Environmental impact assessment of offshore flares in "Sonda de Campeche", Mexico

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ABSTRACT

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An Environmental Impact Assessment of offshore flares located in "Sonda de Campeche", Mexico was performed to evaluate their effect on the regions adjoining offshore development. Air and water contamination besides solid wastes are considered to be the main pollutants. A comparative analysis of the laws pertaining to offshore industry in Mexico, Canada, and United States is addressed.

As a result of this study, it was found that there was no significant impact from water pollutants or waste management residues during the installation or production phases of the flares, due to offshore development in the concerned areas. Moreover, for air pollution, four air contaminants (NO_2, CO, CO_2, and CH_4) were found to comply with environmental laws (Mexican, and International). On the contrary, three other air pollutants (SO_2, H_2S, and PM_{10}) do not comply with the standards. Therefore, three actions are recommended to be implemented in the following order. First, chemical absorption is suggested to remove NO_X, SO_2, and H_2S. Following this, the height of flare is to be increased by 15 meters. Finally, a Floating Storage Re-gasification Unit is to be installed in a relatively isolated region. The last action ensures a drastic reduction of air pollution and provides a reservoir for natural gas. The natural gas can be purchased by a private company or can be utilized by the Mexican Industry.

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A mis padres, hermana y hermanos

To Paul Latour and my friends

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List of abbreviations

ARPEL	Reciprocal Assistance for Latin American Oil Companies
BOD	Biological Oxygen Demand
CAPP	Canadian Association of Petroleum Producers
CFPSO	Concrete Floating Production, Storage and Offloading
CSLC	California State Lands Commission
DVM	Digital voltmeter
EI	Emission Inventory
EPA	Environmental Protection Agency
ERG	Emergency Response Guidebook
ESD	Emergency shutdown system
FGD	Flue Gas desulphurization
FIC	Factor Importance Coefficient
FPSO	Floating Production Storage and Offloading
FSRU	Floating Storage and Re-gasification Unit
FTIR	Fourier Transform Infrared spectrometer
GBS	Gravity Based Structure
GHG	Greenhouse gas
GM	Gas analyzer
HAZID	Hazard Identification
HAZOP	Hazard and Operability Studies
HC	Hydrocarbons
IMSS	Mexican Social Insurance Institute
INE	National Institute of Environment
INEGI	National Institute of Geography, Statistic, and Database
ISSSTE	Social Insurance and Services for Government Workers Institute
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LST	Local Standard Time

mb	Millibar
MMS	Mineral Management Service
MOST	Mobil Oil SOX Treatment
NAAQO	National Ambient Air Quality Objectives
NCEP	National Centers for Environmental Prediction
NEMR	Northeast Marine Region
NOM	Mexican Official Norm
NPDES	National Pollutant Discharge Elimination System
OCS	Outer continental shelf
OM	Ozone monitor
OSHA	Occupational Safety & Health Administration
PAH	Polycyclic Aromatic Hydrocarbon
PEMEX	Mexican Petroleum
PEP	PEMEX Exploration and Production
POM	Princeton Ocean Mode
PROFEPA	Federal Environmental Protection Agency
QRA	Quantitative Risk Analysis
RAMS	Regional Atmospheric Modeling System
SCT	Secretary of Transportation and Communications
SDC	Sonda de Campeche
SEDENA	National Defense Secretary
SEMARNAP	Secretariat of the Environment, Natural Resources and Fisheries
SWMR	Southwest Marine Region
TCEQ	Texas Commission on Environmental Quality
U.S. EPA	United States Environmental Protection Agency
UNAM	National Autonomous University of Mexico
UPMP	Unit of drilling and maintenance for wells
VOC	Volatile Organic Compounds
wESP	wet Electrostatic Precipitator

Chapter One
Introduction and background

1.1 Background

In Mexico, the offshore exploration of hydrocarbons started in 1958 with the installation of a steel offshore platform in the Barra de Santa Ana, in front of Tabasco's shore. In 1975, the first exploratory well was drilled, which was called Chuc-1, at 80 km north of the Carmen Island, Campeche. Later on, the Cantarell's field was discovered in 1977. With the drilling of the wells Akal-1 and Bacab-1, the other two oil fields were opened. By 1979 the "Sonda de Campeche" was already producing oil. It was integrated with production complex Akal-C that consisted of a drilling offshore platform, a linkage offshore platform, and a production offshore platform. Later on, a compression gas platform, and two production platforms and a living quarters platform were installed. By 1980 in the "Sonda de Campeche", 12 production fields had been discovered: Akal, Nohoch, Abkatum, Maloob, Ku, Ixtoc, Kutz, Bacab, Pool, Kanuac, Chuc, and Ek.

Akal field contributes about 90% of current Cantarell oil production. Akal was discovered in 1977 and began their initial production in 1979. Chuc field with less than 4% of Cantarell production was discovered in 1976. However it did not begin producing oil until 1991. Kutz has not yet commenced production. Nohoch, with 5% of the complex's production was discovered in 1978 and began production in 1979.

In 1996, Mexico was extracting oil from over 14 offshore oil fields composing over 330 wells and over 90 onshore fields composing over 3,300 wells to produce an average of 2.961 million b/d of crude oil. Offshore fields are the most productive fields in Mexico. Production from oil fields in the south of the country generally exceeds those in the north. About three-fourths of Mexico's crude oil production comes from offshore sites in the "Sonda de Campeche" (Gulf of Mexico).

In 2002, Pemex started with 185 offshore platforms, 4 590 wells in production, 309 fields in production, a storage capacity of 26.8 millions of oil barrels, and around 12 000 kilometers of pipelines for oil and gas.

Oil is produced in Mexico in the following way. First-stage gas-oil separation is performed at wellhead platforms and the crude is stabilized at three production complexes. It is transported via pipelines to three offshore tanker berths at Cayo Arcas and to storage tanks at Dos Bocas, where part of the production is exported via two offshore berths and the balance is transported inland by pipeline.

Petroleos Mexicanos (Pemex), the state oil company, is the world's fifth largest oil company, the single most important entity in the Mexican economy. It is considered to be the symbol of Mexican sovereignty and independence. Unlike many other major global oil companies, Pemex retains exclusive rights to oil exploration and production in Mexico.

Pemex exploration and production department (PEP) is responsible for the exploration, and exploitation of the Mexican oil and natural gas, as well as, the transportation, storage and sale of both products. PEP divides their activities in four geographical regions that cover the national territory: North, South, Northeast marine region, and Southwest marine region.

1.2 Problem description

The "Sonda de Campeche" is located in front of the coast of Tabasco and Campeche, and represents approximately 80 % of the national production extracted from the offshore wells. The two main industries in this southwest portion of the Gulf of Mexico are the oil production and the shrimp fishery. Both have shared the same area since 1976.

As in any other industry, the oil extraction in the "Sonda de Campeche" has been the source of pollution during all these years. The flares, the discharges to water, the cutting material from drilling activities and crude oil spills have been the causes of contamination. From these four sources, the flares contribute about 82 % of all pollutants discharged into the vicinity in this region. It has been determined from a chemical analysis of the polluted gas dispersed in the air by flares, that unburned hydrocarbons (HC), nitrogen oxides (NO_X), sulfur dioxide (SO_2), carbon monoxide (CO), hydrogen sulfide (H_2S), and particulate matter are the major components.

Actually three different types of offshore flares are utilized worldwide (elevated, boom or ground level flare). In the case of Mexican offshore development, only elevated platforms, and boom flares are used. According to data from the manufacturers of flares, some vertical flares operate at high flow (4.2×10^6 m^3/day) other in low flow (9.1 to 24×10^5 m^3/day). Other platforms have boom flares, for which the average rate is 2.3×10^5 m^3/day (Santiago, 2002). The values mentioned do not include the special circumstances, during which enormous quantities of natural gas are burned in the flare.

In addition to increasing the problem of air pollution offshore, equipment used routinely such as diesel powered pumps; compressors and generators contribute to emissions of volatile organic compounds (VOC), NO_X, and SO_2 in the "Sonda de Campeche". This region is affected annually by 658, 935 tons of air pollutants (figure 1.1). The biggest source is located in the northeastern area of the "Sonda de Campeche". In that area, the platforms of Cantarell field are responsible for 79 % of the sulfur oxides, 77% of the hydrocarbons, 63 % of the carbon monoxide, 62 % of the particle matter with less than 10 μm, and 21 % of the nitrogen oxides of the air pollution emissions. The following table provides more detailed information about air pollution emissions from Northeast, and Southwest marine regions.

Recall that shrimp fishery has shared the same space as the oil industry in the "Sonda de Campeche". However the former has been affected by the latter with the increase in the number of platforms and pipelines. This has caused local fisheries, and mainly the commercial shrimp fisheries, to lose production during the last two decades. So far, it has not been possible to determine the reason for this decline. It could be a combination of over fishing, habitat destruction, and oil pollution.

Region	Oil field	NO_x		SO_x		H_2S		CO		NMCH		PM_{10}		Total[a]	
		Thousands ton/year	$\%NO_x$	Thousands ton/year	$\% SO_x$	Thousands ton/year	$\% H_2S$	Thousands ton/year	% CO	Thousands ton/year	% NMCH	Thousands ton/year	$\% PM_{10}$	Thousands ton/year	% Total
Northeastern marine region	Cantarell	8.795	21.37	138.657	76.60	0.876	79.62	91.924	63.18	214.083	77.33	8.881	61.54	462.340	70.16
	Ku-Malloob-Zaap	1.371	3.33	25.655	14.17	0.142	12.94	12.858	8.84	34.660	12.52	1.351	9.36	75.896	11.52
	Ek-Balam	0.055	0.13	0.008	0.00	0.001	0.08	0.310	0.21	0.256	0.09	0.030	0.21	0.658	0.10
	Atasta	0.602	1.46	1.393	0.077	0.008	0.74	8.377	5.76	2.634	0.95	0.788	5.46	13.794	2.09
	Cayo Arcas & Repumping Station	8.286	20.13	0.132	0.07	0.000	0.00	2.201	1.51	0.246	0.09	0.260	1.80	11.126	1.69
	Total Nrtheastern Region	19.109	46.43	165.845	91.63	1.028	93.38	115.670	79.50	251.879	90.98	11.31	78.38	563.81	85.56
Southwestern marine region	Pool-Chuc	1.098	2.67	7.014	3.88	0.053	4.77	8.213	5.64	12.967	4.68	0.788	5.46	30.081	4.57
	Dos Bocas	12.326	29.95	0.799	0.44	0.004	0.41	4.365	3.00	6.086	2.20	0.485	3.36	24.060	3.65
	Abkatum	2.325	5.65	2.435	1.35	0.016	1.44	16.270	11.18	5.119	1.85	1.541	10.68	27.690	4.20
	Total Southwest Region	15.748	38.26	10.249	5.662	0.073	6.62	28.848	19.83	24.171	8.73	2814	19.50	81.831	12.42
All	Marine and aerial traffic	6.032	14.66	4.905	2.71	0.000	0.00	0.917	0.63	0.767	0.28	0.297	2.06	12.917	1.96
All	Perforation	0.268	0.65	0.004	0.00	0.000	0.00	0.070	0.05	0.020	0.01	0.009	0.06	0.373	0.06
Grand total		41.158	100.000	181.002	100.00	1.101	100.00	145.505	100.00	276.839	100.00	14.431	100.00	658.935	100.00

Fig. 1.1 Air pollutants emission of the offshore and coastal installations of the extraction and production oil company in "Sonda de Campeche" (I)

1.3 Objectives and scope of the study

The aim of this study is to plan, conduct and support the findings of an Environmental Impact Assessment of offshore flares in “Sonda de Campeche”, Mexico and achieve the following objectives.

1. Examine whether or not the water contamination, and solid waste generated during the installation and operation of offshore flares comply with Mexican and International Environmental Regulations
2. Determine whether each emission (CO, CO_2, Particulate Matter, SO_2, NO_X, PAH, H_2S, and other hazardous contaminants) comply with applicable limits according to Mexican Environmental Regulations. Also, compare those emissions with Canadian, and USA environmental regulations, as to determine the significance impacts of there.
3. Evaluate the negative environmental effects caused by pollutants (air, water, solid waste) in the “Sonda de Campeche”, and areas close to the offshore platforms.
4. Interpret and evaluate the potential impacts that have been provoked by the flares in the “Sonda de Campeche” and its surrounding areas.
5. Present alternatives to resolve detrimental conditions actually experienced in the “Sonda de Campeche”, Mexico.
6. Use a decision making process to determine the optimum alternative applicable to the problem of environmental impact caused by the activities of offshore development.

This project will be based on information collected from Pemex, Mexican government, research institutions familiar with the problem, University publications and other sources such as internet, books, and newspapers. Furthermore, this investigation will be complemented by professional experiences of the thesis author in the “Sonda de Campeche”, and the oil industry in Mexico during the last twenty five years.

The scope of the air environmental impact assessment will be to evaluate the air discharges from the offshore platforms located on the Northeast, and Southwest marine regions in the "Sonda de Campeche". The boundaries are set as is described next, for air emissions in the area of influence on "Sonda de Campeche", which covers Northeast marine region (Cantarell, Ek-Balam, Ku-Maloob-Zaap, and Marina Noreste), and Southwest Marine Region (Abkatun, Pol_Chuc, Litoral de Tabasco, Litoral, and Campeche-Golfo de Mexico).

1.4 Methodology to achieve goals

The procedure proposed to develop this project is based on the directions suggested in the text Environmental Impact Assessment by Larry W. Canter (1996). According to Canter (1996) there are six main steps for Air Environmental Impact Studies which are as follows:

Step 1: "Identification of the types and quantities or air pollutants and their impacts"
Step 2: "Description of existing air quality conditions"
Step 3: "Procurement of Relevant air quality standards and regulations"
Step 4: "Impact Prediction"
Step 5: "Assessment of impact significance"
Step 6: "Identification and incorporation of mitigation measures"

1.5 Preliminary work

Pemex is the sole industry administrating the extraction of crude oil in Mexico. It has been the subject of numerous studies. While researchers have made visible efforts to cover Pemex from possible diverse perspectives, no complete systematic air environmental impact assessment in the "Sonda de Campeche" has been published for the general public in Mexico. It is possible that Pemex has requested a similar type of study from a private company. However, no document in the public domain is available to address this environmental impact of this offshore development.

There are a few documents (thesis, research reports, investigations, and books); with Pemex as the object of study. These studies constitute the standing point of the present research. In the following section, a short description of selected studies will be presented to give an overall appreciation of the publications that have dealt with this topic.

Rafael Villasenor (2002) an investigator from Mexican Petroleum Institute, has published "An air quality emission inventory of offshore operations for the exploration and production of petroleum by the Mexican oil industry". His main goal with this investigation was to create an inventory of emissions from flares, processes, internal combustion engines and fugitive emissions provoked by the offshore platforms in the "Sonda de Campeche". In his study, he used a software named CALPUFF to generate a meteorological wind and a temperature model, with the purpose of analyzing the transportation and dispersion of pollutants, especially SO_2. His short report contains very useful data. Some of his tables are shown in the following sections. Moreover, Leon (2001) of the Universidad National Autonoma de Mexico wrote her thesis about: "Emission inventory of oil atmospheric activities on the Sonda de Campeche (Case of study: Compression Platforms)". She describes each type of offshore platform utilized in Mexico, and the pollutant emitted. Following this, the compression platforms and the air pollutant are described. It is noted, however, that her results are based on tabulated data derived from North American sources. Since her studies are based on North American sources rather than in situ measurements, her conclusions may not fully represent the reality of the "Sonda de Campeche".

A thesis entitled: "Operative parameters during the process to remove water from sour gas in offshore platforms (Sonda de Campeche)", was written by Garcia (2003) of the Universidad Nacional Autonoma de Mexico. He made a good description of the natural gas in Mexico, its extraction, processes, production and management by Pemex. In one of his last chapters he narrates the actual process utilized by Mexicans to remove water from sour gas. This investigation contains important data related to Mexican natural gas, which is burned by offshore flares. Consequently this is one of the major causes of pollution in the area.

The Secretariat of the Environment, Natural Resources and Fisheries ("Secretaria del Medio Ambiente, Recursos Naturales y Pesca"-SEMARNAP) is the main environmental authority in Mexico. This secretariat works with two agencies responsible for air pollution control: a National Institute of Environment (INE) and the Federal Environmental Protection Agency (PROFEPA). This last agency has been performing environmental audits and assessments to Pemex in recent years. In January 2000, PROFEPA announced that according to the first environmental assessment of Pemex practices, the overall "Petroleos Mexicanos" obtained 11.2 points from a range between 1 and 100 to be in compliance with environmental regulations. PROFEPA clarified that the score was based upon an evaluation done to 40 minor installations belonging to Pemex. This means that refineries were not included in the assessment. Following the declaration of Antonio Azuela (law attorney for environment Mexico), until that year from a total of 250 Mexican refineries, 70 had already been certified to be of excellent environmental quality, and the rest were in the process of obtaining such certification.

1.6 Value of results

The purpose of this study is to find a realistic solution to the conflicting circumstances present in "Sonda de Campeche" for many years. This final proposal must bring benefits for all the sectors involved with the problem.

Pemex could obtain a report about their air pollution emissions, which would be accessed by all and at the same time, should serve as a viable solution to their air discharges. Moreover, the public opinion could change their perception about "Petroleos Mexicanos", which is viewed to be a monopoly that is concerned with daily production without taking care of the impact on the environment.

For PROFEPA, the results obtained from here could be used as general guidelines to continue planning their environmental audits for the Pemex offshore platforms, because they will be able to evaluate which of these structures require immediate attention, and which are in better conditions.

Chapter Two
Identification of the types and quantities of pollutants and their impacts

During the oil production process, there are some risky events that might threaten the stability and security of the offshore platforms, the environment and personnel involved. To minimize this possibility, security systems have been implemented. For example, ESD (emergency shutdown system), personnel safety system, safety process system, gas and fire system, relief system, are used to offset the dangers posed.

A flare is part of the relief system. It is defined as an equipment built to convert the mass of fluid relieved, generally toxic and flammable through combustion, to substances less harmful. For offshore flares, their main purpose is to burn sour gas in situations caused by shutdown of equipment, overpressure in gas headers, and shutdown of a platform. These offshore structures have safety procedures to evacuate big quantities of released gas. They are built high and far away from the platform in order that their flame and heat do not injure personnel in the working areas, or damage other equipment. Moreover, these gases could contain toxic concentrations, which are dispersed in the air through flares. This flaring system operates 365 days per year, and is designed to handle intermittent gas flows and to work with a low level of noise. It has an electronic starting device.

2.1 Flare package

A flare package includes a flare tower support jacket, and a flare tower both in the shape of a triangular column. One or two tripods support it. They are built to hold the access bridges and to connect a flare with a platform. The access bridges are designed to carry personnel, piping, and any other accessories (figure 2.1).

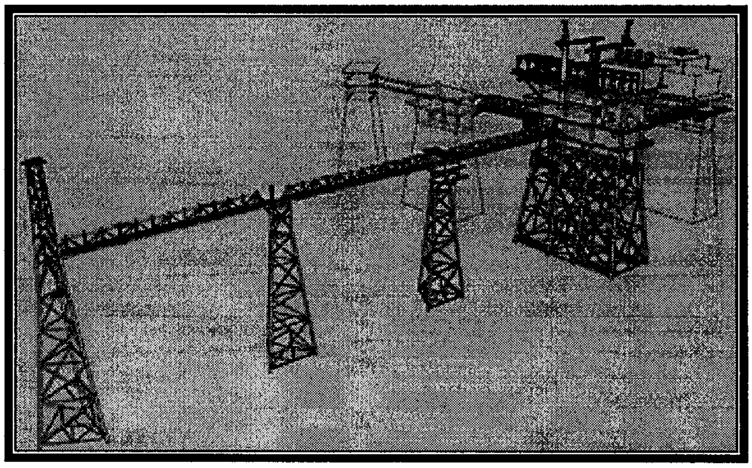


Fig. 2.1 Flare package in SDC (II)

Galvanic corrosion is a common form of deterioration in the marine environments. It occurs when two different metals are brought into electrical contact under water. When a galvanic couple forms, one of the metals in the couple becomes the anode and corrodes faster than it would by itself, while the other becomes the cathode and corrodes slower.

Cathodic protection is based on the principles of galvanic corrosion. In this case the metal is protected using a more anodic metal such as zinc or magnesium. The metals are electrically connected to the structure, and immersed in the seawater in close proximity to the metal causing galvanic corrosion. This technique is only used when fully immersed or in tidal conditions (Bartlett, 1999).

The jackets of the structures underwater are protected against corrosion by a cathodic protection system by making its surface work completely as cathode when it is immersed or buried in one electrolyte (Ramirez Bonilla, 1988). Cathodic protection basically reduces the corrosion rate of a metallic structure by reducing its potential corrosion, bringing the metal closer to an immune state.

Beside, this special protection is placed in any structural element in the jacket and tripods. Table 2.1 shows the kind of special protection provided against corrosion for each structure according to the environmental demands.

Area protected	Special protection
Jacket	Cathode protection
Splash zone	PEMEX RE-32
Deck, bridges, flare tower, and any element over the sea level	PEMEX RP-4B PEMEX RA-26

PEMEX = "Petroleos Mexicanos"

Table 2.1 Cathodic protection of structures (PEMEX, 2001)

PEMEX RE-32 is a strong adhesive based on resins and pigments used in the tidal zone and surge. PEMEX RP-4B is an inorganic paint composed of an organic silicate and a zinc dust pigment. It forms a resistant hard cover to the abrasion, and has an excellent resistance to humid, saline and marine atmospheres. PEMEX RA-26 is an epoxy catalyzed and cured with polyamide. It has an excellent resistance to chemical agents and marine industrial atmosphere. It resists gases derived from sulfur. These products have to be applied in well ventilated areas and with suitable equipment.

The materials that are part of the flare must be adequate to resist ocean environment, corrosion, pressure, temperature, and all kinds of fluid to be transported. To achieve these demands, the structures (deck, jacket, bridges, tripods, etcetera) are built using ASTM-A36 specifications. One should provide propergalvanized grating and handrail. Moreover AWS D.1,1 is to be used for welding during the entire process (PEMEX, 2001).

2.1.1 Deck

It has a cover at a level of 19.10 m; deck elevation rows were identified as A, B, and C, the space between columns is 9.14 m to axes, these columns have an interior diameter of 95.25 cm, to pass through a pile with an external diameter of 91.44 cm plus 1.905 cm in each side between column and pile. This structure has three cones to connect with the jacket (figure 2.2).

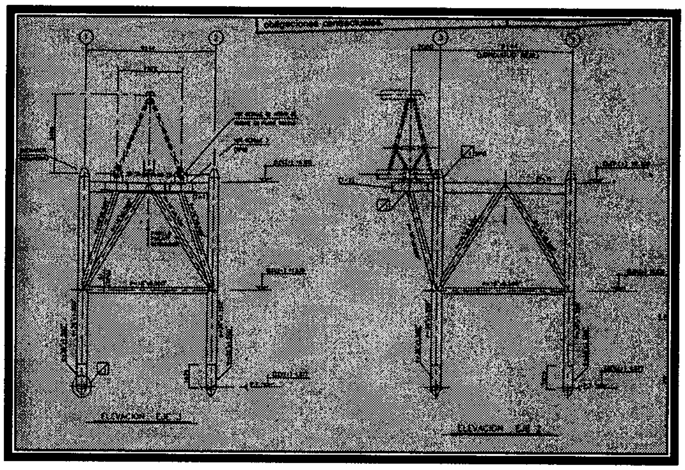


Fig. 2.2 Deck for a flare in SDC (PEMEX, 2001)

A list of materials and their quantities, which are needed to build the deck for flare (QCA-AC-4) are showing in Table 2.2.

Material	Quantity
Tubular structure ASTM A-36	106.56 ton
Plates ASTM A-36	222.44 ton
Structure ASTM A-36	79.90 ton
Paint RP-4B, and RA-26 (atmospheric zone)	445 liters
Galvanized Irving grating	495 m^2
Weld E-6010 and E-7018	525 kg
Paint RP-4B and RA-26 (primary and finished covering)	15 liters

Table 2.2 Deck material (PEMEX, 2001)

2.1.2 Jacket

It is a pyramidal structure with three columns with a slope of $\left({}^{2}\!/\!_{\sqrt{3}} : 8 \right)$.

This structure is supported in the seafloor (44.6 m depth); piles going through their columns will fix it. It has three horizontal reinforcements in the following levels with reference to the sea level + 6.096 m, - 7.720 m, - 24.38, and – 42. 44 m (figure 2.3) [PEMEX, 2001].

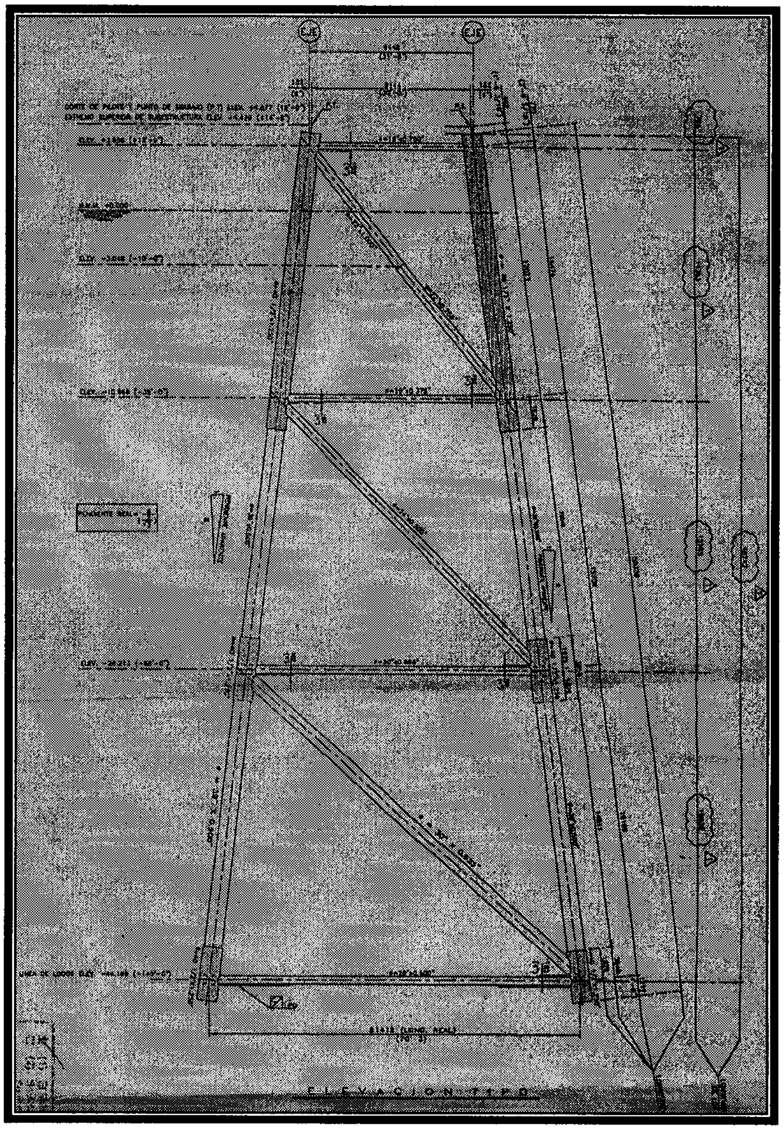


Fig. 2.3 Jacket for a flare in SDC (PEMEX, 2001)

2.1.3 Piles

They will be placed in the interior of each column of the jacket. The three piles are connected to the jacket at level + 6.71 m by plates and to the deck in level + 7.32 m by welding. The piles are build with ASTM A-36 as base material, but for the parts going under seafloor ASTM A-537 class I is used, or ASTM A-633 class A, or API 2H grade 50.

2.1.4 Flare tower

This is another pyramidal structure made of tubular elements. This tower is placed over the deck through connecting cones. Moreover, an access ladder is built to reach the flare tip.

2.2 Procedure for the installation of a flare package

2.2.1 Installation of the jacket

First, the place to unload the jacket is selected depending on wind conditions, surge, submarine currents, and other meteorological conditions. In order to place the jacket a barge, a tugboat, and a heavy lift vessel are indispensable to perform this activity.

2.2.2 Installation of the deck

A similar procedure followed for a jacket is applicable for a deck; a barge carries it to the place where a jacket has been already fixed in the seafloor. A lift vessel places the deck on top of the piles using the connective cones as guide. The most important step here is to cut these piles to the proper level to make the deck even. After this, deck-piling connections are welded around each column.

2.2.3 Work schedule

A representative schedule is shown in Table 2.3, it starts from the moment equipment and materials are received until the entire flare package is running.

Description	1st Month				2nd Month				3rd Month			
	1	2	3	4	5	6	7	8	9	10	11	12
Equipment and materials reception	X	X	X									
Conditioning of routes and areas		X	X									
Transportation of equipment and materials	X		X		X		X					
Installation of deck and pile driving			X	X	X	X						
Installation of deck					X	X	X	X				
Installation of tripods and bridges						X	X					
Installation and connection of pipelines and minor structures						X	X	X	X			
Hydrostatic tests									X	X		
Startup and commissioned into service										X		
Reception of flare package											X	X

Table 2.3 Work schedule for the installation of flare package in SDC (PEMEX, 2001)

2.2.4 Managing generated residues

In any project involving offshore construction generates residues or contaminates. Based on the activities to be accomplished, materials required, machinery used, or manpower needed, residues are produced (organic, inorganic, hazardous, and non hazardous). This situation requires planning for the proper management of them, considering their classification, their recollection, their storage and their transportation (Santiago, 2002).

Metallic containers of 200 liters can be used to temporally store garbage in working areas. Those containers must be completely cleaned and then transferred to trash containers. Container "A" is made of plastic with a capacity of 200 liters, with threaded lip. Container "B" is a metallic barrel with a capacity for 200 liters, without superior lip, with grooves in each side, and steel wire used as handle. Container "C" is metallic with a capacity for 200 liters, threaded lip, and is used to store dirty oil, residues from paints and substances to dilute them, or waste diesel (Santiago, 2002). Sacs made of "Ixtle" (fine, soft fiber of the bromeliaceous plant "Bromelia sylvestris"), are to be re-utilized to collect residues for sandblasting working areas. These sacs are also used to collect light materials such as paper, cardboard, styrofoam cups, and ropes from working places.

Welders have to re-use the weld bars boxes to dispose residues from their welding electrodes that are used during their shifts. At the end of their working period, their helpers are responsible of empty these boxes.

Table 2.4 and 2.5 shows a list of materials created during each activity, and their classification according to where they were generated in the construction area, or in the vessels respectively. Crew from the kitchen handles the organic wastes coming from everyday cooking. Residues from food are disposed immediately, in order to avoid contagious diseases or epidemics onboard. After they are collected from the kitchen, a machine reduces them to less than 2.5 cm, and disposed in the ocean.

The International Convention for the Prevention of Pollution from Ships (MARPOL) deals with pollution by oil, chemicals, and harmful substances in packaged form, sewage and garbage. The Convention includes regulations aimed at preventing and minimizing pollution from ships - both accidental pollution and that from routine operations. One should follow the guide lines established in this convention guide.

Combustible wastes like paper, cardboard, and wood are not kept for long periods of time, because they occupy large space in the warehouse. Those materials are deposited in the ship's incinerator where they are burnt.

Activity	Residue generated	Container
Arrangements of structural elements and pipelines	Welding electrodes	B
	Burr	B
	Junk	B
	Discs from grinding	B
	Used glove	A
Removing corrosion	Sand blast	Ixtle sacs
Application of painting	Cans impregnated with paints and their substances to dilute them	B
	Cotton waste, wool waste, and gloves impregnated with paints and their substances to dilute them	A
Building electrical systems	Plastic and copper cables	A
	Conduit	B
Placing instruments	Steel pipe	B
	Cotton waste impregnated with oil	B
Constructing scaffolding, and lifting up materials	Ropes made of polypropylene	A
	Pieces of wood	A
	Used gloves	A
	Steel cables	B
Maintenance	Used oil	C
	Used diesel	C
	Gloves impregnated with diesel and oil	B
	Used filters	B
	Used batteries	B

Table 2.4 Activities and residues generated by workers in construction area (Santiago, 2002)

Activity	Residue generated	Container
Operation and maintenance (machinery room)	Residues of used oil	C
	Cotton waste, and gloves impregnated with diesel and oil	B
	Residues of diesel	C
Maintenance	Welding electrodes	B
	Junk	B
	Plastic and copper cables	A
	Residues of used oil	C
	Cotton waste, and gloves impregnated with diesel and oil	B
	Burr	B
	Residues of paints	A
	Cotton waste, wool waste, and gloves impregnated with paints and their substances to dilute them	A
	Cans impregnated with paints and their substances to dilute them	B
Cooking in the kitchen	Food (fruits, vegetables, meats, bread, etcetera)	Triturated
	Paper, cardboard, and wood	A
	Plastic bags, glasses and spoons	A
	Cans	B
	Styrofoam cups, plates, containers	A
	Glass bottles	B
Cleaning rooms, and bathrooms	Paper	A
	Plastic bags	A

Table 2.5 Activities and residues generated by crew and workers in vessels (Santiago, 2002)

Due to constant movement of supplies, it is relevant to set-aside a warehouse space inside the ship. Figure 2.4 presents a tentative arrangement for those waste materials in reduced places. In this case they are sorted in hazardous and not hazardous, with precautions for fire or an accident. This classification of waste is based in Mexican Norm NOM-052-ECOL-1993, which establishes the characteristics of hazardous wastes, the list of them and the limits that make a waste hazardous based on its toxicity for the environment.

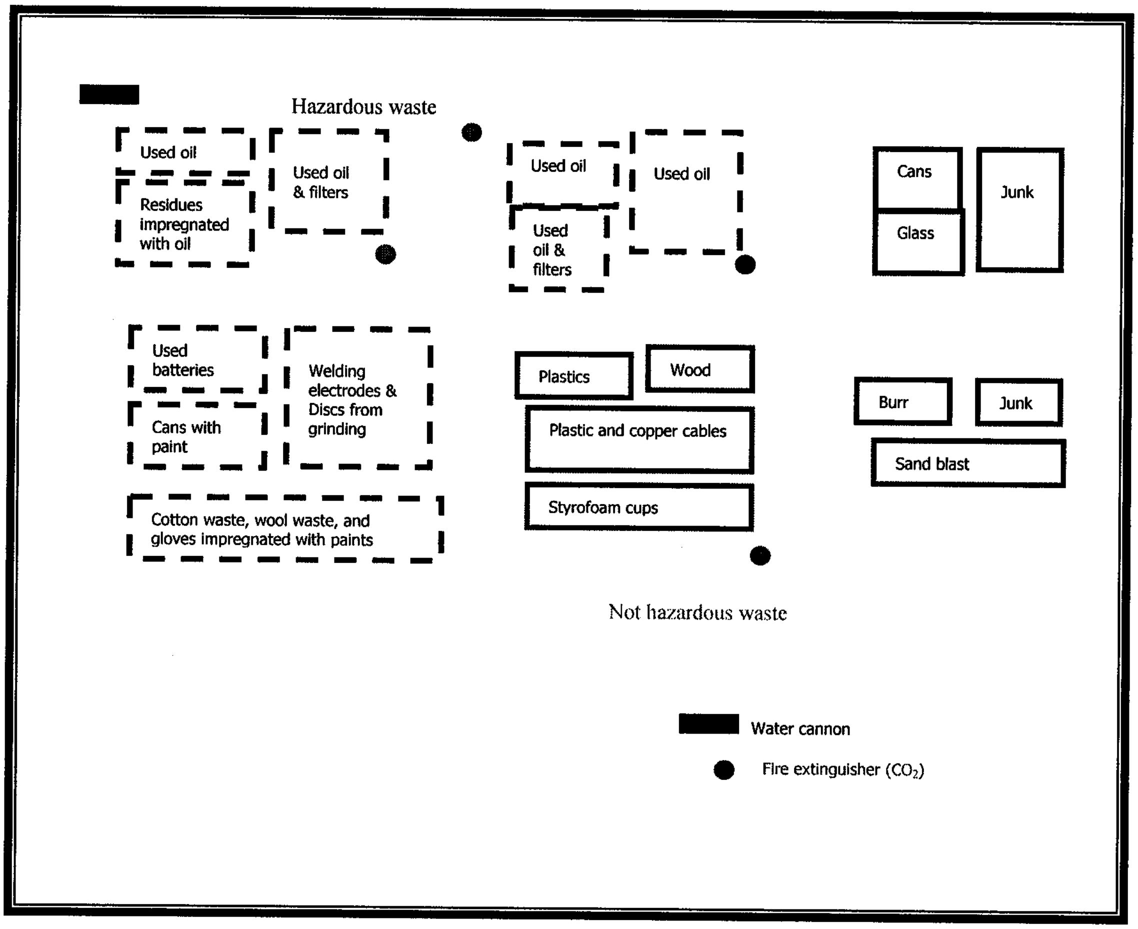


Fig. 2.4 Suggested arrangement for waste materials in ships (Santiago, 2002)

Trash generated during installation process is shipped to "Ciudad del Carmen", but to accomplish this activity there are three main factors to consider for planning a shipment agenda. Firstly, it depends on the volume of residues generated during the regular activities, according to the phase in which the working schedule is running. Secondly, it depends on the weather conditions. Sometimes during bad meteorological conditions the boat in charge of transporting these wastes has a delay (from two days to two weeks). Finally, it depends of how often this particular ship can come to pick these materials up. Usually it is just one boat attending different platforms in SDC at the same time. However, in spite of these circumstances, it is regularly established with this boat to receive its visit every second week.

