AIR-SEA FLUX INTERACTION OF CARBON DIOXIDE CONCENTRATION DUE TO OIL AND GAS INDUSTRY AND CLIMATE CHANGE IN MALAYSIA

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CIVIL ENGINEERING

UNIVERSITI TEKNOLOGI PETRONAS

CERTIFICATION OF APPROVAL

Air-Sea Flux Interaction Of CO_2 Concentration Due To Oil And Gas Industry And Climate Change In Malaysia

By

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Approved by,

……………………………………………….

(DR. NURUL IZMA BINTI MOHAMMED)

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specify in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources or person.

………………………………………..

ELWIN LAU KIENG WUI

ABSTRACT

The air-sea interaction is directly related to several climate impacts such as global warming. The data and statistic shown for the past decades have shown the increase of temperature at the sea surface proven the occurrence of global warming. Several researches have been carried out to study the air-sea interaction. Most of the studies focus on the factors affecting the air-sea interaction and determine the air-sea flux in a specific area during specific season. Hence, these studies are significant as the first important steps toward climate change. The aim of this study is to model the air-sea interaction at Melaka refinery plants located at coastal area using indirect approach, bulk formula, and Fick's law of diffusion. The factor focused on this research will be on wind velocity. The value of carbon dioxide concentration will first be determined by referring to the Petronas Technical Standard which started from the construction of the plant till the current state which is operation. The concentration of carbon dioxide is assumed to be homogeneous. The value of solubility is acquired from solubility of Weiss (1974). Coefficient of wind velocity, k is determined using Schmidt number under Wanninkhof (1992). The determination of air-sea flux will be done using Microsoft Excel. The results would be the air-sea flux against the concentration in which the air-sea flux will increase in accordance of the increase of carbon dioxide concentration in the atmosphere.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Global Warming is the increase of Earth's average surface temperature due to effect of greenhouse gases, such as carbon dioxide emissions from burning fossil fuels or from deforestation, which trap heat that would otherwise escape from Earth (What is Global Warming?, 2015). According to National Aeronautics and Space Administration (NASA), the 10 warmest years in the 134-year record all have occurred since 2000, with the exception of 1998(NASA: Climate Change and Global Warming, 2015). Figure 1 shows the temperature anomaly since year 1880 till year 2013.

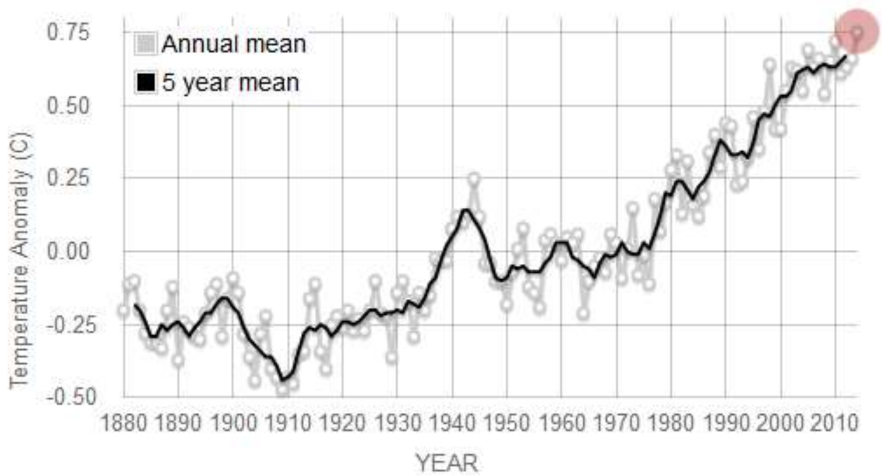


FIGURE 1: Global Land-Ocean Temperature Index

This is one of the vital signs showing the occurrence of global warming. Global warming is caused by human activity and natural event. Both this events release greenhouse gases (GHG), which is the main culprit of global warming. Greenhouse gases mainly consist of methane, carbon dioxide, nitrous oxide, water vapour and fluorocarbon. According to Global Carbon Budget 2014, the emission of carbon dioxide is 36.1 ±1.8 Gt in 2013. The amount is projected for the year 2014 with increment to 37.0±1.9 Gt. The increment is over 61% as compare to the year 1990, showing the increment of greenhouse gases in the atmosphere (Global Carbon Budget, 2014).

The properties of greenhouse gases associated with the global warming. One of the key properties is that greenhouse gases absorb heat. Greenhouse gas molecules absorb energy in the infrared region of the spectrum, which we generally associate with heat (Nash Soonawala, 2015). According to Nash, 90% of the atmospheric energy is absorbed by these greenhouse gases. These gases act as thermal blanket for the Earth, absorbing heat while warming up the surface of heart which then lead to global warming.

Another key properties is that greenhouse gases have a long atmospheric lifetime. The atmospheric lifetime of greenhouse gases referred to the approximate amount of time it would take for the anthropogenic increment to an atmospheric pollutant concentration to return to its natural level (assuming emissions cease) as a result of either being converted to another chemical compound or being taken out of the atmosphere via a sink(Atmospheric lifetime definition | EPA Glossary of Climate Change Terms Dictionary, 2015). Table 1 shows the atmospheric lifetime of 4 greenhouse gases namely, carbon dioxde, methane, nitrous oxide and carbon tetrachloride.

TABLE 1: Atmospheric Lifetime Of Carbon Dioxide, Methane, Nitrous Oxide And Carbon Tetrachloride

Gas	Chemical Formula	Lifetime(years)
Carbon dioxide	CO_2	5-200
Methane	CH_4	12
Nitrous oxide	N_2O	114
Carbon tetrachloride	CCl_4	26

Thus, greenhouse gases will tend to stay in atmosphere for long period and continuously trapping heat due to its properties and causing global warming. As mentioned in global carbon budget 2014, the increase emission of greenhouses gases would then hasten the progress of global warming.

Global warming most obvious and direct impact would be the melting of ice in both northern and southern hemisphere. According to NASA, the arctic ice reaches its minimum volume every September and we are losing approximately 13.3 % of arctic ice each decade. Figure 2 shows the artic volume during September since year 1980.

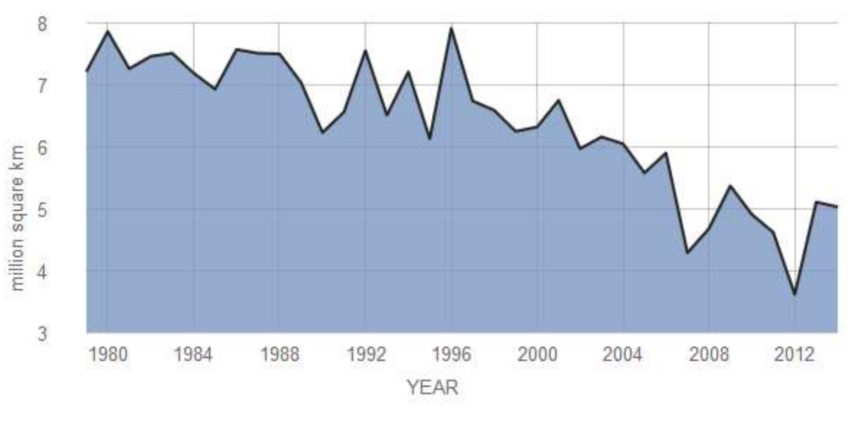


FIGURE 2: Artic Ice Volume During September

This directly lead to the increase of mean sea level globally which is 3.24 mm per year from year 1993 till 2014 (NASA, 2015). Figure 3 shows the sea level change since year 1993.

