relevant factors affecting the daily VOCs venting volume of Volatile Natural Gas Liquid in storage tanks vessel.
- To examine chemical components of Volatile Natural Gas Liquid in storage tanks vessel.
- To estimate the baseline of VOCs emission from storage tanks.
- To predict the concentration of the VOCs using Gaussian plume dispersion model
- To propose vent gas emissions mitigation guidelines.

5.1.1 Relevant factors affecting the daily VOCs venting volume of Volatile Natural Gas Liquid in storage tanks vessel

In conclusion, the effect of condensate onboard seem the most influent trend to venting volume compared with other the relationship between venting volume and four factors of wave height, natural gas liquid's Reid Vapor Pressure (RVP), ambient temperature, and cargo tank temperature which were tested by multiple regressions analysis. It was found that the factor related to the venting volume is the total condensate onboard (P value < 0.001). The regression equation is Y (Venting volume) = 118,980.788 + 0.096x (Total condensate) and adjusted R² was 0.023 which indicates poor relationship between the two variables. This finding was against

research hypothesis assumed that 5 independent variables are related to dependent variable. It may come from the independent variables in this study were varied too narrow range to find a relationship. Moreover there may have others factors influent venting volume from Floating Storage and offtake (FSO).

However, it is important to understand why selecting related factor for study, structure, quality of product, physical of area, geographic to aware the possibility and data collecting period are very importance in make the accuracy.

5.1.2 Chemical components examined of Volatile Natural Gas Liquid in storage tanks vessel.

Thirteen samples of vent gas mixture were collected to analyze gas compositions by using gas chromatography techniques. It was found that the average composition was 55% nitrogen, 7% carbondioxide, 3% oxygen and six VOCs of 2.63% ethane, 14.60% propane, 14.87% butane, 1.96% pentane, 0.26% hexane and 0.17% heptane. It is clearly showed that Propane and Butane are dominated in VOCs composition. Butane (most found of VOCs in this study), Pentane and Hexane have odor, thus they can make adverse effects on health to the workforce on the FSO, whereas the others VOCs are odorless.

The averaged components of VNGL compose of 34.49% of hydrocarbons and 65.51% of non-hydrocarbons (55.34% N₂, 7.45% CO₂ and 2.27% O₂). N₂ and CO₂ were produced into the condensate tanks by inert gas generator for using as a topping and to prevent explosion. The spontaneous oxygen mixed in the tank have monitored also but it should not over than 8% so as to maintain a safe atmosphere within a ship's cargo tanks [27]

5.1.3 Baseline of VOCs emission from storage tanks.

It was found that the annual average of VOCs emission was 3,907 tons/year. The second method used Pring et al (2010) equation which applied VOCs's emission factor from condensate and total production of VNGL a year .The calculation gave the emission of 10,172.67 tons/year which was greater than baseline emission calculates from study area around 2.6 times. The difference may come from the application of different factors and different number of factors used in each equation.

However, the first method may give the result closer to the actual value because the data were from the measurement.

5.1.4 The concentration of the VOCs predicted by use Gaussian plume dispersion model

After screen view was applied to predict the air pollutants in scenarios of emission predicted in two situations:

5.1.4.1 Average emission in normal daily operation

The scenario1 and scenario 2 observed the air pollutants occurred in both scenarios which mean the receptor should be aware, especially in case of the emission of VOCs were vent from both stack, Personal protective equipment and personal gas detector should be in place while working to monitor of air pollutants in real time working area (R1), while vent stack B found air pollutants concentrations at working area (R3) was greater than living area (R4) after screen view was applied.