A regular comment that is expressed by workers with more than one decade of experience in “Sonda de Campeche” is that before all kinds of residues were disposed in the sea. As a result of this, divers have trouble inspecting or repairing submarine pipelines in some areas, due to the number of physical obstacles found on the seafloor.

Seawater is used to clean the working areas, with an estimate rate of 3,000 liters per day (PEMEX, 2001). After it is utilized it needs to be cleaned in the Barge’s treatment system before being discharged back to the ocean. On the other hand, for the hydrostatic tests seawater is passed through pipelines. Then, the liquid is discharged directly to the sea. It is considered that the water properties are not drastically modified by the small particles removed from those pipes.

The sources of noise pollution include heavy lift vessels, tugboats, barges, ships transporting supplies or personnel, cranes, welding equipment, steam hammers, and power generators. To decrease negative effects, all personnel working in the field must wear hearing protection, as it is indicated in NOM-011-STPS-2001 (“conditions of security and hygiene in the work centers where noise is generated”). The vessels involved during this installation in conjunction with their electrical power generators and their machinery use combustibles or lubricants for their operation. Consequently supply boats fill them up with those products directly to their tanks, or by sealed containers to avoid spills during this procedure.

2.3 Flare package in operation

The following section is based on the details provided in ARPEL (1998) and U.S. EPA (2000). The Mexican Petroleum Institute compiled in 2001 an emission inventory detailing in a quantitative way the release of certain gases and particulate matter during the activities of perforation, exploitation, distribution and storage of crude oil and natural gas for the year 2000. This study was directed by Villasenor (2001) of the Mexican Petroleum Institute.

Emission factors specific to the petroleum operations in the SDC do not exist. Thus an Emission Inventory (EI) had to be constructed from international emission factors reported in the literature for the regulated air pollutants in Mexico: sulfur oxides, nitrogen oxides, carbon monoxide, and particulate matter. Other air pollutants like total hydrocarbons and hydrogen sulfide were included because of their toxic characteristics. The impacts of atmospheric emissions of current petroleum operations in the region can be assessed through a screening study using records of flaring operations taken by the personnel at the gas and oil production sites and an estimate of pollutants emissions obtained using the application of emission factors reported in literature. The compilation of the EI included mass fluxes of flares, pits, and stationary sources such as compressors, pumps and diesel generators. Incorporated in the EI are the emission sources of the offshore fields, the recompression station of “Atasta” and the crude-oil treatment terminal at “Dos Bocas” and the “Cayo Arcas” port. The methodology and details pertaining to the collection of this data by the Mexican Petroleum Institute is well documented. The emission inventory was based on mass balance calculations and on previous studies conducted by PEMEX (2000) and COMIMSA (1997 and 2000).

Air emissions in SDC are grouped by marine regions Northeast (“Cantarell”, “Ek-Balam”, “Ku-Maloob-Zaap”, and “CTO” as “Atasta”), and Southwest (“Pool-Chuc”, “Abkatum”, and “Dos Bocas”), also by Unit of drilling and maintenance for wells

(UPMP, in Spanish), and emissions caused by Marine traffic. Moreover, these emissions are classified by group of contaminant (NO_X, SO_X, H_2S, CO, HC as hydrocarbons, and particles). Finally greenhouse gases are included (CO_2, and CH_4). As result of this EI, the following two tables summarize the general information obtained, first showing values (table 2.6) and second in percentages (table 2.7).

REGION	ACTIVO O AREA	NO_X (tt/y)	SO_X (tt/y)	H_2S (tt/y)	CO (tt/y)	HC (tt/y)	PM (tt/y)	TOTAL* (tt/y)
NEMR	CANTARELL	8.80	138.66	0.88	91.92	214.08	8.88	462.34
	EK-BALAM	1.37	25.66	0.14	12.86	34.66	1.35	75.90
	KU-MALOOB-ZAAP	0.06	0.01	0.001	0.31	0.26	0.03	0.66
	CTO-ATASTA	8.89	1.53	0.01	10.58	2.88	1.05	24.92
	SUBTOTAL NEMR	19.11	165.85	1.03	115.67	251.88	11.31	563.81
SWMR	POOL-CHUC	1.10	7.01	0.05	8.21	12.97	0.79	30.08
	DOS BOCAS	12.33	0.80	0.004	4.36	6.09	0.49	24.06
	ABKATUM	2.32	2.43	0.02	16.27	5.12	1.54	27.69
	SUBTOTAL SWMR	15.75	10.25	0.07	28.85	24.17	2.81	81.83
NEMR/SWMR	MARINE & AIR TRAFFIC	6.03	4.90	0.00	0.92	0.77	0.30	12.92
UPMP		0.27	0.004	0.00	0.07	0.02	0.01	0.37
TOTAL SONDA DE CAMPECHE		41.16	181.00	1.10	145.51	276.84	14.43	658.68

H_2S is excluded from Total, because it is treated separately

REGION	ACTIVO O AREA	CO_2 (tt/y)	CH_4 (tt/y)	TOTAL (tt/y)
NEMR	CANTARELL	11768.3	31.2	11799.5
	EK-BALAM	1929.3	5.1	1934.4
	KU-MALOOB-ZAAP	33.0	0.033	33.1
	CTO-ATASTA	1325.1	0.4	1325.4
	SUBTOTAL NEMR	15055.7	36.7	15092.3
SWMR	POOL-CHUC	932.5	1.9	934.4
	DOS BOCAS	720.1	0.5	720.6
	ABKATUM	1720.8	0.7	1721.5
	SUBTOTAL SWMR	3373.4	3.1	3376.4
NEMR/SWMR	MARINE & AIR TRAFFIC	599.0	0.0	599.0
UPMP		13.1	0.0	13.1
TOTAL SONDA DE CAMPECHE		19041.2	39.7	19081.0

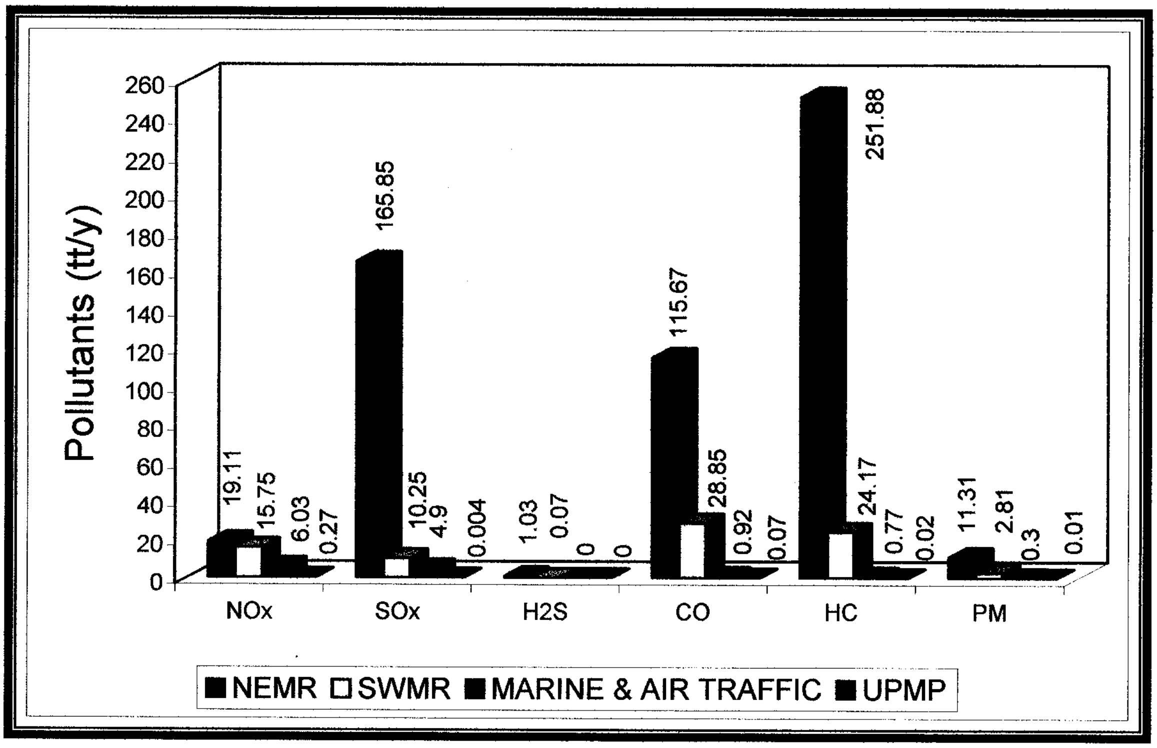
tt/y= thousand tons per year

Table 2.6 Air Emission Inventory for SDC (Villasenor, 2001)

REGION	ACTIVO O AREA	% NO_X	% SO_X	% H_2S	% CO	% HC	% PM	% Total
NEMR	CANTARELL	21.37	76.60	79.62	63.18	77.33	61.54	70.19
	EK-BALAM	3.33	14.17	12.94	8.84	12.52	9.36	11.52
	KU-MALOOB-ZAAP	0.13	0.00	0.08	0.21	0.09	0.21	0.10
	CTO-ATASTA	21.59	0.84	0.74	7.27	1.04	7.27	3.78
	SUBTOTAL NEMR	46.43	91.63	93.38	79.50	90.98	78.38	85.60
SWMR	POOL-CHUC	2.67	3.88	4.77	5.64	4.68	5.46	4.57
	DOS BOCAS	29.95	0.44	0.41	3.00	2.20	3.36	3.65
	ABKATUM	5.65	1.35	1.44	11.18	1.85	10.68	4.20
	SUBTOTAL SWMR	38.26	5.66	6.62	19.83	8.73	19.50	12.42
NEMR/SWMR	MARINE & AIR TRAFFIC	14.66	2.71	0.00	0.63	0.28	2.06	1.96
UPMP		0.65	0.00	0.00	0.05	0.01	0.06	0.06
TOTAL SONDA DE CAMPECHE		100.00	100.00	100.00	100.00	100.00	100.00	100.00

REGION	ACTIVO O AREA	% CO_2	% CH_4	% TOTAL
RMNE	CANTARELL	61.80	78.58	61.84
	EK-BALAM	10.13	12.76	10.14
	KU-MALOOB-ZAAP	0.17	0.08	0.17
	CTO-ATASTA	6.96	0.89	6.95
	SUBTOTAL NEMR	79.07	92.30	79.10
RMSO	POOL-CHUC	4.90	4.75	4.90
	DOS BOCAS	3.78	1.26	3.78
	ABKATUM	9.04	1.69	9.02
	SUBTOTAL SWMR	17.72	7.70	17.70
NEMR/SWMR	MARINE & AIR TRAFFIC	3.15	0.00	3.14
UPMP		0.07	0.00	0.07
TOTAL SONDA DE CAMPECHE		100.00	100.00	100.00

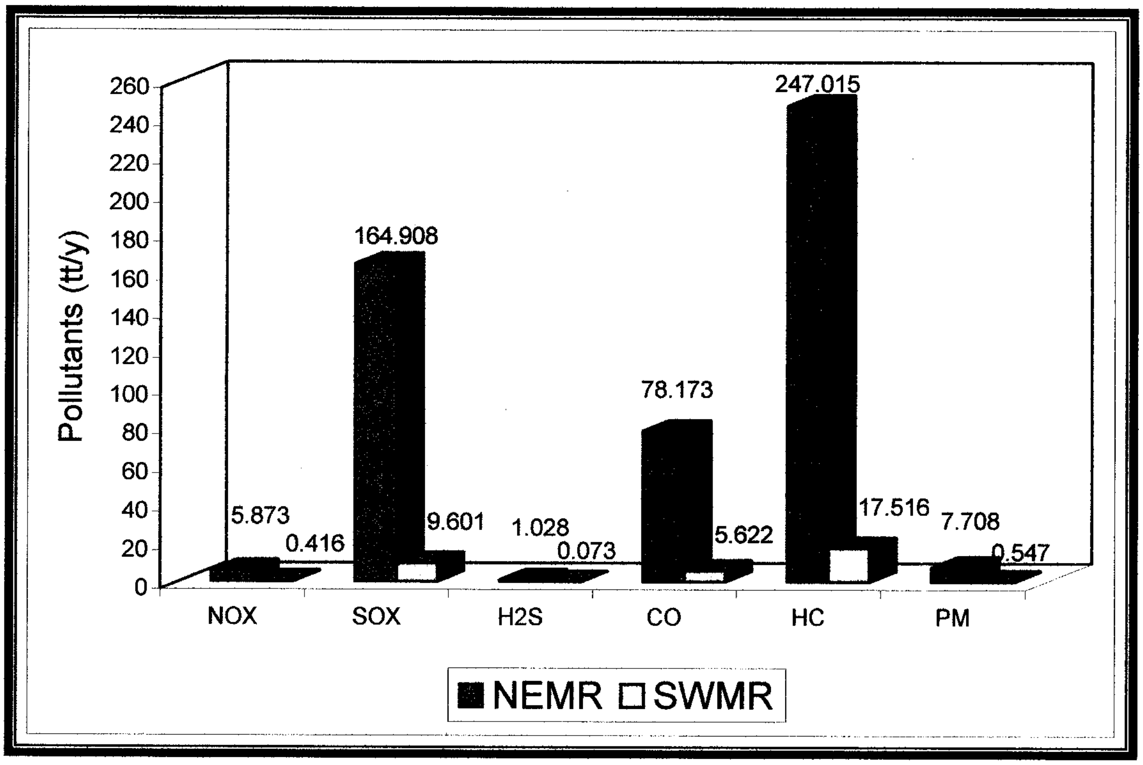
Table 2.7 Air Emission Inventory in SDC (percentages) [Villasenor, 2001]



tt/y= thousand tons per year

Fig. 2.5 Air emissions in SDC (Villasenor, 2002 b)

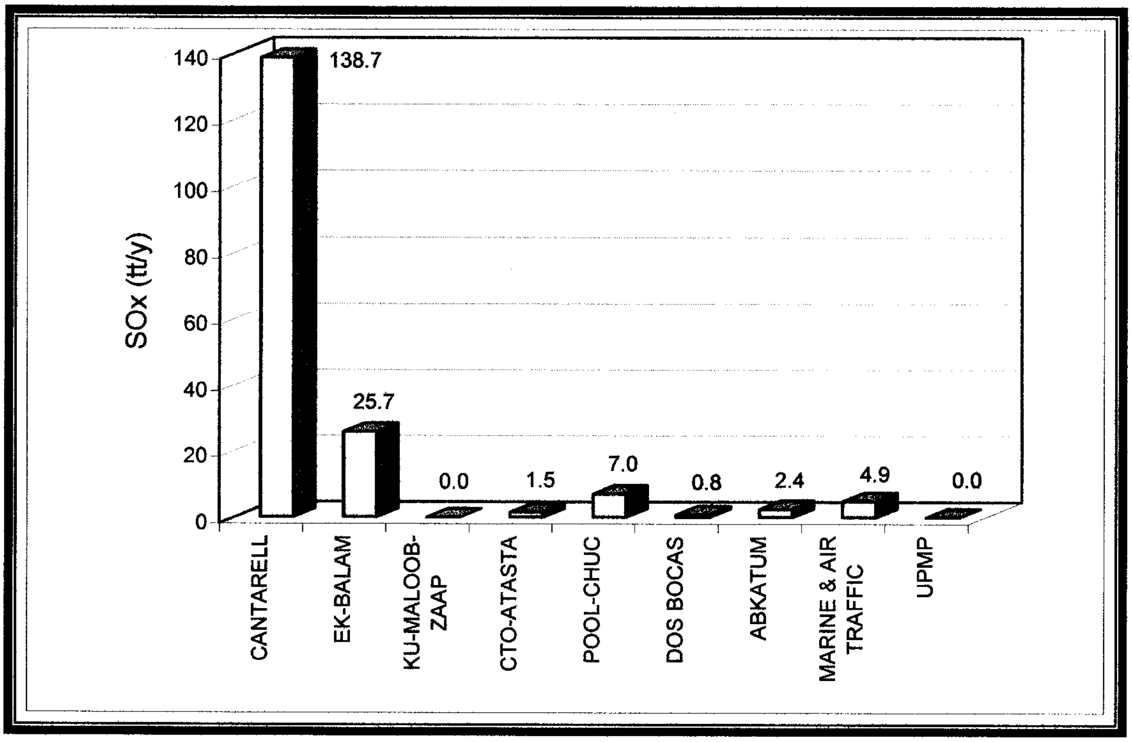
The Northeast Marine Region (NEMR) is the main source of air pollution. It creates 563.81 thousand tons per year (86 %) from the total of 658.68 thousand tons per year in the entire "Sonda de Campeche". It is important to mention that greenhouse gases and H_2S are excluded from this last value. The Southwest Marine Region (SWMR) provides 81.83 thousand tons per year. Marine traffic contributes 12.92 thousand tons per year and drilling activities are the lowest contributors with just 0.37 thousand tons per year (figure 2.5).



tt/y= thousand tons per year

Fig. 2.6 Air emissions caused by flares in SDC (Villasenor, 2002 b)

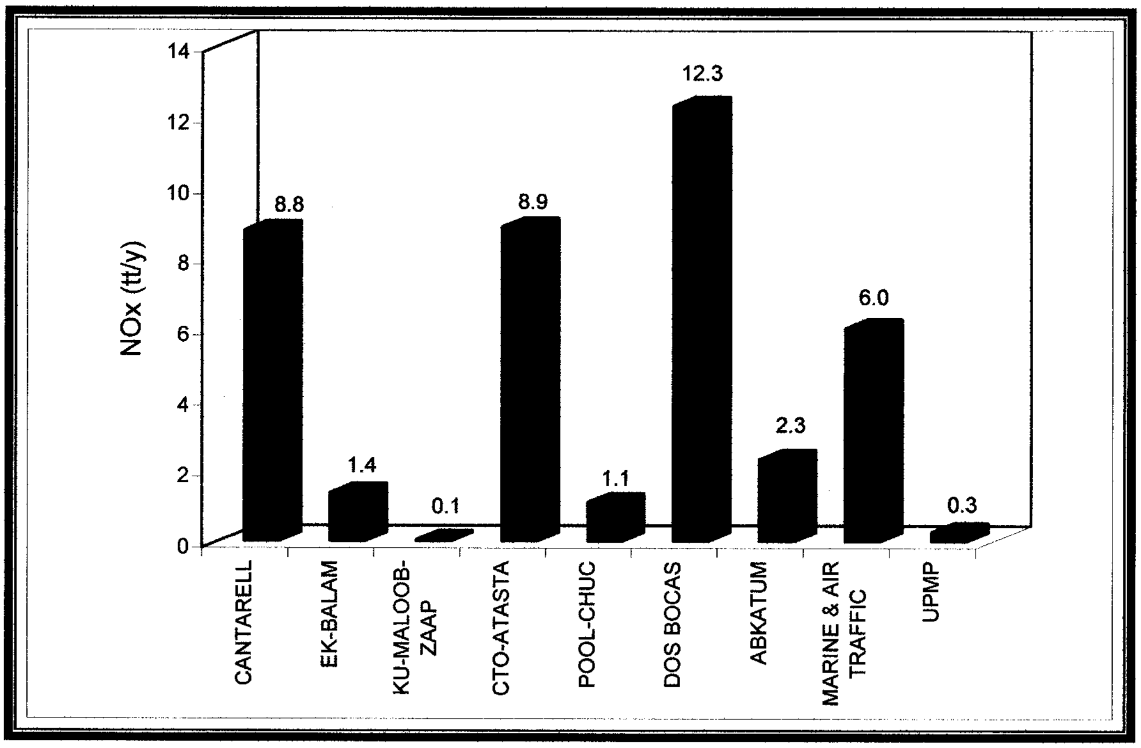
Figures 2.6 shows air emissions in SDC produced by flares in offshore platforms. Here elevated, boom, and ground level flares are included. It is observed that these sources contribute 538 thousand tons per year. This is equivalent to 82 % of the emissions. Among them, hydrocarbons are the main pollutants with volumes of 264 thousand tons per year. It is followed by SO_X with 174 thousand tons per year, and CO with 84 thousand tons per year. In the NEMR, 94 % of the global emissions are produced.



tt/y= thousand tons per year

Fig. 2.7 SO_X Air emissions in SDC (Villasenor, 2002 b)

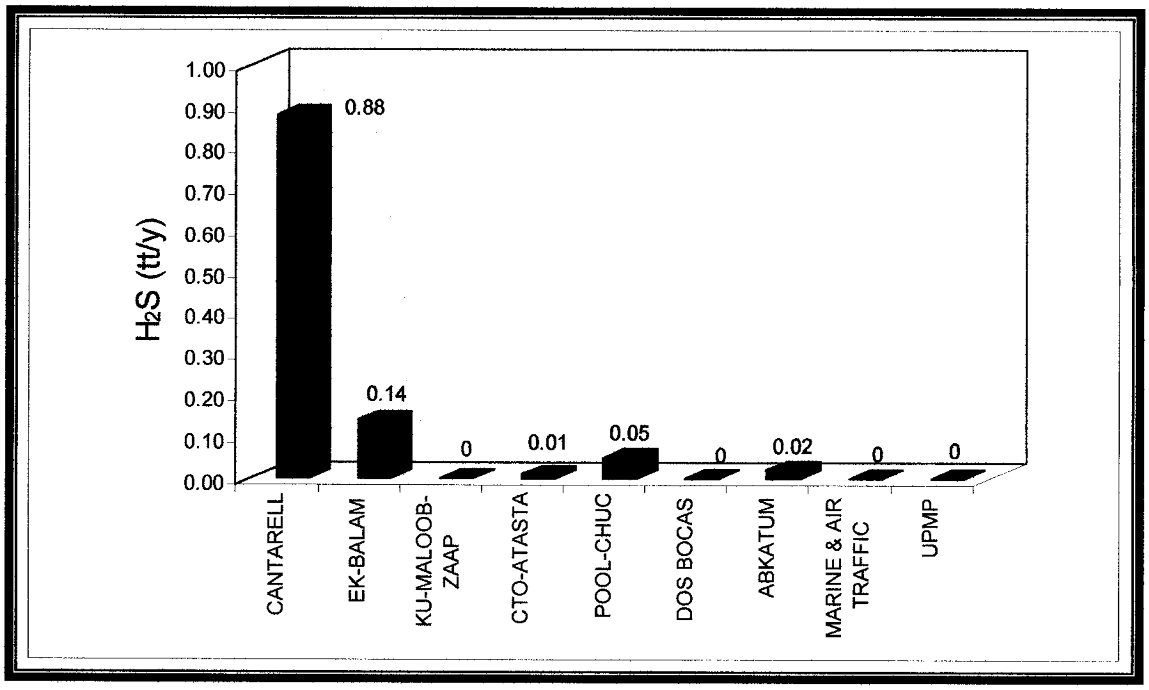
Figure 2.7 represents emissions from SO_X by area. A total of 181 thousand tons per year of this gas is released in the atmosphere. "Cantarell" is the biggest contributor with 193 thousand tons per year (77%). It is followed by "Ek-Balam" that produces 26 thousand tons per year (14%). Lastly "pool-Chuc" produces just 7 thousand tons per year (4%). The majority of SO_X comes from elevated flares offshore.



tt/y= thousand tons per year

Fig. 2.8 NO_X Air emissions in SDC (Villasenor, 2002 b)

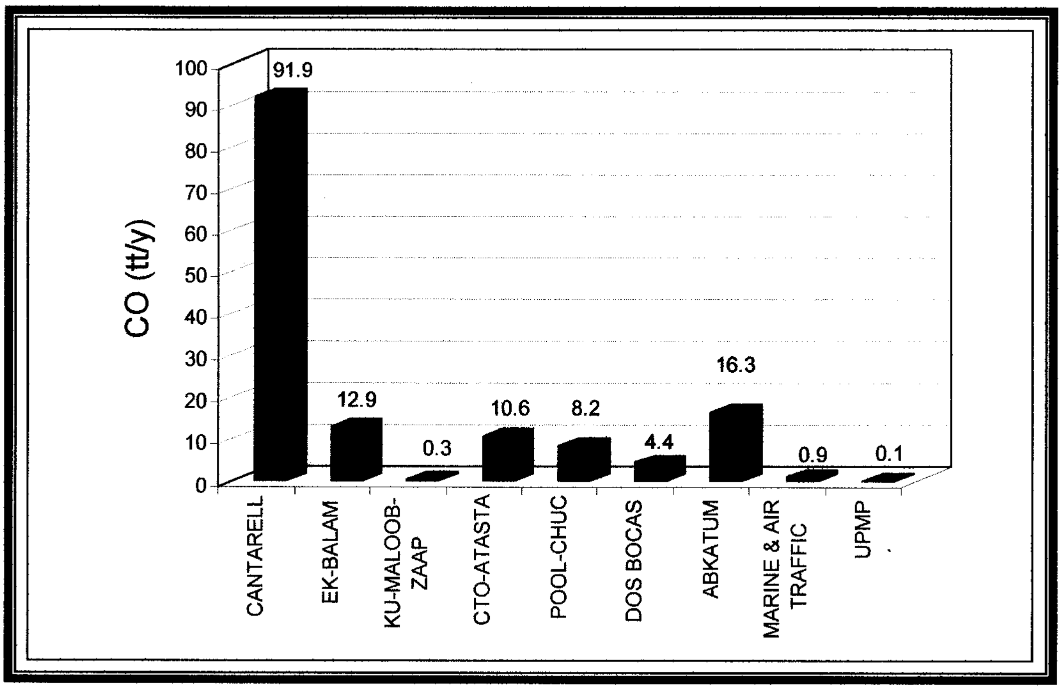
NO_X has a more equitable distribution among marine regions (figure 2.8). The total emission is 41 thousand tons per year. "Dos Bocas" is identified as the principal source with 12 thousand tons per year (30%). It is followed by "CTO" or Atasta with 22%, and in the third place "Cantarell" contributes 21 %. This distribution of NO_X is traced to combustion by diesel which generates bigger quantities of NO_X per litter than the combustion of natural gas.



tt/y= thousand tons per year

Fig. 2.9 H_2S Air emissions in SDC (Villasenor, 2002 b)

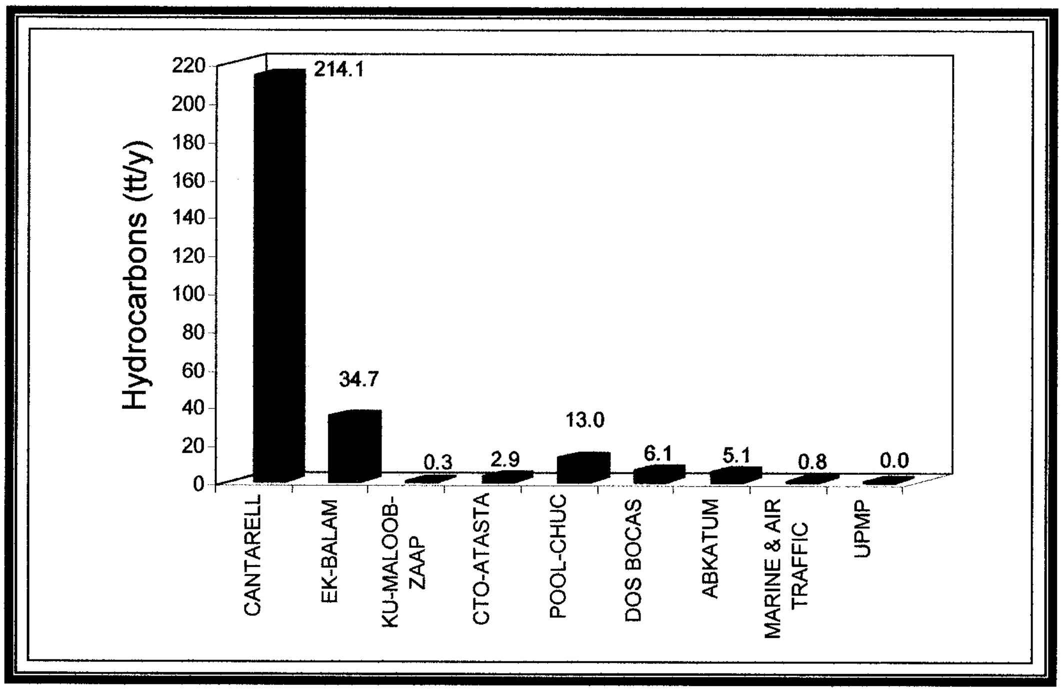
Figure 2.9 shows a distribution of H_2S in SDC. For these emissions it is considered that they come only from elevated flares. The contribution of this contaminant measured by mass is the lowest compared with the other pollutants. “Cantarell” is the main provider with 0.88 thousand tons per year (78%). This is followed by “Ek-Balam” with 0.14 thousand tons per year (13%).



tt/y= thousand tons per year

Fig. 2.10 CO Air emissions in SDC (Villasenor, 2002 b)

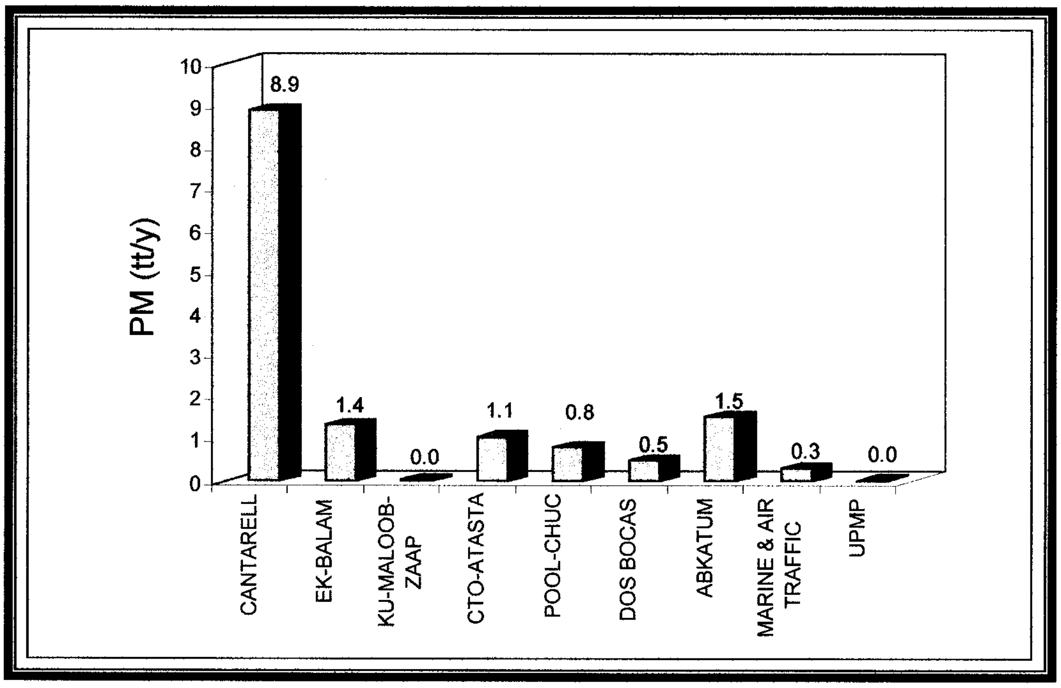
Emissions of CO add up to a total of 145 thousand tons per year (figure 2.10). Principal sources of CO are located in "Cantarell". It contributes with 92 thousand tons per year (63%). This is followed by "Abkatum" with 16 thousand tons per year (11%). Finally, "Ek-Balam" provides 13 thousand tons per year (8.8%).



tt/y= thousand tons per year

Fig. 2.11 Hydrocarbons Air emissions in SDC (Villasenor, 2002 b)

Figure 2.11 represents the hydrocarbon emissions for the areas that integrate SDC. Talking about quantities, this is significant. The emissions shown do not include methane, because it is considered as part of the greenhouse gases. The total mass released is 277 thousand tons per year. 77% of this (214 thousand tons per year) comes from "Cantarell". The second in diminished order is "Ek-Balam" with 13 % (34.6 thousand tons per year), and in third place is "Pool-Chuc" with 4.7% (13 thousand tons per year). Combustion generated in elevated flares is the main contributor for these hydrocarbons, because they do not include technology for control of emissions.

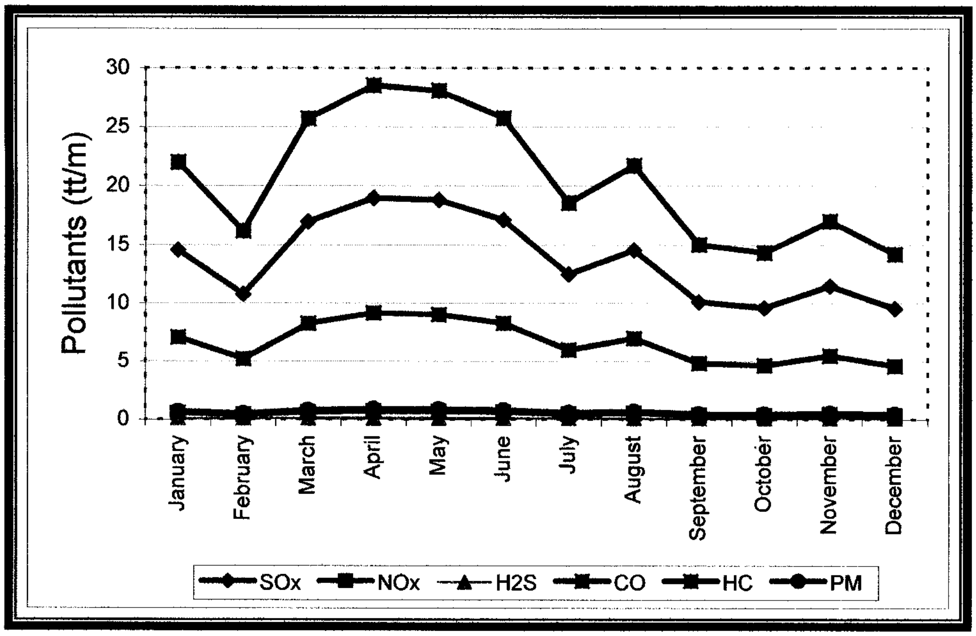


tt/y= thousand tons per year

Fig. 2.12 PM Air emissions in SDC (Villasenor, 2002 b)

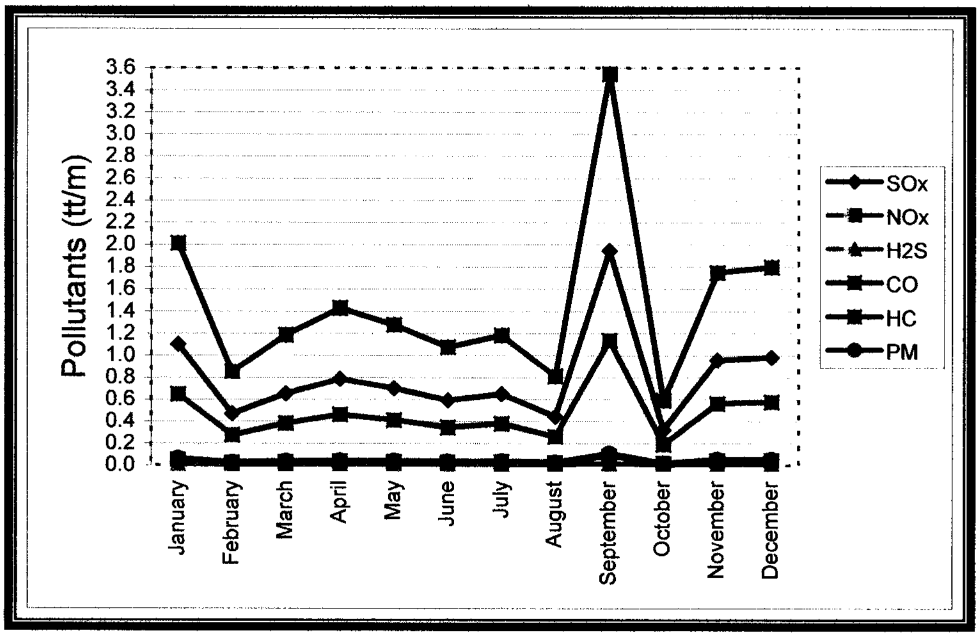
Particle emission in SDC is shown in figure 2.12. The volume of particulates released is 14.43 thousand tons per year. They are generated by the combustion of liquid combustibles. "Cantarell" is identified as the principal source. It contributes 8.88 thousand tons per year (62%). Next, "Abkatum" generates 1.5 thousand tons per year (10.7%). Finally, "Ek-Balam" contributes 1.34 thousand tons per year (9.4%).

Figure 2.13 and 2.14 show a monthly distribution of air emission (SO_X, NO_X, H_2S, CO, HC, and PM) caused by flares in NEMR, and SWMR respectively for 2000. There is a critical period (figure 2.13) during which the pollutants are higher compared with other months. This occurs from March to June, specifically with a peak value in April. This path is repeated for each one of the constituents. On the other hand, for SWMR the maximum record is presented in September (figure 2.14) with elevated air emissions from November to January.