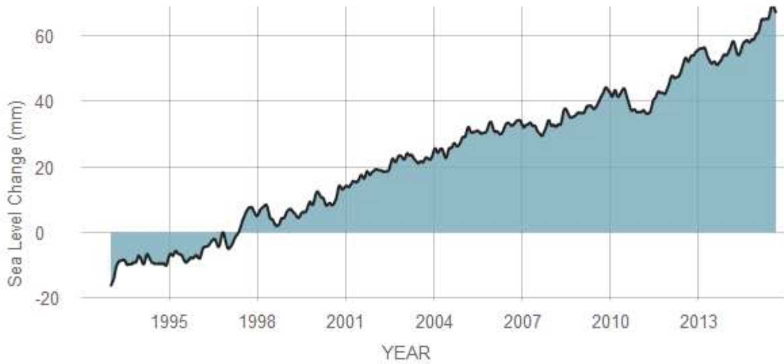


FIGURE 3: Sea Level Change (Mm) Since Year 1993

1.2 Problem Statement

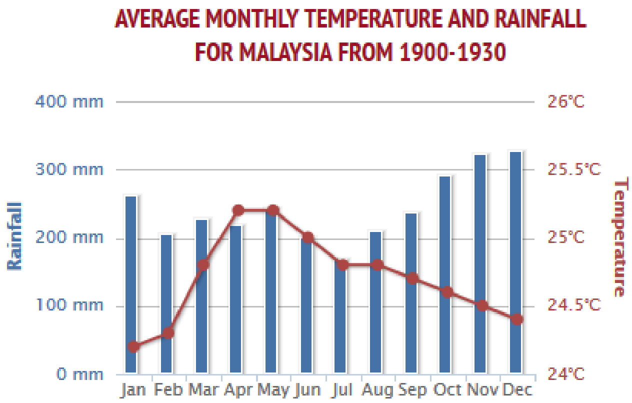
The demand for oil and natural gas is increasing worldwide due to a steadily growing population, economic growth, and rapid industrialization and urbanization (Wood, 2015) which drive the market of oil and gas industries. The location of these oil and gas platforms or refinery plant located near the sea which directly encourage the air-sea interaction. On 2011, February 5, the US Environmental Protection Agency (EPA) released new data indicating that oil and gas sector was the second-highest contributor of greenhouse gases (Oil and Gas Production a Major Source of Greenhouse Gas Emissions, EPA Data Reveals | Center for Effective Government, 2015). One of the major components of greenhouse gases is carbon dioxide which will be the topic of this research. According to the data released by the EPA, the refinery plant released 182 million tons of carbon dioxide which ranked second in the oil and gas industry. Table 2 shows the emission of carbon dioxide in year 2011 in United State of America.

TABLE 2: Emission Of Carbon Dioxide In Year 2011 In United State Of America

Rank	**Source Categories**	**Emissions (millions tons)**
1	Power plant	2,221
2	Refineries	182
3	Onshore oil and gas production	94
4	Natural gas processing	62
5	Petrochemical	53

The greenhouse gases emitted from the oil and gas industry is discharged directly into the atmosphere. The area of refinery plant located near the coastal area that has less greenery which take in carbon dioxide and aid in reducing the concentration of carbon dioxide in the atmosphere. Earth is constituents with 71% of ocean and 29% of land. The ocean is a sink of a significant fraction of anthropogenically produced carbon dioxide(Mcgillis, Edson, Hare, & Fairall, 2001). The heat carrying greenhouse gases will then undergo air-sea interaction with the exchange of heat and mass. Kinetic theory of gas for diffusion, describe that the diffusion takes place from the region of higher gas concentration to the region of lower gas concentration (Boundless, 2015). Thus, with the increasing concentration of greenhouse gases in the atmosphere, the interaction rate increased causing a rise of the temperature in the sea. Its impacts include global warming, changing of landscapes, rising mean sea levels, habitat loss, extreme heat, stronger storm, risk of drought, wildfire, flooding and economic losses.

In Malaysia, we are experiencing frequent heat, flood, loss of habitat and changing of landscape in the coastal area. Figure 4 shows the recorded rainfall data and temperature for year 1900-1930 and 1990-2012.



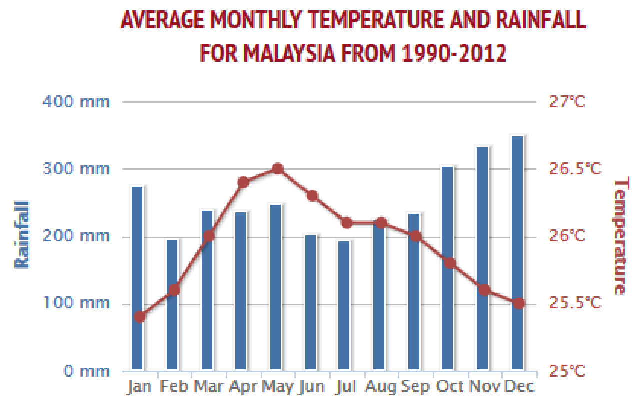


FIGURE 4: Average Monthly Temperature And Rainfall In Malaysia

Currently, lots of researches are focusing on the impacts of greenhouse gases and also providing solutions. Up to date, the possible solutions and financially sound method to reduce carbon dioxide is by reducing the activities that releases it by carbon taxation, more greenery and carbon capture and sequestration. If left unattended, the environment will be severely damaged to a point which is utmost close to wasteland.

1.3 Objectives

This research will be focus on this 3 main objectives:

1. To determine coefficient of mass transfer rate of carbon dioxide

2. To determine the dominant factor affecting air-sea flux in the selected region

3. To model air-sea flux interaction using Newton's Law of cooling

1.4 Scope of Study

The study will be conducted at Melaka Refinery Plant which located at Sungai Udang, Melaka. The surrounding area has less greenery and it is close to coastal region. The site is of 926 acre in the Mukim of Sungai Udang and Tangga Batu facing Malacca Straits. It has a combined capacity of 370,000 barrels per stream day. The refinery plant focused on petrochemical processes.

This research, the focus will be only on carbon dioxide and not the other greenhouse gases. All the data used is from Melaka Refinery Plant and used for the air-sea interaction at the coastal area. The factors studied will be the atmospheric temperature and near surface wind velocity. Figure 5 shows the location of study area.

FIGURE 5: Location Of Petronas Penapisan (Meelaka) Sdn. Bhd.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Over the last two centuries, the anthropogenic carbon fluxes, which have become comparable in magnitude with the natural carbon fluxes in the global carbon cycle, have had a significant impact on global climate and ecological safety (Global Carbon Budget, 2014). In Malaysia, oil and gas industry is one of the top contributor for carbon dioxide emission according to US Department of Energy, Office of Science as shown in figure 6.

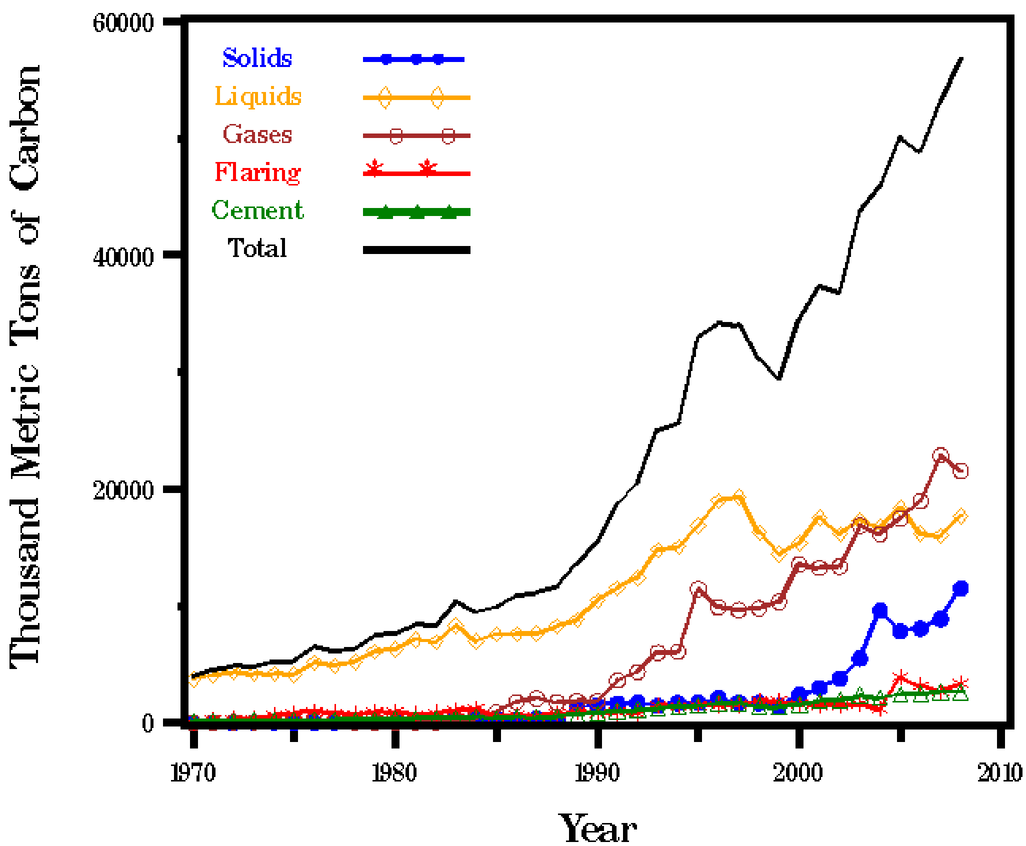


FIGURE 6: Graph Of Carbon Dioxide Emission In Malaysia

Figure 6 shows that the emissions of carbon dioxide are mainly due to the usage of fossils fuels. The refinery plant has a several level of processes. According to McIvaine Company, the most significant air emission sources in oil refineries are catalytic or thermal cracking unites, catalytic reformer units and fluid coking unites wastewater streams. Table 3 below shows the emission of gases from different refinery processes.