5.1.4.2 Maximum emission in worst case operation

The scenario3 and scenario 4 observed that the air pollutants occurred in the study area in both scenarios. The concentration was greater than scenario1 and scenario 2 approximately 2.29 times which mean the receptor or worker should be aware more to use the personal protective equipment and personal gas detector should be in place while working to monitor of air pollutants in real time. It was found the relation of concentration from vent stack A, air pollutants concentrations of living area(R2) was greater than working area(R1), while vent stack B found air pollutants concentrations at working area(R3) was greater than living area(R4). The situations may occurred or not from no venting process , current wind direction, dilution in the air and the predictions derived will obviously be highly affected by the quality of the input data, as well as the inherent difficulty in obtaining accurate predictions under conditions of very low wind speeds or unstable atmospheric conditions, A previous study of Pemberton, Maurice Thyer and Ledin [33] applied the dispersant model for ignition hazard area and found the density of the VOCs was

greatly influences in low wind speeds where vent plumes may fall or be pulled to FSO deck level.

However the real time monitor at the working area suggest performing according to safety reason to Time Weight Averaged (TWA) to prevent the workforce over exposure. In case of portable gas detectors found the VOCs from area sampling, personal protective equipment such as face shield, respiratory protection, gloves and protective clothing may be appropriate during work or stop work authority and job postpone. The severity was come from vent stack A. in maximum emission at the accommodation and vent stack B at the working area.

5.1.5 Mitigation guidelines conclusion

The summaries main problems and mitigations provided to cover source, pollution path and receptor and propose mitigation guidelines from IMO as following

5.1.5.1 VOCs emission problem. IMO recommend Vapour recovery unit to reduce emissions of VOCs led to the installation or development of VRU which can recover VOCs in all operational phases. The study area may have opportunity to improve VRU installation, but study for economics, engineering design and risk assessment required, the additional mitigation as following

- The venting stack must be situated downwind to accommodation.
- Reviews the design of pollution path in case of apply the ship using by engineer.
- Air model should be applied before design, to study the prognosis in normal operation and worst case scenario.
- Air model should be applied during operation in normal operation and worst case scenario.

5.1.5.2 Workers have risk to air pollutants exposure. IMO mitigation guidelines recommended programme training is to be conducted for the workforce intended to assume overall charge of the VOCs management on board and completed a programme training in VOCs management as follow the VOCs

management plan while mitigation guidelines recommendation for study area concern with the training same as IMO recommended. The training course should provide hazards identification related to exposure to VOCs vapour and the additional recommendations as following

- Occupational Health Program to apply with all personal onboard working.
- For example pre-posttest urine for urine mucuniacid after tank entry
- Personal protective equipment must in good condition. Best practice inspection program conduct every 3 months.
- Work force must be train in Hazmat course and refresh every 3 years.
- Intensive monitoring of vapor while maximum emission could be predicted, such as high volume of condensate onboard, high RVP and sea condition swell and encourage employee to use stop work procedure immediately when found abnormal condition.
- Qualified gas tester training course.

5.2 Recommendations

5.2.1 Recommendations for Future Research

The following recommendations for related research are offered in the emission from storage tank vessel

- Given the data collection, based on location, would document trends of API gravity addition, regarding the composition and quality of VNGL would be relatively current emission from different API Gravity.
- The relevant factors should always apply multiple regression is a statistical technique to concentrate in the relationship between one variable and more than one independent variables.

- While the current emission study, it may be advantageous to conduct research which considers the emission of the different products such as crude oil and or other complex toxic factors need to predict such as mercury incoming line compare on main deck by physical measurement to developmentally-related needs of the company's field or benefits.

- Research related to emission of VOCs from storage tank vessel that provides a composition contribution on main deck prediction and to the goals of best practice would be of value to the company's field of work force education.

- Data collection period could extend the possibility 5 years retrospective. The reason is there were more populations, in case of the time and data are available.

- It is recommended that researchers check the areas of specialization of composition the area study. Further, clearly identifying which faculty crew is involved by urine test for mercury, urine mucuniacid for benzene's exposer monitor.

5.2.2 Recommendations for Oil and Gas field.

The following recommendations are offered for practitioners in the field of storage tank vessel or Oil and Gas field.

- Based on the results of this research, according from emission in ton/year, the calculation should use the composition from the area study.

- It's recommended that recovery unite should be study Oil and gas production in future in construction period.

- A real time monitor at the working area suggests preforming according to safety reason to Time Weight Averaged (TWA) to prevent the workforce over exposure to reduce air pollutants exposures in workforce and risk of experiencing health problems reduction.