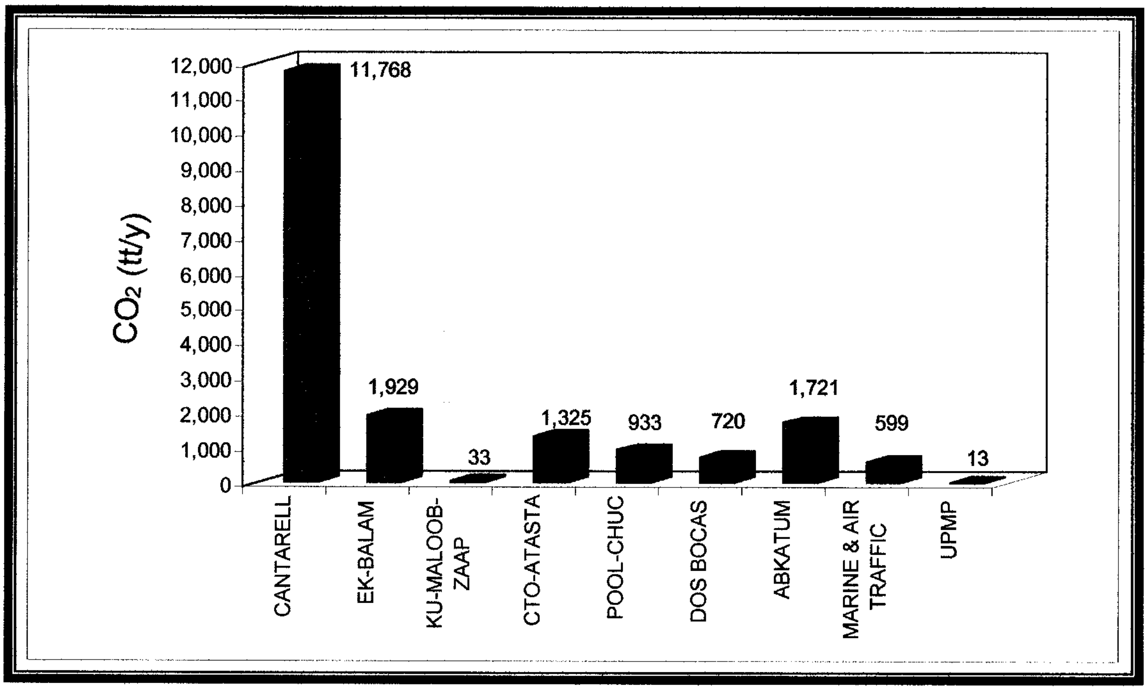
tt/m= thousand tons per month

Fig. 2.13 Monthly air emissions in NEMR caused by flares (Villasenor, 2001)



tt/m= thousand tons per month

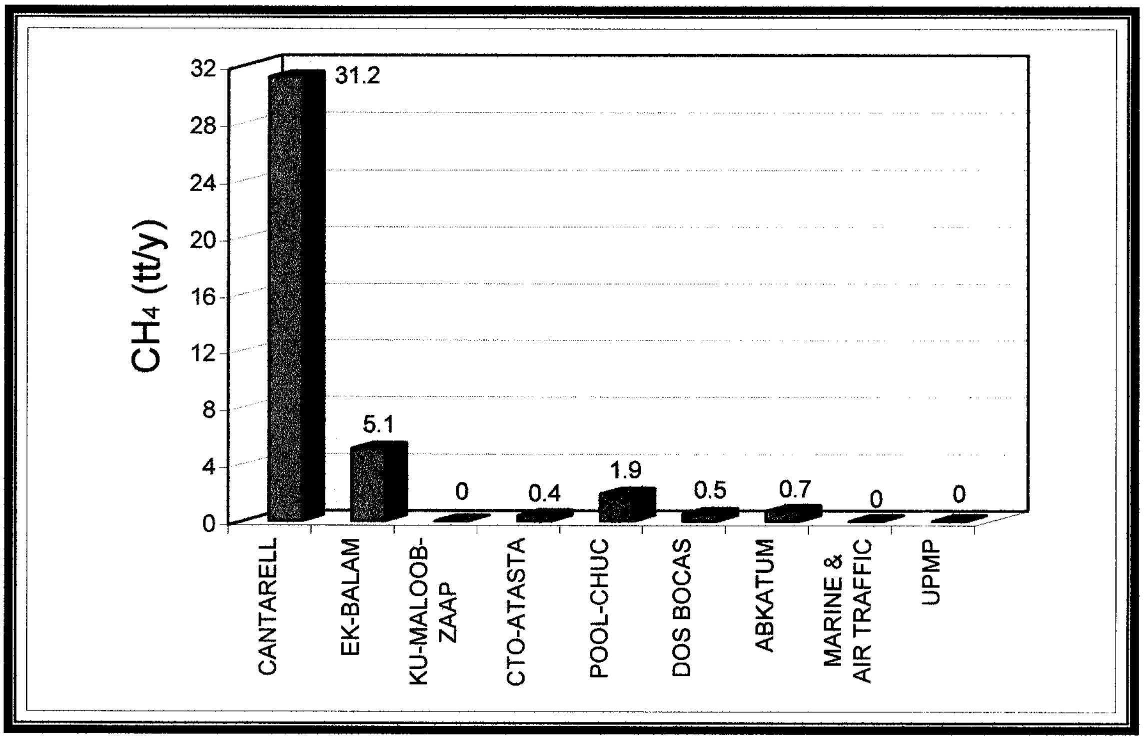
Fig. 2.14 Monthly air emissions in SWMR caused by flares (Villasenor, 2001)



tt/y= thousand tons per year

Fig. 2.15 CO_2 Air emissions in SDC (Villasenor, 2002 b)

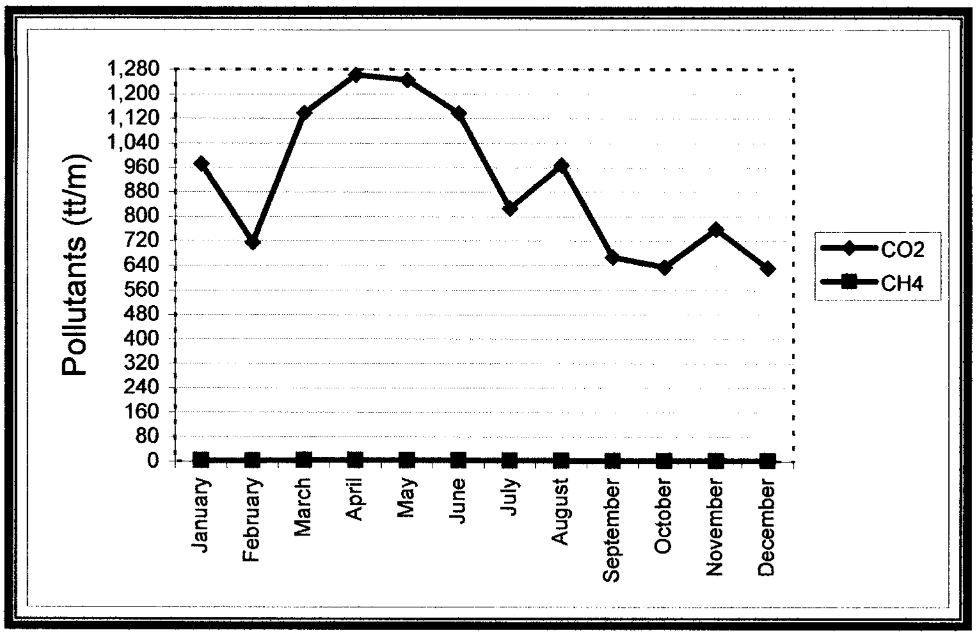
With regard to greenhouse gases, both carbon dioxide and methane are important. 19000 thousand tons per year of CO_2, and 40 thousand tons per year of CH_4 are identified. For CO_2, NEMR is the major contributor with 15 050 thousand tons per year. This is followed by SWMR that creates 3, 370 thousand tons per year. In NEMR, "Cantarell" contributes 62 % of CO_2 (11,800 thousand tons per year), and 79% of CH_4 (31 thousand tons per year). It is followed by "Ek-Balam" with 10% of CO_2, and 13 % of CH_4, (figures 2.15 and 2.16).



tt/y= thousand tons per year

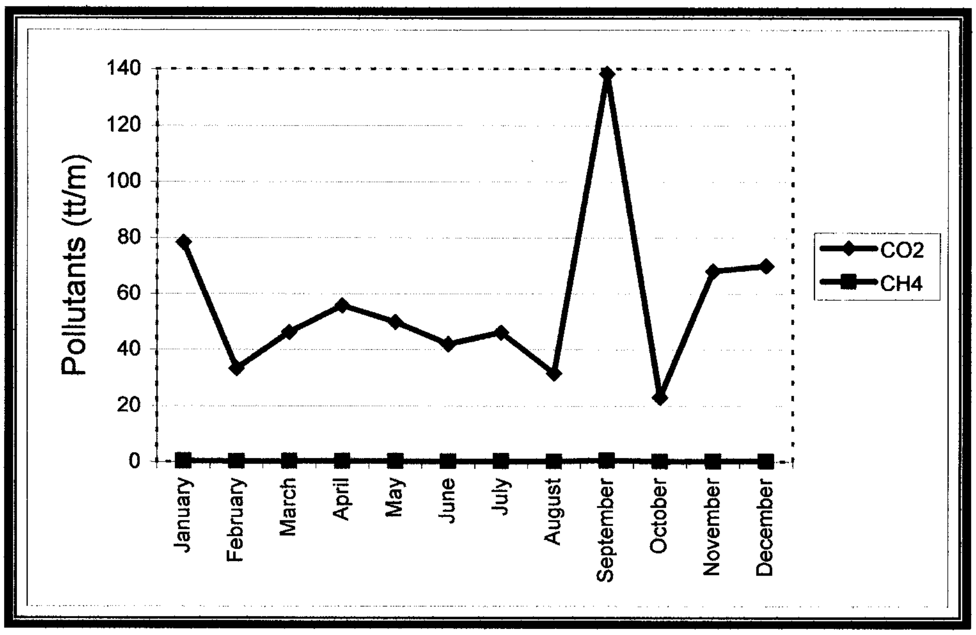
Fig. 2.16 CH_4 Air emissions in SDC (Villasenor, 2002 b)

CO_2 and CH_4 are showed in figure 2.17 (for NEMR) and 2.18 (for SWMR), both are represented with a monthly distribution of greenhouse gases caused by flares in 2000. From March to June (figure 2.17) there is a critical period in which the pollutants are higher compared with the rest of the year. It is important to emphasize that during April, a crest point is reached for each one of the air contaminators. Similarly figure 2.18, SWMR presents its maximum record in September and high air emissions from November to January.



tt/m= thousand tons per month

Fig. 2.17 Monthly greenhouses gases in NEMR provoked by flares (Villasenor, 2001)



tt/m= thousand tons per month

Fig. 2.18 Monthly greenhouse gases in SWMR provoked by flares (Villasenor, 2001)

2.4 Maintenance program for flare package

As any other structure installed to extract crude oil in the Gulf of Mexico, flares and theirs different elements are part of a permanent preservation plan. For instance, in each jacket, twice a year, inspections of cathode protection are performed, making the necessary changes in anodes. For the deck, cleaning it and painting it with anticorrosion covering in any requested area is part of the program. Usually, twice per year grating, handrails, and secondary structural elements are repaired. Change of damaged gaskets, valves, instruments (mechanical or electrical), or equipment is done as frequently as it is needed. Also replacement of damaged pipelines by new ones is done according to the needs. There is a possibility that during the operation or maintenance phases an accident could occur by conducting exceeded gas to the flare and cause enhanced pollution. In a decreasing order of probability of occurring: a) rupture of pipelines caused by flaws in materials or accessories; b) rupture of pipelines by overpressure; c) fires; and d) oil spills through the flare.

In spite of quality controls applicable during installation and construction of gas pipelines, accidents might happen. Any event involving hydrocarbon leak may provoke a fire, which increases during maintenance operations. A crude oil leak could take place when the knock out drum (oil/water/gas mix) goes over its regular level, allowing passing crude oil to the gas pipeline directed to the flare. To keep this in control, a system implemented with overflow valves is desirable. For high-pressure conditions, there are indicators, controls, and alarms that reduce the operational pressure.

2.5 Platform abandonment

According to its design, materials, construction, and maintenance program, a flare package will be working for 20 years. At the end of this time a new re-evaluation will consider whether it will continue in service or it will be dismantled.

2.6 Personnel required

Common and specialized workforce is demanded during transportation, installation, for startup and to commission a flare package; for each of these phases, temporal personnel are hired according to each activity and its duration. On the other hand, permanent workers are required for phases such as operation and maintenance.

As long as temporal or permanent personnel are working on the flare, trash always will be generated. For instance, leftovers occur from food, cans, cloths, plastics, glass, stoneware, paper, cardboard, and wood. Moreover, waste paper, boxes and cardboard are created in the administrative offices. These wastes are carried by ships to the mainland to be treated, or recycled, or properly disposed.

Solid waste coming from sanitary installations has to be kept in special containers for certain periods of time and later be carried to the municipal garbage dump in “Ciudad del Carmen”.

Potable water consumption has been estimated to be 21, 400 liters per day. Based on a demand of 200 liters per person every day (Pemex, 2001), to obtain these numbers it has been considered an average of 107 people working at the same time in this project. Besides, black and gray water (sewage and soapy water) generated by the same personnel has to be treated in the vessel’s sewage treatment system, or collected and sent to “Ciudad del Carmen” for appropriate management.

Chapter Three
Description of environment in "Sonda de Campeche"

The Sonda de Campeche is located south of the Gulf of Mexico; geographically it is delimited in the east by Yucatan peninsula, to the south by Campeche shore covering from Grijalva-Usumacinta River to "Laguna de Terminos". The 200 m isobath is a good reference for the offshore boundary. The SDC covers approximately 9,000 km^2 between 18° 30' to 20° 15' North, and 91° 00' to 93° 00 West, (figure 3.1).

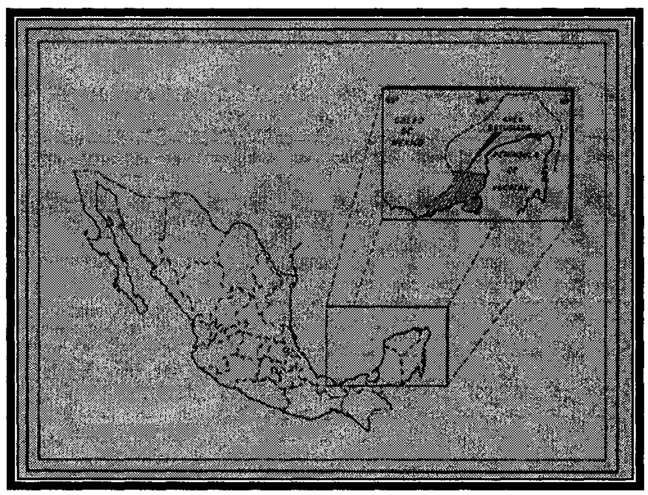


Fig. 3.1 Area of study "Sonda de Campeche" (VIII)

3.1 Atmospheric conditions

The Gulf of Mexico and the Campeche bay are regions where meteorological parameters are very important to comprehend the relation between marine currents and air. The dynamics of these elements are strongly affected by cold fronts during winter, affecting the area for one or two days severely depending on wind speed (Monreal Gomez and Salas de Leon, 1990).

The state of Campeche is located in a tropical humid area. The weather in this region is classified as Am (tropical monsoon climate) and Aw (tropical wet and dry or savanna), with heavy rain during the summer, and part of the fall. During the rainy season, the amount of water received is 10 times more than in the dry season (Garcia, 1987 b).

Table 3.1 shows temperature data for 1998. They were taken at three different locations ("Ciudad del Carmen", "Dos Bocas", and "Cayo Arcas"). An average temperature of water per month in the surface of ocean varies between 19.4° C and 28° C. However, 26° C can be taken as annual average. Also during summer times the highest values are registered being over 29° C.

	Onshore stations		Offshore station
Month	Ciudad del Carmen (° C)	Dos Bocas (° C)	Cayo Arcas (° C)
January	23.3	27.4	24.4
February	24.3	27.0	24.6
March	25.3	28.0	25.1
April	28.2	29.4	26.7
May	30.0	29.0	27.5
June	29.9	28.5	28.4
July	28.6	28.0	28.7
August	28.5	27.6	28.5
September	28.1	28.0	28.4
October	26.5	27.5	28.0
November	25.0	25.5	26.0
December	23.4	26.5	25.1
Annual average	26.8	27.7	26.8

Table 3.1 Monthly temperatures in "Sonda de Campeche" (PEMEX, 2001)

The relative humidity changes generally from 40% to 100%. It is observed that the lowest value occurs during the months of November, December, February, and March (Salas de Leon, 1992). Atmospheric pressure for the region fluctuates between 1,002 hPa (hectopascal = millibar), during March and 1,026 hPa for December. It could be considered 1,016 hPa as an average value. Solar radiation is a general term for the electromagnetic radiation emitted by the sun. 900 W/m^2 (watts per square meter) is the maximum radiation reached during February and March (Salas de Leon, 1992). The average intensity of solar radiation reaching the upper atmosphere is about 1,367 W/m^2 or 434 British thermal units (Btu) per square foot.

Predominant winds from east to southeast are present in March and April and continue until September. After this North to Northwest winds blow from October until February, which is called the period of the "North" (Dominguez Brito and Granadillo Perez, 1995); this atmospheric condition usually goes on for a maximum of two days, but severe storms can be prolonged to four days, causing rain, cloudburst, and a strong decrease in the ambient temperature. Wind velocities reach a maximum of 21 m/s.

3.2 Seasons

Weather is a combination of diverse factors as temperature, relative humidity, rain, and atmospheric pressure, which are reflected in the biological and oceanographic conditions. In the Sonda de Campeche three seasons have been identified through observations throughout the years, those are:

a. Dry season: from May to June
b. Rainy season: from July to September
c. "North" season: from October to February

It is important to mention that during the rainy season, the rivers contribute a considerable amount of water to the Campeche bay. This phenomenon has been perceived particularly when hurricanes hit the area. Eventually, rain and low temperatures, tides and currents along the Campeche's coastline, characterize the "North" season or commonly named "cold fronts" (Soto Gonzalez and Escobar Briones, 1995).

3.3 Geology

The Gulf of Mexico is a geological area that has experienced some ascending movements; it is part of the American plate, and according to Molnar and Sykes (1969) any movement in North America is reflected in the Gulf. The origin of the Gulf, according to Butterlin (1972) is a river basin formed by collapse, whose reduction and collapse are associated with the growth of the carbonated platforms of Campeche and Florida. Geologically speaking the Gulf of Mexico covers seven provinces. Campeche bay and Campeche bank are the two provinces covering the area of interest for this study.

Campeche bay is a marine extension of a river basin originated in Tabasco and Campeche. According to Antonie (1972), its geological history is associated with the latest period of the Paleozoic, when river basis and bays were created in that region. During the Cretaceous period, carbonated pieces of rock and terrigenous were deposited (Worzeel, 1968). Campeche Bay is strongly influenced by estuarine waters, and sediments of slime and clay with high a content of organic material (Yanez Arancibia; Sanchez Gil, 1988).

Campeche bank is a calcareous region delimited in the West by Tabasco-Campeche river basin and to the East by Yucatan strait. This continental platform was created by carbonated deposits as product of marine organisms during the Cretaceous period (Antonie, 1972). In the east part of this bank, sediments are modified gradually. They go from carbonated to terrigenous. This phenomenon is caused particularly by discharges from rivers as “Grijalva” and “Usumacinta” (Ayala Castanares; Gutierrez Estrada, 1990). Carbonated sediments are formed by a big organic productivity, particularly from Yucatan platform. Sediments produced by the Earth are transported by the two rivers mentioned before.

3.4 Hydrology

This region receives the highest precipitation in Mexico (Table 3.2), which is reflected in the runoff collected in deltas, swamps, canals, rivers, and lagoons. While the topography of Mexico is characterized by large range of mountains, the topography of SDC is predominantly flat. Given this topographic arrangement, there is a considerable accumulation of sediments in the SDC brought by the rivers.

The fluvial systems running to the Gulf of Mexico in Tabasco and Campeche contribute by bringing sediments with different sizes throughout the coastal line. For example, one finds alluvial deposits, sandbanks, mangrove, and marine terraces from Cenozoic. Similarly from mountainous, igneous rocks from Cenozoic, sedimentary rocks from Mesozoic and Cenozoic, and Metamorphic rocks from Paleozoic were brought there.

State	1995 (mm)	2001 (mm)	2002 (mm)
Campeche	1639.5	1488.1	1641.2
Chiapas	2104.6	2268.6	2092.7
Oaxaca	1922.5	1737.7	1499.2
Quintana Roo	1515.0	1549.8	1519.6
Tabasco	3266.9	2548.4	2318.0
Veracruz	1472.4	1980.3	1290.0
Yucatan	909.9	877.8	976.3

Table 3.2 Rain per states in Sonda de Campeche area (INEGI, 2004)

Campeche bay receives a big amount of inland water. Grijalva-Usumacinta Rivers are the most important contributors because they supply 59.4 X 10^9 m^3/ year of liquids coming from runoff systems (Soberon Chavez, 1985). It has been estimated that from 1948 to 1999 their average flow per year is 2 154.0 m^3/s (INEGI, 2004). They have so much influence in their surroundings that they modify texture and chemical composition of sediments, in the same manner as decreasing salinity and temperature in their flows (figure 3.2).

The Grijalva and Usumacinta rivers are part of a big pluvial system, which end in a delta. Both rivers are generated in the Chucumatanes' mountains in Guatemala. The web created by them covers 90 % of Tabasco, and a big portion of Campeche and Chiapas. They add up to a total of 608 km. Their basin is 83213 km^2. The rivers San Pedro and San Pablo are tributaries to Grijalva. They have formed an estuarine system, which includes Paliza River and some small Lagoons located west of Terminos lagoon.

Chumpan River is originated in Campeche's coastal flatness, which drains the west part of Yucatan peninsula, and ends in Terminos Lagoon. The Candelaria river flows east of the same lagoon, it goes along for 150 km; its current initiates in Guatemala. Based in a study from 1953 to 2 000, its flow has been estimated in 51.4 m^3/s, and its basin is 9 628.0 km^2 (INEGI, 2004).

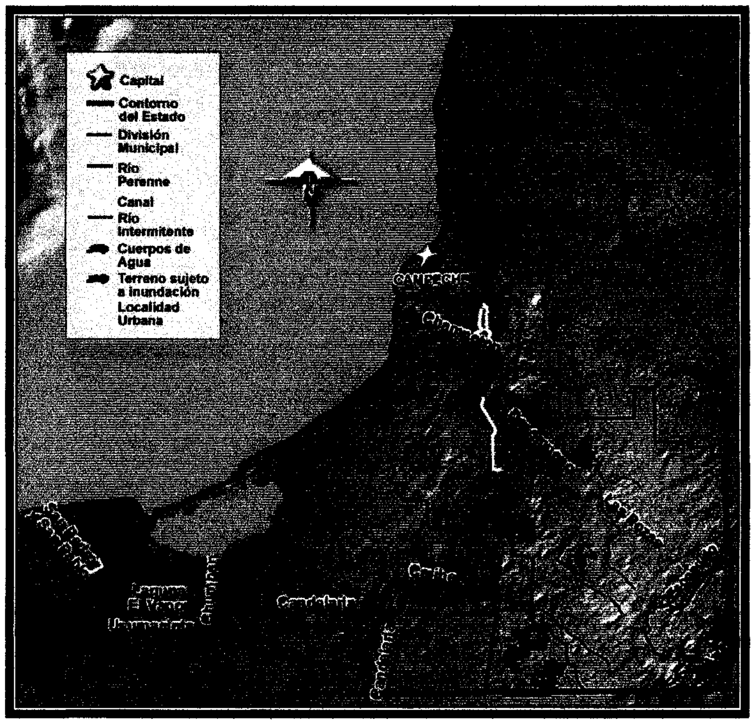


Fig. 3.2 Rivers around Campeche bay (IV)

A series of coastal lagoons surround the Tabasco delta to the west and the Campeche delta plain to the east. Terminos Lagoon is the largest of these coastal lagoons (figure 3.3), its total surface area is 2 500 km^2. Terminos Lagoon is situated between latitudes N 18° 27' 37" and N 18° 47' 36" and longitudes W 91° 14' 44" and W 91° 53' 55". It has and average depth of four meters. This Lagoon is a shallow, calm, and semi-isolated water body from the Gulf of Mexico by Carmen Island. The lagoon forms an eastern boundary to the Usumacinta-Grijalva delta complex; located 90 and 65 km east of the main Grijalva and Usumacinta distributaries, respectively. The lagoon is connected to the Gulf of Mexico by two ocean inlets at both ends of Carmen Island, a 38 km long and 2.5 km wide Holocene, calcareous-sand barrier island. These two ocean inlets are significantly deeper than the lagoon. The southwestern inlet, Carmen inlet, has a mean depth of 6.4 m, a maximum depth of 14 m and measures 3.4 km across. The eastern inlet, Puerto Real, has a mean depth of 5 m, a maximum depth of 12 m and measures 3.2 km across. Highway bridges connect both inlets actually. Another smaller inlet, Sabancuy inlet, connects Terminos Lagoon to the Gulf of

Mexico 43 km to the northeast of Puerto Real inlet via a narrow shore-parallel lagoon system, but the net flow exchange is very small compared to the exchange through the main inlets.

Terminos Lagoon is the link between fresh water coming from Usumacinta River to the south, and seawater of the Gulf of Mexico from North. This marine water mixes with nutrient-rich new water in the Lagoon and returns to the Gulf of Mexico through Carmen inlet. As result, enriched flow of nutrients out Terminos Lagoon supplies with food for numerous fisheries offshore in Campeche bay. Many of these fisheries depend from the shallow waters and mangrove ecosystems of the Lagoon as proper habitat for young fish.

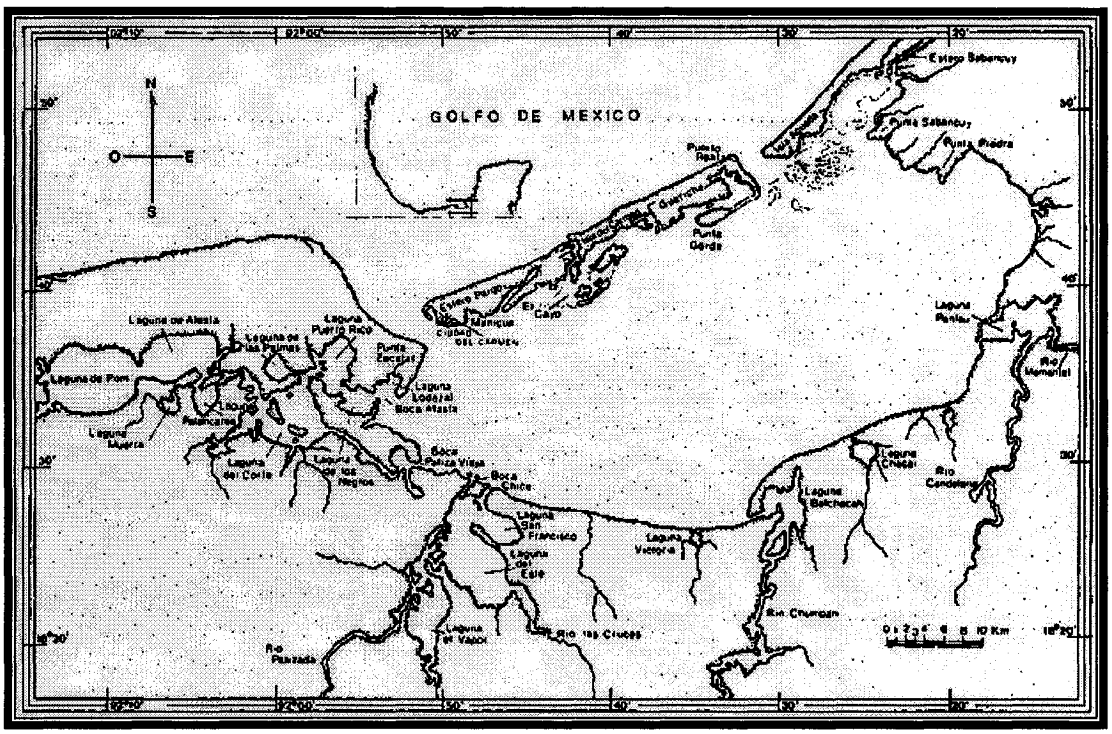


Fig. 3.3 Terminos Lagoon in Campeche bay (V)

3.5 Currents in Gulf of Mexico

The currents in Campeche Bay are affected by those coming from the Caribbean, which go to the North through Yucatan Channel. This current can reach a speed of one knot (one nautical mile per hour, or 1852 meters per hour), in the oriental coastal of the channel, and over five knots in the east of Yucatan peninsula.

The maximum speed is observed from July to September, and the minimum speed from January to February (Pica and Pineda, 1991) In general, Gulf of Mexico and Campeche bay flows follow the same trend that describes an ellipse moving southeast forming a cyclonic ring. However, the topography in Campeche Bank, characterized by low depth and pronounced continental slope, produces changes in currents causing in this way cyclonic and anti-cyclonic rings (Salas de Leon, 1991).

A current path has been identified, and some specific flows have been well defined, as it is illustrated next. First, there is a current getting in from Yucatan Channel to Campeche bay, and then escaping through Florida Strait. It is named "Corriente de Lazo", or loop current, which is showed in figure 3.4. The speed of the current has been estimated to be 1.0 m/s in the Yucatan Strait, falling off to 0.4 m/s at 1000 m depth (Vidal, 1994).

This water movement creates a cyclonic ring from February to April, tending to disappear in SDC. Secondly, a main current goes with direction Northeast during August to December; it is intensified by winds arriving from the North, which causes a cyclonic ring moving east throughout the coastal line in opposite direction. Finally, an anti-cyclonic ring is formed from the "Corriente de Lazo", and it moves west, in conjunction with small anti-cyclonic rings located on Campeche Bay.

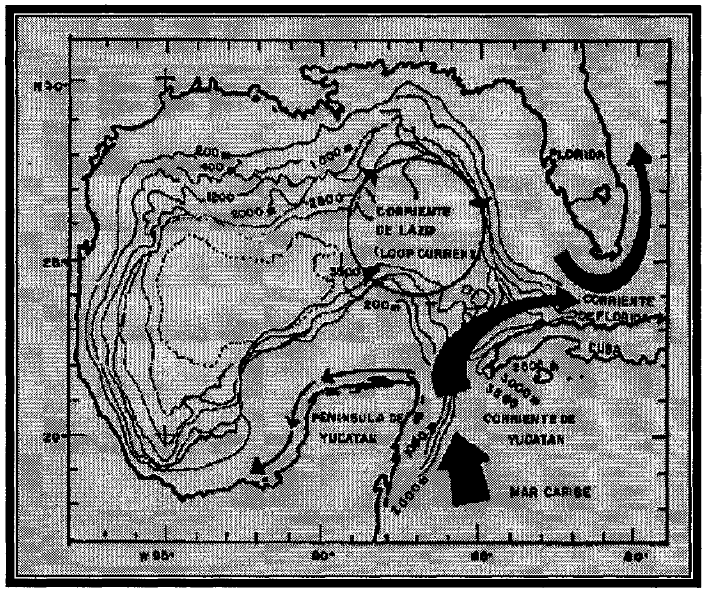


Fig. 3.4 “Corriente de Lazo” in the Gulf of Mexico (VI)

The cyclonic ring in Campeche Bay has been studied for many years (Monreal Gomez, and Salas de Leon, 1990), and important information has been obtained from those observations. For instance, during February the ring covers the entire bay until March; its center moves slightly west, increasing the magnitude of the current. In April the ring gets weak, and the flow decreases in the interior of the bay, mainly in the south coast; this variation is necessary to make a change in direction for the coming months. In May the cyclonic ring almost disappears completely, and the current goes from east to west. In June the current is intensified, but still does not form a cyclonic ring, it starts on the west coast of Yucatan Peninsula during July. Next, from August to September, the currents are modified obtaining a new cyclonic twist, which is extended to the whole Bay continuing it throughout from September to December. During all this time its center just changes locations going somewhat west.

3.6 Atmosphere

The Gulf of Mexico is influenced by the exchange of cold and dry air coming from North America with tropical marine air coming from the Gulf. The interaction generates formation of weather fronts, mainly between October and April. On the other hand, tropical and homogeneous characteristics, caused by trade winds, are seen during summer periods along the Gulf of Mexico.

The direction of winds varies in the region, however a tendency from North and Northwest are observed more often. Winds coming from North are experienced 36 % along a year, commonly from November to March, their average speed is 20.4 km / h, and reaches a maximum of 21 m/s from December to February (Salas de Leon, 1992). Winds have a big influence on the atmosphere around Campeche bay, causing cooling and mixture among them. During April and May winds arrive from the Southeast with a speed of 14.8 km/h. From June to August they come from the East with an average speed of 11 km/h, and from September to October they blow from the Northeast at 16.47 km/h.

3.7 Marine area

Campeche bay is described as a large flat surface. It is 160 km wide with an approximate slope of 1:580 until marine abysmal is reached between 45 and 65 km offshore (Ayala Castanares, and Gutierrez Estrada, 1990). To this point, the ocean depth is 130 m and from there, increases rapidly (figure 3.5).

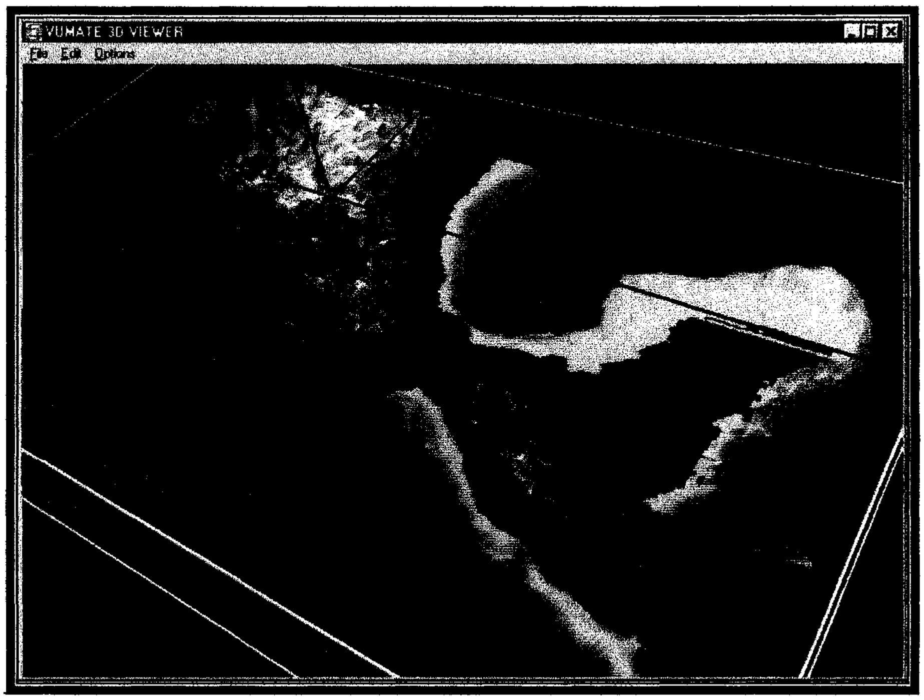


Fig. 3.5 Bathymetry in the Gulf of Mexico (VII)

3.8 Marine flora

Several factors such as temperature, solar radiation, light intensity, salinity, depth in the ocean, nutrients, and currents affect distribution and abundance of marine plants. Based on temperature, the flora in Gulf of Mexico has been categorized into three areas: a) tropical with affinity to Caribbean b) moderated temperature with affinity to Northeast of U.S.A. and c) wide distribution and tolerance to temperatures.

3.8.1 Macro-Algae

Mexico has great diversity of natural resources. Among them, seaweeds represent a main component of aquatic environment. The main purpose of seaweeds in natural communities is primarily reproduction, they give re-circulation to dissolved organic substances, and moreover they accumulate and consolidate the sea floor decreasing their erosion (Santelices, 1977). There are some factors that determine the seaweed's distribution as light, temperature, depth in the ocean, nature of sea floor and tides (Lobban and Harrison, 1997; Graham and Wilcox, 2000).

In Tabasco, 30 species have been reported. One classified as Phaeophyta, and 29 of these classified as Rhodophyta. It is important to notice that there are no green seaweeds (Callejas, 2002). The lack of rocky substrate in Tabasco's coastal line is confirmed. Data reported for Campeche State indicates a total of 149 species, from which 60% (90 species) are grouped as red seaweeds, 30% (44 species) as green seaweeds, and 10% (15 species) as brown seaweeds. Callejas (2002) has recently found 24 new species; as examples for Chlorophyta (green seaweed) are Cladophora prolifera, Acetabularia schenckii, Ulva lactuca, and Halimeda tuna. As for Phaeophyta (brown algae), Dictyota cervicornis, Padina pavonica, Dictyopteris jamaicenis, and Sargassum vulgare are very representative. Finally, in the group of Rhodophyta (red algae), the most representative are Dasya ocellata, Gracilaria mammillaris, Scinaia complanata, and Halimenia floresia. In addition to this, there are some algae that have been present for many years in SDC, for example: Caulerpa cupressoides, Halimeda discoidea, Acetabularia crenulata, Padina gymnospora, Hincksia mitchelliae, Acanthophora spicifera, Meristiella gelidium, and Gracilaria blodgettii, just to mention some.

From an economic point of view, algae in SDC are divided in to three groups. Red algae are used in the medical, cosmetology, and food industry. Green seaweeds are utilized as antibiotics and as human food. Brown algae are used as food and in the cosmetology industry (Aguilar, 1998 and Robledo, 1998).

Two species of seaweed plants have been registered, which are Sargassum Natans, and S. Fluitants. The first is the most common with 95 % of floating community. Moreover, 12 species of benthic plants (table 3.3) live in the area (El-

Sayet, 1972). From the biological point of view, the region of concern is a highly productive area comparing with the rest of Gulf of Mexico and Caribbean.