TABLE 3: Refinery Process Gas Emission For Carbon Monoxide

Refinery Process	**Emission Factor**
Catalytic cracking (Fluid bed)	13,700
Catalytic cracking (Moving bed)	3,800
Steam boiler, process furnace	5 lbs/1,000 gallon
Compressor engine (Reciprocating)	0.43 lbs/1000 cubic feet gas fuel
Compressor engine (Gas turbine)	0.12 lbs/1000 cubic feet gas fuel

An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant (Office of Air Quality Planning and Standards, 2015).

$$E = A \times EF \times (1 - ER/100) \quad \textbf{Eq. 1}$$

Where:

- E = emissions;
- A = activity rate;
- EF = emission factor, and
- ER =overall emission reduction efficiency, %

Equation 1 gives us the emissions of gases for different chemical process for chemical plant. From the equation 1, the higher emission factor will give larger emissions of gas by the process. Carbon monoxide is much more hazardous compared to carbon dioxide.

In Malaysia, under Environmental Quality Act 1974 [Act 127], carbon monoxide falls on Third Schedule – Noxious and Offensive Substance under Regulation 32 – Occupier to use best practicable means which states the occupier shall use the best means to prevent emission of those substance. Thus, it is compulsory to treat carbon monoxide before discharging to the atmosphere. One of the most common technique is by steam reforming or water-gas shift technique in which will produce hydrogen gas and carbon dioxide in the end. Equation 2 shows the process of steam reforming or water-gas shift which produce carbon dioxide and hydrogen gases in the end.

Steam reforming or water-gas shift: $\mathbf{CO + H_2O \rightarrow CO_2 + H_2}$ **Eq. 2**

The hydrogen gas will be used in petrochemical industry for the production of fertilizer while the carbon dioxide will be discharged into atmosphere.

2.2 Carbon monoxide

A poisonous colorless, odorless, tasteless gas. Carbon monoxide combines with hemoglobin to form carboxyhemoglobin, which has no oxygen carrying capacity(carbon monoxide | CO - PubChem, 2015). Carbon monoxide can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, it can cause death (US EPA, 2015). Table 4 shows the properties of carbon monoxide.

TABLE 4: Properties Of Carbon Monoxide

Properties of Carbon Monoxide	**Value**
Molecular Weight	28.01g/mol
Specific Gravity	0.97 at 21^{o}C
Density	1.14 kg/m^3
Stability	High

2.3 Carbon dioxide

Carbon dioxide is a slightly toxic, odorless, colorless gas with a slightly pungent, acid taste. Carbon dioxide is a small but important constituent of air. It is a necessary raw material for most plants, which remove carbon dioxide from air using the process of photosynthesis (Universal Industrial Gases, Inc, CO2 Carbon Dioxide Properties, Uses, Applications - Recovery from Industrial Sources, 2015). Carbon dioxide is denser compared to other gases which further encourage the process of air-sea interaction. Moreover, carbon dioxide is tend to be soluble in seawater. Table 5 shows the properties of carbon dioxide.

TABLE 5: Properties Of Carbon Dioxide

Properties of Carbon Dioxide	**Value**
Molecular Weight	44.01g/mol
Specific Gravity	1.53 at 21^{o}C
Density	1.98 kg/m^3
Stability	High

One of the properties of carbon dioxide is its heat capacity. It has the optimum specific heat capacity at 25^{o}C to 30^{o}C. Table 6 list down the specific heat capacity of carbon dioxide at different temperature.

TABLE 6: Specific Heat Capacity Of Carbon Dioxide At Different Temperature

Temperature, (^{o}C)	**Specific heat capacity, (10^3 J/kg K)**
-30	1.97
0	2.47
30	**36.4**

2.4 Air-sea interaction

Air-sea interaction is the exchanges of gases, of heat and of moisture or mass between the atmosphere and ocean are central to the dynamics of both fluids. Some factors affecting air-sea interaction according to Wanninkhof, wind speed variance, concentration gradient, chemical enhancement of carbon dioxide and the solubility of the gaseous in liquid. For this paper, the factor chosen would be the atmospheric temperature difference and the surface wind speed.

The calculation for the air sea flux can be done by using Fick's Law of Diffusion. The major component affecting the temperature difference would be by mass transfer thus the model used is Fick's law of diffusion which will cover mass transfer. Air sea interaction is a multiphase interaction between solid and fluid. The diffusion factors include atmospheric temperature, concentration gradient, wind speed, solubility of the component which is carbon dioxide for this case and the chemical composition in the aqueous. Equation 3 considered the factors of all of the above except for chemical composition.

$$\mathbf{N_A = k.s.\Delta C_A} \qquad \textbf{Eq. 3}$$

where,

N_A is mass transfer rate

k is the mass transfer coefficient

s is the solubility of the gases in liquid (Weiss, 1974)

C_A is concentration differences between two phases, gas and liquid

The value k is calculated using bulk formula. The k value takes the wind velocity vector into the consideration.

$$\mathbf{k = 0.27\, U^2 \,(660/S_c)^{0.5}} \qquad \textbf{Eq. 4}$$

Where,

U is the wind velocity at 2 meters

Sc is the Schmidt number (Wanninkhof, 1992)

Schmidt number having value of atmospheric temperature to be incorporate into the equation.

$$S_c = A - Bt + Ct^2 - Dt^3 \quad \textbf{Eq. 5}$$

t is the atmospheric temperature of near sea surface in degree Celsius around 8.5 m.

2.5 Critical Literature Review

Air sea interaction accounts for the interaction between two phases which are liquid and gases. Multiple researches and studies have been done on this topic due to its impact on global scale. The interaction can be occurred by the exchange of mass, heat, and momentum. There are 2 major approaches in obtaining air-sea flux which are direct and indirect method. Direct methods are done by sampling at the specific site while indirect methods are carried by scientific approach. Direct approach require researcher to get the data for the concentration of gases in both atmosphere at sea, temperature for the atmosphere above the sea surface and on surface of the sea, partial pressure difference and the near surface wind velocity which is usually around 2m. Only the selected points for sampling will be collected. Indirect approach will be using the results such as solubility of gases in seawater, the near surface wind velocity and concentration difference to get the air sea flux.

In China, the methane air-sea flux in the East China Sea during summer of 2013 has been carried out by using direct approach. The samples were collected using R/V "Dong Fang Hong 2". The water samples from the different depths were collected by using 12L Niskin bottles mounted to a Seabird 911 plus CTD Rosette. The depth collection for this study is around 2m. The temperature both for atmosphere and the ocean were taken. After 60 days, all the samples were retrieved. The analysis of the samples were done onshore. The methane gas concentration in the seawater was measured using a gas-stripping method and a GC-14B gas chromatograph. For the concentration of methane in the atmosphere, global mean atmospheric methane mixing ratio is used. The flux calculation were then calculated using basic formula.

For the indirect method, it requires bulk formula or by volume rendering to determine the air sea flux. Volume rendering will provides a view on spatio-temporal visualization of air-sea flux. The data will be getting from the pass researches or project such as global carbon budget. The bulk formula provide the value of air-sea flux depending on which factors that the study focus. The factors affecting include concentration of the gases, temperature differences between both phases, near surface wind velocity, atmospheric stability and partial pressure. The equation involved will be the variety of Fick's law of diffusion, Newton's law of cooling and Henry's law. It has a more accurate result as compared to volume rendering method.

Comparing both approaches, direct method requires much more manpower and money for the sampling and the analysis of collected sample. The direct approach is time consuming and the results can be affected due to human error during sampling thus less accurate. While collecting data, the faulty of the machine will render the data useless. If it was not noticed, the result shown will not be reliable. The gas stripping technique can be quite expensive and hardly available. The result is much easier to be analyzed and understood. It shows the relationship between the each factors affecting air-sea interaction which includes even depth profile.