- Area toxic air pollutants conduct risk assessment, combines results of studies on the health effects of human exposures to the pollutant with results of studies that estimate concentration of workforce exposures at different risky distances from the source of the pollutant which can be apply in the future reach.

- Other air pollution model applies such as gas leak scenario for the future research.

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APPENDICES

APPENDIX A

EQUIPMENT'S INFORMATION

1. Temperature of cargo tank: using PT100 sensor (see in Appendix A. Figure 1) at Cargo tank which is fixed probe and Kongsberg GL-300 computation system shown in Appendix A. Figure 2. Temperature sensors are delivered in tailored lengths according to tank heights. The connection box and signal converter are designed for installation of up to 3 sensors each.



Figure A1 Temperature sensors

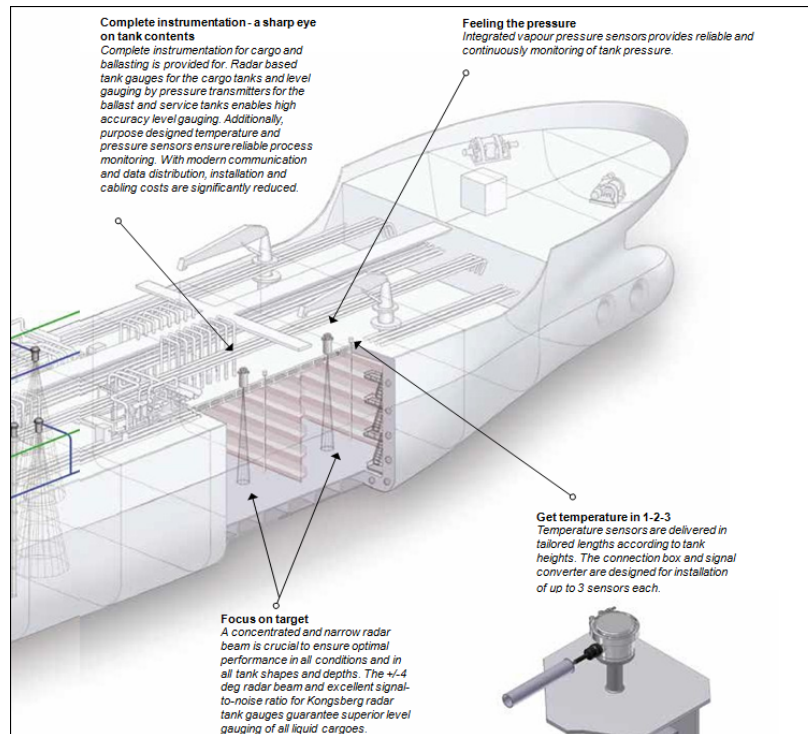


Figure A2 Kongsberg GL-300 computation system

[http://www.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/5020D2BB63B74BE8C12575CC002D1139/\\$file/K-Gauge-brochure.pdf?OpenElement](http://www.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/5020D2BB63B74BE8C12575CC002D1139/$file/K-Gauge-brochure.pdf?OpenElement)



Figure A3 Area of study's 2 Kongsberg GL-300 computation systems

2. GF868 Ultrasonic Flare Gas Flow meter

The GF868 flow meter which shown in Appendix I Figure 3 operates reliably even under unsteady flow, pulsating pressure, varying composition and temperature, harsh environments and the wide flow ranges typical of flare systems. Flow velocity is measurable from 0.1 to 275 ft/s (0.03 to 85 m/s) standard bi-directionally in pipe or stack sizes up to 120 in (3 m) in diameter. Extended performance range configuration is available to 395 ft/s (120 m/s) velocity. There are no moving parts or orifices to wear or clog. The GF868 flow measurement is independent of the gas properties, and it does not require regular maintenance.