Species
Acanthophora spicifera
Botbryeladia occidentails
Colpomenia sinuosa
Digenia simplex
Halimeda opuntia
Sargassum pteropleuron
Acetabularia crenulata
Caulerpa mexicana
Cymopolla obstusada
Galaxaura obtusada
Halymenia floresia
Stypopodium zonale

Table 3.3 Benthic plants in SDC (PEMEX, 2001)

3.8.2 Phytoplankton

The phytoplankton is a community conformed by micro-algae suspended in the water column. They are exposed to water movements. In a marine environment the most abundant ones are diatoms and dinoflagellates. Other groups named phytoflagellates are relevant for the coastal portion. In general, diatoms dominate the marine phytoflagellate communities when there are nutrients in abundance. However, when nutrients increase, some species of dinoflagellates or phytoflagellates are able to respond creating algal blooms (red tides).

Red tides or brown tides are basically an increased abundance of any species above normal background numbers in a specific geographic area. When the bloom occurs out at sea, there's usually little negative impact. Fish in the open ocean usually are accustomed to traveling large distances, and water is deep. But when it happens close to shore, blooms suck all the oxygen out of the water, suffocating less mobile fish (Brahm Rosensweig, 1998).Throughout Tabasco and Campeche coastal line, the plankton flora has registered 416 taxa (species, varieties, and forms) related to nine groups of algae, being the most diverse Bacillariophyta (Meave del Castillo, Ma. Esther, 2000), see table 3.4.

Group	Classes	Families	Genres	Species
Bacillariophyta	3	55	101	303
Chlorophyta	2	5	5	5
Chrysophyta	2	2	3	5
Cryptophyta	1	1	1	1
Cyanophyta	1	4	7	12
Euglenophyta	1	1	1	1
Prymnesiophyta	1	8	8	11
Dinophyta	1	22	22	77
Rhodophyta	1	1	1	1
Total	13	99	149	416

Table 3.4 Algae by taxonomic group in SDC (Meave del Castillo, 2000)

Data about primary productivity in costal area in SDC is scarce. However Terminos Lagoon shows the biggest amount of data, but the majority of them are in different units, they were obtained from diverse methodologies, or they correspond to different climatic seasons. But over all, the value of Terminos Lagoon during dry season is about 276 mg C/m^2/year (milligrams of carbon incorporated into cellular material per unit area of ocean per year) according to Day (1981).

The lowest produced biomass in Gulf of Mexico is made during spring and summer. In the same period, there is a production of 422 mg C/m^2/day in the

Campeche Bank, which means that for the same period of time, there are areas where its fertility differs from the Bank (Licea and Santoyo, 1991).

3.9 Marine fauna

Ecosystems around the study area are considered as particularly important for Mexico, from the point of view for fishing and energy. It is an essential biological area, due to its great heterogeneity in habitat, likewise its connection with diverse delta systems that favors the establishment of diverse animal groups. In general, marine fauna there add a total of 584 species (table 3.5).

Taxonomic group	Number of species
Crustaceans	204
Polychaete	142
Nematodes	107
Mollusks	78
Fishes	39
Mammals	5
Echinoderms	5
Cnidarians	2
Nemertinos	1
Sipunculans	1
Total	584

Table 3.5 Number of species by taxonomic group in SDC (PEMEX, 2001)

3.9.1 Zooplankton

In Campeche Bay three main communities have been identified: Zooplankton, Ichthyoplankton, and Fish larvae. It has been found that the distribution of these organisms is linked to the cyclonic ring and the discharge from Usumacinta

River; which works as a transporting system between oceanic and coastal waters.

Gomez Ponce (1997) mentions salinity as a relevant factor for distribution and abundance of larvae, being summer-fall seasons more favorable for them to survive (table 3.6).

Family	Scientific name	Season
Bothidae	Syacium guntari	"North" and raining
Bregmacerotidae	Bregmaceros cantori	"North" and raining
Carangidae	Chicroscombrus chrysurus	"North" and raining
Clupeidae	Etrumeus teres	Raining
Cynoglossidae	Symphurus plagiusa	"North" and raining
Scombriade	Auxis spp	Raining
Synodontidae	Synodus spp	Raining

Table 3.6 Zooplankton (Ichthyologic larvae) in SDC [PEMEX, 2001]

3.9.2 Marine Mammals

Migratory marine mammals are usually observed in SDC. The most abundant species are dolphins; especially Bottlenose Dolphins, Spotted Dolphin, and Common dolphin (Delphinus spp) see table3.7.

Common name	Scientific name	Season
Bottlenose Dolphins	Tursiops truncatus	Dry and rain
Spotted Dolphin	Stenella plagiodon	Dry and rain
Common dolphin	Delphinus spp	Dry and rain
Bryde's whale	Balaenoptera edeni	Dry and rain
Humpback Whale	Megaptera novaengliae	Dry and rain

Table 3.7 Marine mammals in SDC (PEMEX, 2001)

3.9.3 Fishes

The richness of its fishing sources and ecological diversity in SDC are dependant on the diversity of habitats in the coastal line zone. 75 % of fishing species depend on lagoon systems. Several studies (Yanez Arancibia, 1994), have suggested the existence of certain patterns for migration and colonization of coastal habitat, and numerous interactions among the fishes from the continental platform, and the others from inland-protected waters.

Species of fish live preferably in the continental platform. They move to lagoons for alimentation and upbringing. They stay seasonally offshore and partially in lagoons where they grow, and feed. The fishes spend the majority of their time inside a lagoon. Species related with estuaries, they are found in the continental platform without evident fluctuations Yanez Arancibia, (1994). Fishes in the area have been classified with 39 species.

3.9.4 Benthos

Benthos refers to all organisms spending their lives partially or totally in a close relation with the sea floor. Usually they have little mobility depending on the texture, and consistency of the place where they live as well as their capacity to transform it. These organisms base their importance in their close dependency with the place that they occupy. Benthos can be used as indicators in case of an environmental accident in whatever sea floor place because sediments can catch and store more substances and materials that have been accumulated.

a) Polychaetes

They can be found in any latitude and depth, as well as in any kind of environment. Usually they constitute between 50% and 70% in benthos fauna under regular conditions, and between 50% and 90% in contaminated or disturbed environments. For these reasons some of these species have been used as indicators of pollution for monitoring studies (Reish and Gerlinger, 1997). The majorities of the 80 species, grouped as polychaetes, are observed during the dry and rain season, while 41 of them are just seen during the dry season, and 21 during rain season. In general a decrease in abundance of dominant species is detected during the dry season, which might be related to severe conditions during that period. On the contrary, species such as Cossura delta takes advantages of these conditions to reproduce because there are less fauna competing for the same space and resources (Granados Barba, 1994).

b) Crustaceans

From a fishing point of view, SDC is a very important area for the volume and high commercial value of these species, in particular macro-crustaceans are the most diverse and abundant group in that area (Vazquez Bader, 1996). The Campeche Bank constitutes a perfect habitat for a considerable number of crustaceans. Approximately 90% of them are captured in that Bank, which is composed of estuarine and coastal species. They lay their eggs in shallow waters (continental platform), while larvae move to be better-protected areas in the coast, where they stay until achieving enough maturity to survive by themselves.

c) Mollusks

As part of the benthic fauna, they are very important group of invertebrates in conjunction with the other two mentioned before. Mollusks are abundant in density and biomass, and well distributed. Sometimes they are associated with disturbance in environments because some of their species has been registered as bio-indicators; in fact after polychaetes they are the most resistant group to harmful conditions. Dominant species for the Gasteropoda class are: Marginella lavalleena, Nautica pusilla, Olivella dealbata, Niteoliva minuta, Strombus alatus, and Dentalium rebeccaense. In the case of mollusks classified as Scaphopoda, Dentalium rebeccaense shows the major abundance, and they are seen during the dry season.

3.9.5 Species with commercial value

According to "Atlas pesquero de Mexico 1994" (Secretaria de Pesca, 1994), there are five species of crustaceans, nine of fishes, and one of mollusks that are commercially important to Mexico (table 3.8)

Group	Scientific name	Common name
Crustaceans	Penaeus aztecus	Brown Shrimp
	Penaeus duorarum	Pink Shrimp
	Penaeus setiferus	White shrimp
	Callinectes sapidus	Blue Crab
	Callinectes similis	Lesser blue crab
Fishes	Arius felis	Hardhead Catfish
	Carcharhinus ssp.	Bull shark
	Cynoscion nothus	Silver Seatrout
	Raja texana	Prickly Skate
	Bagre marinus	Gafftopsail Catfish
	Epinephelus niveatus	Snowy grouper
	Harengula jaguana	Scaled sardine
	Lutjanus campechanus	Red snapper
	Lutjanus synagris	Lane snapper
	Eucinostomus gula	Jenny mojarra
	Cynoscion nothus	Silver seatrout
	Syacium gunteri	Lenguado
	Cyclopsetta chittendeni	Mexican flounder
Mollusks	Busycon perversum	Lightning Whelk

Table 3.8 Fauna with commercial value in SDC (PEMEX, 2001)

3.9.6 Species with sport fishing value

There are some favorite species preferred by sport fishers in SDC (table 3.9). Among these animals, the Lutjanus campechanus is in great demanded by fishermen.

Group	Scientific name	Common name
Fishes	Carcharhinus spp.	Bull shark
	Epinephelus niveatus	Snowy grouper
	Lutjanus campechanus	Red snapper
	Lutjanus viridis	Blue and Gold Snapper

Table 3.9 Species with sport fishing value in SDC (PEMEX, 2001)

3.9.7 Threatened or endangered species

The regulation NOM-059-ECOL-2001 stipulates the Humpback Whale (Megaptera novaengliae) as an animal protected by the Mexican legislation; officially it is categorized as specie with special protection. SDC five types of marine turtles, four species of marine mammals, which are registered as threatened or endangered species; they are shown in table 3.10.

Group	Scientific name	Common name	Categorization
Marine turtles	Eretmochelys imbricata	Hawksbill Turtle	Endangered specie
	Dermochelys coriacea	Leatherback Sea Turtle	Endangered specie
	Chelonia mydas	Green sea turtle	Endangered specie
	Lepidochelys kempii	Kemp's ridley sea turtle	Endangered specie
	Caretta caretta	Loggerhead sea turtle	Endangered specie
Marine Mammals	Megaptera novaengliae	Humpback Whale	Special protection
	Tursiops truncates	Bottlenose Dolphins	Special protection
	Delphinus spp	Common dolphin	Special protection
	Balaenoptera edeni	Bryde's whale	Special protection

Table 3.10 Endangered fauna in SDC (PEMEX, 2001)

There are eight varieties of plants that has been categorized as protected by law, see table 3.11.

Group	Scientific name	Common name	Categorization
Flora	Bravaisia integerrima	Zenate	Threatened specie
	Tabebuia chrysantha	Trumpet Tree	Threatened specie
	Conocarpus erecta	Buttonwood	Special protection
	Laguncularia racemosa	White mangrove	Special protection
	Avicennia germinans	Black mangrove	Special protection
	Rhizophora mangle	Red Mangrove	Special protection
	Vatairea lundellii	Danto	Endangered specie
	Nelumbo lutea	American Lotus	Threatened specie

Table 3.11 Endangered flora in SDC (PEMEX, 2001)

3.10 Social and Economic Environment

The extraction of crude oil in "Sonda de Campeche" has provoked constant changes in the society structure in that area. Oil industry directly or indirectly affects other businesses related to their services. It creates demand for medical services, accommodations, restaurants, transportation, collection of garbage, beside water and electricity supplies.

The demand for personnel (to attend the oil industry requirements) has resulted in a concentration of population with a big demand for goods and services. Contrary to what could be expected with an increase labor source, a rise in services would come together; these circumstances have not been observed in SDC. The economic development brought by oil industry has not guaranteed the development of the local society. There is a lack of better distribution of economic benefits, or sustainability of the natural environment.

A lack of a better social program in the area led to two main problems. First, a temporally migration has caused an over population in the nearby principal cities in SDC to the detriment of their functionality. Also, population has been perceived to be economically not sustainable around these places. An irrational use of land and a deterioration of natural resources in the region are the result of this development.

3.10.1 Demography

The demographical increase in "Sonda de Campeche" region has been accelerated due to their direct relation to economic activities related to management of natural resources (fishing and oil industries mainly). The opportunity to find better-remunerated jobs has increased the immigration to specific cities in SDC's area, as Carmen municipality (Carmen Island, and Atasta) in Campeche State, also Centro municipality (Villahermosa), and Paraiso municipality (Dos Bocas) in Tabasco State.

According to the most recent census in 2000 in Carmen municipality there is a population of 172 076 habitants (INEGI, 2000). In 2002 Campeche State registered 736,839 inhabitants, in a surface of 57,033 km^2, and a coastal line of 425 km (SCT, 2002). In the 2000 census, the Centro municipality shows 520 308 habitants, with 252, 955 categorized as men, and 267, 353 as women. For Paraiso municipality statistics display that there are 70, 764 habitants, being 34, 906 males, and 35, 858 females (INEGI, 2000). The total population in 2002 for Tabasco State was 1,996,050 individuals, in an area of 24,612 km^2, and a coastal line of 200 km (SCT, 2002).

3.10.2 Migration

The oil industry has created a demand for working labor specialized in diverse areas corresponding to their production, which usually attracts personnel from other areas of Mexico. This migratory tendency has contributed to the increase of the population in SDC, mainly in "Ciudad del Carmen" (figure 3.6). This city was not prepared to absorb that increase in population. A social and environmental unbalance is experienced in that place. Since 1990, concentration of population has become a critical issue in "Ciudad del Carmen". It is caused by a temporary migration that moves to the Island, but never stays permanently. A study has been done by the "Instituto Mexicano del Petroleo" in 1999, which has determined that the temporary migration is 5,200 persons/day.

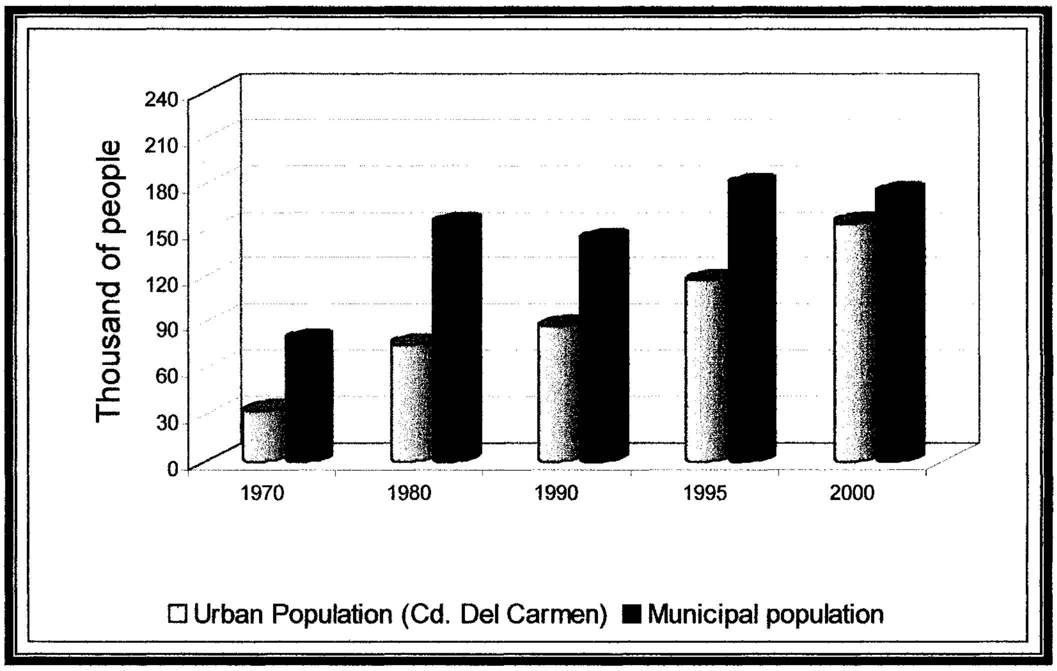
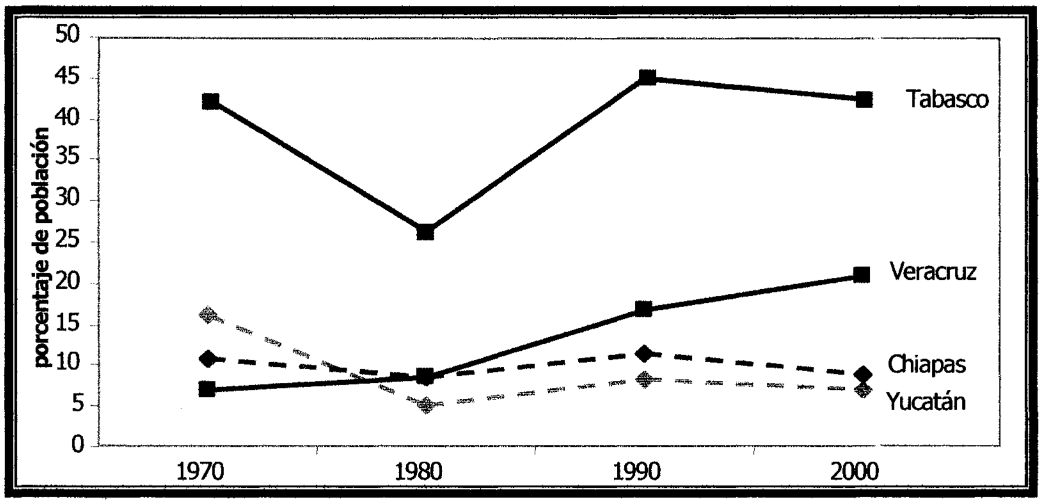


Fig. 3.6 Population in "Ciudad del Carmen" from 1970 to 2000 (Guzman Gaytan, 2002)

Censuses show an important displacement of people to Carmen municipality, they came from outside Campeche's borders. The first migration was induced by fishing fever for shrimp, and creating the infrastructure for oil production in the decade of the seventies (14% of total population augmented) according to "INEGI, IX Censo General de Poblacion y Vivienda del Estado de Campeche 1970" (Guzman Gaytan, 2002). During those years, 76.4% of immigrants arrived from States with fishing skills, and low training in manufacturing as "Tabasco", "Yucatan", "Chiapas" and "Veracruz" (figure 3.7). The second displacement of people was provoked by activities associated exclusively with the exploitation of crude oil during the eighties, and nineties (9.3 % of total population increased), based in "INEGI, IX Censo General de Poblacion y Vivienda del Estado de Campeche 1990".



"porcentaje de poblacion" = population percentage

Fig. 3.7 Population in Carmen municipality according to their place of birth from 1970 to 2000 (Guzman Gaytan, 2002)

3.10.3 Ethnic groups

Mayas is the most important ethnic group in Campeche State, who are distributed all over Yucatan Peninsula. Three main indigenous communities including 4,475 "Maya", 4,475 "Chol", and 266 "Tzeltal" were living in Carmen municipality in 1995.

3.10.4 Housing and urban development

Fast oil industrial development linked by a migration of workers to specific municipalities in SDC ("Carmen", "Centro", and "Paraiso"), has resulted in a lack of municipal and public services, and inadequate housing (table 3.12).

Material	Campeche State	Carmen Municipality	Tabasco State	Centro Municipality	Paraiso Municipality
Total housings	156,125	39,964	410,388	122,376	15,166
Floors					
Soil (nh)	21,841	4,614	52,039	6,160	1,133
Cement (nh)	76,423	22,612	278,624	72,547	11,110
Wood, mosaic and another covering (nh)	57,203	12,493	77,975	43,119	2,852
Walls					
Cardboard sheet (nh)	4,533	3,040	3,287	1,089	16
Reed, bamboo or palm (nh)	1,706	992	28,426	3,031	1,519
"Embarro"* (nh)	6,760	39	485	52	10
Wood (nh)	32,922	6,812	37,188	2,631	253
Metallic sheet or asbestos sheet (nh)	1,621	1,196	16,456	7,490	37
Adobe (nh)	353	69	583	91	11
Partition, brick, block, stone (nh)	106,889	27,327	319,961	106,960	13,168

"Embarro"* is similar to adobe, but it is made from a mixture of clay, water, animal Manure, and smashed cactus

nh = number of houses

Table 3.12 Housing in Campeche and Tabasco classified by materials used in floors, walls, and ceilings (INEGI, 2000)

Material	Campeche State	Carmen Municipality	Tabasco State	Centro Municipality	Paraiso Municipality
Roofs					
Cardboard sheet (nh)	23,043	4,244	7,574	852	572
Palm or wood (nh)	15,853	1,453	16,408	901	135
Metallic sheet or asbestos sheet (nh)	48,667	17,054	215,996	48,288	7,192
Roofing tile (nh)	779	257	45,196	5,988	4,364
Concrete, partition or brick (nh)	66,694	16,557	121,010	65,614	2,797

nh = number of houses

Table 3.12 Housing in Campeche and Tabasco classified by materials used in floors, walls, and ceilings (cont.) [INEGI, 2000]

In recent years, distributors of construction material have speculated with their merchandise provoking auto construction. To eliminate monopolistic characteristics, and to solve the unregulated housing problem, planning of proper urbanized growing areas in the cities has been implemented. It has not given the expected results because there is a lack of capital to support basic public projects as drainage, sewage, and treatment of residual waters.

3.10.5 Transportation infrastructure

Since 1995 the Carmen Municipality have had a road infrastructure of 345.5 km main paved roads, from which 82.3 km correspond to secondary paved roads, 229.8 km rural paved roads, and 4 km not paved roads. The federal road 180, connects “Ciudad del Carmen” with the rest of the country along the Gulf of

Mexico, and its north limit "La unidad" bridge was built (3.2 km long) to connect them to "Arena" Island. In the south "Zacatal –Carmen" bridge was built in 1994 (3.5 km long) to link Carmen with "Atasta" peninsula. Moreover, there are other smaller bridges as "Sabancuy" bridge with a length of 500 meters, and others with a length of only 10 meters (Guzman, 2002).

Train service is very important for SDC as it is for Carmen municipality. In total, 715.8 km of train road between Campeche and Tabasco is available to transport almost all goods. For instance, 602 422 ton of petroleum and its sub-products, 27 503 ton of industrial products, 6, 710 ton of agricultural products, and 142 ton of forest products were transported by train in 1998 (INEGI, 1999).

Domestic and international flights have been increased in the last 20 years in SDC. Campeche State has two airports ("Campeche" and "Ciudad del Carmen"), and Tabasco state just one ("Villahermosa"). The aerial infrastructure in SDC is complemented by heliports located in several offshore platforms, which permits the transport of specialized personnel and lightweight equipment by helicopter to those platforms. In 1997, 120,342 passengers were received in Carmen airport through 4,470 flights, divided in 4, 139 domestic, 331 international (INEGI, 1999).

Marine transportation in Carmen Municipality is supported by shipyard areas. Wharves extend for 2 km of coastal line.

A short description of transportation details are given in table 3.13.

		Campeche State	Tabasco State
Highways and roads	Paved roads with two rails (Km)	3,305	3,855
	Paved roads with fourth or more rails (Km)	57	118
	Not Paved roads (Km)	1,407	4,647
	Total (Km)	4,769	8,620
Train road	Main railroad (Km)	358.9	256.5
	Secondary railroad (Km)	32.9	29.5
	Railroad constructed with private capital (Km)	23.8	14.2
	Total (Km)	415.6	300.2
Airports	Campeche airport, landing strip (m^2)	112,500	NA
	Ciudad de Carmen airport, landing strip (m^2)	99,000	NA
	Villahermosa airport, landing strip (m^2)	NA	99,000
Marine ports	Cayo Arcas, movement of load (tons)	49,293,588	NA
	Ciudad del Carmen, movement of load (tons)	173,335	NA
	Lerma, movement of load (tons)	712,431	NA
	Seybaplaya, movement of load (tons)	32,163	NA
	Dos Bocas, movement of load (tons)	NA	31,000,237

NA = Not Applicable

Table 3.13 Transportation in Campeche and Tabasco (SCT, 2002)

3.10.6 Potable water, sewage system, drainage, and electricity

In “Ciudad del Carmen” in 1995 there were 15, 145 houses with potable water inside the house, 11 586 outside the house but still on their property, 525 from a public valve or hydrant, 12 234 did not have direct supply, and 79 were not specified. The sources for potable water in the municipality have been deep wells. In 1997, 73 sources existed, from which 67 were deep wells with an extraction flow of 25 100 m^3/day. Also there were four drainage galleries, from which 200 m^3/day were taken, (INEGI, 1999). The drainage system has improved compared with 1995, when 1, 428 houses were connected to public drainage, 26,739 were discharging in septic pits, 214 to rivers or to the ocean, 197 to ravines, and 10, 925 houses did not have drainage (INEGI, 1999). The electric system in the island is formed by two electrical substations. With respect to housings in the municipality, in 1995 there were 34, 036 homes with electricity, and 5,470 without the service (INEGI, 1999). To complement the formation mentioned above table 3.14 is included to show more recent information (2000) about the sewage system, drainage, water supply, and electricity in Campeche and Tabasco (Guzman, 2002).

Public services	Campeche State	Carmen Municipality	Tabasco State	Centro Municipality	Paraiso Municipality
Total housings	156,125	39,964	410,388	122,376	15,166
Sewage system					
With sanitary exclusive service (nh)	126,421	35,936	360,678	114,964	13,742
Without sanitary exclusive service (nh)	29,704	4,028	49,710	7,412	1,424

nh = number of houses

Table 3.14 Housing in Campeche and Tabasco with sewage system, drainage, and water supply, and electricity (INEGI, 2000)

Public services	Campeche State	Carmen Municipality	Tabasco State	Centro Municipality	Paraiso Municipality
Drainage					
With service (nh)	99,589	30,805	350,280	116,469	13,817
Without service (nh)	56,536	9,159	60,108	5,907	1,349
Water supply					
With direct water supply (nh)	133,668	32,336	307,368	112,815	12,054
Without direct water supply (nh)	22,457	7,628	103,020	9,561	3,122
Electricity					
With service (nh)	142,420	37,628	385,569	120,121	14,596
Without service (nh)	13,705	2,336	24,819	2,255	570

nh = number of houses

Table 3.14 Housing in Campeche and Tabasco with sewage system, drainage, and water supply, and electricity (cont.) [INEGI, 2000]

3.10.7 Health and education systems

In the health department, the service is supported by medical centers as “IMSS” (Mexican social insurance Institute), “ISSSTE” (Social insurance and Services for Government workers Institute), “SEDENA” (National Defense Secretary), private hospitals, Red Cross, and PEMEX hospital. The help given by these institutions is considered first and second level. First level corresponds to emergency attention, and second level refers to minor surgery, hospitalization, and surgery.

Public and private schools sustain the educational system in Mexico, and "Ciudad del Carmen" is not an exception. In table 3.15 shows the general perspective of the health and educational system in Campeche and Tabasco.

Public services	Campeche State	Carmen Municipality	Tabasco State	Centro Municipality	Paraiso Municipality
Total population (hab)	690,689	172,076	1,891,829	520,308	70,764
Health system					
Covered by health system (hab)	265,189	76,661	555,359	234,341	21,564
Not covered by health system (hab)	425,500	95,415	1,336,470	285,967	49,200
Education system					
From grade one to six (ns)	282,020	65,818	802,129	174,449	31,346
From grade seven to nine (ns)	110,580	30,800	331,800	100,797	12,845
From grade ten to twelve (ns)	70,319	20,018	188,091	76,104	7,285
Undergraduate studies (ns)	41,612	10,598	104,296	58,012	3,689
Graduate studies (ns)	2,077	667	3,900	2,376	161

hab = habitants; ns= number of students

Table 3.15 Health and education systems in Campeche and Tabasco (INEGI, 2000)

3.10.8 Employment

Tabasco and Campeche are especially relevant for Mexican economy, some activities such as exploration, extraction, processing, distribution, and commercialization of petroleum; activities related to fishing industry, and loading and unloading of goods in marine ports are distinctive to that region. A special mention has to be made for construction, installation and operation of offshore platforms, which demand an immense amount of manpower. This demand is temporary; the increases are during the construction and installation periods. It decreases during the operation phase.

An indirect demand for services is created by the oil industry as supply of food, fuel and materials to the platforms. Transportation of personnel for each subcontracted company is also important. Likewise a request for services as communication, education, health, and commerce has been generated by the same industry (table 3.16).

Activities	Campeche State	Carmen Municipality	Tabasco State	Centro Municipality	Paraiso Municipality
Agriculture, cattle, forest utilization, fishing and hunting (w)	60,737	10,184	167,315	15,341	4,840
Mining industry (w)	6,006	5,073	17,137	6,814	2,304
Electrical industry and water supply services (w)	999	194	3,066	1,495	103
Construction industry (w)	22,959	7,004	44,227	15,531	1,647
Manufacturing industry (w)	22,153	4,219	46,763	15,354	1,867
Commerce (w)	34,271	9,370	86,521	36,173	2,835
Transports, post office and storage (w)	8,031	2,617	22,078	9,831	800
Media industry (w)	1,557	352	4,379	2,574	78
Financial services and insurances (w)	1,030	273	2,360	1,680	30
Real-estate services and rent of furniture (w)	627	228	1,611	1,106	35

w = number of workers

Table 3.16 Employments in Campeche and Tabasco classified by activities (INEGI, 2000)

Activities	Campeche State	Carmen Municipality	Tabasco State	Centro Municipality	Paraiso Municipality
Professional services (w)	3,600	1,246	9,416	5,556	293
Services of support for businesses (w)	3,314	1,541	8,180	4,569	246
Educational services (w)	16,925	2,942	34,881	13,764	1,273
Health services and social assistance (w)	7,165	1,351	18,094	10,015	407
Recreation and cultural Services (w)	1,488	354	3,439	1,629	97
Hotels and restaurants services (w)	11,233	3,855	24,009	10,688	814
Other services, except working for the government (w)	21,747	5,859	58,982	22,613	2,290
Working for the government (w)	14,841	2,201	33,758	13,713	778
Not specified (w)	4,640	2,072	14,094	5,235	572
TOTAL	243,323	60,935	600,310	193,681	21,309

w = number of workers

Table 3.16 Employments in Campeche and Tabasco classified by activities (cont.) [INEGI, 2000]

In Mexico there are three economic regions ("A", "B", and "C"); from which Campeche and Tabasco are part of the "C" region that correspond to certain minimum salary. The minimum salary (MS) is the lower remuneration that a worker must receive for his or her services during a working day (eight hours) according to Mexican laws. In 1998 the MS for those states was 26.05 Mexican pesos (approximately 3.25 Canadian dollars). The 33 % of economical active population were receiving from one to two MS, and 9.6 % were obtaining more than five MS (INEGI, 1999). Since January first 2004, the MS for a "C" region has been increased to 42.11 Mexican pesos (5.25 Canadian dollars more or less). However the salaries of oil workers vary depending of some factors as: benefits, extra time, and level in their companies. New data from 2000 are shown in table 3.17; it represents the number of workers employed in Tabasco and Campeche, categorized by percentages or number MS that they receive for their work.

Minimum salary	Campeche State	Carmen Municipality	Tabasco State	Centro Municipality	Paraiso Municipality
Until 50% (w)	16,690	1,814	32,087	6,037	1,259
From 50% to 99% (w)	37,776	6,479	123,360	21,441	4,515
One (w)	17	1	6	1	0
From 1.1 to 2 (w)	69,570	17,160	148,432	51,550	5,711
From 2.1 to 2.9 (w)	25,822	8,162	69,207	30,027	2,163
From 3 to 5 (w)	27,107	9,350	64,939	30,765	2,265
From 5.1 to 10 (w)	17,361	6,724	47,417	24,390	2,100
More than 10 (w)	8,363	4,686	19,975	12,447	931
Not specified (w)	8,658	2,991	24,868	9,188	1,416
Without salary (w)	31,959	3,568	70,019	7,835	949

w = number of workers

Table 3.17 Salaries in Campeche and Tabasco by minimum salaries (INEGI, 2000)

Chapter Four
Procurement of relevant quality standards and regulations

Offshore oil industry generates a variety of potential effects in the marine environment, and the health of employees living and working in the affected area. For instance, air emissions and water discharges from platforms and their related onshore support operations, or residues from materials used during the explorations and production processes result in the spread of pollution. In Mexico, as in any other part of the world, governmental agencies regulate water discharges, air emissions, and waste management operations. In this section, legislation from Mexico, Canada, and United States related to the offshore industry is addressed. A comparative analysis related to wastewater and atmospheric gas releases will be provided. These regulations cover discharges in air and water for the three countries, as well as waste management of residues for Mexico. All pollutants are generated during the installation and operation of offshore flares. Mexican laws serve to evaluate environmental impacts created in "Sonda de Campeche" by the oil industry for over 30 years in that region.

4.1 Mexican Regulations

Actually, Mexico has environmental regulations covering the entire nation. Nevertheless, there is not a specific law applicable for offshore oil industry operations. Hence, environmental laws from United States and Canada have been used as complementary standards in order to reinforce Mexican regulatory process concerned with this matter.

4.1.1 Atmospheric gas releases

Most of the offshore flares are located downwind from the main platforms in SDC. The pollutants released from the flares are dispersed away from the working personnel or equipment. Only platform HA-AJ-1 is occasionally downwind from flares during morning hours (6:00 AM to noon). This platform is five kilometers away from four large flares. Unfortunately, so far "no data is available to evaluate the impact of this condition in that platform. However, air modeling results suggest that this is not likely to be an area of concern" (Villasenor, and Magdaleno, 2002).

Table 4.1 shows the Mexican environmental limits applicable to the most frequent pollutants coming from offshore flares. As can be noted there are two standards for almost each pollutant; first the "NOM" (standing for Mexican Official Norm), which is applicable for whatever industry under the jurisdiction of the National Mexican territory; second the "PEMEX" internal regulation (NRF-031-PEMEX-2003), Systems for vents and flares in installations belonging to PEMEX for exploitation and production), which has always a higher value compared to "NOM".

Air pollutant	Limit	Regulation	Comments
NO_2	395 μg/m^3 (0.21 ppm)	NOM-023-SSA1-1993	In an hour once a year
	9 400 μg/m^3 (5 ppm)	NRF - 031 - PEMEX - 2003	Parts of gas or steam per million parts of air (in volume)
SO_2	341 μg/m^3 (0.13 ppm)	NOM-022-SSA1-1993	In 24 hours once a year
	79 μg/m^3 (0.03 ppm)	NOM-022-SSA1-1993	In an arithmetical annual average
	26 200 μg/m^3 (10 ppm)	NRF - 031 - PEMEX - 2003	Parts of gas or steam per million parts of air (in volume)

ppm = parts per million; μg/m^3 = micrograms per cubic meter; NA= Not available

Table 4.1 Mexican air environmental regulations used for offshore flares (PEMEX, 2003)

Air pollutant	Limit	Regulation	Comments
PM_{10}	150 µg/m^3	NOM-025-SSA1-1993	In 24 hours once a year
	50 µg/m^3	NOM-025-SSA1-1993	In an arithmetical annual average
CO	12 595 µg/m^3 (11 ppm)	NOM-021-SSA1-1993	In average of eight hours once to the year
	114 500 µg/m^3 (100 ppm)	NRF - 031 - PEMEX - 2003	Parts of gas or steam per million parts of air (in volume)
CO_2	5 000 ppm (9 000 000 µg/m^3)	NRF - 031 - PEMEX - 2003	Parts of gas or steam per million parts of air (in volume)

ppm = parts per million; µg/m^3 = micrograms per cubic meter; NA= Not available

Table 4.1 Mexican air environmental regulations used for offshore flares (cont.) [PEMEX, 2003]

4.1.2 Water discharges

There is no specific norm for discharges of seawater after being used to clean working areas, especially the ones utilized in hydrostatic test for pipelines, or sewage and soapy water generated by workers. However, the international convention for the prevention of pollution from ships (MARPOL 73/78) has been used as a reference for these issues, in the Annex IV (Prevention of Pollution by Sewage from Ships), which indicates that sewage discharges are forbidden except: a) when the ship is releasing sewage previously treated at a distance of more than four nautical miles (7.408 Km) from the closest land, or discharge of sewage without treatment at more than twelve nautical miles (22.224 Km) from the nearest land, ("Ciudad del Carmen" is approximately 43 nautical miles from the platforms) and b) the ship has an approved treatment plant in operation, and two considerations are met; first the result from the plant meets the Ship's

International Sewage Pollution Prevention Certificate, and second the effluent will not have visible floating solids, or discoloration in the surrounding waters.

4.1.3 Waste management of residues

Solid residues created during the installation and operation of offshore flares are regulated mainly by the Mexican standard NOM-052-ECOL-93 and the Annex V from MARPOL 73/78 (Regulations for the Prevention of Pollution by garbage from Ships). NOM-052-ECOL-93 is the Mexican Official Norm which establishes the characteristics of hazardous wastes; it presents a list of them and their limits. This list classifies them as dangerous according to their toxicity. In Mexico, hazardous materials are categorized based on six principal characteristics as follows: how corrosive it is (C), how reactive the substance is (R), how explosive it is (E), their toxicity (T), their inflammability (I), and how biologically infectious it is (B); this criterion is named CRETIB. The procedure to follow to determine that waste is hazardous or not is presented in figure 4.1.