Indirect approach costs less money and manpower but it requires lots of reading. Volume rendering method is only available for certain area due to limitation of data. The final data analysis using volume rendering proved to be quite a hassle due to its complexity. Bulk formula is limited to certain gases only. It cannot consider all the factors affecting air-sea flux in the equation thus limiting its reliability. Bulk formula uses handful of equation to get the air-sea flux. The improper usage of certain equation and constant can be lethal for the end result render the result useless. Bulk formula meanwhile is cheaper and much accurate compare to the other methods.

However, the study on this topic is quite lacking in Malaysia. The data for the carbon dioxide concentration is limited to selected few areas onshore. Moreover, some of the data is labeled private and confidential causing more complications for researchers to obtain the data. Thus, getting the carbon dioxide concentration through Petronas Technical Standard under carbon footprint would give its approximation.

CHAPTER 3

METHODOLOGY

3.1 Location of the site

The site chosen is Melaka Refinery Plant, which has an area of 926 acre, facing Malacca Strait at the coastal area. From the satellite view using Google Map, the area has very less of greenery. Thus, the assumption of carbon dioxide in the atmosphere through the time is the same without being taken in by plant. The Melaka Refinery Plant focused on petrochemical processes.

3.2 Air-sea flux

The approach used in this research is indirect approach utilizing Fick's law of diffusion bulk formula:

$$\mathbf{N_A = k.s.\Delta C_A} \qquad \textbf{Eq. 3}$$

where,

N_A is mass transfer rate

k is the mass transfer coefficient

s is the solubility of the gases in liquid (Weiss, 1974)

C_A is concentration differences between two phases, gas and liquid

The value k is calculated using bulk formula. The k value takes the wind velocity vector into the consideration.

$$\mathbf{k = 0.27\ U^2\ (660/S_c)^{0.5}} \qquad \textbf{Eq. 4}$$

Where,

U is the wind velocity at 2 meters

Sc is the Schmidt number (Wanninkhof, 1992)

Schmidt number having value of atmospheric temperature to be incorporate into the equation.

$$\mathbf{S_c = A - Bt + Ct^2 - Dt^3} \qquad \textbf{Eq. 5}$$

t is the atmospheric temperature of near sea surface in degree Celsius around 8.5 m.

The constant of A, B, C and D can be obtained from Rik Wanninkhof as in table 7.

TABLE 7: Value Of A,B,C And D Of Carbon Dioxide In Seawater

Gas	**A**	**B**	**C**	**D**
Seawater				
Carbon Dioxide	2073.1	125.62	3.6276	0.043219

The atmospheric temperature data was obtained from Malaysia Meteorological Department at latitude 2° 16' N and longitude 102° 15' E at the elevation of 8.5m in the year 2015. Monthly mean temperatures are selected for this paper.

According to Weiss (1974), the constant solubility of carbon dioxide in seawater can be affected by salinity of the aqueous solution. Table 8 shows the data for ocean temperature 22 °C and 24 °C at salinity of 35 ppt for seawater.

TABLE 8: Solubility Data Based On Temperature and Salinity

T(°C)	Salinity (%)								
	0	10	20	30	34	35	36	38	40
-1	-	-	7.273	6.903	6.760	6.724	6.689	6.620	6.551
0	7.758	7.364	6.990	6.635	6.498	6.465	6.431	6.364	6.298
1	7.458	7.081	6.723	6.382	6.251	6.219	6.187	6.123	6.060
2	7.174	6.813	6.469	6.143	6.017	5.986	5.955	5.894	5.833
3	6.905	6.558	6.229	5.916	5.795	5.766	5.736	5.677	5.619
4	6.650	6.317	6.001	5.701	5.585	5.557	5.528	5.472	5.416
5	6.408	6.088	5.785	5.497	5.386	5.358	5.331	5.277	5.223
6	6.178	5.871	5.580	5.303	5.196	5.170	5.144	5.092	5.040
8	5.751	5.469	5.200	4.945	4.846	4.822	4.797	4.749	4.702
10	5.366	5.105	4.857	4.621	4.529	4.507	4.485	4.440	4.396
12	5.017	4.776	4.546	4.327	4.243	4.222	4.201	4.160	4.119
14	4.700	4.477	4.264	4.062	3.983	3.964	3.945	3.906	3.869
16	4.412	4.205	4.008	3.820	3.747	3.729	3.712	3.676	3.641
18	4.149	3.958	3.775	3.600	3.533	3.516	3.499	3.466	3.434
20	3.910	3.732	3.562	3.400	3.337	3.322	3.306	3.275	3.245
22	3.691	3.526	3.368	3.217	3.158	3.144	3.130	3.101	3.073
24	3.491	3.337	3.190	3.050	2.995	2.982	2.968	2.942	2.915
26	3.307	3.164	3.027	2.897	2.846	2.833	2.821	2.796	2.771
28	3.138	3.005	2.878	2.756	2.709	2.697	2.685	2.662	2.639
30	2.983	2.859	2.741	2.627	2.583	2.572	2.561	2.540	2.518
32	2.840	2.725	2.615	2.509	2.468	2.457	2.447	2.427	2.407
34	2.708	2.601	2.498	2.400	2.361	2.352	2.342	2.323	2.305
36	2.587	2.487	2.391	2.299	2.263	2.254	2.246	2.228	2.211
38	2.474	2.382	2.292	2.207	2.173	2.254	2.246	2.228	2.124
40	2.370	2.284	2.201	2.121	2.090	2.082	2.074	2.059	2.044

Figure 7 summarizes all the steps involved for the completion of the project.

1
- Collecting data for atmospheric temperature and near surface wind velocity at Sungai Undan

2
- Calculating Schmidt's number by getting value A,B,C, and D from Wanninkhof Graph and atmospheric temperature obtained

3
- Calculating the value constant *k* using Schmidt's number and near surface wind velocity collected

4
- Determine the solubility of carbon dioxide diffuse into the ocean based on its salinity assumed at 35 ppt for South China Sea and for ocean temperature of 22 °C (Case 1) and 24 °C (Case 2)

5
- Assume that the concentration of anthropogenic carbon dioxide to be 26% in the ocean

6
- Calculate the air-sea flux value based on the Newton's Law of Diffusion equation

7
- Using graphical approach to get the graph for mean atmospheric daily temperature, near surface wind velocity and air-sea flux value against month

8
- Determine which factor is more likely to affect the air-sea interaction for both cases

FIGURE 7: Summary For Methodology

3.3 Data Analysis

For the paper, due to the ease of calculation, the data can be calculated using Microsoft Excel with graphical presentation. Figure 7 and 8 show the Microsoft Excel interface and its graphical function.