The GF868 flare gas flow meter improves the efficiency of petrochemical plants, refineries and offshore platforms. It uses a proprietary algorithm to determine instantaneously the molecular weight and mass flow rate of the flare gas. The meter is used to conserve energy and reduce product loss by identifying sources of leaks into the flare systems. It also helps improve compliance with pollution-control regulations and reduces energy usage by accurately controlling the amount of steam fed to the flare tip

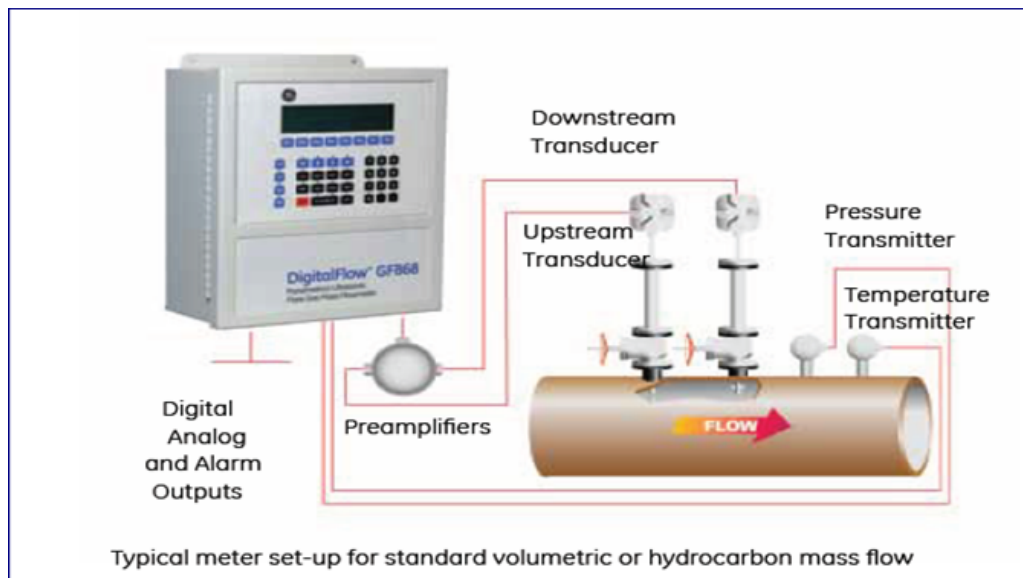


Figure A4 GF868 Ultrasonic Flare Gas Flow meter

<http://www.ge-mcs.com/download/co2-flow/920-009K-LR.pdf>

3. Ambient Temperature: using PT100 sensor which is Fugo Survey computation system (See in Appendix I Figure 4) The Sensor enables measurements in a 4-wire system. The measurement range of the Ambient Temperature Sensor is between -30°C and $+80^{\circ}\text{C}$. Connect the sensor to Sunny. Sensor Box for further processing of the ambient data and display in computer as seen in **Appendix A. Figure A5.**