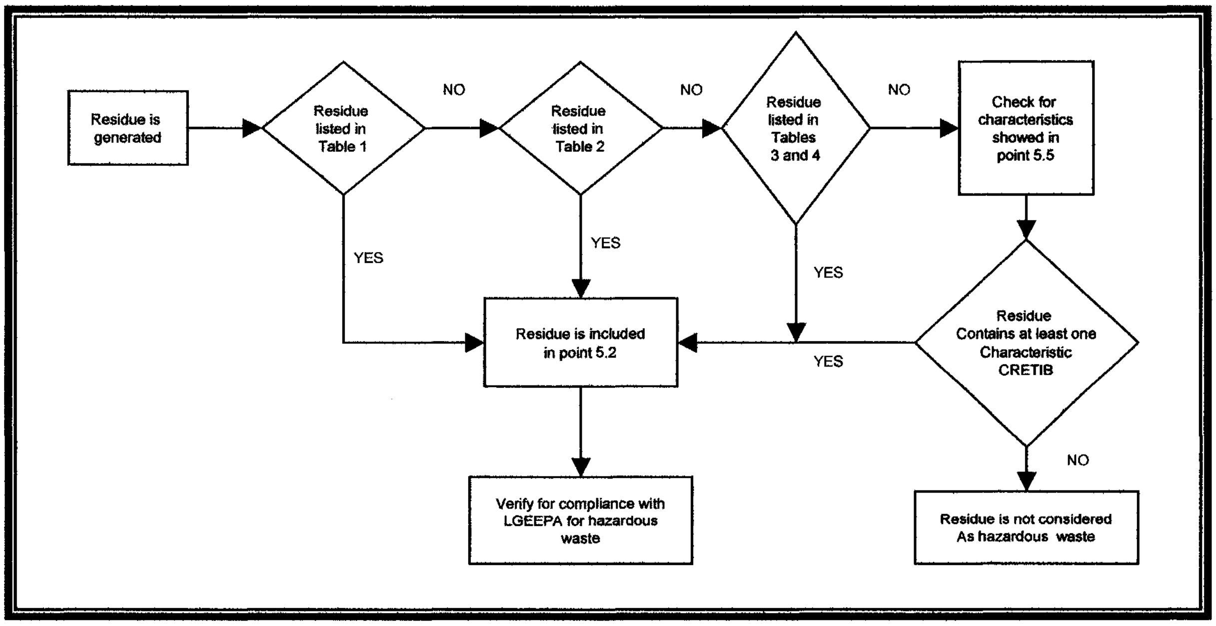


Fig. 4.1 Flow chart used to identify hazardous waste according to Mexican regulation (III)

In this case particularly of offshore flares, the only materials classified as hazardous by NOM-052-ECOL-93 are displayed in table 4.2. Beside the materials displayed in the table below, there are other items generated from offshore flares that are not included in this regulation. However, they are traditionally separated, classified and sent back to the land for final disposal. These materials are sand blast, welding electrodes, plastic and cooper cables, ropes made of polypropylene, oil filters, plastics (bags, glasses, and spoons) and styrofoam (cups, plates, and containers).

Table	Hazardous Waste	Criterion	Classification
1	Discs from grinding	Toxic	RP8.1/02
1	Gloves impregnated with paint their substances to dilute them	Toxic, and Inflammability	RP8.1/05
1	Cans impregnated with paints and their substances to dilute them	Toxic, and Inflammability	RP8.1/05
1	Cotton waste, and wool waste impregnated with paints and their substances to dilute them	Toxic, and Inflammability	RP8.1/05
2	Used oil	Toxic, and Inflammability	RPNE1.1/03
2	Used diesel	Toxic, and Inflammability	RPNE1.1/03
1	Used batteries	Toxic	RP14.1/03 RP14.1/04
1	Paints and solvents	Toxic, and Inflammability	RP8.1/05

Table 4.2 Materials from flares considered as hazardous waste according to Mexican regulations (III)

On the other hand, Annex V from MARPOL 73/78 establishes the disposal of materials into the sea. The garbage disposal has to be done far from the main land, but in any case it is forbidden in a distance less than: a) 25 nautical miles for packing materials that will float, or b) 12 nautical miles for food waste and garbage such as paper products, rags, glass, metal, bottles, and similar. Moreover, the disposal of food waste may be allowed when those residues are able to pass through a screen with openings no bigger than 25 millimeters, as long as the generator is further than 12 nautical miles from the land and all other ships, when the vessel is within 500 meters from a fixed or floating platform.

Currently, Annex I and II from MARPOL are obligatory in Mexico, the rest are optional. Annex V has been approved by Mexico and will soon become obligatory when it will be published in the Official Journal of the Federation. Meanwhile, Mexico has signed other documents related to the prevention of marine pollution as: a) International Convention on high seas intervention in case of accidents that cause pollution by oil spills (Brussels Belgium, 1969), b) International Convention on high seas intervention in case of pollution caused from substances different from oil (London England, 1973), and c) United States of Mexico and United States of America Agreement of cooperation on environmental pollution by oil spills and other toxic substances.

4.2 Canadian Regulations

In this section issues related to air pollution and water discharges for Canadian offshore platforms will be addressed. Inside the section of air contamination, there are two subdivisions. The first regulation is related to air pollution control from the federal point of view. It includes federal regulations and offshore waste treatment guidelines. The second is related mainly to laws of Newfoundland and Labrador, and Nova Scotia.

In the last section regulations for water discharges will be discussed. In this case, the main policy applicable is still the offshore waste treatment guidelines, which makes reference to the maximum values allowed for six important water discharges generated by the oil industry located within Canadians waters.

4.2.1 Atmospheric gas releases

To prevent air pollution in regions under Canadian jurisdiction, the National Ambient Air Quality Objectives (NAAQO) have been created by the federal government through the Canadian council of the environment. These objectives are summarized the table 4.3, which shows the three main levels of pollutants concentration (desirable, acceptable and tolerable) for conventional pollutants (H_2S, NO_2, SO_2, Particulate Matter, CO, and Ozone), based on periods of time of 1 hour, 24 hours, or annually. According to this standard, the three expected values are defined as follows: a) Desirable is considered the most severe of the three, it provides a basis for anti-degradation plan for unpolluted parts of the country and for continuing development of control technology, b) Acceptable provides adequate protection against adverse effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well being, and c) Tolerable (least strict), indicates appropriate abatement strategies needed as soon as possible to prevent further deterioration of the air quality, or to protect the health of the general population.

The Offshore Waste Treatment Guidelines (National Energy Board, 2002) is a document that recommends practices and standards for the treatment and disposal of wastes from petroleum drilling and production operations in Canada's offshore areas and for sampling and analyzing of waste streams to ensure compliance with Canadian standards. The Guidelines were prepared by the National Energy Board, the Canada- Newfoundland Offshore Petroleum Board, and the Canada-Nova Scotia Offshore Petroleum Board, with the assistance of a committee formed by government, industry and public representatives.

Pollutant	Period of time	Desirable	Acceptable	Tolerable
NO_2	1 hour	NA	400 µg/m^3 (0.21 ppm)	1 000 µg/m^3 (0.53 ppm)
	24 hours	NA	200 µg/m^3 (0.11 ppm)	300 µg/m^3 (0.16 ppm)
	Annual	60 µg/m^3 (0.032 ppm)	100 µg/m^3 (0.05 ppm)	NA
SO_2	1 hour	450 µg/m^3 (0.17 ppm)	900 µg/m^3 (0.34 ppm)	NA
	24 hours	150 µg/m^3 (0.06 ppm)	300 µg/m^3 (0.11 ppm)	800 µg/m^3 (0.30 ppm)
	Annual	30 µg/m^3 (0.01 ppm)	60 µg/m^3 (0.02 ppm)	NA
Particulate Matter	24 hours	NA	120 µg/m^3	400 µg/m^3
	Annual	60 µg/m^3	70 µg/m^3	NA
CO	1 hour	15 000 µg/m^3 (13.0 ppm)	34 600 µg/m^3 (30.0 ppm)	NA
	8 hours	6 000 µg/m^3 (5.0 ppm)	12 700 µg/m^3 (11.0 ppm)	20 000 µg/m^3 (17.3)
	24 hours	NA	NA	NA

Note: For standard atmospheric conditions (25°C, 760 mm Hg); µg/m^3 = micrograms per cubic meter; ppm = parts per million; NA= Not available

Table 4.3 Canadian National Ambient Air Quality Objectives (25°C, 760 mm Hg) [Villasenor, 2002 b]

Similarly to the NAAQO, the offshore waste treatment guidelines have been created to conserve good quality values in those regions. It has been considered that air emissions from installations located offshore probably do not provoke important effects in a specific part of the flora or fauna in the surroundings, but they may contribute to increase the values of “greenhouse gas” (GHG). As part of the measures stipulated in these guidelines, each corporation responsible for the offshore installation should, provide an estimate of the annual quantities of GHG that will be emitted from its offshore installation(s) and a description of its plans toward controlling and reducing these gases. This estimation has to be submitted annually to the Chief Conservation Officer no later than March 31 of the following year. These estimates and calculations should be made in accordance with Canadian Association of Petroleum Producers' (CAPP) Global Climate Change Voluntary Challenge Guide (5th Edition. CAPP Publication number 2000-0004, Calgary, Alberta, Canada, June 2000).

Meanwhile, a report determining the type and significance of volatile organic compound (VOC) emissions has to be submitted. This has to be done in accordance with existing best management practices for oil and gas operations in Canada based on two publications: a) CH_4 and VOC Emissions from the Canadian Oil and Gas Industry. CAPP Publication numbers 1999-0009 to 1999-0012, Calgary, Alberta, Canada, July 1999, and b) Best Management Practices for the Control of Benzene Emissions from Glycol Dehydrators. CAPP Publication number 2000-0035 Calgary, Alberta, Canada, December 2000.

Provincial standards have been implemented to keep these concerns under control. Because the focus is in offshore flares, the writer will present, in the consecutive sections, the norms applicable for the only two Canadian provinces involved with the extraction and exploitation of crude oil offshore: they are first Newfoundland and Labrador, and second Nova Scotia. Newfoundland and Labrador regulation 39/04 is the most recent law (2004), which was issued to establish the ambient air quality standards valid for this part of Canada. Table 4.4 shows the maximum permissible values allowed by this province to maintain their air quality. To be sure that those values are respected, the minister may: a) Specify a condition (Part XI of the Act), or b) Develop an air quality management plan specifying the requirements to reduce the level of pollution generated by each facility mentioned in the plan, and the owner or operator of each facility shall provide any information, related to the creation of the air quality management plan, demanded by the minister, and comply with the steps specified in the plan.

Name of Contaminant	Period of time	Concentration	Unit of Concentration
H_2S	1 hour	15	Micrograms per cubic meter of air
	24 hours	5	
NO_2	1 hour	400	Total micrograms of nitrogen oxides per cubic meter of air, expressed as NO_2
	24 hours	200	
	Annual	100	
SO_2	1 hour	900	Micrograms per cubic meter of air
	3 hours	600	
	24 hours	300	
	Annual	60	
PM_{10}	24 hours	50	Micrograms per cubic meter of air
CO	1 hour	35 000	Micrograms per cubic meter of air
	8 hours	15 000	

$\mu g/m^3$ = micrograms per cubic meter; NA= Not available

Table 4.4 Ambient Air Quality Standards in the province of Newfoundland and Labrador (IX)

Nova Scotia has its own air quality regulations since 1995. The criteria for ambient air quality all over the province are given in table 4.5 and are expressed as maximum permissible ground level concentrations. In places where generators of air pollution are identified and constantly they have exceeded the maximum permissible concentration showed in this table, the Minister may require them to submit a plan for approval to reduce those high values.

Contaminant	Averaging Period	Maximum Permissible Ground Level Concentration	
		μg/m³	pphm
H_2S	1 hour	42	3
	24 hours	8	0.6
NO_2	1 hour	400	21
	Annual	100	5
SO_2	1 hour	900	34
	24 hours	300	11
	Annual	60	2
CO	1 hour	34 600	3 000
	8 hours	12 700	1 100

μg/m³ = micrograms per cubic meter; pphm = parts per hundred million; NA= Not available

Table 4.5 Maximum Permissible Ground Level Concentrations applicable in Nova Scotia (X)

4.2.2 Water discharges

In the case of water discharges the main reference is the offshore waste treatment guidelines, which focus on six critical water discharges to the sea: a) storage displacement water, b) bilge and ballast water, c) deck drainage, d) cooling water, e) water for testing fire control systems, and f) other substances, wastes and residues.

Storage displacement water is water that is pumped into and out of oil storage chambers on certain types of production installations during oil production and off-loading operations. Before discharging, this water has to be treated to reduce its oil concentration to 15 mg/L or less. If this concentration is higher, then it must be reported to the Chief conservation officer in an approved manner within 24 hours of the event. Bilge water is seawater that may stay or flow into the structure of the offshore installation. Ballast water is water used to maintain the stability of an offshore facility. Oil concentrations in both waters should be reduced to levels of 15 mg/L or less before discharge. If this maximum value is exceeded then it has to be reported to the Chief Conservation Officer within 24 hours of the occurrence. Deck drainage is water that reaches the deck of offshore installations and it is caused by rain, sea spray or from routine activities, for instance wash-down and fire drills. Deck drainage that has been contaminated with oil should be treated to reduce its oil concentration to 15 mg/L or less. Oil concentrations in the discharge greater than 15 mg/L must be reported to the Chief Conservation Officer within 24 hours of the occurrence. However, deck drainage with no contamination of oil may be discharged directly to sea. In the case of cooling water under some situations, the Chief Conservation Officer may impose restrictions on the level of residual chlorine in the cooling water to be discharged. In particular the Chief Conservation Officer should approve the use of biocide agents other than chlorine in cooling water. But usually these discharges are allowed without previous treatment. Water for testing fire control systems may be discharged without treatment, because it has been considered that this water after being used did not have their properties affected.

Other wastes created on offshore installations, for example sludges from oil-water separation systems, spent lubricants and all plastic material, along with excess or damaged supplies of chemicals, should be reused or recycled, or recovered and sent to shore for their final disposal, obviously according to local authorities, and with the approbation of the Chief conservation officer. Consequently, no substances should be discharged without the prior notification and approval of the Chief conservation officer, unless it meets the requirements to be considered as exception under the offshore waste treatment guidelines.

All critical water discharges mentioned before are summarized in table 4.6. This shows the maximum limit permissible according to Canadian standards for offshore installation under their jurisdiction.

Discharge	Parameter	Limit by regulation
Storage Displacement Water	Oil	15 mg/L
Bilge and Ballast Water	Oil	15 mg/L
Deck Drainage	Oil	15 mg/L
Cooling Water	Discharge	Not restrictions
Water for Testing Fire Control Systems	Discharge	Not restrictions
Other Substances, Wastes and Residues	Discharge	Not discharge allowed

mg/L = milligrams per liter

Table 4.6 Limits for water discharges related to offshore installations in Canada (Villasenor, 2002 b)

4.3 United States Regulations

Atmospheric gas releases and water discharges from United States offshore platforms will be presented in this segment. The part related with air regulations has been subdivided into two portions. First policies to legislate air pollution for platforms located under Federal waters (particularly in the Gulf of Mexico), which are under the supervision of the Mineral Management Service; and second a section where specific regulations for each one of the States surrounding the Gulf of Mexico (Texas, Alabama, Louisiana, and Mississippi) will be introduced.

In the final part of this section, regulations for water discharges from North American platforms will be presented. Particular examples from the States of Texas and Louisiana will be presented to illustrate how environmental standards are accomplished in waters during the installation, and operation of offshore flares in USA.

4.3.1 Atmospheric gas releases

Based on the Clean Air Act Amendments of 1990, U.S. Environmental Protection Agency's (USEPA) Administrator, the Secretary of the Interior and the Commandant of the Coast Guard, have created the requirements to control air pollution in OCS (outer continental shelf) in USA's areas of the Pacific, Atlantic, Arctic, and eastward of 87°30' W longitude in the Gulf of Mexico. For OCS sources located within 40.2 km (25 miles) of the coastal line, the requirements would be the same as they were located in the corresponding onshore area (Alabama, Louisiana, Mississippi, or Texas). For sources located further than 40.2 km of the States' limits, the sources are subject to Federal requirements for Prevention of Significant Deterioration (PSD). For those cases EPA regulates federal waters in the Atlantic and Pacific, and Mineral Management Service (MMS) for those corresponding to federal waters in the Gulf of Mexico. The regulated pollutants include carbon monoxide, suspended particulates, sulphur dioxide, nitrogen oxides, total hydrocarbons, and volatile organic compounds. In areas where hydrogen sulfide may be present, operations are regulated by 30 CFR 250.67. The MMS classifies an area of proposed operations as (1) a zone known to contain H_2S, (2) a zone where the presence of H_2S is unknown, or (3) a zone where the absence of H_2S has been confirmed. An H_2S Contingency Plan must be submitted for approval prior to conducting operations on a lease when the H_2S classification meets the criteria of (1) or (2) and must include contingencies for simultaneous drilling, well-completion, well-work over, and production operations. The company must take all necessary and practical precautions to protect personnel from the toxic effects of H_2S and to mitigate the adverse effects of H_2S to property and the environment.

The company is not allowed to use natural gas with more than 50 ppm of hydrogen sulfide as combustible without the previous approval of MMS. Also any combustion of gas containing H_2S must keep the same organization informed. MMS could request for plume dispersion models for combustion in flares, in cases where gases are coming from wells containing a concentration higher than 500 ppm of H_2S. In general, whether concentrations of H_2S exceeds 20 ppm, or the ones from SO_2 are higher than 5 ppm in any non-inhabited or inhabited offshore platform, it must close operations until mitigation measures are taken to reduce those levels to acceptable standards.

The requirements for platforms located in USA's federal waters, and specifically for the Gulf of Mexico have been addressed. Further in this section, regulations from the states surrounding the Gulf of Mexico will also be addressed.

Texas:

According to the Air Permits Division of the Texas Commission on Environmental Quality (TCEQ), the state of Texas does not have air emission limits specifically for offshore oil platforms in the Gulf of Mexico. Nevertheless, the criteria for air pollutants as SO_2, CO, NO_2, and PM_{10} have federal ambient air limits. They are expressed in the 40 Code of Federal Regulations Part 50 (Table 4.7). This compliance is guaranteed through the facility permitting requirements for stationary sources and general source regulations for those pollutants. Air pollution sources on oil platforms in their jurisdiction are subject to these requirements.

Beside those federal ambient air limits, there are official TCEQ rules applicable for the state of Texas (table 4.8). They do not currently have regulations addressing greenhouse gases.

Pollutant	Period of time	Maximum Permissible	Comments	Source
NO_2	Annual	0.053 ppm (100 µg/m^3)	Annual arithmetic mean concentration	National primary and secondary ambient air quality standards for nitrogen dioxide
SO_2	3 hour	0.5 ppm (1310 µg/m^3)	It not to be exceeded more than once per calendar year	National secondary ambient air quality standard for sulfur oxides
	24 hours	0.14 ppm (370 µg/m^3)	It not to be exceeded more than once per calendar year	National primary ambient air quality standards for sulfur oxides
	Annual	0.030 ppm (80 µg/m^3)	It not to be exceeded in a calendar year	National primary ambient air quality standards for sulfur oxides
PM_{10}	24 hours	150 µg/m^3	24-hour average concentration	National primary and secondary ambient air quality standards for PM10
	Annual	50 µg/m^3	It not to be exceeded in a calendar year	National primary and secondary annual standards for particulate matter
CO	1 hour	35 ppm (40 000 µg/m^3)	For a 1-hour average concentration not to be exceeded more than once per year	National primary ambient air quality standards for carbon monoxide
	8 hours	9 ppm (10 000 µg/m^3)	For an 8-hour average concentration not to be exceeded more than once per year	National primary ambient air quality standards for carbon monoxide

µg/m3 = micrograms per cubic meter; ppm = parts per million; µg/m^3 = micrograms per cubic meter; NA= Not available

Table 4.7 Federal ambient air limits applicable in United States (XI)

Pollutant	Period of time	Maximum Permissible	Comments	Source
H_2S	30 minutes	0.12 ppm 170 µg/m³	Note 1*	Texas Natural Resource Conservation Commission Chapter 112 - Control of Air Pollution From Sulfur Compounds
NO_2	2 hours	0.7 lb/MMBtu 860 µg/m³	An "opposed-fired" steam	Texas Commission on Environmental Quality Chapter 117 - Control of Air Pollution from Nitrogen Compounds
	2 hours	0.5 lb/MMBtu 615 µg/m³	A "front-fired" steam	
	2 hours	0.25 lb/MMBtu 310 µg/m³	A "tangential-fired" steam	
SO_2	30 minutes	0.4 ppm 1 050 µg/m³	Averaged over any 30-minute period	Texas Natural Resource Conservation Commission Chapter 112 - Control of Air Pollution From Sulfur Compounds
PM_{10}	1 hour	400 µg/m³	Averaged over any one-hour period	Texas Natural Resource Conservation Commission Chapter 111 - Control of Air Pollution From Visible Emissions and Particulate Matter
	3 hours	200 µg/m³	Averaged over any three consecutive hours	

µg/m³ = micrograms per cubic meter: ppm = parts per million; lb/MMBtu = pound per million British thermal units; NA= Not available

Table 4.8 Texas Natural Resource Conservation Commission; Chapter 111, 112, and 117 (XII)

Note 1*: Averaged over any 30-minute period if the downwind concentration of hydrogen sulfide affects only property used for other than residential, recreational, business, or commercial purposes, such as industrial property and vacant tracts and range lands not normally occupied by people.1 lbs/MMBtu = 1 225 μg/m^3.

Alabama:

The air emission limits for offshore oil & gas platforms that are located in state of Alabama waters are the same as those that would be required by the US EPA Prevention of Significant Deterioration program.

The Director of the state environmental agency shall declare an Alert when any one of the following contaminant concentrations is measured at any monitoring site and when adverse meteorological conditions can be expected to remain at these levels or higher for the next twelve hours or more: a) Sulfur Dioxide measured in 24 hour average with an accumulation of 0.30 ppm (800 μg/m^3), b) PM_{10} measured in 24 hour average with a value of 350 μg/m^3, c) Carbon Monoxide measured in 8 hour average with a maximum of 15 ppm (17184 μg/m^3), d) 0.15 ppm (282 μg/m^3) of Nitrogen Dioxide measured in 24 hour average, or 1 hour average with a value of 0.6 ppm (1130 μg/m^3). A warning shall be declared by the Director when the concentrations of any of the following air contaminants registered in the State jurisdiction, and when adverse meteorological conditions can be expected to remain at these levels or higher for the next 12 hours or more: a) Sulfur Dioxide measured in 24 hour average registering a value of 0.6 ppm (1600 μg/m^3), b) PM_{10} measured in 24 hour accumulation of 420 μg/m^3, c) 30 ppm (34370 μg/m^3) of Carbon Monoxide measured in 8 hour average, d) Nitrogen Dioxide measured a value of 0.30 ppm (565 μg/m^3) in a period of 24 hour, or 1 hour average with a maximum of 1.20 ppm (2260 μg/m^3).

An Emergency shall be declared by the Director when the following concentrations of air contaminants have been reached or when meteorological conditions can be expected to reach or exceed these levels at any monitoring site in the State for a period of twelve hours or more: a) 0.8 ppm (2100 µg/m3) of Sulfur Dioxide measured in 24 hour average, b) PM_{10} calculated in 24 hour accumulation with a concentration of 500 µg/m^3, c) 40 ppm (45825 µg/m^3) of Carbon Monoxide estimated in a period of 8 hour average, d) Nitrogen Dioxide measured in 24 hour average with a value of 0.40 ppm (750 µg/m^3), or 1 hour average with a value of 1.60 ppm (3000 µg/m^3). The values for these three episode stages (alert, warning and emergency) are shown in table 4.9.

Pollutant	Period of time	Alert	Warning	Emergency
NO_2	1 hour	0.6 ppm (1130 µg/m^3)	1.20 ppm (2260 µg/m^3)	1.60 ppm (3000 µg/m^3)
	24 hours	0.15 ppm (282 µg/m^3)	0.30 ppm (565 µg/m^3)	0.40 ppm (750 µg/m^3)
SO_2	24 hours	0.30 ppm (800 µg/m^3)	0.6 ppm (1600 µg/m^3)	0.8 ppm (2100 µg/m^3)
PM_{10}	24 hours	350 µg/m^3	420 µg/m^3	500 µg/m^3
CO	8 hours	15 ppm (17 mg/m^3)	30 ppm (34 mg/m^3)	40 ppm (46 mg/m^3)

µg/m^3 = micrograms per cubic meter; ppm = parts per million; NA= Not available; mg/m^3 = milligrams per cubic meter

Table 4.9 Episode stages for air pollution in the State of Alabama (Alabama, 2000)

Louisiana

Air Quality program within the Department of Environmental Quality apply to any source of emissions existing in this State. The standards of ambient air quality listed in table 4.10 and table 4.11. They define the limits of air contamination by particulates and gases, above which limits the ambient air is declared to be unacceptable and requires air pollution control measures.

Air contaminant	Maximum Permissible Concentration	
PM_{10}	50 µg/m^3	Annual geometric mean
	150 µg/m^3	Maximum 24-hour concentration not to be exceeded more than once per year
Sulfur Dioxide (SO_2)	80 µg/m^3 (0.03 ppm)	Annual arithmetic mean
	365 µg/m^3 (0.14 ppm)	Maximum 24-hour concentration not to be exceeded more than once per year
Carbon Monoxide (CO)	10,000 µg/m^3 (9 ppm)	Maximum 8-hour concentration not to be exceeded more than once per year
	40,000 µg/m^3 (35 ppm)	Maximum 1-hour concentration not to be exceeded more than once per year
Nitrogen Dioxide (NO_2)	100 µg/m^3 (0.05 ppm)	Annual arithmetic mean

µg/m^3 = micrograms per cubic meter; ppm = parts per million

Table 4.10 Primary Ambient Air Quality Standards for the State of Louisiana (Louisiana, 2004)

Air contaminant	Maximum Permissible Concentration	
PM_{10}	50 µg/m^3	Annual arithmetic mean
	150 µg/m^3	Maximum 24-hour concentration not to be exceeded more than once per year
Sulfur Dioxide (SO_2)	1 300 µg/m^3	Maximum 3-hour concentration not to be exceeded more than once per year
Carbon Monoxide (CO)	10 000 µg/m^3 (9 ppm)	Maximum 8-hour concentration not to be exceeded more than once per year
	40 000 µg/m^3 (35 ppm)	Maximum 1-hour concentration not to be exceeded more than once per year
Nitrogen Dioxide (NO_2)	100 µg/m^3 (0.05 ppm)	Annual arithmetic mean

µg/m^3 = micrograms per cubic meter; ppm = parts per million

Table 4.11 Secondary Ambient Air Quality Standards for the State of Louisiana (Louisiana, 2004)

Mississippi

According to the Mississippi Code 49-17-17, the following regulations are mandatory for the purpose of preventing, reducing, and controlling air pollution caused by air contaminants being discharged into the atmosphere.

Stack emissions testing for demonstration of compliance with these regulations may be performed in accordance with the Test Methods of the U. S. Environmental Protection Agency, or otherwise approved by the staff of the Mississippi Office of Pollution Control and the U. S. Environmental Protection Agency. Table 4.12 shows the maximum permissible values for the State of Mississippi according to the Air Emission Regulations.

Pollutant	Period of time	Maximum Permissible	Comments
SO_2	NA	4.8 lb/MMBtu 5 880 µg/m3	The maximum discharge of sulfur oxides from any fuel burning installation in which the fuel is burned primarily to produce heat or power by indirect heat transfer
Particulate Matter	1 hour	0.19 lb/MMBtu 230 µg/m3	Emissions from installations equal to or greater than 10,000 million BTU per hour heat input
CO	NA	40 ppm (46 000 µg/m3)	Hospital, Medical, Infectious Waste Incinerators

µg/m^3 = micrograms per cubic meter; ppm = parts per million; lb/MMBtu = pound per million British thermal units; NA= Not available; 1 lbs/MMBtu = 1 225 µg/m^3

Table 4.12 Air Emission Limits for the State of Mississippi (Mississippi, 2002)

4.3.2 Water discharges

Different types of waste are generated in exploration and production offshore platforms. The volume of them represents, in general, a small fraction from the volume of fluids and solids created from exploration activities or produced water. The permits from National Pollutant Discharge Elimination System (NPDES) include limitations for those discharges. Regularly, they are treated in order to eliminate their toxicity, and then they are discharged to the ocean. In the cases of water collected from the deck drainage, and fluids coming from repair, maintenance, and treatment of wells are sent to the system separating oil from water, and they are mixed with produced water for a final discharge in the sea. Every time that this procedure is done, the mixed effluent must be restricted to the same environmental regulations as for the produced water.

Discharges of dispersants and detergents coming form offshore platform must be minimized. Even if using these substances is necessary to clean surfaces in offshore platform, these chemicals must suit the requirements demanded by Occupational Safety & Health Administration (OSHA), and MMS. NPDES has issued permits to release residuals from platforms in waters under the jurisdiction of Texas and Louisiana. For instance, in Texas it is forbidden to discharge drilling mud, but on the other hand, it is allowed to discharge treated water coming from wells with very low production (less than 10 barrels a day).

Sanitary wastes (showers, bathrooms, and kitchen) discharging in Texas' waters must not have floating solids, and suit the following characteristics; a) they must not exceed a maximum daily of 45 mg/L of BOD; and b) their Fecal Coliforms have to be between 200 per hundred milliliters and 100 per hundred milliliters. Other flows from residual waters can be discharged if they do not contain oil.

Permits from NPDES for discharges of liquid or solid residues from drilling are forbidden in new or existing platforms in waters belonging to the State of Louisiana, those limitations are showed in table 4.13.

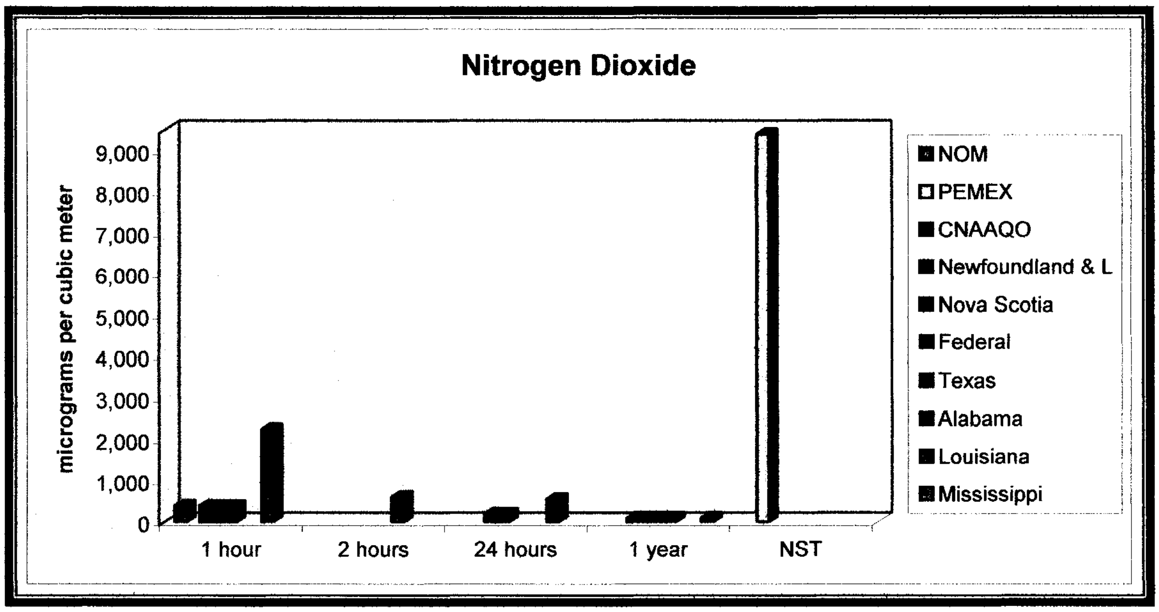
Discharge	Monitored or regulated parameter	Limit
Deck drainage	Oil	Any discharge
Produced water	Total Oil and Grease	42 mg/L daily maximum discharge, 29 mg/L monthly average
Sanitary waste	Residual chlorine	1 mg/L minimum
	Solids	Any floating solid
	BOD	45 mg/L
Domestic waste	Solids	Any floating solid or foams
	Trash	Any discharge
Miscellaneous discharges	Oil	Any discharge
	Chemical products used in treatments	Dose recommended by the fabricant or 500 mg/L

mg/L = milligrams per liter

Table 4.13 NPDES' limits for offshore platforms under the jurisdiction of the State of Louisiana (Villasenor, 2002 b)

4.4 Comparing among Mexican, Canadian, and USA regulations for atmospheric gas releases

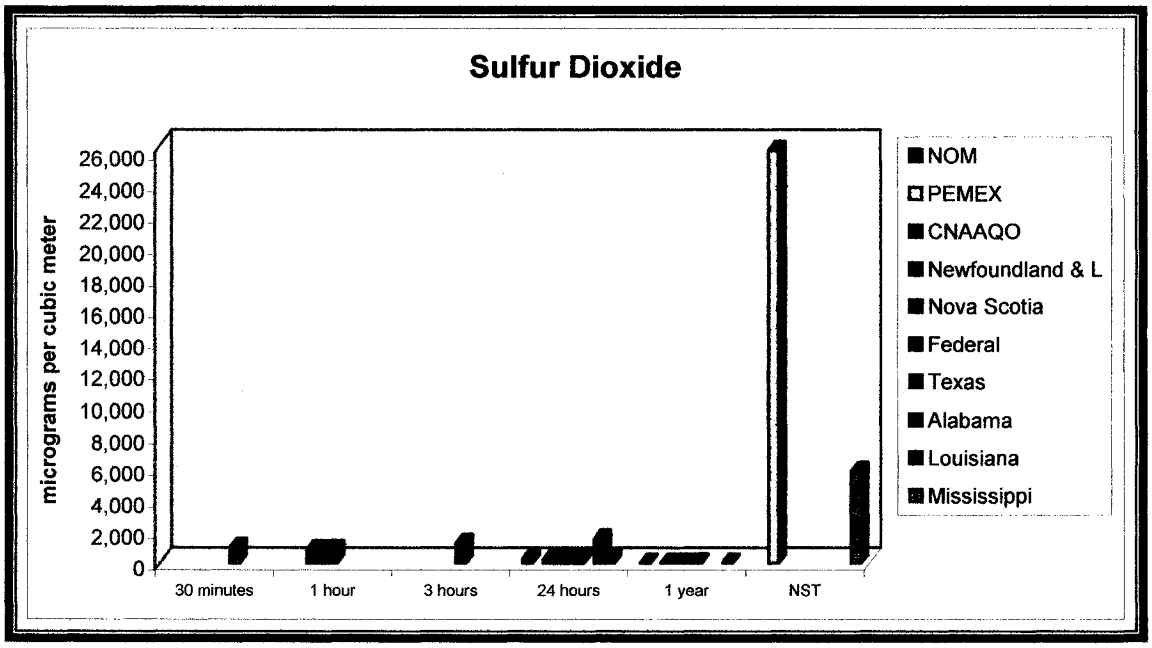
With respect to the NO_2 emission, it has been observed that the highest value is given by PEMEX (9 400 μg/m^3), without a specified period of time. Except this, the limits from these air pollutants are quite similar among the three countries. Moreover, there is an exclusion for Alabama for the periods of one hour and twenty-four hours with higher values than the others. However they are not as big as PEMEX, (figure 4.2).



NST = Not specified time

Fig. 4.2 Comparison of maximum permissible values among governmental agencies (Mexico, Canada, and USA) for NO_2 (III)

For SO_2 PEMEX was the high record with 26 200 μg/m^3, and again there is not a specified time for which this value is considered. The second exception is given by the State of Mississippi under the same conditions of timing as with PEMEX. A minor exception is seen with Alabama regulations for the period of twenty-four hours that specify a limit of 1 600 μg/m^3, (figure 4.3).



NST = Not specified time

Fig. 4.3 Comparison of maximum permissible values among governmental agencies (Mexico, Canada, and USA) for SO_2 (III)

Figure 4.4 shows a condense data about air pollution regulations for PM_{10} in the three countries of interest. Here, the only interesting fact is related to the period of 24 hours. The minimum value is provided by Newfoundland and Labrador (50 $\mu g/m^3$), while the maximum value is presented by Alabama (420 $\mu g/m^3$). The second peculiarity is that for the state of Texas, the value for one hour (400 $\mu g/m^3$), is almost the same as for Alabama but this time factor is for twenty-four hours.