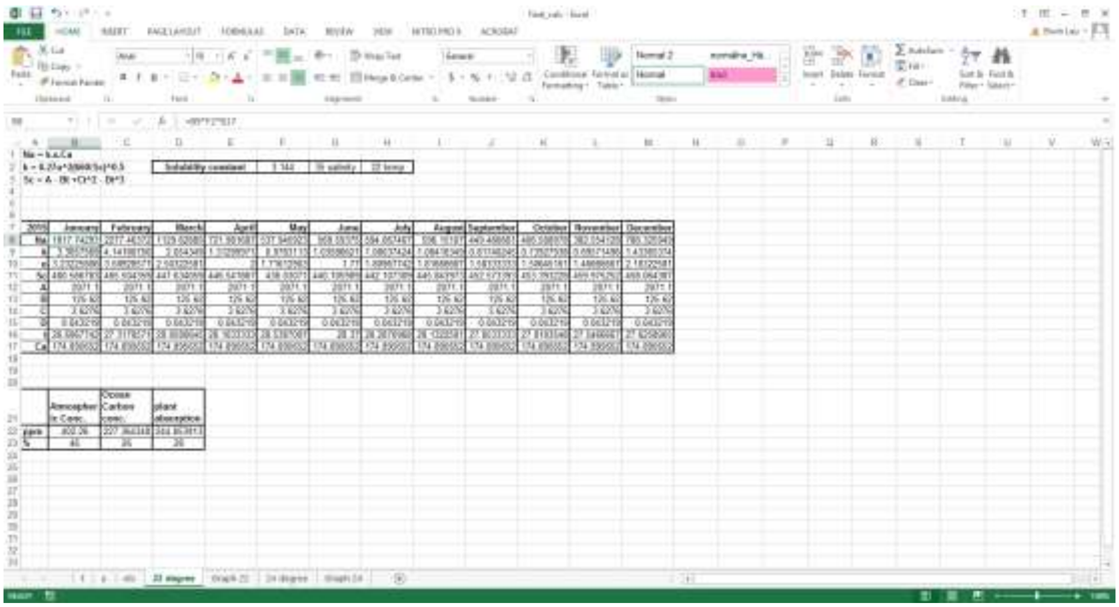


FIGURE 8: Micosoft Excel Interface

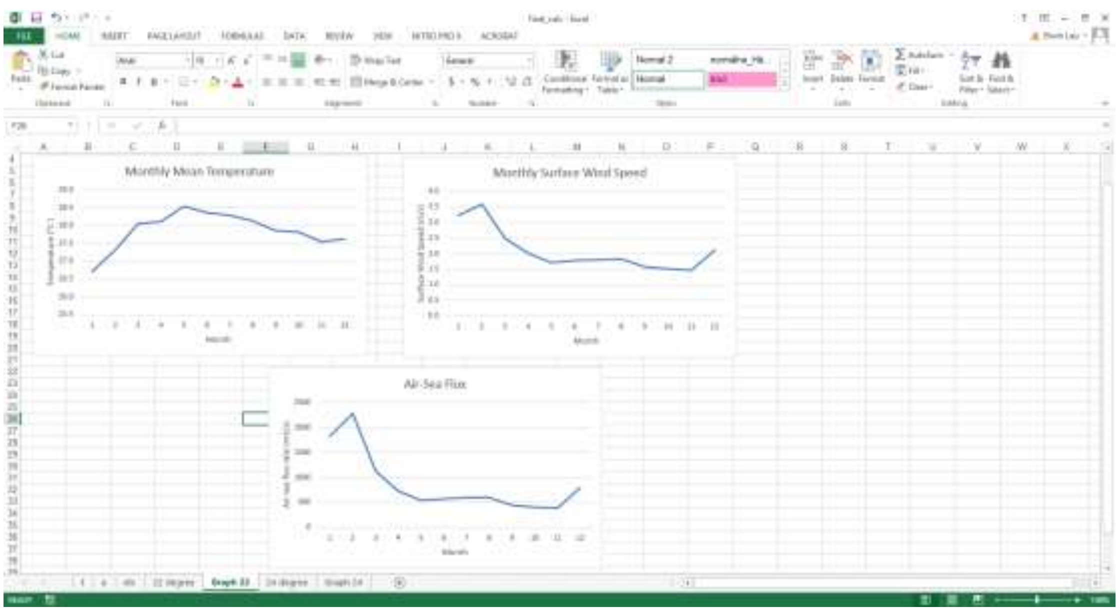


FIGURE 9: Microsoft Excel Graphical Function

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The analysis for air-sea interaction at the area of Melaka Refinery Plant set to be for the whole year round of year 2015. The data for mean daily atmospheric temperature and mean daily near surface wind velocity at the coordinates of 2° 16' N 102° 15' E at elevation of 8.5 meters. A total of 365 days of data are gathered to study the factors affecting air-sea interaction in the region of Straits of Malacca.

The data is analyzed based on monthly and presented with a time series line graph. There are 3 graphs that will be used. The atmospheric temperature against months, near surface wind velocity against month and air-sea flux against month. The result will then be compared to determine which factor, wind velocity or temperature affects air-sea flux at a greater rate based on equation 1.

Some assumptions are made for the calculation. First of all is the salinity of the ocean. The salinity of the ocean is generally 35 ppt. Second is the concentration of carbon dioxide in the atmosphere and ocean. The concentration of carbon dioxide in the atmosphere can be obtained from NASA which is at 402.26 ppm. Generally, 46% of anthropogenic carbon dioxide is maintained in the atmosphere, 28% is absorbed by the plant and 26% is diffuse into ocean which is at 227.36 ppm.

There are two categories of data. The first one assumed the ocean temperature to be at 22 °C and the other one would be at 24 °C. Both are compared to check the difference of the ocean temperature affecting the air-sea flux interaction.

4.2 Data Presentation for Both Cases

The data for collected for both temperature and near surface wind speed against month for the year 2015 are plotted in line graph as whon in figure 10 and 11.These graph will later be used to compare and determine which one of it is the dominant factor.

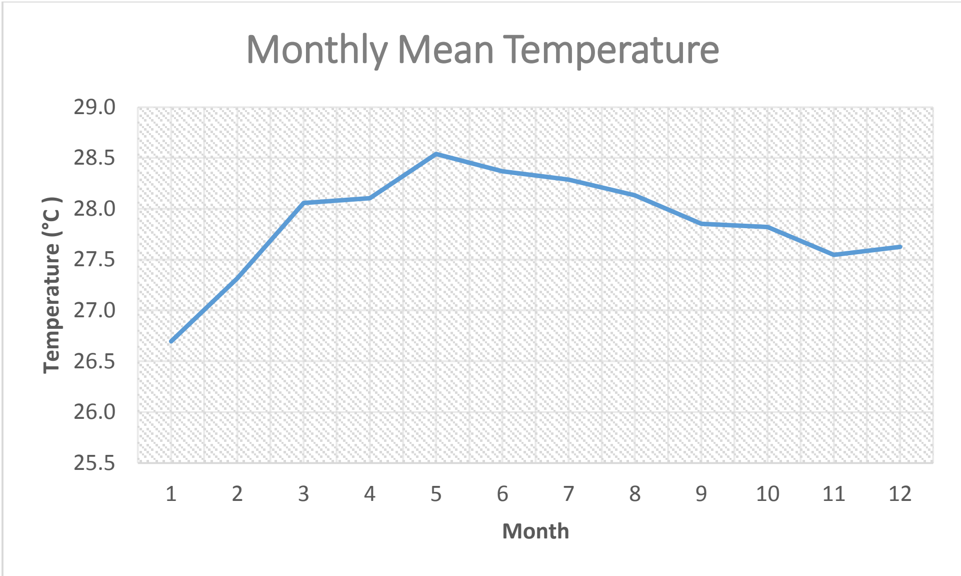


FIGURE 10: Graph Of Monthly Mean Temperature Against Month

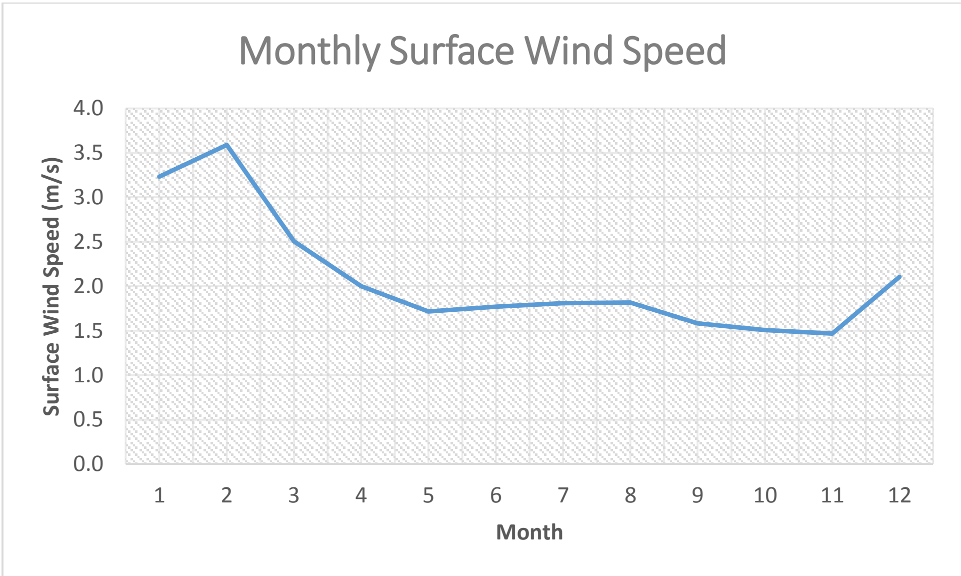


FIGURE 11: Graph Of Monthly Surface Wind Speed Against Month

The salinity of the seawater is assumed at 35 ppt at the studied region for both cases. Case 1 will have ocean temperature at 22 °C while case 2 will have ocean temperature at 24 °C. Using table 9, the solubility value for case 1 and 2 are 3.144 and 2.982 respectively. Table 9 shows the data of carbon dioxide solubility in seawater in all salinity and temperature.