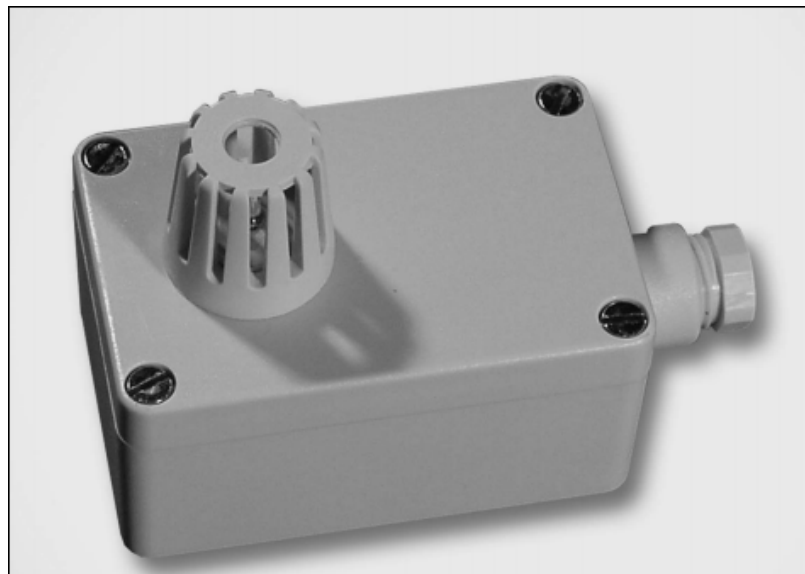


Figure A5 Ambient Temperature Sensor

<http://files.sma.de/dl/9330/TempsensorAmb-IEN110610.pdf>

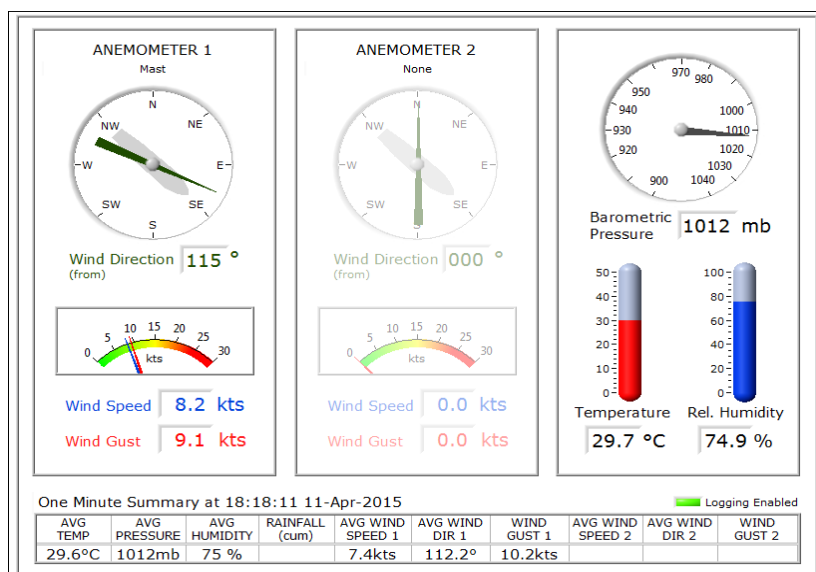


Figure A6 Meteorological Oceanographic Sensor Display of area studied

4. Chemical components: using gas chromatography and the emission's chemical component will be compared with the case study of ship emissions in the previous studies. The machine name is Agilent 7890B GC with Integrated Intelligence is built on over 40 years of gas chromatography experience. The advanced features of the 7890B GC help you get more done in less time while the quality design and reliability mean the system will maintain its high level of performance for years to come.



Figure A7 Gas Chromatography.

<http://www.chem.agilent.com/en-US/products-services/Instruments-Systems/Gas-Chromatography/7890B-GC/Pages/default.aspx#>

5. Gas Alert Micro 5

Gas Alert Micro 5 has an extensive selection of user-settable field options and is available as either a standard toxic gas model, a PID model for the detection VOCs, or an IR model for CO₂ detection. Use the passcode function to prevent

unauthorized modifications of the instrument's settings. Compatible with BW's Micro Dock II automatic test and calibration system, the Gas Alert Micro 5 is unparalleled in its versatility, performance and overall value



FigureA8. Gas Alert Micro 5

<http://www.bw-gasmonitors.com/xyy-m5pid.html>

6. Photovac EnviroFID VOC Monitor

For accurate, reliable detection of VOCs, the Photovac EnviroFID VOCs Monitor is the right choice in flame ionization detection. At just over 8 pounds (3.7 kg.), the EnviroFID is the smallest and lightest Flame Ionization Detector (FID) available. The EnviroFID VOCs monitor is easy to use. One tutor key prompts you through basic operations. Critical data is displayed and logged in less than 3 seconds within the concentration range of 0.5 - 50,000 PPM. A simple two-step calibration holds for a full workday.

The EnviroFID VOCs Monitor is completely self-contained in a single hand-held package, so transportation and operation are simplified. The EnviroFID's ergonomic design includes a built-in handle and a rubberized keypad that can be used even while wearing gloves. The EnviroFID has an integrated, refillable fuel gas (hydrogen) mini-cylinder to allow up to 12 hours of field operation. Replaceable and rechargeable battery packs operate for 15 hours. With a wide linear range, the

EnviroFID responds to almost all VOCs. The flame ionization detector is stable and virtually immune to possible interferences such as water vapor.