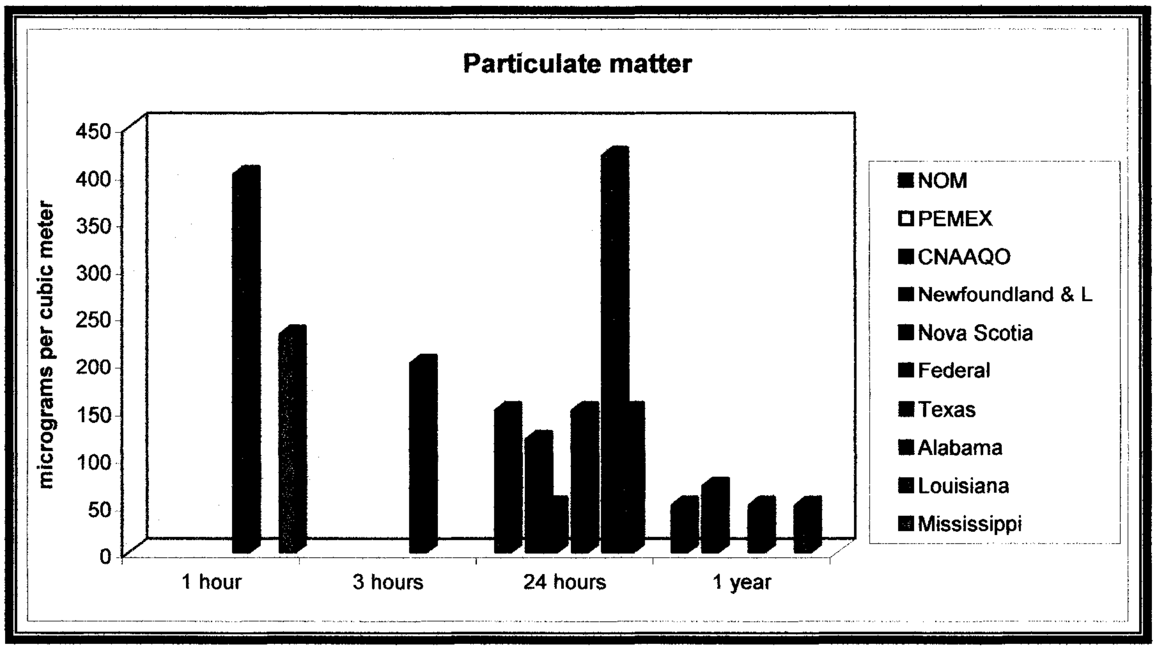
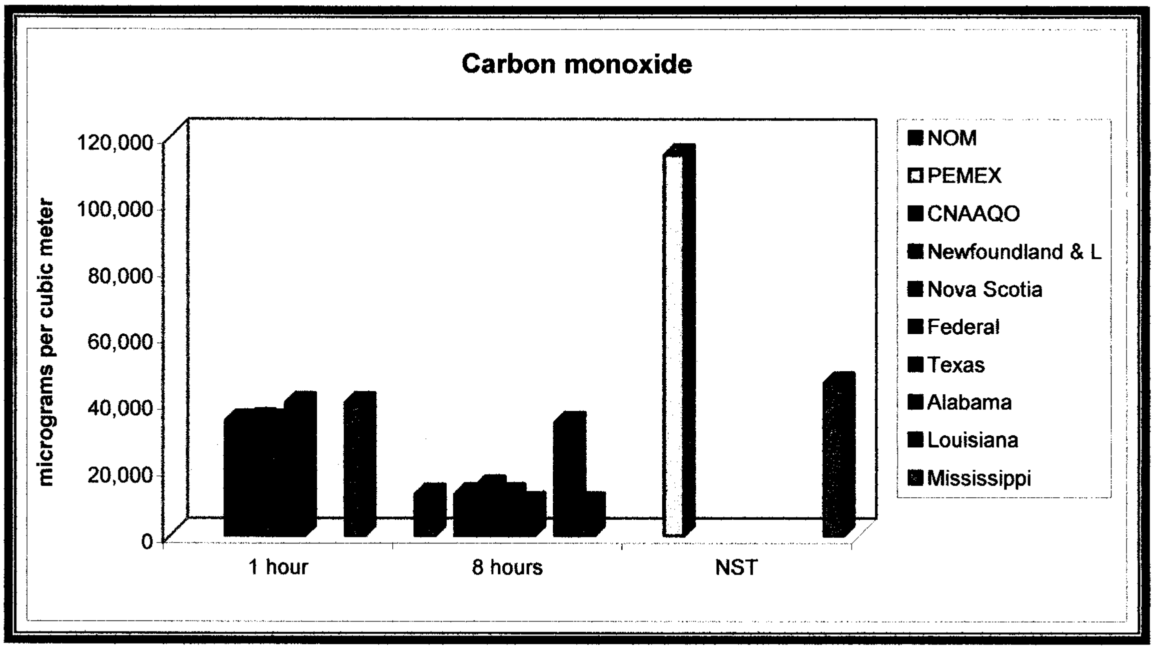


Fig. 4.4 Comparison of maximum permissible values among governmental agencies (Mexico, Canada, and USA) for PM_{10} (III)

Maximum values applicable for CO are presented in figure 4.5 as part of this comparison among Mexico, Canada, and USA. As with NO_2, and SO_2, PEMEX has the highest value (114 500 μg/m^3), followed by Mississippi (46 000 μg/m^3) for an unspecified period. The second observation corresponds to Alabama regulation for the period of eight hours (34 000 μg/m^3). It is almost three times higher than for the other standards.



NST = Not specified time

Fig. 4.5 Comparison of maximum permissible values among governmental agencies (Mexico, Canada, and USA) for CO (III)

For H_2S, the most important comment is that for this pollutant, a specific standard related to offshore flares, does not exist. For instance, neither in Mexico (Mexican Official Norm or PEMEX), or in the federal level in Canada (Canadian National Ambient Air Quality Objectives), or in USA, or in the others three States (Alabama, Louisiana, and Mississippi). On the contrary, in the two Canadian provinces and Texas H_2S it is regulated. For Texas the value is very high for 30 minutes (170 $\mu g/m^3$) compared to the rest (figure 4.6).

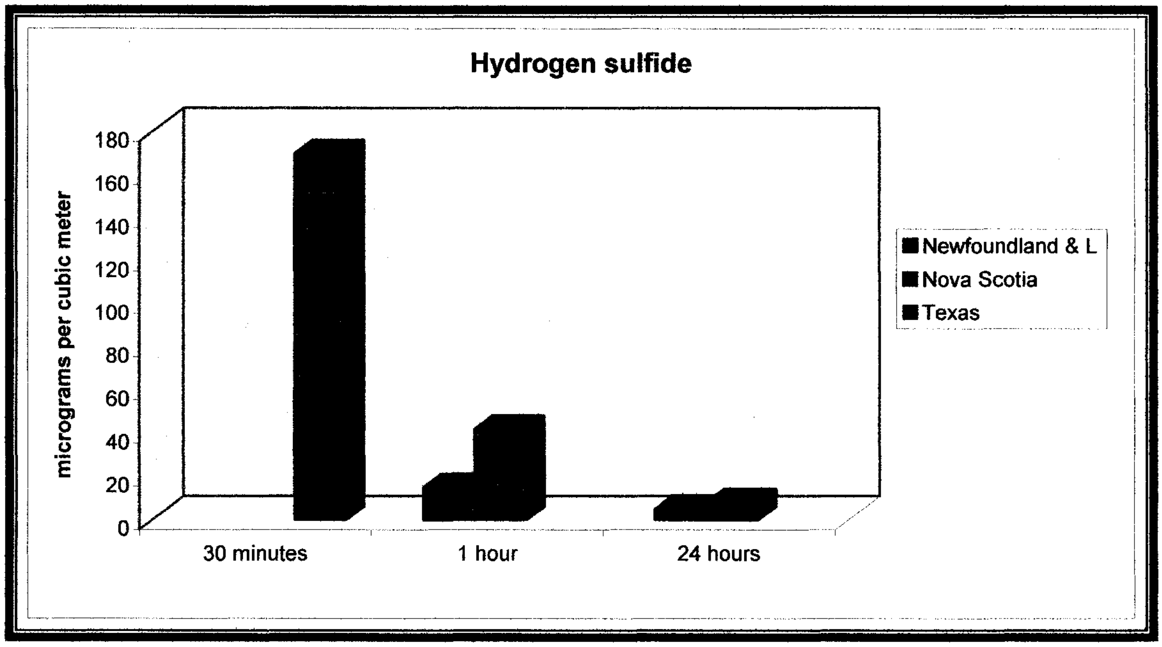
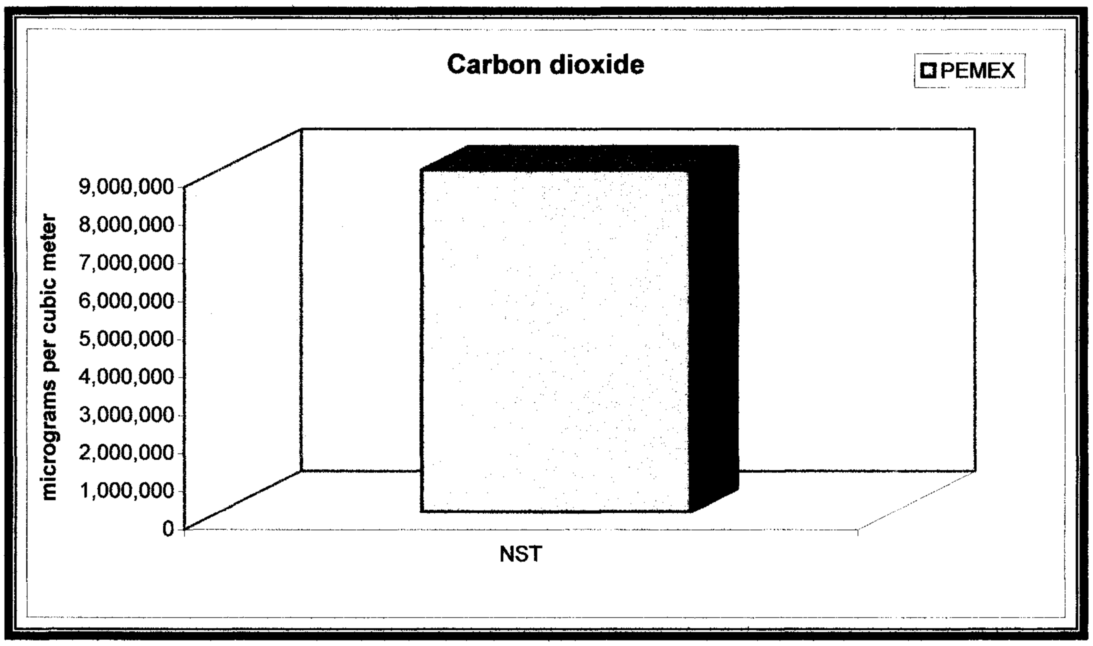


Fig. 4.6 Comparison of maximum permissible values among governmental agencies (Canada, and USA) for H_2S (III)

PEMEX is the only body that contributes to the standards applicable to CO_2. It gives a very high value (9 000 000 µg/m^3) and its time is not specified. It is still a reference to evaluate the emissions caused by this air pollutant (figure 4.7).



NST = Not specified time

Fig. 4.7 Maximum permissible value for CO_2 according to PEMEX (III)

According to the graphics presented in this section, it can be summarized that regulations promulgated to control air pollution among Mexico, Canada, and United States are quite similar in values for NO_2, SO_2, PM_{10}, CO, and H_2S. The exception is provoked in some cases by PEMEX. The PEMEX values are always very high in comparison with the other organizations, and often for unspecified times. However, it has to be considered that this norm is just internal for PEMEX, and applicable for their installations.

Methane (CH_4) is considered to be the second main contributor of air pollution in "Sonda de Campeche". This is based on their high volumes released from offshore flares in that area. However, norms are not set in any of the three countries to regulate this pollutant. Nevertheless, the value of 328 073 µg/m^3 (500 ppm) was obtained from one of the security data sheets published by PEMEX for its contaminants (PEMEX Exploracion y Produccion, 2001). Fortunately, PEMEX has specified a standard for CO_2. It is considered to be the principal air pollutant in that region.

Chapter Five
Impact predictions

This chapter contains three main sections: a) the hydrodynamic modeling of particles in the southern Gulf of Mexico, b) the SO_2 emissions from the Mexican oil and gas industry and, c) Dispersion modeling of SO_2, NO_2 H_2S, CO, PM_{10}, CO_2, and CH_4 for a single offshore flare in "Sonda de Campeche".

The first section covers the behavior of air pollutants in the ocean within the "Sonda de Campeche" using two models. The reduced gravity model is described first, which considers the Campeche Bay as a macro-scale phenomenon. A second model is considered by the Princeton Ocean Mode (POM), which achieves a better resolution, and creates a more accurate description of the water model dispersion in "Sonda de Campeche". The second section contains a description of the meteorological conditions present in the atmosphere in Sonda de Campeche, next to a meteorological model of SO_2 using RAMS / CALMET software. Finally a discussion about the transport and dispersion of this air pollutant using another software named CALPUFF will be discussed.

In the last section, a dispersion model of seven air pollutants for a single offshore flare in Sonda de Campeche will be presented. For each air pollutant, most favorable and worst-case scenarios will be discussed. To accomplish this task, a computer code called PhiStack20k was used. This program follows the Pasquill-Gifford equation and runs on Excel.

5.1 Hydrodynamic modeling of particles in the Southern Gulf of Mexico

Results from the numerical simulations of currents in Campeche Bay, and their possible trajectories followed by particles are showed in this section. This study directed by Salas de Leon (2002) of the National Autonomous University of Mexico (UNAM). The outcomes from the modeling show a cyclonic ring that conditions the currents in the bay. "Sonda de Campeche" represents a converging region with a potential for accumulation of material. As a way to confirm this proposal, the current paths obtained by modeling coincide with the path created by the Ixtoc-1 oil spill.

The hydrodynamics of Campeche Bay is conditioned by two mechanisms. First, the interchange of the bay momentum with the rest of the Gulf of Mexico, and second by the influence of local winds. This movement is affected directly by the intensity of the loop current (called "Corriente the lazo" in Spanish), which depends in their annual intensity variation, and their incidence angle provoked by the Yucatan's current. The loop current transfers momentum directly to the Bay. A cyclonic ring has been the most notorious structure in the central part of Campeche Bay, and intrusion current to the south of the bay and west of Campeche Bank (Vazquez de la Cerda, 1975); both structures creates an interchange in momentum with the rest of the Gulf of Mexico.

5.1.1 Methodology

Hydrodynamic studies are performed to know currents in oceans. Numerical models simulate current paths under different conditions. Two numerical models were utilized to simulate the circulation of currents in the area of interest. First, a model of reduced gravity, which simulates this circulation in a macro-scale in the entire Campeche Bay.

On the other hand, the second model, the Princeton Ocean Mode (POM) simulates the currents with a better resolution, and more accurate for the Sonda de Campeche, with the intention to obtain its circulation paths but this time is affected by the wind and by the flow through the open established boundaries as part of the requirements demanded by POM.

This model applies to oceanographic problems in the Atmosphere and Oceans. It was developed by the Geophysical Fluid Dynamics Laboratory of NOAA and Dynalysis of Princeton University. The model is referenced as the Princeton Ocean Model (POM).

5.1.2 Current circulation in the Campeche Bay by the model of reduced gravity

During the oil spill caused by Ixtoc-1 there was an opportunity to monitor an oil slick in a tropical marine environment (Ross, 1980). Superficial water in the central part of the Gulf presents an anti-cyclonic movement. Besides, the Yucatan's current gets in the Gulf of Mexico through the Yucatan's Channel, and it gets out through Florida Strait, in approximately 100 days (Elliott, 1982). Wind and supplies from rivers are other factors conditioning the circulation of currents in the Gulf. At the moment of the Ixtoc's spill, the penetration of the loop current was in its maximum value. At the same time, contribution of rivers were really important (raining season), to create a barrier during the transportation of the oil slick to Mexican coasts. After a slow movement occurred for approximately two months, the oil slick arrived to Texas' coasts, that trajectory was observed thought satellite images provided by NOAA as it is showed on figure 5.1.

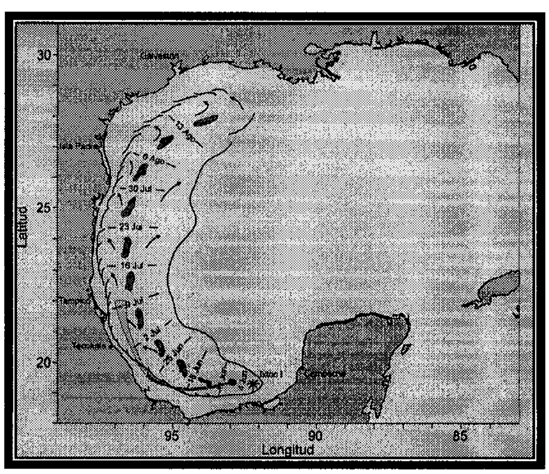


Fig. 5.1 Oil slick trajectory obtained through NOAA during the Ixtoc-1 oil spill (Salas de Leon, 2002)

An important factor is the presence of a macro-scale cyclonic ring covering almost the entire Campeche Bay, which conditions the coastal current paths in that Bay. There is a relationship among the current paths generated by the macro-scale model obtained by Monreal Gomez and Salas de Leon in (1990), the trajectory obtained through satellite images by NOAA, and the one predicted by Emilsson (1979).

From the macro-scale simulation (Salas de Leon, 2002), the results are presented for each month during one year of study with the figure 5.2 to figure 5.12

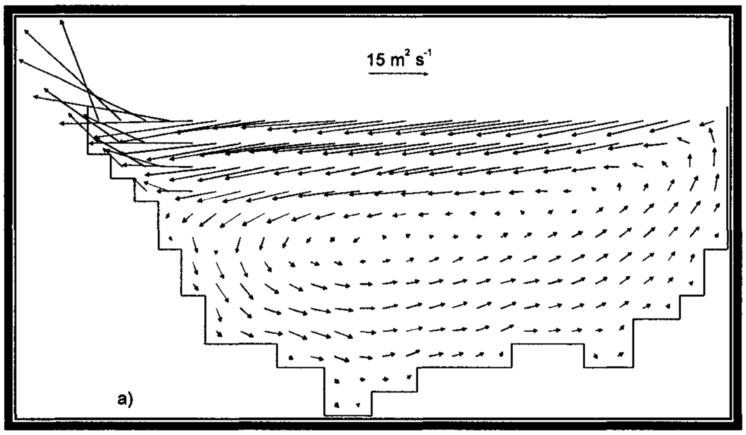


Fig. 5.2 Current circulation paths in Campeche Bay in February (Salas de Leon, 2002)

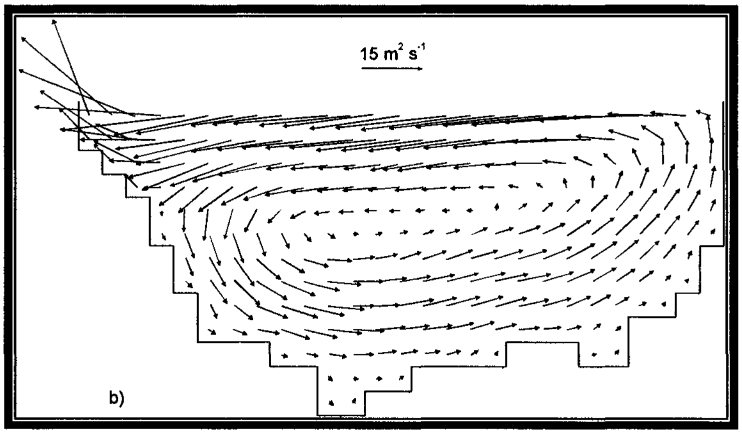


Fig. 5.3 Current circulation paths in Campeche Bay in March (Salas de Leon, 2002)

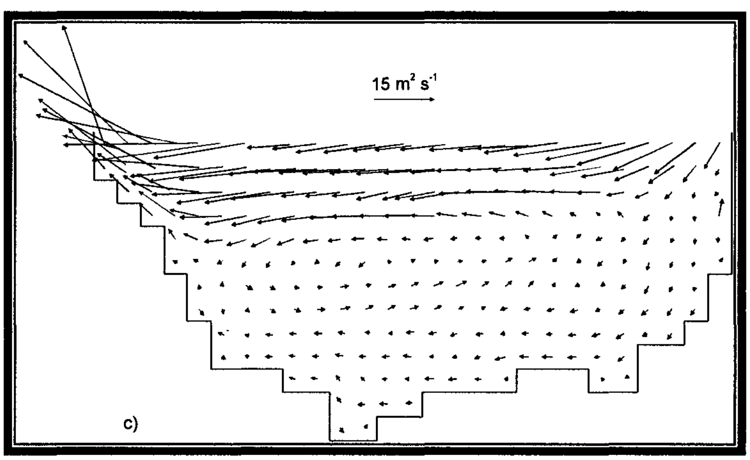


Fig. 5.4 Current circulation paths in Campeche Bay in April (Salas de Leon, 2002)

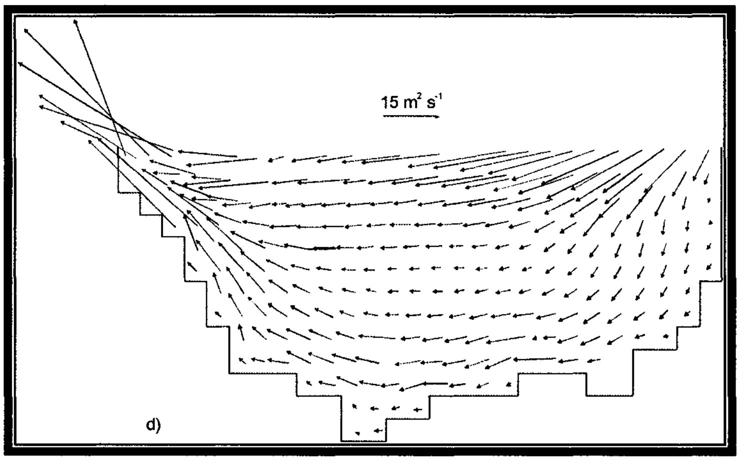


Fig. 5.5 Current circulation paths in Campeche Bay in May (Salas de Leon, 2002)

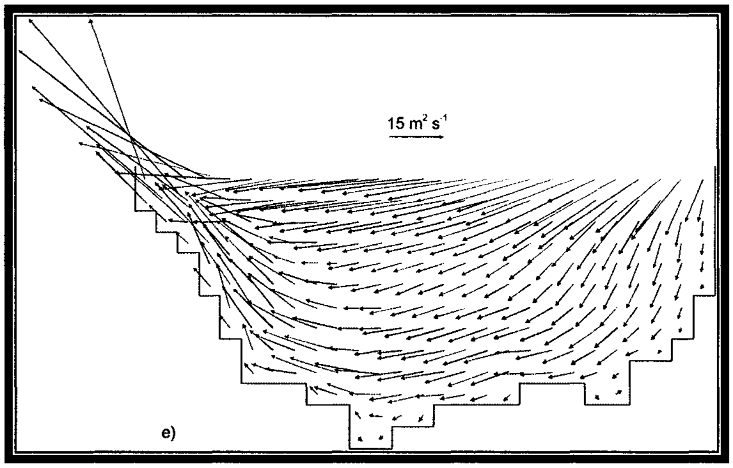


Fig. 5.6 Current circulation paths in Campeche Bay in June (Salas de Leon, 2002)

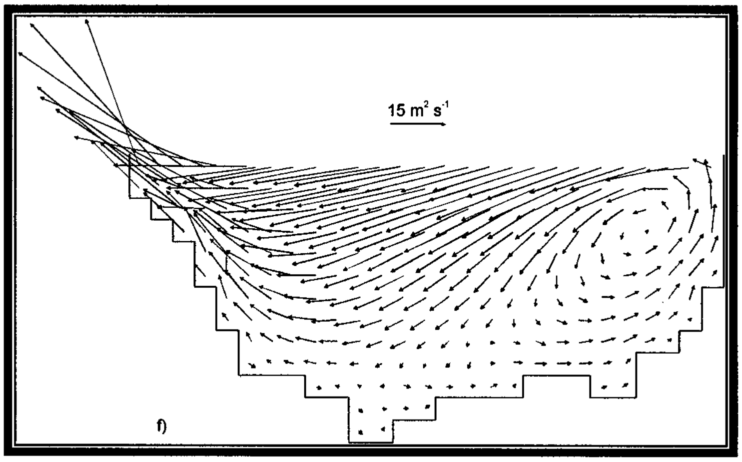


Fig. 5.7 Current circulation paths in Campeche Bay in July (Salas de Leon, 2002)

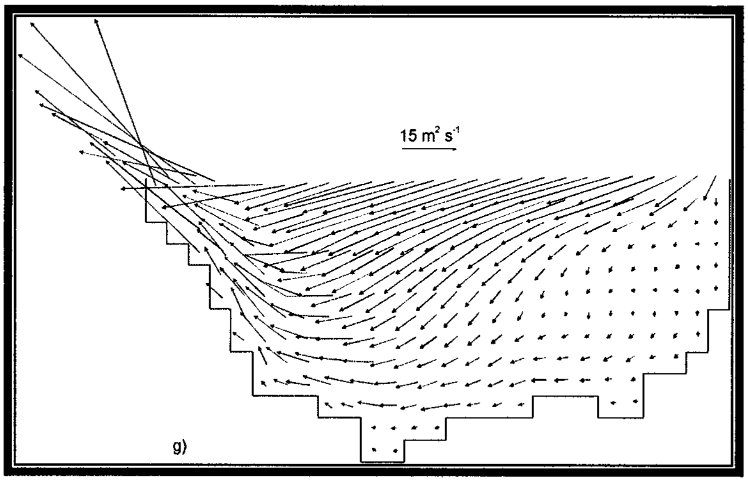


Fig. 5.8 Current circulation paths in Campeche Bay in August (Salas de Leon, 2002)

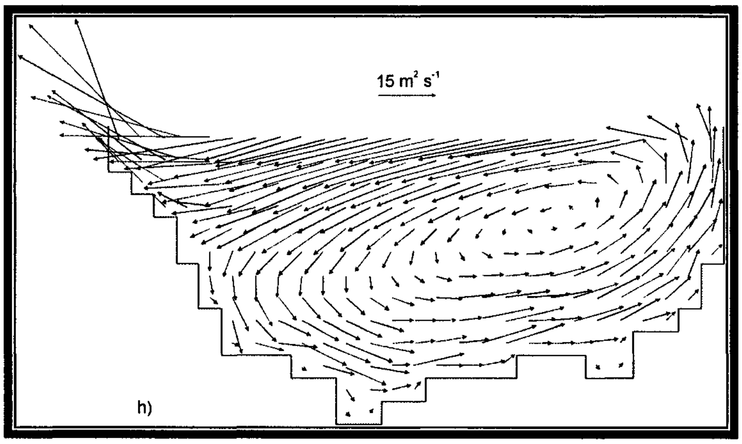


Fig. 5.9 Current circulation paths in Campeche Bay in September (Salas de Leon, 2002)

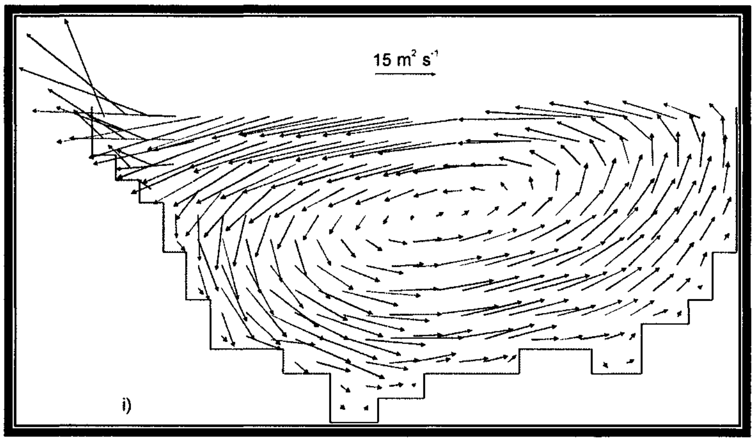


Fig. 5.10 Current circulation paths in Campeche Bay in October (Salas de Leon, 2002)

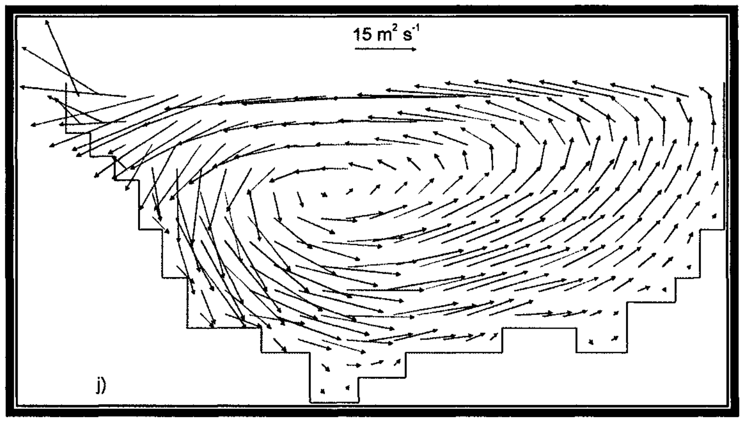


Fig. 5.11 Current circulation paths in Campeche Bay
in November (Salas de Leon, 2002)

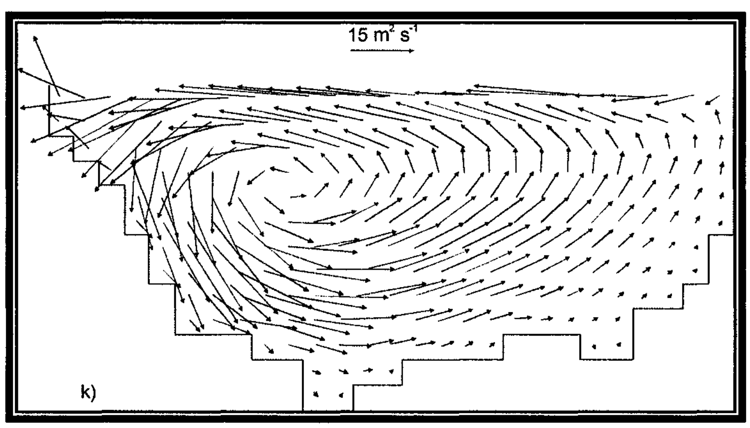


Fig. 5.12 Current circulation paths in Campeche Bay
in December (Salas de Leon, 2002)

From the figures observed above, it follows that macro-scale cyclonic ring covers almost the entire Campeche Bay, and it is the main conditioner for the current circulation paths in the Bay. This ring initiates its formation during the fall, it is intensified during the winter, it decreases its intensity during the spring, and finally disappears during the summer, allowing in this way the intrusion of the Yucatan's current to the south. Besides, these current paths coincide with the trajectory observed during the oil spill caused by Ixtoc-1 (figure 5.1).

5.1.3 Current circulation in "Sonda de Campeche" by POM

To simulate the current circulation in "Sonda de Campeche" some considerations were taken. For instance, a dominant wind from the East with a magnitude of 3.0 m/s, and mass exchange in the open boundaries. The results of this modeling indicate that coastal currents from west to east are present in front of river discharges, and from north to south throughout the Yucatan's Peninsula (figure 5.13). Both currents establish a convergence line west of the offshore platforms and later on this flow is detoured north.

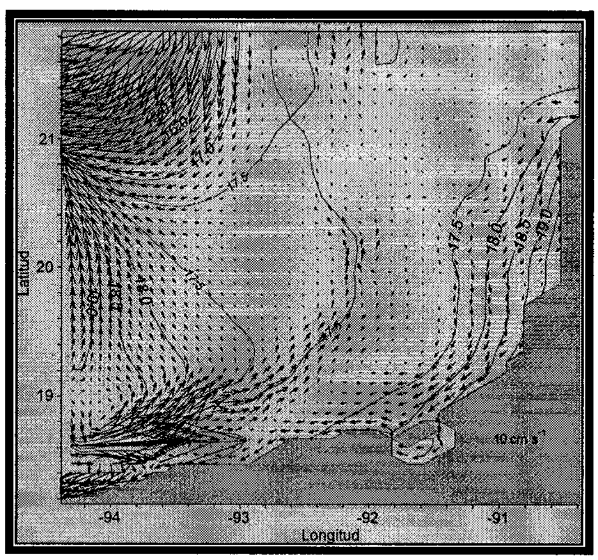


Fig. 5.13 Current paths in "Sonda de Campeche" by POM (Salas de Leon, 2002)

Results from this model show a macro-scale cyclonic ring influencing the circulation in the west of Campeche Bank. Moreover, it is observed that a current going from southwest in the east part of the bank, and northeast in its west part, creates a convergence area that might provoke accumulation of floating material in the Sonda de Campeche. With this current path it is most likely that particles generated by air contaminants or oil spills in offshore platforms will be pushed away from the coastal line in that particular region (Salas de Leon, 2002).

5.2 SO_2 emissions from the Mexican oil and gas industry

An air quality study was done by Villasenor of the Mexican Petroleum Institute in 2002 to evaluate impacts caused by SO_2.

The impact of sulfur dioxide produced from offshore, and onshore facilities was evaluated using the historical database from the concerned area. Moreover, the air quality simulation was based on meteorological data for February 1999, complemented by air quality data from 1999 to 2001 obtained from "Atasta", and "Dos Bocas". CALMET (diagnostic meteorological model) was used to know the meteorological wind and temperature in the area. The program was supplied with data from surface observations and upper air region based on a four day field operation (February, 1999). The selection of the macro-scale physical domain for the simulation was based on a previous run made with the Regional Atmospheric Modeling System (RAMS). The CALMET meteorological output and the generated emission inventory for point sources to predict spatial and temporal SO_2 concentrations were used to run the EPA transport and dispersion model, CALMET/CALPUFF. The transport and dispersion simulation CALMET/CALPUFF predicted concentrations of that air pollutant in the early hours, and in the late evening hours, when the nocturnal boundary layer has been formed. Between these two time intervals when the warming of the water surface happens, CALPUFF underestimates mass concentrations due to the inactivity of CALMET to properly resolve the land-sea breeze circulation effect along the coastal line (Villasenor, 2002 a).

5.2.1 Meteorological conditions

Local winds near the surface and within the boundary layer are influenced by large-scale winds conditions that are typical for winter storms in the Gulf of Mexico during February. This particular condition causes from moderate to strong northeast winds near the surface helping transportation of pollutants inland and very efficient dispersion near the flares. February 3rd 1999 was chosen to simulate the transport and dispersion of SO_2. This date was chosen because the plumes from offshore facilities are more horizontal to cover the coastal communities during the day.

Data obtained from the National Centers for Environmental Prediction (NCEP) for February 1999 at 850 mb geo-potential height shows a high pressure center over the Gulf of Mexico that is moved about 10° towards the east relative to the climatologically high pressure center. As a consequence, a stronger easterly wind component over the Campeche Bay is observed (figure 5.14) during the month of February of 1999.

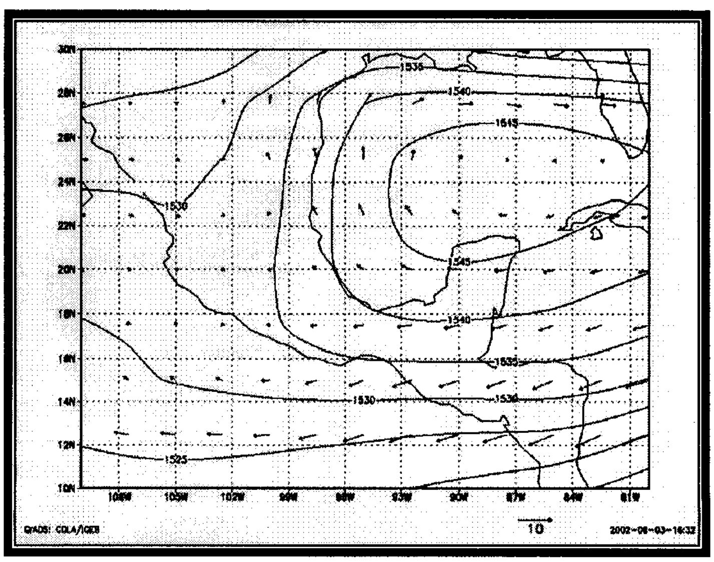


Fig. 5.14 February 1999 monthly mean for 850 mb geo-potential height (m) and wind field (Villasenor, 2002 a)

An average of days 2 and 3 of February (figure 5.15) shows easterly winds over much of south central and the southeastern portions of the country. A wind associated with a frontal zone is noted over to the west part of Mexico at this period of time. The movement of this cold front to the east caused the winds in the Campeche area to change from northeasterly to southeasterly (figure 5.16) during days 3 and 4. On February 4 and 5 the cold front weakened substantially as the high pressure center that previously remained stationary on days 2 and 3 of February at about 80°W moved 8° to the west. As a result, wind direction over the Campeche area shifted to the northeast during the last part of the campaign (Villasenor, 2002 a).