TABLE 9: Table for Carbon Dioxide Solubility in Seawater

T(°C)	Salinity (%)								
	0	10	20	30	34	35	36	38	40
-1	-	-	7.273	6.903	6.760	6.724	6.689	6.620	6.551
0	7.758	7.364	6.990	6.635	6.498	6.465	6.431	6.364	6.298
1	7.458	7.081	6.723	6.382	6.251	6.219	6.187	6.123	6.060
2	7.174	6.813	6.469	6.143	6.017	5.986	5.955	5.894	5.833
3	6.905	6.558	6.229	5.916	5.795	5.766	5.736	5.677	5.619
4	6.650	6.317	6.001	5.701	5.585	5.557	5.528	5.472	5.416
5	6.408	6.088	5.785	5.497	5.386	5.358	5.331	5.277	5.223
6	6.178	5.871	5.580	5.303	5.196	5.170	5.144	5.092	5.040
8	5.751	5.469	5.200	4.945	4.846	4.822	4.797	4.749	4.702
10	5.366	5.105	4.857	4.621	4.529	4.507	4.485	4.440	4.396
12	5.017	4.776	4.546	4.327	4.243	4.222	4.201	4.160	4.119
14	4.700	4.477	4.264	4.062	3.983	3.964	3.945	3.906	3.869
16	4.412	4.205	4.008	3.820	3.747	3.729	3.712	3.676	3.641
18	4.149	3.958	3.775	3.600	3.533	3.516	3.499	3.466	3.434
20	3.910	3.732	3.562	3.400	3.337	3.322	3.306	3.275	3.245
22	3.691	3.526	3.368	3.217	3.158	3.144	3.130	3.101	3.073
24	3.491	3.337	3.190	3.050	2.995	2.982	2.968	2.942	2.915
26	3.307	3.164	3.027	2.897	2.846	2.833	2.821	2.796	2.771
28	3.138	3.005	2.878	2.756	2.709	2.697	2.685	2.662	2.639
30	2.983	2.859	2.741	2.627	2.583	2.572	2.561	2.540	2.518
32	2.840	2.725	2.615	2.509	2.468	2.457	2.447	2.427	2.407
34	2.708	2.601	2.498	2.400	2.361	2.352	2.342	2.323	2.305
36	2.587	2.487	2.391	2.299	2.263	2.254	2.246	2.228	2.211
38	2.474	2.382	2.292	2.207	2.173	2.254	2.246	2.228	2.124
40	2.370	2.284	2.201	2.121	2.090	2.082	2.074	2.059	2.044

According to NASA, carbon dioxide atmospheric concentration is at 402.26 ppm. It is assumed that 26 % of carbon dioxide undergoes air-sea flux interaction, and 28% are being absorbed by plants. Table 10 shows the concentration of carbon dioxide in ocean and plant absorption based on this assumption.

TABLE 10: Concentration of Carbon Dioxide

	Atmospheric Conc.	Ocean Carbon conc.	Plant absorption
ppm	402.26	227.36	244.85
%	46	26	28

Case 1 uses ocean temperature at 22 °C and thus different value of air-sea flux rate. The coefficient of value k is calculated using the formula:

$$\mathbf{k = 0.27\ U^2\ (660/S_c)^{0.5}} \qquad \textbf{Eq. 4}$$

Where,

U is the wind velocity at 2 meters

Sc is the Schmidt number (Wanninkhof, 1992)

Schmidt number having value of atmospheric temperature to be incorporate into the equation.

$$\mathbf{S_c = A - Bt + Ct^2 - Dt^3} \qquad \textbf{Eq. 5}$$

t is the atmospheric temperature of near sea surface in degree Celsius around 8.5 m.

Table 11 shows the result calculated using Microsoft Excel with appropriate data plugged in the spreadsheet. The value of A, B, C and D are obtained from table 12.

TABLE 11: Results Calculated for Coefficients, k and Air-Sea Flux, Na for Case 1

2015	January	February	March	April	May	June	July	August	September	October	November	December
Na	1817.74293	2277.46372	1129.62885	721.981687	537.945923	569.59375	594.067467	596.15107	449.466661	406.508978	382.554128	788.325949
k	3.3057569	4.14180756	2.054349	1.31299971	0.9783113	1.03586621	1.08037424	1.08416349	0.81740245	0.73927938	0.69571496	1.43365374
u	3.23225806	3.58928571	2.50322581	2	1.71612903	1.77	1.80967742	1.81666667	1.58333333	1.50645161	1.46666667	2.10322581
Sc	480.566783	465.504359	447.634059	446.541867	436.03071	440.105909	442.107309	445.843973	452.573393	453.393228	459.975252	458.064387
A	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1
B	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62
C	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276
D	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219
t	26.6967742	27.3178571	28.0580645	28.1033333	28.5387097	28.37	28.2870968	28.1322581	27.8533333	27.8193548	27.5466667	27.6258065
Ca	174.895652	174.895652	174.895652	174.895652	174.895652	174.895652	174.895652	174.895652	174.895652	174.895652	174.895652	174.895652

TABLE 12: Value of A, B, C, and D in Seawater and Freshwater

Gas	*A*	*B*	*C*	*D*
		Seawater		
He*	410.14	20.503	0.53175	0.0060111
Ne*	855.1	46.299	1.254	0.01449
Ar	1909.1	125.09	3.9012	0.048953
O_2	1953.4	128.00	3.9918	0.050091
CH_4^*	2039.2	120.31	3.4209	0.040437
CO_2^*	2073.1	125.62	3.6276	0.043219
N_2	2206.1	144.86	4.5413	0.056988
Kr*	2205.0	135.71	3.9549	0.047339
N_2O	2301.1	151.1	4.7364	0.059431
Rn*	3412.8	224.30	6.7954	0.08300
SF_6	3531.6	231.40	7.2168	0.090558
CCl_2F_2 (F-12)	3713.2	243.30	7.5879	0.095215
CCl_3F (F-11)	4039.8	264.70	8.2552	0.10359
		Fresh Water		
He*	377.09	19.154	0.50137	0.005669
Ne*	764	42.234	1.1581	0.013405
Ar	1759.7	117.37	3.6959	0.046527
O_2	1800.6	120.10	3.7818	0.047608
CH_4	1897.8	114.28	3.2902	0.039061
CO_2	1911.1	118.11	3.4527	0.041320
N_2^*	1970.7	131.45	4.1390	0.052106
Kr*	2032.7	127.55	3.7621	0.045236
N_2O^*	2055.6	137.11	4.3173	0.054350
Rn*	3146.1	210.48	6.4486	0.079135
SF_6	3255.3	217.13	6.8370	0.086070
CCl_2F_2 (F-12)	3422.7	228.30	7.1886	0.090496
CCl_3F (F-11)	3723.7	248.37	7.8208	0.098455

Case 2 uses ocean temperature at 24 °C. Table 13 shows the results calculated for mass transfer coefficient and air-sea flux value. The calculation method is the same with case 1.

TABLE 13: Results Calculated for Coefficients, k and Air-Sea Flux, Na for Case 2

2015	January	February	March	April	May	June	July	August	Septembe	October	Novembe	December
Na	1724.081	2160.113	1071.423	684.7803	510.2273	540.2445	563.4571	565.4334	426.3071	385.5629	362.8424	747.7061
k	3.305757	4.141808	2.054349	1.313	0.978311	1.035866	1.080374	1.084163	0.817402	0.739279	0.695715	1.433654
u	3.232258	3.589286	2.503226	2	1.716129	1.77	1.809677	1.816667	1.583333	1.506452	1.466667	2.103226
Sc	480.5668	465.5044	447.6341	446.5419	436.0307	440.1059	442.1073	445.844	452.5734	453.3932	459.9753	458.0644
A	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1	2071.1
B	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62	125.62
C	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276	3.6276
D	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219	0.043219
t	26.69677	27.31786	28.05806	28.10333	28.53871	28.37	28.2871	28.13226	27.85333	27.81935	27.54667	27.62581
Ca	174.8957	174.8957	174.8957	174.8957	174.8957	174.8957	174.8957	174.8957	174.8957	174.8957	174.8957	174.8957

The calculated result for air-sea flux case 1 and case 2 are presented in the graph in figure 12 and 13. Comparing both cases, case 2 has a lower rate of air-sea flux as compare to case 1. It is mainly due to ocean is approaching its ocean uptake limit for carbon dioxide.