FigureA9. EnviroFID VOCs Monitor

<http://www.eco-rentalsolutions.com/photovac-envirofid-voc-monitor-flame-ionization-detecto>

7. Wave Buoys

These buoys measure the frequency and size of wave energy (known as the spectra) from which significant sea conditions, dominant wave period, and average wave period are derived. Even the direction of wave propagation is measured on many moored buoys. This information can be used to greatly improve the prediction and warnings for dangerous storms.



Figure A10. Oceanographic and Meteorological (Metocean) Services for Offshore Applications

<http://www.offshoretechnology.com/contractors/hydrographic/fugrogeos/fugrogeos4.html>

8. Reid Vapor Pressure Testing. The gasoline to be tested is poured into the shorter lower portion of the stainless steel cylinder, which unscrews from the hollow upped air chamber. After the lower chamber is filled with gasoline to be tested, it is attached to the upper chamber. The RVP bomb sitting in the Koehler circulating water bath at 100 °F .It holds about 20 gallons of 100 °F water agitated by a propeller driven by the motor on the upper right

After the assembled vapor pressure apparatus has been immersed in the bath for 5 minutes, tap the pressure gauge lightly and record the reading. Withdraw the apparatus from the bath, invert it, shake it vigorously and immediately place back in the bath. At intervals of about 10 minutes, repeat this agitation and gauge observation at least five times, until the last two gauge readings are constant. These operations normally require 60 to 90 minutes. Read the final gauge pressure to the nearest 0.05 psig for gauges with intermediate graduations of 0.1 psig and to the nearest 0.1 psig for gauges with graduation of 0.2 to 0.5 psig. The value obtained is the Reid Vapor Pressure of the sample under test.



Figure A11 hollow upped air chamber.

<http://www.koehlerinstrument.com/products/K11201.html>

<http://www.baaqmd.gov/~media/Files/Records/MOP/vol%203/MOP-13.ashx?la=en>

APPENDIX B

DOUGLAS SEA SCALE

The Douglas Sea Scale is a scale which measures the height of the waves and also measures the swell of the sea. Also called the "international sea and swell scale", was devised in the 1920s by Captain H.P. Douglas, who later became vice admiral Sir Percy Douglas and hydrographer of the Royal Navy.

Table 1 state of the sea

Degree	Height (m)	Description
0	no wave	Calm (Glassy)
1	0–0.10	Calm (rippled)
2	0.10–0.50	Smooth
3	0.50–1.25	Slight
4	1.25–2.50	Moderate
5	2.50–4.00	Rough
6	4.00–6.00	Very rough
7	6.00–9.00	High
8	9.00–14.00	Very high
9	14.00+	Phenomenal

http://www.metoffice.gov.uk/media/pdf/b/7/Fact_sheet_No._6.

APPENDIX C
DESIGNED TABLE FOR RECORD RELEVANT FACTORS

2014 Relevant factors						
Day	Sea conditions/wave height(m)	RVP (psia)	Ambient temperature (°C)	Cargo tank temperature (°C)	Total condensate onboard (Barrel.)	Venting (SCF)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
..						
365						

APPENDIX D
ADJUSTED R SQUARE TABLE

Model 1		Coefficients		Sig.
		B		
	(Constant)	- 152,959.599		0.38744
	Waveheight	7,286.920		0.32967
	RVP	9,416.176		0.13833
	Ambient	122.983		0.96316
	Tanktemperature	4,623.527		0.29813
	Totalbbls	0.100		0.00843 *
	Dependent Variable: Ventingvolume			
	R Square		0.042	
	Adjusted R Square		0.02187	
Model 2		Coefficients		Sig.
		B		
	(Constant)	118,980.788		0.000 *
	Totalbbls	0.096		0.011 *
	Dependent Variable: Ventingvolume			
	R Square	0.027		
	Adjusted R Square	0.023		

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