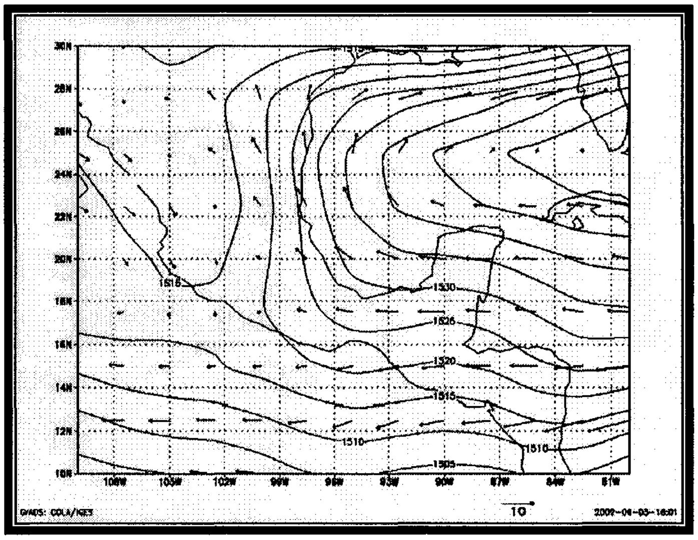


Fig. 5.15 Days 2 and 3 of February 1999 for 850 mb geo-potential height (m) and wind field (Villasenor, 2002 a)

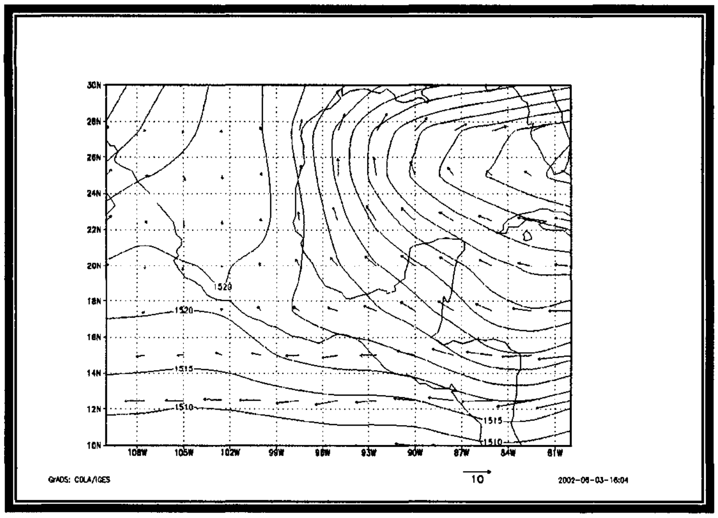


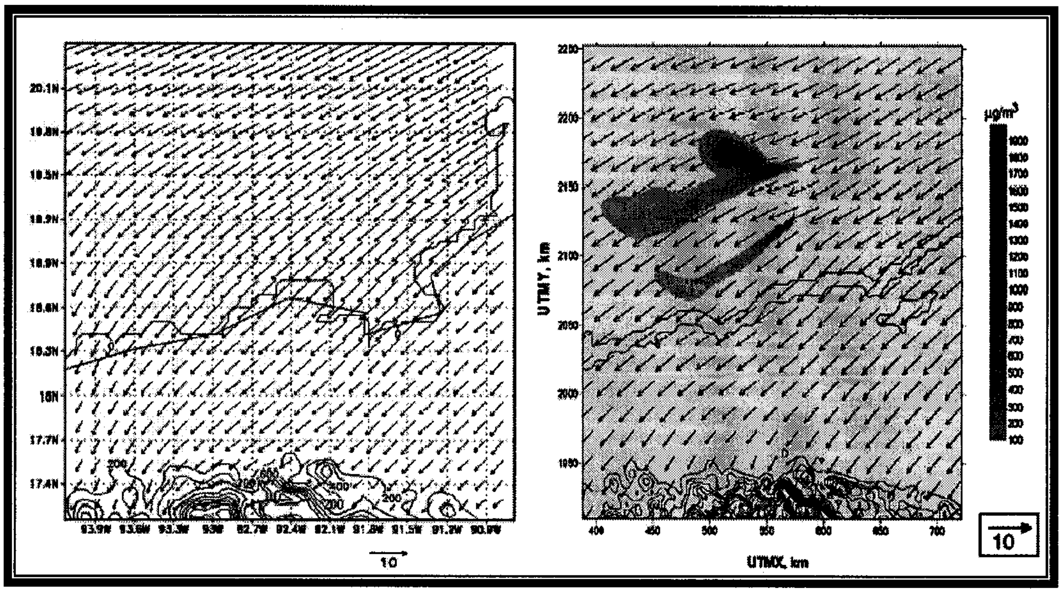
Fig. 5.16 Days 3 and 4 of February 1999 for 850 mb geopotential height (m) and wind field (Villasenor, 2002 a)

These results may suggest that if the dispersing plumes were able to penetrate into the upper air layers (approximately 1,500 meters) by vertical mixing during midday, the trend would indicate that from days 2 to 4 of February pollutants at 850 mb will be transported into the Gulf of Mexico(Villasenor, 2002 a).

5.2.2 Meteorological modeling using RAMS/CALMET

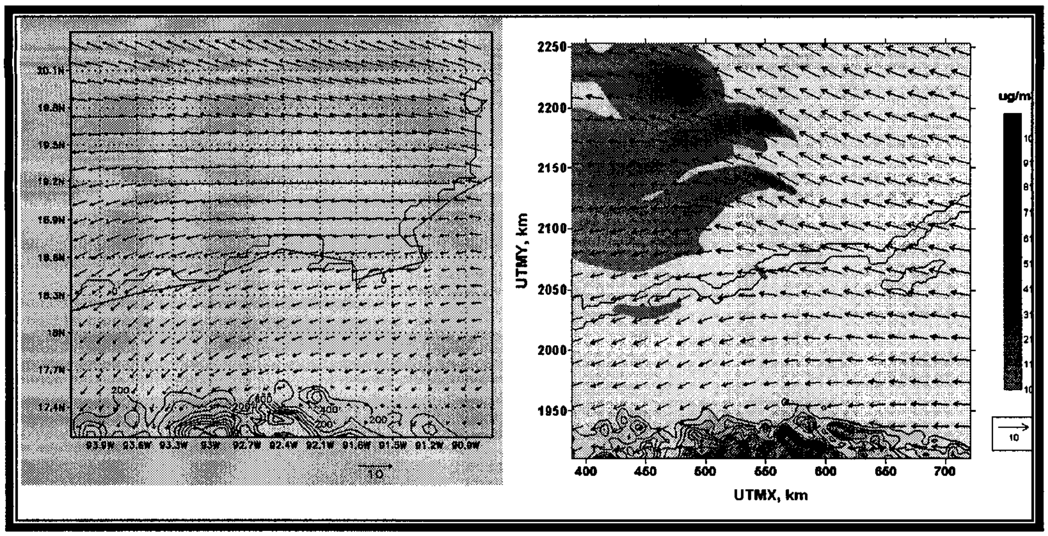
Figures 5.17 through 5.21 show simulated surface wind fields by RAMS (left panel) and CALMET (right panel) for February 3 at several local times. Surface concentrations of SO_2 are adjacently displayed to show the horizontal patterns of the plumes near and far from the sources overlay with the CALMET vector field.

It is important to mention that a direct comparison between these two models are to be executed with caution because there is not a one-to-one correspondence since both used different spatial resolutions, even if their identical size domain. Figures 5.17 and 5.18 can be said to be “similar” but the differences in figures 5.19 through 5.21 are highly significant. CALMET fails to reproduce the surface flow structure along the beach, which is necessary for estimating the transport of pollutants in the coastal zone. The most important differences among the wind fields that need to be mentioned are observed at 1200 hrs LST. The RAMS simulation shows a well-defined line of convergence along the western coast of Tabasco (figure 5.19 left panel). Besides, the effect of the mountains to the southwest is clearly represented by RAMS, but not by CALMET whose simulation shows a southeasterly wind. At 1800 LST the RAMS simulation shows a sea breeze pattern along the coast of Tabasco and Campeche that changes the wind field over the ocean, while CALMET shows a southeasterly wind over the western coast of Tabasco (figure 5.20). The breeze effect in RAMS stays well into the night (figure 5.21).



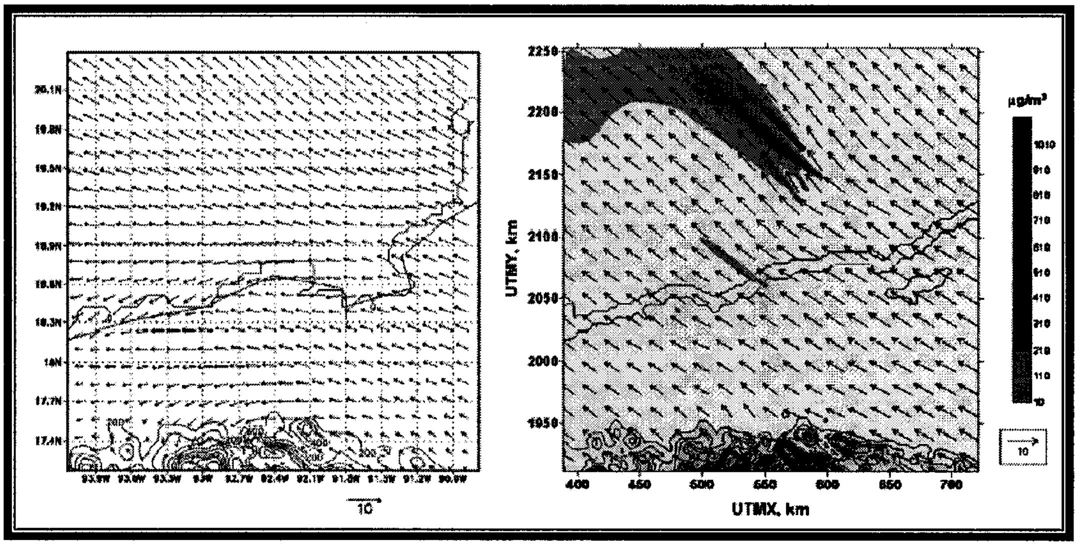
ug/m3 = micrograms per cubic meter

Fig. 5.17 Left panel: RAMS surface wind simulations. Right panel CALMET surface wind simulations and surface concentration predicted with CALPUFF for 0300 LST (Villasenor, 2002 a)



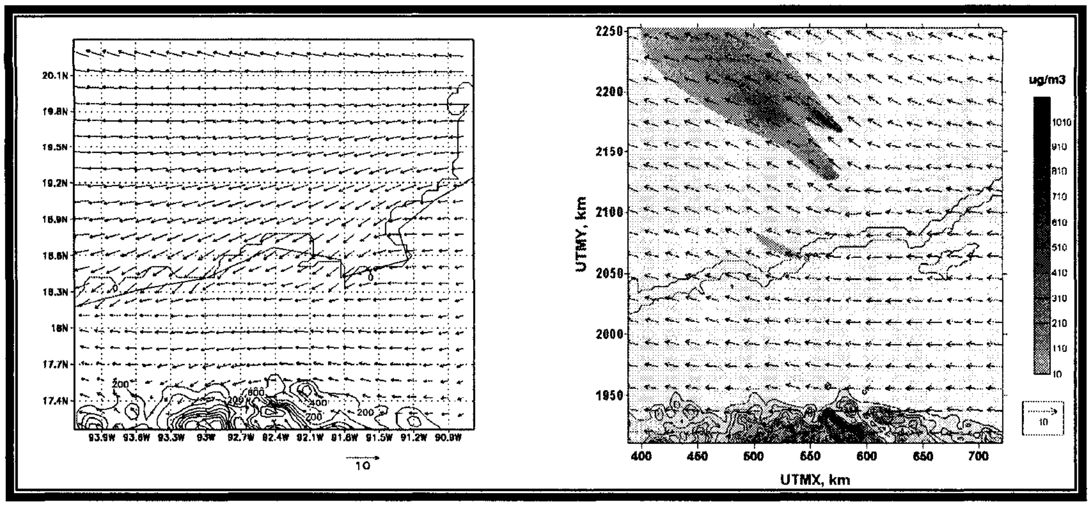
ug/m3 = micrograms per cubic meter

Fig. 5.18 Left panel: RAMS surface wind simulations. Right panel CALMET surface wind simulations and surface concentration predicted with CALPUFF for 0600 LST (Villasenor, 2002 a)



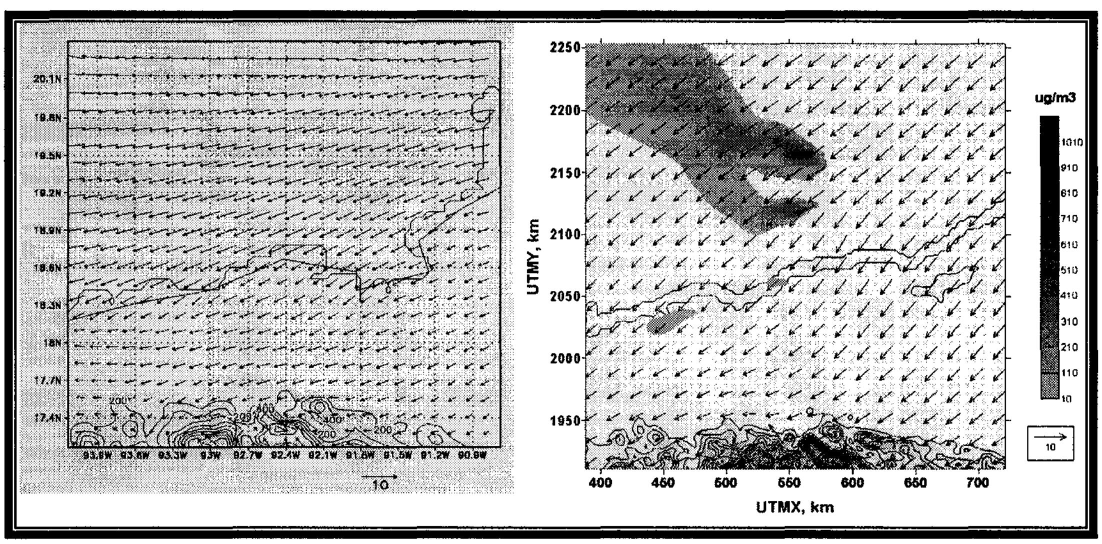
ug/m3 = micrograms per cubic meter

Fig. 5.19 Left panel: RAMS surface wind simulations. Right panel CALMET surface wind simulations and surface concentration predicted with CALPUFF for 1200 LST (Villasenor, 2002 a)



ug/m3 = micrograms per cubic meter

Fig. 5.20 Left panel: RAMS surface wind simulations. Right panel CALMET surface wind simulations and surface concentration predicted with CALPUFF for 1800 LST (Villasenor, 2002 a)



ug/m3 = micrograms per cubic meter

Fig. 5.21 Left panel: RAMS surface wind simulations. Right panel CALMET surface wind simulations and surface concentration predicted with CALPUFF for 2100 LST (Villasenor, 2002 a)

5.2.3 Transport and dispersion of SO_2 using CALPUFF

It can be observed from figures 5.17 through 5.21 that the major pollutant sources are found offshore where a large number of flares exist. Besides, it can be observed from the same figures that emission rates of SO_2 at both the Atasta (compression station) and the Dos Bocas (crude-oil facility treatment) are smaller compared with the flares. In fact, data from Atasta and Dos Bocas indicated that the observed maximum 24-hour average concentrations of SO_2 were significantly below the 341 $\mu g/m^3$ (0.13 ppm) Mexican regulatory standard (NOM-022-SSA1-1993). At mid day when vertical mixing is strong over the sea, the plumes will be more diluted. At 1900 hours (not shown) the CALMET wind vector field starts to change from easterly to northeasterly winds, deflecting the plumes accordingly into the coastline of Tabasco and Campeche. Two hours later, a more uniform northeasterly wind causes a plume shift towards the coastline, thus, bringing polluted air masses that can impact onshore air quality (Villasenor, 2002 a).

5.3 Dispersion modeling of SO_2 and NO_2 for a single offshore flare in "Sonda de Campeche"

Several dispersion models have been developed which are appropriate to model the behavior of SO_2 and NO_2 in the atmosphere. In this section the basis of the Gaussian plume dispersion model known as Pasquill-Gifford equation will be used in order to state it in its most practical form. Further more, numerical manipulation will be performed in order to predict the concentration of both contaminants in the atmosphere and in the ground once it has been emitted from an offshore flare within the "Sonda de Campeche". To perform this task it will be considered two case scenarios, the most favorable circumstances and the worst case scenarios. The result of these calculations will be presented with the aid of a computer code written in Excel.

5.3.1 Gaussian Plume Model

After a pollutant is released to the atmosphere by a single point source (e.g. stack), the pollutant mixes with the air and the plume begins to expand progressively in size. If one observes a plume originating from a stack at any instant in time, one would promptly conclude that it is randomly shaped. Yet, over an extended period of time the plume can be modeled as contained within an overall envelope as shown in the figure 5.22.

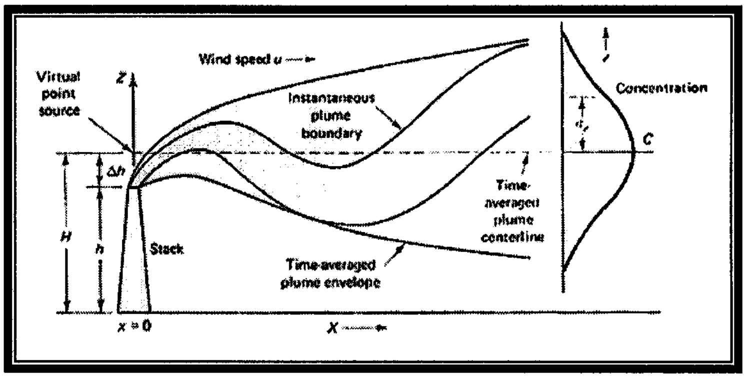


Fig. 5.22 Time averaged Gaussian plume (Peavy, 1984)

Another distinctive characteristic of the Gaussian plume model is that the crosswind plume concentration distribution is taken to have a normal (or Gaussian) distribution as shown in the figure 5.22. The understanding of the three dimensional system is the fundamental starting point for the modeling. In the following session, the frame of reference as defined by the Pasquill-Gifford equation will be presented.

5.3.2 Frame of reference

The horizontal distance moving in the wind direction away from the source defines the x-axis. Thus, x is usually a positive number with the source being the origin. The lateral distance of dispersion from the centerline of the wind direction constitutes the y-axis. Consequently y is measured as a positive or negative distance from the centerline. The ground's surface delimitates the boundary on the vertical, or z-axis, dispersion. Accordingly, z is always measured as the vertical distance from the ground, and z is always positive (figure 5.23).

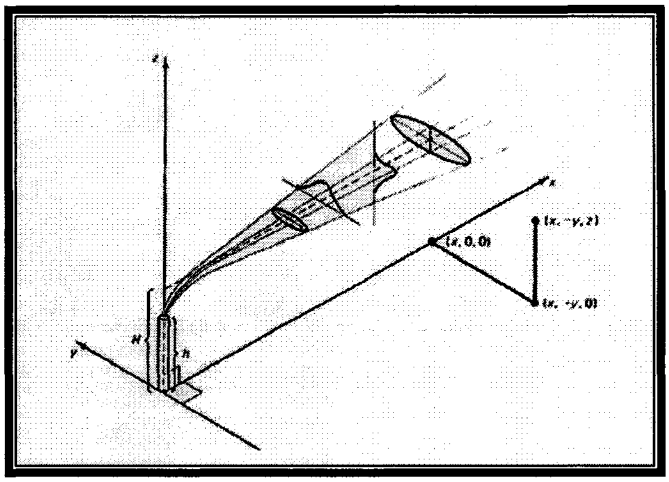


Fig. 5.23 Frame of reference used in the Pasquill-Gifford equation (Peavy, 1984)

The Pasquall-Gifford equation allows us to determine the concentration (C) of pollution at any given point downwind at the coordinates P (x, y, z).

In order to continue with the systematic explanation of the Pasquill-Gifford equation, we must open a parenthesis to present the concept of atmospheric stability. The reason for this parenthesis will become evident shortly once we discuss the dispersion coefficients (σx, σy, σz).

$$C(x,y,z)=\frac{Q}{2\pi u\sigma_y\sigma_z}\times e^{\left(-\frac{y^2}{2\sigma_y^2}\right)}\times\left(e^{\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)}+e^{\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)}\right)\qquad \text{Eq.5.1}$$

Where;

C = pollutant concentration (g/m^3)

Q = pollution emission rate (g/s)

π = pi, 3.14159

u = mean wind speed (m/s)

σ_y = horizontal dispersion coefficient, which represents amount of plume spreading in crosswind direction at distance x downwind from source (m)

σ_z = vertical dispersion coefficient that represents amount of plume spreading in vertical direction at distance x downwind from the source (m)

H = effective stack height (m)

x = downwind distance along plume mean centerline from point source (m)

y = crosswind distance from the centerline of the plume (m)

z = vertical distance from the ground (m)

5.3.3 Atmospheric stability

During the day, the ground's surface and the overlaying air are heated causing the air to rise. During the night, the warm air mass is cooled and consequently sinks. The atmospheric stability has a significant influence on the patterns of atmospheric dispersion. For these reasons, time of the day and the amount of cloud cover (i.e. direct insulation) serves as the basis for determining the atmospheric stability classes shown in table 5.1.

Normally, the values of dispersion coefficients (σ_x, σ_y, σ_z) are determined from knowledge of atmospheric stability. The next section properly presents these coefficients and proposes one scheme found in the literature to quantify their numerical value (Barratt, 2001).

Stability category	Classification	Natural phenomena	Most likely occurrence
A	Extremely unstable	Strong thermal instability, bright sun	Late morning to mid afternoon in spring and summer
B	Moderately unstable	Transitional period, moderate mixing	Day time transition all year
C	Slightly unstable	Transitional periods, slight mixing	Day time/cloudy, night-time, high wind
D	Neutral	Strong winds, overcast, day/night transition	Day/night time cloudy, high wind
E	Slightly stable	Transitional periods, moderate winds	Night time transition all year
F	Moderately stable	Clear night time skies, very limited vertical mixing	Night, clear skies, light winds

Table 5.1 Understanding Atmospheric Stability Categories, adapted from (Barratt, 2001)

5.3.4 Dispersion Coefficients

The three dispersion coefficients (σ_x, σ_y, σ_z) represent Gaussian standard deviations of the concentration of pollutants in the downwind (x), crosswind (y) and vertical (z) planes respectively. One should be able to note that the larger the value of σ, the broader the distribution along the center line of the plume. Since the numerical values of the diffusion coefficients are critical to the application of the Gaussian plume model. Ways of determining the values of the three dispersion coefficients are described below. It should be stressed here that these coefficients represent an atmosphere without an inversion layer.

5.3.5 Scheme Proposed by Briggs

Classifying the land-use near sources of air pollution is necessary because urban areas cause greater rates of dispersion than rural areas. The Briggs equations are summarized in table 5.2.

Condition	Stability	σ_y	σ_z
Rural	A	$0.22x(1+0.0001x)^{-0.5}$	$0.20x$
	B	$0.16x(1+0.0001x)^{-0.5}$	$0.12x$
	C	$0.11x(1+0.0001x)^{-0.5}$	$0.08x(1+0.0002x)^{-0.5}$
	D	$0.08x(1+0.0001x)^{-0.5}$	$0.06x(1+0.0015x)^{-0.5}$
	E	$0.06x(1+0.0001x)^{-0.5}$	$0.03x(1+0.0003x)^{-1}$
	F	$0.04x(1+0.0001x)^{-0.5}$	$0.016x(1+0.0003x)^{-1}$
Urban	A - B	$0.32x(1+0.0004x)^{-0.5}$	$0.24x(1+0.001x)^{-0.5}$
	C	$0.22x(1+0.0004x)^{-0.5}$	$0.20x$
	D	$0.16x(1+0.0004x)^{-0.5}$	$0.14x(1+0.0003x)^{-0.5}$
	E - F	$0.11x(1+0.0004x)^{-0.5}$	$0.08x(1+0.00015x)^{-0.5}$

Table 5.2 Formula recommended by Briggs, (Barratt, 2001)

The last parameter of the Pasquill-Gifford equation needing some clarification is namely the effective stack height (H), which is presented next.

5.3.6 The Effective Stack Height

Gases released by stacks will rise due to either the buoyancy rise (low specific density) or momentum rise (due to upward kinetic energy). Due to the combination of these two phenomena, the pollutant is taken as if it was emitted from a point situated higher than the real physical height of the stack. In other words, the effective height (H) is defined as the sum of the physical height of the stack (h) and the plume rise (Δh) as suggested in the figure 5.22.

A number of techniques have been proposed in the literature for dealing with plume rise. The US EPA recommends a model based on the work of Briggs (1972) to estimate the plume rise at intermediates distance from the stack (Barratt, 2001), as described next:

$$\Delta h = 1.6F^{\frac{1}{3}}\frac{x^{\frac{2}{3}}}{u} \qquad \text{Eq. 5.2}$$

Where F is the buoyancy flux parameter (m^4/s^3) and can be used for all stability conditions. F is defined as follows:

$$F = g\frac{d^2V}{4}\left(\frac{T_s - T_a}{T_s}\right) \qquad \text{Eq. 5.3}$$

Where:

T_s = temperature of the stack emission (°K)

T_a = atmospheric temperature (°K)

d = diameter of the stack (m)

V = velocity of the stack gas

5.3.7 Modeling of SO_2 using PhiStack20k

PhiStack is a user-friendly, interactive computer code written to compute the dispersion of air pollutants emitted to the atmosphere from a smokestack. PhiStack20k follows the Pasquill-Gifford equation and runs on Excel. It is important to mention that more precise description of this computer code is presented in appendix “A”.

The main objective of this section is to show surface concentrations of SO_2 from one single flare under two case scenarios, a) the worst case scenarios, which happened in April, and b) the most favorable circumstances, which occurred in October. Another goal is to verify if each of those two representative flares are in compliance with Mexican Official Norm (NOM) applicable for SO_2. For both cases, the flares were located in Cantarell, but not in the same platform. The input data and the results for each case scenario are presented in (table 5.3 and 5.4). Values for the data entry are taken from the study directed by Villasenor (2001) including the wind velocity. Moreover, stability “C” is considered to be the most representative condition in the affected area, however it could change during the year depending of the atmospheric conditions.

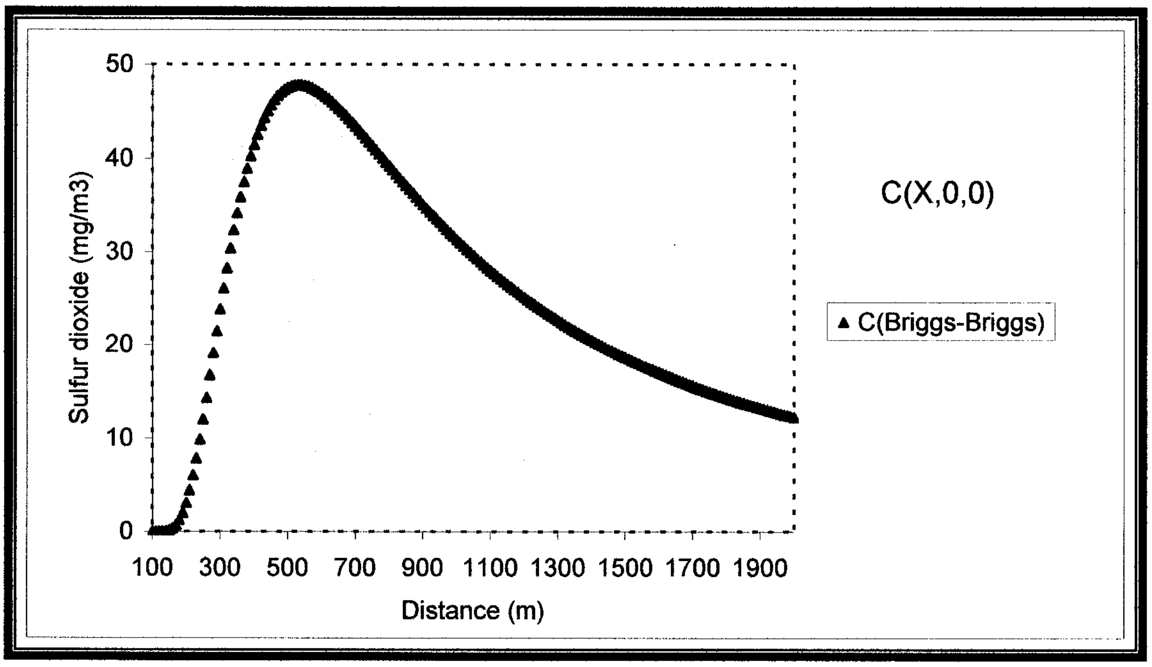
Data Entry		
General Information		
Name of User	Francisco Sanchez	
Date	DD/MM/YY	26/01/05
Air pollutant		
Name of Pollutant	Sulphur Dioxide (SO_2)	
Rate of emission (Qp)	Qp (g/s)	4.3
Threshold concentration	TC (µg/m3)	341.000
Stack		
Height	h (m)	39.9
Diameter	d (m)	0.3
Overall emission rate (g/s)	Qs (g/s)	305.7
Emission temperature	Ts (°C)	1000.0
Atmospheric Conditions		
Temperature	Ta (°C)	28.0
Wind Velocity	u (m/s)	3.0
Atmospheric Stability	Ast (a to f)	c
Urban or Rural	U or R	r

Table 5.3 Data entry for the most favorable circumstances SO_2

Data Entry		
General Information		
Name of User	Francisco Sanchez	
Date	DD/MM/YY	26/01/05
Air pollutant		
Name of Pollutant	Sulphur Dioxide (SO2)	
Rate of emission (Qp)	Qp (g/s)	2242.644
Threshold concentration	TC (µg/m3)	341.000
Stack		
Height	h (m)	53.6
Diameter	d (m)	0.6
Overall emission rate (g/s)	Qs (g/s)	163006.3
Emission temperature	Ts (°C)	1000.0
Atmospheric Conditions		
Temperature	Ta (°C)	26.7
Wind Velocity	u (m/s)	3.0
Atmospheric Stability	Ast (a to f)	c
Urban or Rural	U or R	r

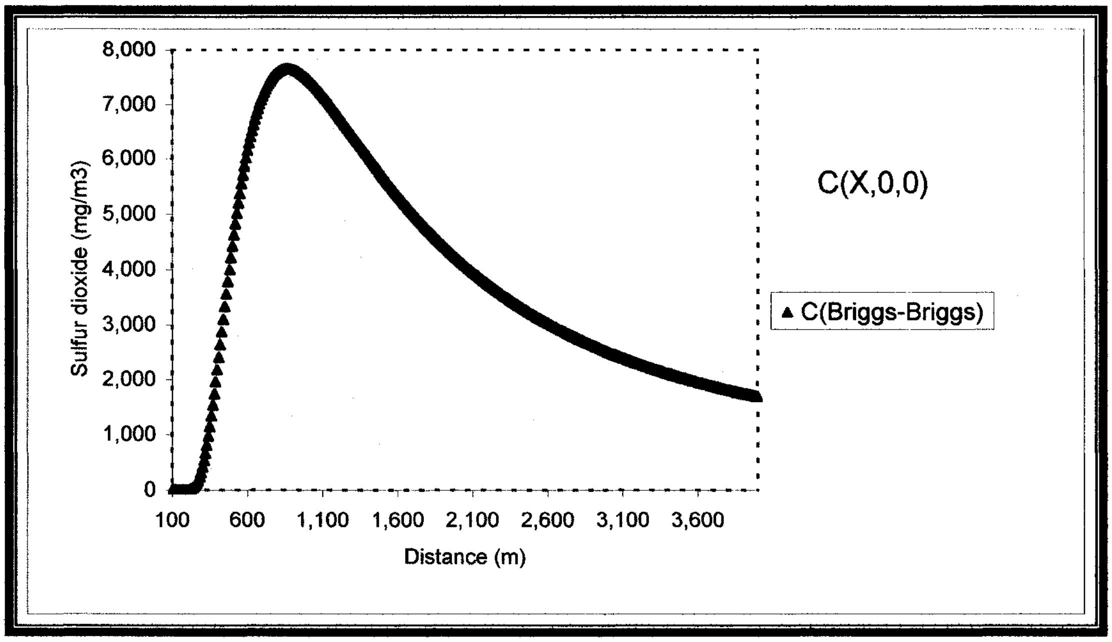
Table 5.4 Data entry for the worst-case circumstances SO_2

The first graphics obtained from the PhiStack20k are the ones showing the dispersion profile along the center-line of the flare (X-axis), at the ground level for each case scenario. Both are illustrated below on figures 5.24, and 5.25. Two important parameters are obtained from one of these graphics. First the maximum concentration obtained at ground level, which is referred in the PhiStack20k as "C max ground" (maximum y-axis value), and second the concept of “X max ground” (x-axis) that represents the downwind distance at which “C max ground” occurs.



mg/m3 = micrograms per cubic meter

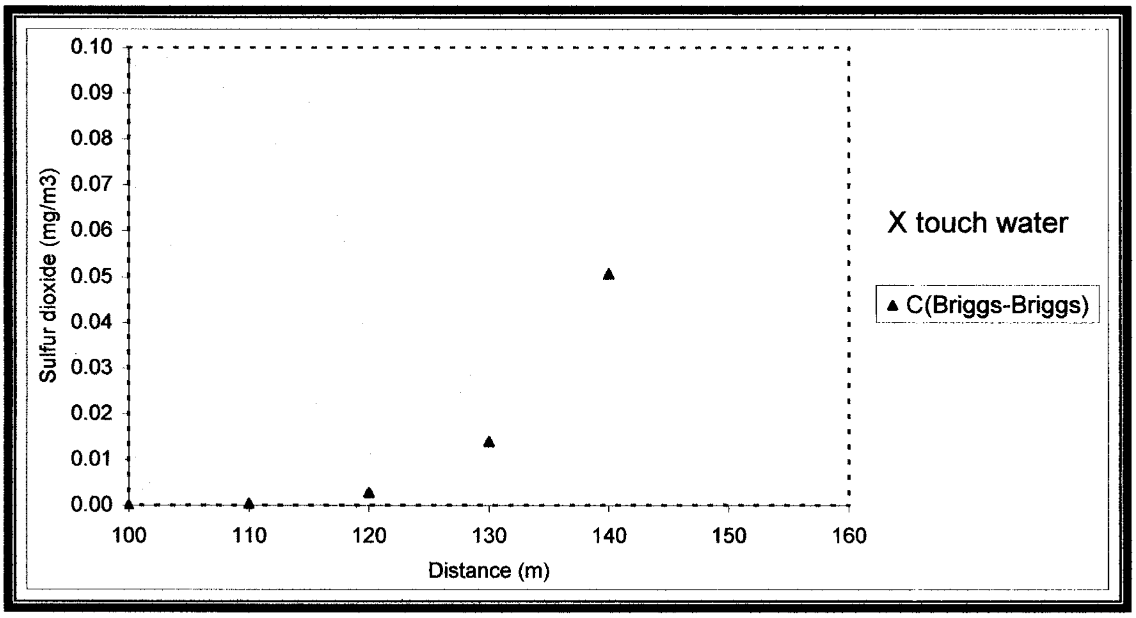
Fig. 5.24 Dispersion profile in X for the most favorable circumstances



mg/m3 = micrograms per cubic meter

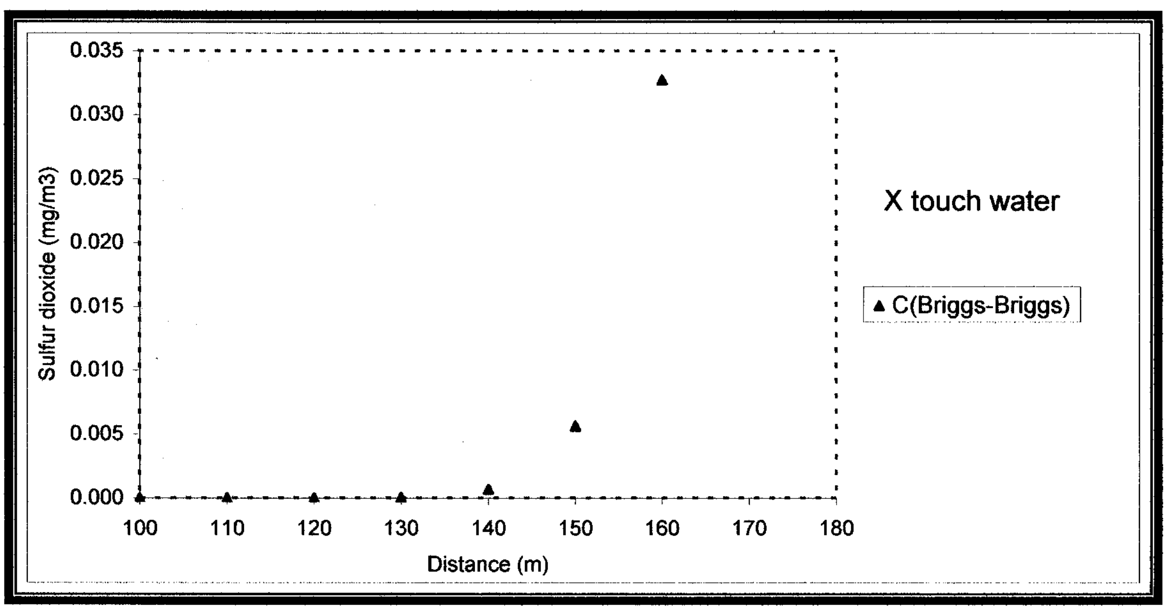
Fig. 5.25 Dispersion profile in X for the worst-case circumstances

The second result obtained from the computer code is the distance at which the plume touches the ground or water in this case, see figures 5.26, and 5.27. What is important to look at here is what is called "X touch ground" defined as the downwind distance from the stack at which the plume reaches the ground, or water as in the case of offshore flares. This value can be located following the X-axis, when the first value that changes from zero in its concentration is observed, and then this is the "X touch ground".



mg/m3 = micrograms per cubic meter

Fig. 5.26 Distance at which the plume touches the water for the most favorable circumstances

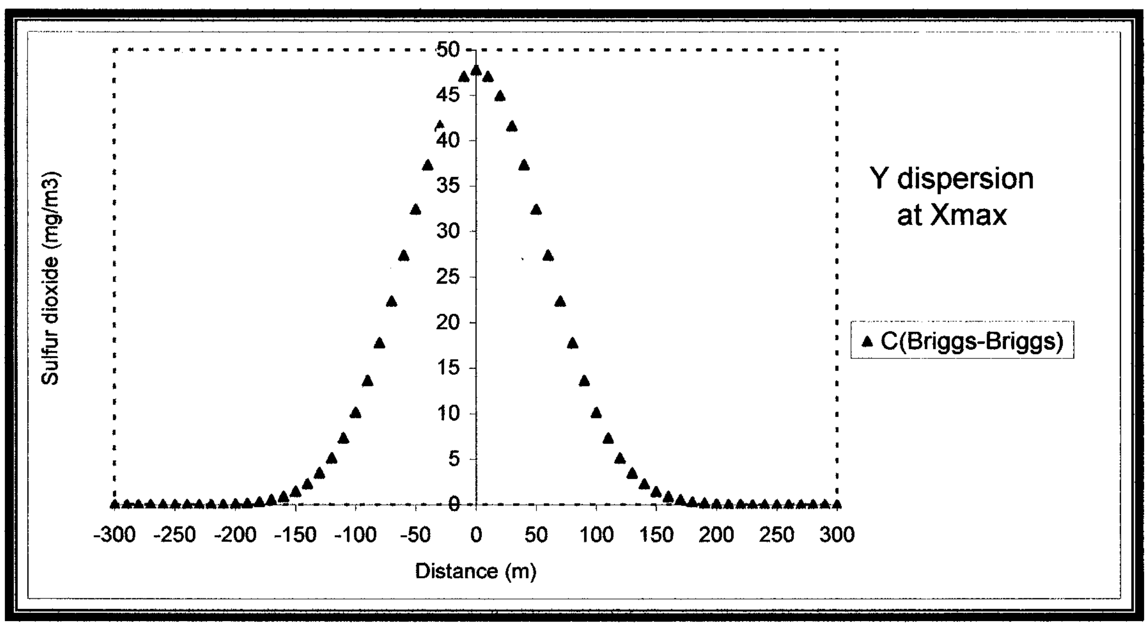


mg/m3 = micrograms per cubic meter

Fig. 5.27 Distance at which the plume touches the water for the worst-case circumstances

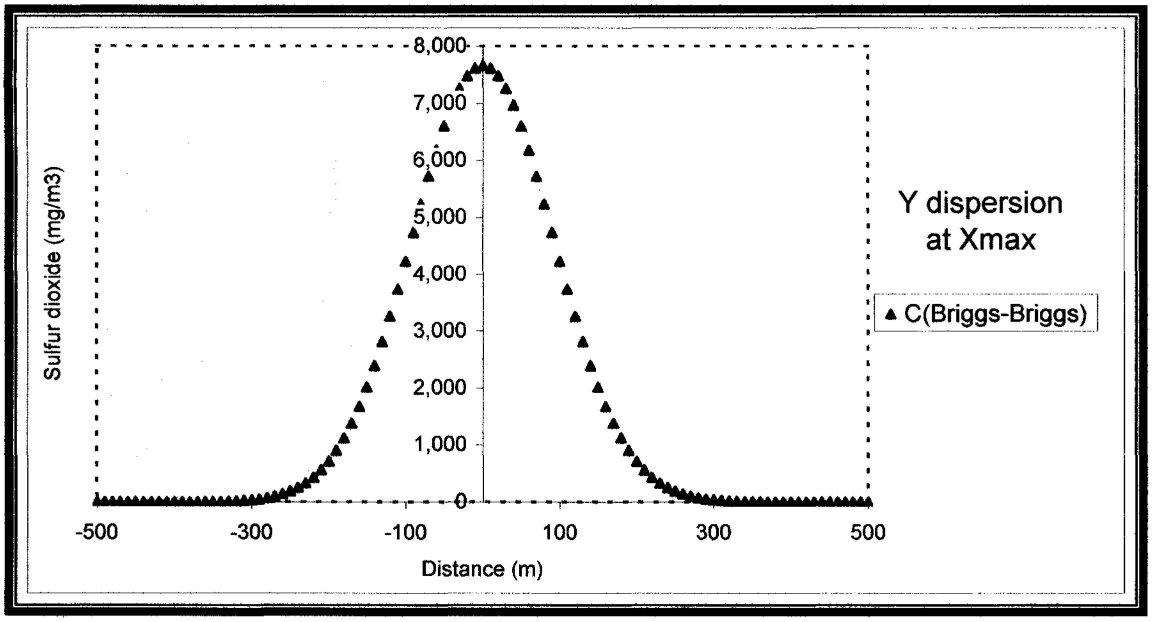
All maximum values were calculated at x = 100m (away from the stack in the downwind direction), since the dispersion coefficient equations given have restrictions for values of x smaller than 100 meters (Baratt, 2001). Phistack20K was used to find the average maximum atmospheric concentration. To avoid computational errors, the computer code PhiStack20K does not include dispersion coefficients for the domain X bigger than 100m.