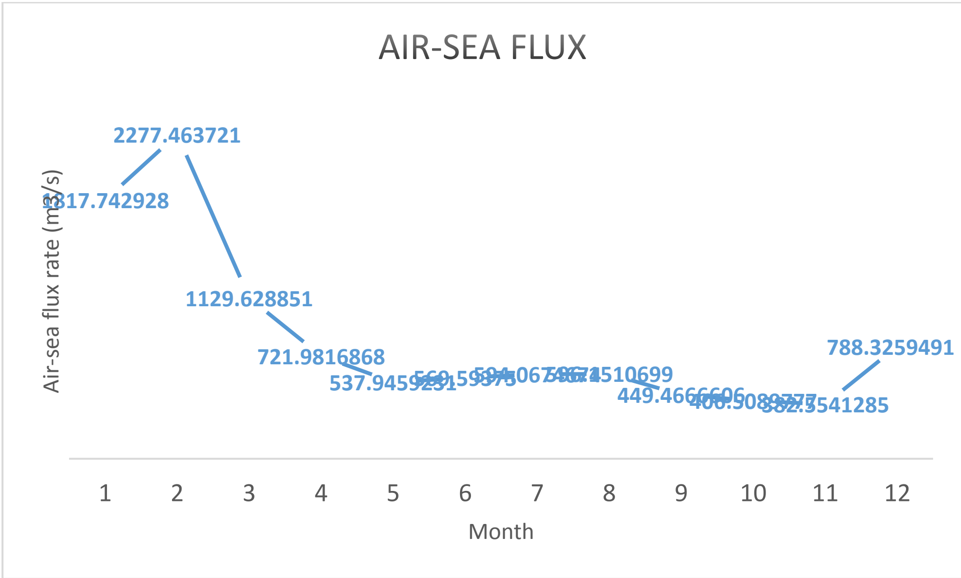


FIGURE 12: Air-Sea Flux Against Month For Case 1

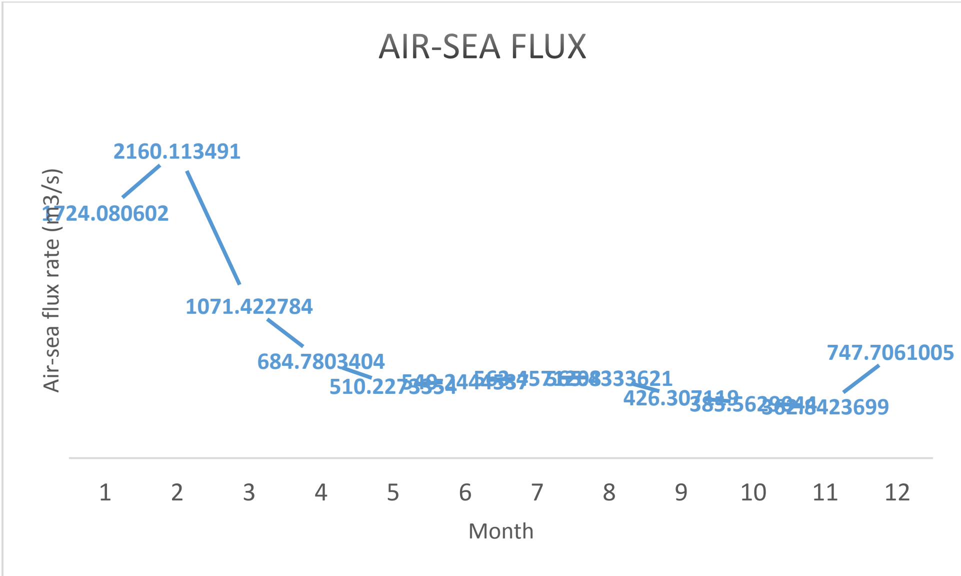


FIGURE 13: Air-Sea Flux Against Month Case 2

Figure 12 and 13 is then compared with the recorded data for near surface wind velocity and atmospheric temperature graph. It is clear that the graph pattern of air-sea flux is similar to the graph pattern of near surface wind velocity. Thus, the dominant factor for this region is near surface wind velocity.

4.3 Overall Discussion

For both cases, near surface wind velocity is the dominant factor affecting the air-sea interaction in the studied region. As the theory for heat transfer for multiphase, the transfer of heat is mainly via mass transfer instead of direct heat transfer. Thus, showing that with increased wind velocity, the rate of collision of carbon dioxide molecules with the ocean water increases and then increase the flux occurrence.

Comparing case 1 and case 2 for its air-sea flux value, case 2 which has 2 °C higher temperature than case 1, case 2 exhibits greater air-sea flux value. Showing that with higher ocean temperature do increase the effect of air-sea interaction for carbon dioxide. This is due to its stability.

For this study, the dominance factor affecting air –sea flux value is near surface wind velocity for carbon dioxide. There are cases where wind velocity effect is minor. For instance methane will have different factors affecting its air-sea interaction due to its volatility at different temperature. Another criteria would be location atmospheric pressure. Due to its stable pressure, main factor will probably be different.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The increase of concentration of greenhouse gases in the atmosphere due to human activities is a major problem currently especially for methane gas and carbon dioxide. Greenhouse gases has the properties of acting as a blanket to prevent heat from escaping from earth due to its high specific heat capacity. Moreover, carbon dioxide has an atmospheric lifetime more than 70 years which is a long period compared to other greenhouse gases. Furthermore, issues such as deforestation has further contribute to the increase of carbon dioxide concentration in the atmosphere. The result showed that the near surface wind speed is the major factor affecting the air-sea flux interaction for the studied region. Ocean areas usually have high intensity of wind as compared to land. Thus, air-sea flux interaction will always at high amount. Not to mention the increase of concentration of carbon dioxide, the temperature has been increase slowly and a global wide change it would melt the ice caps at North and South Pole. This will then lead to increase of mean sea level and thermocline which then cause loss of habitat of sea creatures and living things. When the carbon dioxide diffuse into ocean, carbon sink occurred which will then cause ocean acidification.

Based on the observation, with the higher ocean temperature, the solubility of carbon dioxide actually dropped which decrease the air-sea flux interaction. The main issue is that the prolong impacts on the ocean wildlife. The interaction rate may decrease but it is still continuous as long as there is still difference of concentration of carbon dioxide between atmosphere and ocean.

5.2 Recommendation

There are several recommendations to further enhance the results on this topic. First, the results can further be improved by study the air-sea flux interaction during night time and day time due to the difference of temperature and breeze at the ocean. Secondly, it would be better to obtain the carbon dioxide at specific location for ocean and atmosphere to achieve a much precise result. The equipment for carbon dioxide tracing can be quite pricy as well. Third, using different equation to obtain the air-sea flux value which include factor such as area, volume, time and calculate only anthropogenic carbon dioxide concentration would be very much better. Last but not least, study at different region and compared the result for each region would give new insight regarding air-sea flux interaction.

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APPENDICES

Temperature Data For Year 2015

Date	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
1	26.4	26.7	28.5	27.0	28.8	28.9	27.9	27.5	28.9	28.5	27.1	27.2
2	26.6	26.2	27.7	27.4	28.6	27.6	28.3	28.3	29.1	26.2	27.4	27.6
3	26.9	26.8	28.3	27.6	27.3	28.2	28.1	26.8	28.7	27.7	28.2	28.8
4	26.9	26.3	28.1	28.8	27.7	28.9	27.0	26.5	28.0	28.2	27.4	28.6
5	26.5	27.0	27.5	28.0	28.5	29.1	28.5	28.2	28.7	28.3	28.2	28.2
6	26.2	27.2	27.5	28.6	28.5	27.9	28.6	25.5	27.8	27.5	28.0	28.0
7	25.8	27.2	28.3	28.3	29.0	27.0	27.9	27.2	28.0	27.0	27.9	27.9
8	25.3	27.0	28.1	29.1	28.4	27.7	28.2	27.7	26.7	27.0	27.1	27.9
9	24.3	26.8	27.0	29.2	29.0	27.8	29.6	27.8	26.2	27.9	27.3	28.2
10	27.3	27.2	27.5	27.2	28.3	27.3	30.2	27.7	27.4	28.2	27.2	27.9
11	26.3	26.2	28.0	27.4	29.4	28.3	29.9	27.4	27.5	28.3	26.6	26.8
12	27.2	27.1	28.1	27.6	29.7	27.4	28.4	27.1	27.8	28.2	27.7	26.7
13	27.2	27.1	27.1	28.7	28.4	27.7	27.3	28.7	28.3	28.6	28.3	25.7
14	27.3	27.2	27.9	28.3	28.4	26.8	28.0	29.1	27.7	28.6	27.9	27.5
15	26.9	27.6	28.4	28.6	28.9	27.9	28.8	29.3	27.6	28.6	27.4	28.0
16	26.4	28.2	27.8	29.2	29.2	27.3	28.9	28.4	28.1	28.5	26.1	27.6
17	26.3	27.3	28.6	29.1	28.0	28.2	27.9	28.4	26.0	28.3	27.4	27.0
18	26.6	27.2	28.6	29.0	28.0	28.1	28.9	29.1	27.7	28.6	28.6	27.8
19	26.7	26.2	28.8	29.1	28.6	28.7	28.5	29.0	27.8	28.7	28.9	28.3
20	26.4	27.5	28.4	29.3	27.7	29.0	28.6	28.6	27.7	27.7	26.8	27.1
21	26.9	27.5	28.7	28.8	28.7	29.5	27.1	29.5	28.4	28.1	27.1	27.0
22	26.8	27.8	28.0	28.0	28.3	29.4	28.2	29.6	28.6	28.5	28.0	28.5
23	27.0	27.9	28.3	26.7	27.2	28.6	28.8	28.1	27.2	29.1	28.9	29.2
24	26.6	27.9	28.4	27.4	28.5	29.0	28.5	27.6	27.9	26.9	27.5	27.3
25	26.9	28.4	28.7	27.4	28.6	29.3	28.5	27.5	27.9	28.5	27.2	27.8
26	27.3	28.3	29.2	26.9	28.4	29.3	26.8	27.3	28.2	27.0	26.3	28.5
27	26.9	28.5	29.3	26.4	28.1	29.2	27.7	28.2	27.4	26.9	27.2	28.3
28	27.6	28.6	27.5	27.2	28.4	29.1	28.1	29.2	28.0	25.8	27.7	26.1
29	27.1		27.1	28.7	29.4	29.1	28.3	29.2	28.6	27.6	27.2	27.2
30	27.4		27.5	28.1	29.4	28.8	28.5	29.1	27.7	27.0	27.8	27.8
31	27.6		26.9		29.3		26.9	28.5		26.4		25.9
Mean	**26.7**	**27.3**	**28.1**	**28.1**	**28.5**	**28.4**	**28.3**	**28.1**	**27.9**	**27.8**	**27.5**	**27.6**

Near Surface Wind Speed Data For The Year 2015

Date	**Month**											
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1	3.5	4.2	2.8	2.0	1.7	1.5	1.2	2.0	2.4	1.4	1.8	1.3
2	3.5	4.3	2.8	1.9	2.1	1.6	1.3	1.9	2.6	1.2	1.7	1.1
3	1.9	3.9	2.4	1.5	1.3	1.4	1.4	1.8	2.6	1.4	1.8	2.6
4	1.7	3.9	2.2	1.7	1.4	2.1	1.5	1.3	1.9	1.9	1.1	1.7
5	1.3	4.7	2.4	2.1	1.5	1.8	1.5	Def.	2.0	1.4	1.5	2.2
6	1.7	4.6	1.9	1.5	1.4	1.3	1.6	1.2	1.2	1.5	1.9	2.8
7	1.8	4.9	2.6	2.7	1.8	1.4	1.3	1.5	1.3	1.4	1.6	2.4
8	2.3	5.1	1.8	2.7	1.8	1.3	1.4	1.6	1.2	1.2	1.0	1.6
9	2.1	5.2	2.6	3.4	1.6	1.7	1.7	1.5	1.2	1.3	0.7	1.8
10	2.5	4.4	2.1	2.3	1.5	1.1	2.0	1.8	1.2	1.3	1.5	1.6
11	2.6	3.1	2.1	1.9	1.9	1.5	2.1	1.5	1.6	1.6	1.5	1.4
12	4.1	3.4	2.8	1.8	2.0	1.3	1.5	1.3	2.2	1.4	1.3	1.2
13	5.0	3.5	3.5	2.3	1.6	1.5	1.1	1.8	1.3	1.7	1.4	1.3
14	4.7	2.9	2.9	Def.	1.7	1.3	1.5	1.6	1.3	1.7	1.8	1.5
15	4.1	3.3	2.8	2.6	1.6	1.5	1.7	1.9	1.5	1.4	1.1	1.0
16	3.4	3.5	1.9	2.7	2.3	1.8	2.4	2.2	1.9	1.3	1.3	1.5
17	3.3	3.2	2.1	2.7	1.4	1.9	1.6	1.7	1.6	1.2	1.1	2.9
18	3.8	2.9	2.0	1.3	1.5	1.9	2.6	2.1	2.0	1.3	1.8	2.9
19	3.9	2.4	2.1	2.0	1.6	2.7	1.9	1.6	1.7	1.3	1.7	2.8
20	4.2	3.6	1.5	1.6	1.3	1.9	2.5	1.7	1.7	1.0	1.3	1.5
21	3.9	3.5	2.0	2.2	1.5	1.8	1.6	2.3	1.2	1.7	1.0	1.1
22	3.8	3.1	1.6	2.0	1.7	1.8	2.5	1.6	1.6	1.6	1.4	1.7
23	3.9	3.0	2.1	1.4	1.2	1.8	2.3	1.6	1.5	2.1	1.4	1.8
24	3.0	2.7	3.2	1.3	1.5	1.9	2.0	2.1	1.0	1.4	1.3	1.6
25	3.1	2.4	3.8	Def.	1.6	2.2	1.8	1.6	1.4	2.0	1.4	2.9
26	3.8	2.4	4.3	Def.	1.5	2.3	1.8	1.6	1.2	1.7	1.2	3.9
27	2.9	3.3	3.8	Def.	2.4	2.8	1.8	2.0	1.2	1.4	2.0	3.5
28	2.8	3.1	2.9	1.6	1.7	2.6	2.6	2.5	1.1	1.4	2.2	2.5
29	3.9		2.7	1.2	2.4	1.9	2.3	2.3	1.3	1.7	1.8	3.3
30	3.3		2.2	1.6	2.7	1.5	2.1	2.4	1.6	1.8	1.4	3.5
31	4.4		1.7		2.0		1.5	2.5		2.0		2.3
Mean	**3.2**	**3.6**	**2.5**	**2.0**	**1.7**	**1.8**	**1.8**	**1.8**	**1.6**	**1.5**	**1.5**	**2.1**

Solubility of Carbon Dioxide In Seawater At Different Temperature And Salinity Of Seawater

T(°C)	Salinity (%)								
	0	10	20	30	34	35	36	38	40
-1	-	-	7.273	6.903	6.760	6.724	6.689	6.620	6.551
0	7.758	7.364	6.990	6.635	6.498	6.465	6.431	6.364	6.298
1	7.458	7.081	6.723	6.382	6.251	6.219	6.187	6.123	6.060
2	7.174	6.813	6.469	6.143	6.017	5.986	5.955	5.894	5.833
3	6.905	6.558	6.229	5.916	5.795	5.766	5.736	5.677	5.619
4	6.650	6.317	6.001	5.701	5.585	5.557	5.528	5.472	5.416
5	6.408	6.088	5.785	5.497	5.386	5.358	5.331	5.277	5.223
6	6.178	5.871	5.580	5.303	5.196	5.170	5.144	5.092	5.040
8	5.751	5.469	5.200	4.945	4.846	4.822	4.797	4.749	4.702
10	5.366	5.105	4.857	4.621	4.529	4.507	4.485	4.440	4.396
12	5.017	4.776	4.546	4.327	4.243	4.222	4.201	4.160	4.119
14	4.700	4.477	4.264	4.062	3.983	3.964	3.945	3.906	3.869
16	4.412	4.205	4.008	3.820	3.747	3.729	3.712	3.676	3.641
18	4.149	3.958	3.775	3.600	3.533	3.516	3.499	3.466	3.434
20	3.910	3.732	3.562	3.400	3.337	3.322	3.306	3.275	3.245
22	3.691	3.526	3.368	3.217	3.158	3.144	3.130	3.101	3.073
24	3.491	3.337	3.190	3.050	2.995	2.982	2.968	2.942	2.915
26	3.307	3.164	3.027	2.897	2.846	2.833	2.821	2.796	2.771
28	3.138	3.005	2.878	2.756	2.709	2.697	2.685	2.662	2.639
30	2.983	2.859	2.741	2.627	2.583	2.572	2.561	2.540	2.518
32	2.840	2.725	2.615	2.509	2.468	2.457	2.447	2.427	2.407
34	2.708	2.601	2.498	2.400	2.361	2.352	2.342	2.323	2.305
36	2.587	2.487	2.391	2.299	2.263	2.254	2.246	2.228	2.211
38	2.474	2.382	2.292	2.207	2.173	2.254	2.246	2.228	2.124
40	2.370	2.284	2.201	2.121	2.090	2.082	2.074	2.059	2.044