The last graphics supplied are the dispersion profile of ground (or water) level of SO_2 in the crosswind direction about the point where maximum ground-level concentration is reached (C max ground); those profiled are illustrated in the figures 5.28, and 5.29. These graphics are called "Y-dispersion at X max Ground".



mg/m3 = micrograms per cubic meter

Fig. 5.28 Dispersion profile of ground level SO_2 in the crosswind direction at Xmax for the most favorable circumstances



mg/m3 = micrograms per cubic meter

Fig. 5.29 Dispersion profile of ground level SO_2 in the crosswind direction at Xmax for the worst-case circumstances

All the results obtained from the dispersion modeling of SO_2 for two offshore flares in "Sonda de Campeche", considering two different case scenarios (most favorable and worst case), are summarizing in table 5.5.

It can be observed from this table that the rate of emission does not influence the distance where the SO_2 is deposited for the first time (X touch ground). On the other hand it makes a difference for the Y dispersion at the point of maximum concentration, in which for the worst-case scenarios it is almost double compared with the most favorable scenario.

Item	Most favorable circumstances	Worst-case circumstances
Rate of emission Qp (g/s)	4.3	2242.64
X touch ground (m)	110	140
X max ground (m)	530	870
Y-dispersion at X max ground (m)	480	880
C max ground (μg/m^3)	47.8	7655.6

Table 5.5 Results for dispersion modeling of SO_2 for two case scenarios in "Sonda de Campeche"

5.3.8 Modeling of NO_2 using PhiStack20k

As in the previous section, two main objectives are sought. First, the dispersion modeling of NO_2 for one single flare under two case scenarios is considered, they are the worst case (April), and the most favorable circumstances (October). For both cases, the flares were located in Cantarell, but they do not belong to the same offshore platform. A second purpose is to verify that those flares meet the environmental law applicable for this pollutant. The input data and the results for each case scenario are presented in table 5.6 and 5.7.

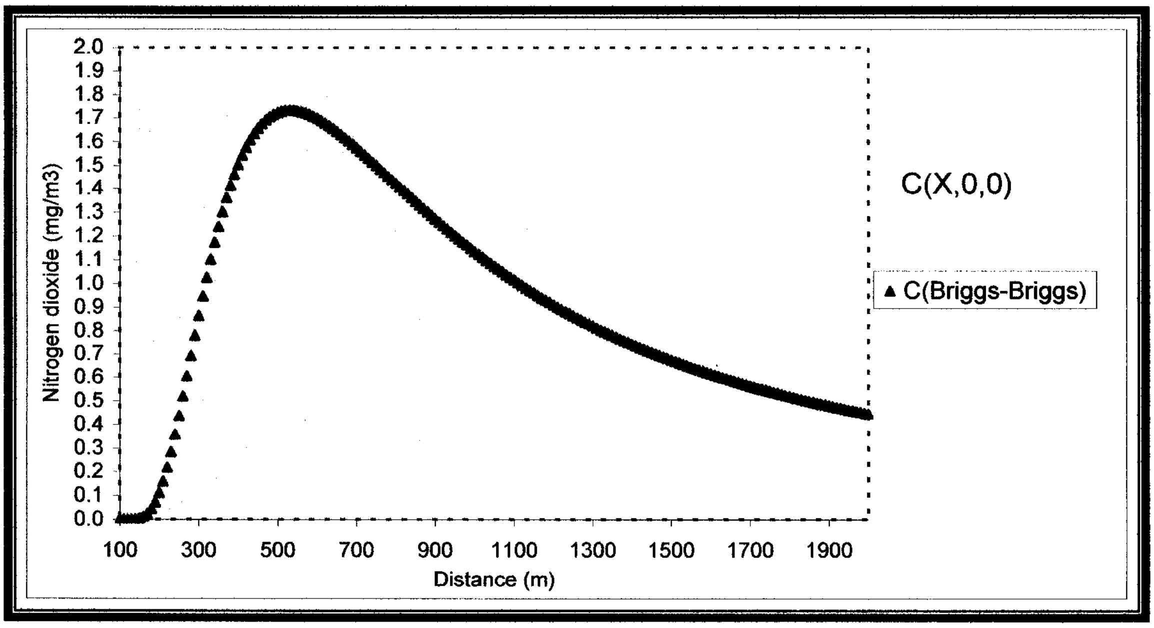
Data Entry		
General Information		
Name of User	Francisco Sanchez	
Date	DD/MM/YY	28/01/05
Air pollutant		
Name of Pollutant	Nitrogen Dioxide (NO_2)	
Rate of emission (Qp)	Qp (g/s)	0.16
Threshold concentration	TC (µg/m3)	395.00
Stack		
Height	h (m)	39.9
Diameter	d (m)	0.3
Overall emission rate (g/s)	Qs (g/s)	305.7
Emission temperature	Ts (oC)	1000.0
Atmospheric Conditions		
Temperature	Ta (°C)	28.0
Wind Velocity	u (m/s)	3.0
Atmospheric Stability	Ast (a to f)	c
Urban or Rural	U or R	r

Table 5.6 Data entry for the most favorable circumstances NO_2

Data Entry		
General Information		
Name of User	Francisco Sanchez	
Date	DD/MM/YY	28/01/05
Air pollutant		
Name of Pollutant	Nitrogen Dioxide (NO_2)	
Rate of emission (Qp)	Qp (g/s)	88.6
Threshold concentration	TC (µg/m3)	395.0
Stack		
Height	h (m)	53.6
Diameter	d (m)	0.6
Overall emission rate (g/s)	Qs (g/s)	163006.3
Emission temperature	Ts (oC)	1000.0
Atmospheric Conditions		
Temperature	Ta (°C)	26.7
Wind Velocity	u (m/s)	3.0
Atmospheric Stability	Ast (a to f)	c
Urban or Rural	U or R	r

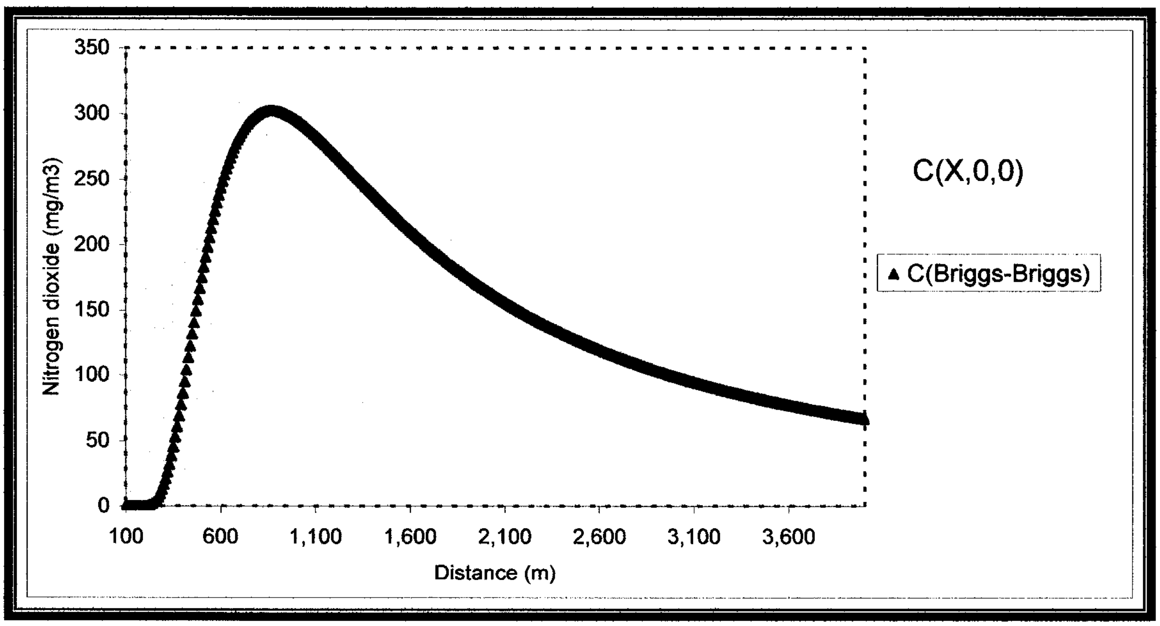
Table 5.7 Data entry for the worst-case circumstances NO_2

The dispersion profile along the center-line at the ground level is illustrated below in figures 5.30, and 5.31. "C max ground" and "X max ground" are the important points from these figures.



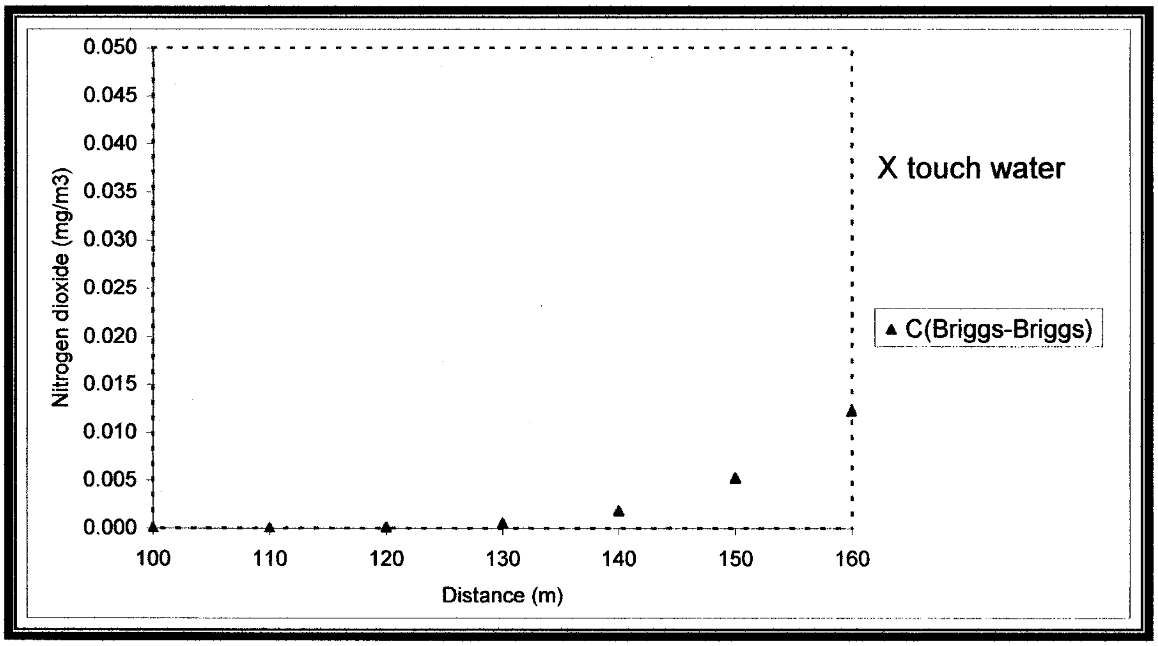
mg/m3 = micrograms per cubic meter

Fig. 5.30 Dispersion profile in X for the most favorable circumstances



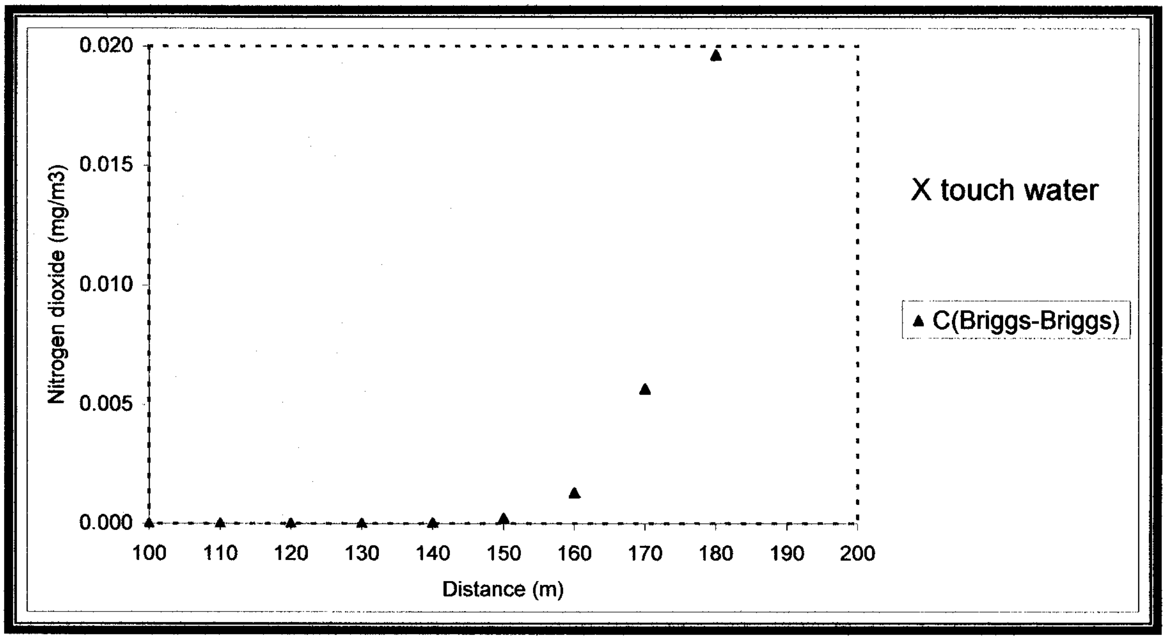
mg/m3 = micrograms per cubic meter

Fig. 5.31 Dispersion profile in X for the worst-case circumstances



mg/m3 = micrograms per cubic meter

Fig. 5.32 Distance at which the plume touches the water for the most favorable circumstances

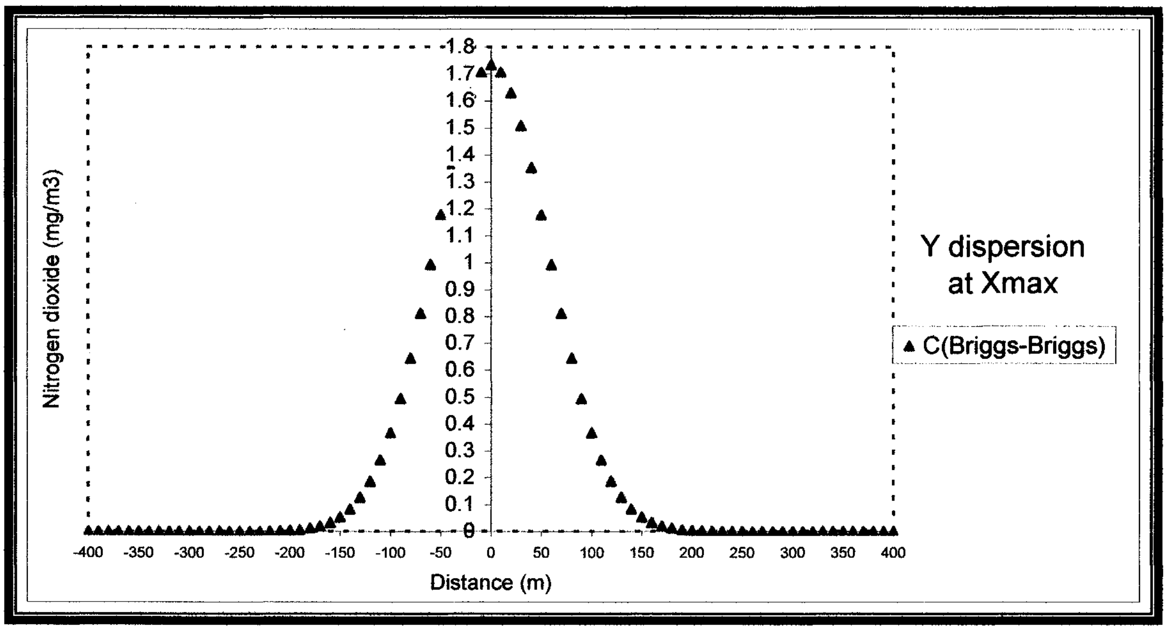


mg/m3 = micrograms per cubic meter

Fig. 5.33 Distance at which the plume touches the water for the worst-case circumstances

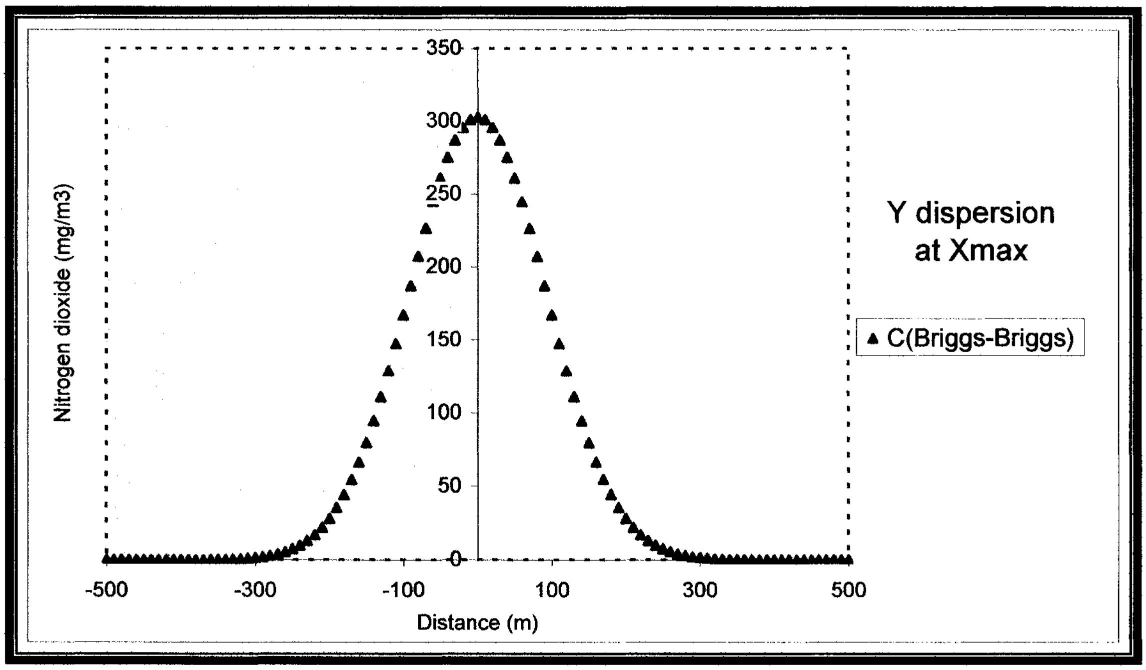
The distance at which the plume touches the ground can be determined graphically (figures 5.32, and 5.33). From those graphics the "X touch water" point can be obtained.

The dispersion profile of ground level NO_2 in the crosswind direction about the point where maximum ground-level concentration is reached, is illustrated in the figures 5.34, and 5.35.



mg/m3 = micrograms per cubic meter

Fig. 5.34 Dispersion profile of ground level NO_2 in the crosswind direction at Xmax for the most favorable circumstances



mg/m3 = micrograms per cubic meter

Fig. 5.35 Dispersion profile of ground level NO_2 in the crosswind direction at Xmax for the worst-case circumstances

Outcome obtained from the dispersion modeling of NO_2 trough PhiStack20k for two offshore flares in "Sonda de Campeche", considering two different case scenarios (most favorable and worst case), are summarizing in table 5.8.

Item	Most favorable circumstances	Worst-case circumstances
Rate of emission Qp (g/s)	0.16	88.6
X touch ground (m)	130	150
X max ground (m)	530	870
Y-dispersion at X max ground (m)	380	980
C max ground ($\mu g/m^3$)	1.7	302.6

Table 5.8 Results for dispersion modeling of NO_2 for two case scenarios in "Sonda de Campeche"

In the same way as it was described for the previous air pollutant, it is observed from Table 5.8 that the rate of emission does not influence the X touch ground. However, it does change the Y dispersion point of maximum concentration. For the worst-case, it is more than double compared to the most favorable case.

5.3.9 Modeling of H_2S, CO, PM_{10}, CO_2, and CH_4 using PhiStack20k

After presenting the modeling dispersion for the two previous air contaminants, it is quite clear for the reader what shape in each graphic can be expected for each one of the significant values of the PhiStack20k, under this consideration the table below is introduce as a way to summarize the results for H_2S, CO, PM_{10}, CO_2, and CH_4, after the computer code is used.

Similarly as for the cases of SO_2, and NO_2, it can be concluded from table 5.9 that the rate of emission does not influence the X touch ground; but it is important to mention that for all the cases, including SO_2 and NO_2, the “X max ground” was always located at 530 and 870 meters from the flare for best and worst scenarios respectively.

On the other hand, rate emission has an influence in the Y dispersion at the point of maximum concentration, which for the worst-case is almost double compared with the most favorable, with exception of H_2S in which the ratio is more than three to one.

Pollutant	Item	Most favorable circumstances	Worst-case circumstances
H_2S	Rate of emission Qp (g/s)	0.03	15.5
	X touch ground (m)	140	160
	X max ground (m)	530	870
	Y-dispersion at X max ground (m)	300	1040
	C max ground (μg/m^3)	0.3	53.0
CO	Rate of emission Qp (g/s)	2.12	1,196.6
	X touch ground (m)	110	140
	X max ground (m)	530	870
	Y-dispersion at X max ground (m)	460	900
	C max ground (μg/m^3)	23.4	4084.7
PM_{10}	Rate of emission Qp (g/s)	0.21	116.3
	X touch ground (m)	120	150
	X max ground (m)	530	870
	Y-dispersion at X max ground (m)	380	980
	C max ground (μg/m^3)	2.3	397.1
CO_2	Rate of emission Qp (g/s)	291.31	155,069.9
	X touch ground (m)	100	120
	X max ground (m)	530	870
	Y-dispersion at X max ground (m)	580	760
	C max ground (μg/m^3)	3216.0	529,357.7
CH_4	Rate of emission Qp (g/s)	0.97	548.4
	X touch ground (m)	120	140
	X max ground (m)	530	870
	Y-dispersion at X max ground (m)	440	920
	C max ground (μg/m^3)	10.7	1,872.2

Table 5.9 Results for dispersion modeling of H_2S, CO, PM_{10}, CO_2, and CH_4 for two case scenarios in “Sonda de Campeche”

Chapter Six
Assessment of impact significance

This section is subdivided into three main parts as follows: a) the impact significance in the air pollution; b) the impact significance related to water contamination; and c) waste management of residues and their impact significance.

The section of air pollution begins with a description of the air contaminants that are in compliance for the worst and most favorable scenario, and the ones that are not in compliance according to their respective environmental regulation. Then, the significant impact of those contaminants on "Ciudad del Carmen" will be explained. After that, the overlapping effect of the "Y dispersion" for two flares located at a distance of 180 meters from each other will be addressed. This will be performed to calculate the significance of overlapping of the two flares into the threshold concentration. Then sensitivity analysis considering the variation of three factors in the PhiStack20k (wind speed, temperature, and atmospheric stability) will be introduced. Changes in wind speed will range from + 2 m/s to – 2 m/s, while temperature changes range from + 5 °C to - 5 °C. Also, the atmospheric stability will be varied from "A" to "E". The significant impact of runoff water, water used by workers in their daily activities, seawater used to clean working areas, and water for hydrostatic tests will also be discussed in the second section related to water pollution. In the last section of this chapter a description of the significant impact of solid waste, residues from the kitchen, and combustible waste will be mentioned.

6.1 Air pollution

The results obtained by the computer code PhiStack20k in chapter five will be used to model the air dispersion for each pollutant. A comparison between the maximum concentration obtained for each air pollutant in the worst-case scenario, and their respective threshold concentration is shown in table 6.1. A value in percentage representing the extent of this concentration compared with its respective limit is also included (Percentage of TC*). As can be observed from table 6.1, the concentrations obtained from PhiStack20k are not significant for the four air contaminants (NO_2, CO, CO_2, and CH_4). Their values are lower than their respective maximum permissible limits. However, there are a few pollutants that are not in compliance with their threshold concentrations. These are sulfur dioxide, hydrogen sulfide, and particulate matter. For these three specific air contaminants their concentrations have a significant impact on the flora and fauna in the immediate vicinity of their respective sources. These concentrations are identified as 880 m for SO_2, 1040 m for H_2S, and 870 m for PM_{10} from the flare. Table 6.2 displays the comparison between maximum concentrations and their respective limits for the most favorable circumstances that can be achieved in "Sonda de Campeche" for the same air pollutants. Table 6.2 also shows that there is no significant impact on the biota around those flares, because their concentrations are really small. They fluctuate from 14 % to 0.003 % of their respective threshold concentrations.

Pollutant	Item	Worst-case circumstance
SO_2	C max ground (μg/m^3)	7655.6
	Threshold concentration (μg/m^3) (1)	341.0
	Percentage of TC*	2,245 %
NO_2	C max ground (μg/m^3)	302.6
	Threshold concentration (μg/m^3) (2)	395.0
	Percentage of TC*	77 %
H_2S	C max ground (μg/m^3)	53.0
	Threshold concentration (μg/m^3) (3)	42
	Percentage of TC*	126 %
CO	C max ground (μg/m^3)	4084.7
	Threshold concentration (μg/m^3) (4)	12,595
	Percentage of TC*	32 %
PM_{10}	C max ground (μg/m^3)	397.1
	Threshold concentration (μg/m^3) (5)	150
	Percentage of TC*	265 %
CO_2	C max ground (μg/m^3)	529,357.7
	Threshold concentration (μg/m^3) (6)	9,000,000
	Percentage of TC*	6 %
CH_4	C max ground (μg/m^3)	1,872.2
	Threshold concentration (μg/m^3) (7)	328,073
	Percentage of TC*	0.57 %

(1) NOM-022-SSA1-1993 (24 hours); (2) NOM-023-SSA1-1993 (1 hour); (3) Nova Scotia (1 hour); (4) NOM-021-SSA1-1993 (8 hours); (5) NOM-025-SSA1-1993 (24 hours); (6) NRF - 031 - PEMEX – 2003 (NST); (7) NOM; TC* = Threshold concentration

Table 6.1 Results for dispersion modeling of SO_2, NO_2, H_2S, CO, PM_{10}, CO_2, and CH_4 for worst-case circumstances in "Sonda de Campeche"

Pollutant	Item	Most favorable circumstance
SO_2	C max ground (µg/m^3)	47.8
	Threshold concentration (µg/m^3) (1)	341.0
	Percentage of TC*	14 %
NO_2	C max ground (µg/m^3)	1.7
	Threshold concentration (µg/m^3) (2)	395.0
	Percentage of TC*	0.43 %
H_2S	C max ground (µg/m^3)	0.3
	Threshold concentration (µg/m^3) (3)	42
	Percentage of TC*	0.71 %
CO	C max ground (µg/m^3)	23.4
	Threshold concentration (µg/m^3) (4)	12,595
	Percentage of TC*	0.19 %
PM_{10}	C max ground (µg/m^3)	2.3
	Threshold concentration (µg/m^3) (5)	150
	Percentage of TC*	1.53 %
CO_2	C max ground (µg/m^3)	3216.0
	Threshold concentration (µg/m^3) (6)	9,000,000
	Percentage of TC*	0.04 %
CH_4	C max ground (µg/m^3)	10.7
	Threshold concentration (µg/m^3) (7)	328,073
	Percentage of TC*	0.003 %

(1) NOM-022-SSA1-1993 (24 hours); (2) NOM-023-SSA1-1993 (1 hour); (3) Nova Scotia (1 hour); (4) NOM-021-SSA1-1993 (8 hours); (5) NOM-025-SSA1-1993 (24 hours); (6) NRF - 031 - PEMEX – 2003 (NST); (7) NOM; TC* = Threshold concentration

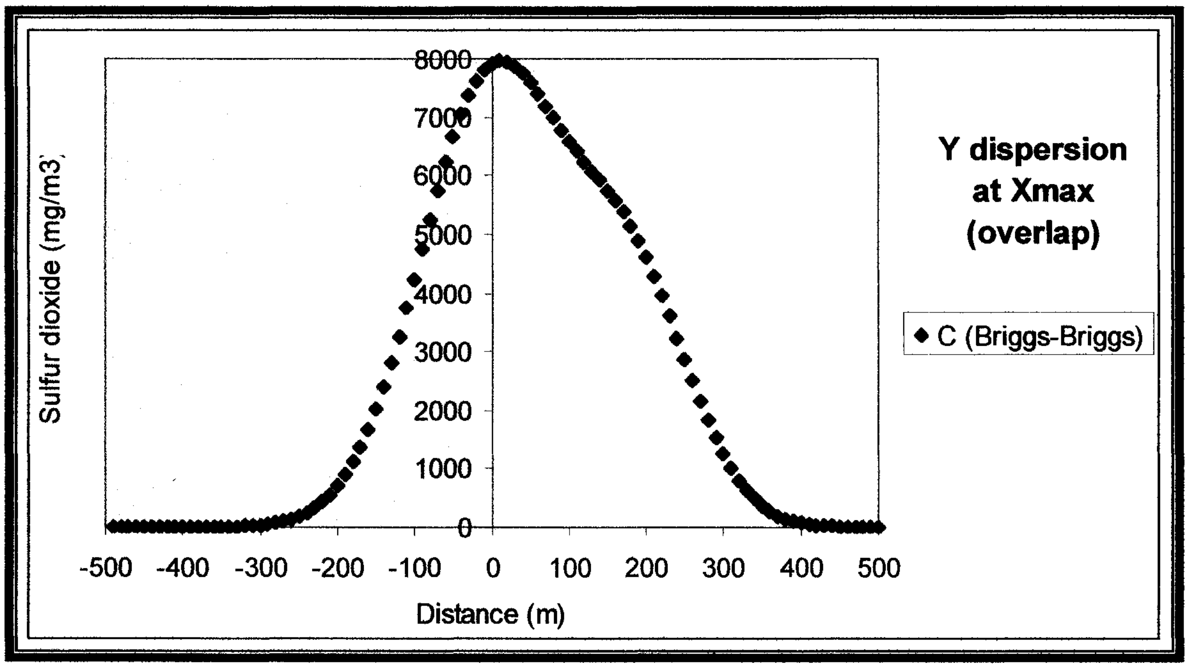
Table 6.2 Results for dispersion modeling of SO_2, NO_2, H_2S, CO, PM_{10}, CO_2, and CH_4 for most favorable circumstances in “Sonda de Campeche”

"Ciudad del Carmen"

In order to determine significance of the impact of the pollution at the ground level at "Ciudad del Carmen", the unlikely event that wind blows directly inland must be considered. First, one must recall that the platforms in the Sonda de Campeche are located 80 km away from the "Ciudad del Carmen". Then, one must recall, as demonstrated in chapter five, that in the worst-case scenario, the ground-level pollutant concentrations are negligible anywhere beyond 3 km downwind from the source. Finally, one must consider the water and wind current patterns in the "Sonda de Campeche", as described in chapter five. Therefore, no significant impact occurs in "Ciudad del Carmen" by any of the air pollutants.

Overlapping flares

For the dispersion modeling performed in the chapter five, it was observed that for the worst case scenario for each contaminant (SO_2, NO_2, H_2S, etcetera), all these pollutants were originated from the same flare FL-02. Then there is another flare FL-01 located 180 meters from FL-02. It is necessary to make a separate analysis to see the interference effect caused by the possible overlapping effects of the two flares. To quantify this effect of the two flares, the concentrations from FL-02 and FL-01 were added at points of influence. Figure 6.1 shows results for SO_2.



mg/m3 = micrograms per cubic meter

Fig. 6.1 Overlapping flares FL-01 and FL-02 (Y dispersion at Xmax)

The same analysis of overlapping concentration in the "Y" axis was done for each pollutant for a wind speed of 3.0 m/s, and atmospheric stability C. One notes that the maximum concentration (Cmax Ovelap) in these new graphics was always located 10 meters from FL-02 towards FL-01. Also an increase from 4.1 % to 4.3% from the maximum concentration of FL-02 was observed for each pollutant. More details are shown in table 6.3. As the "% Change" is around 4 % due to interference, it can be concluded that the overlapping for Cmax's concentrations from FL-02 and FL-01 is not significant for those pollutants that are in compliance with regulations for the worst case scenario (NO_2, CO, CO_2, and CH_4).

Overlapping does not play a significant role for the pollutants, which are exceeding the threshold concentrations. The additional concentration due to overlapping can be considered negligible in most cases. On the other hand, in some scenarios this overlapping can make the difference between acceptable readings in the ground-level concentration to non-acceptable readings. For example, the overlapping at wind speeds of 1.8 m/s and atmospheric stability B accounts for some 6.2%. The worst case scenario for flare FL-02 yields a concentration of NO_2 of 390.9 μg/m^3. The contribution of flare FL-01 is 25.4 μg/m^3 which with the overlapping yields a ground-level concentration of 416.4 μg/m^3 which exceeds the threshold concentration for NO_2 of 395 μg/m^3. Therefore, it can be stated that overlapping can be significant and cause non-compliance for NO_2 if certain atmospheric conditions are met.

	SO_2	NO_2	H_2S	CO	PM_{10}	CO_2	CH_4
Cmax FL-02 *	7655.6	302.6	53	4084.7	397.1	529357.7	1872.2
Cmax Overlap*	7973.5	315.2	55.2	4255.53	413.7	552045.6	1950.5
Cmax Diff *	317.9	12.6	2.2	170.8	16.6	22687.9	78.3
% Change	4.2 %	4.2 %	4.1 %	4.2 %	4.2 %	4.3 %	4.2 %

* μg/m^3 = micrograms per cubic meter

Table 6.3 Overlapping flares FL-01 and FL-02

Sensitivity Analysis

Fluctuations in the modeling parameters must be considered to determine how representative the obtained concentration levels are over a 24-hour period. The modeling parameters that can vary during the diurnal cycle include a) the wind speed, b) the atmospheric temperature, and c) the atmospheric stability.

a) Wind speed

Variations of +/- 2 m/s in the wind speed have been considered. By keeping all other modeling parameters constant, a + 2.0 m/s variation in the wind speed yields a 22% increase in the concentration of H_2S. Similarly, a variation of – 2.0 m/s yields a 94% decrease in the ground-level concentrations of H_2S. It would seem appropriate to deduce that there is a positive correlation between wind speed and ground-level concentration. However, this is not the case since at higher wind speeds the ground-level concentrations drop. The focus of this assessment is on compliance and non-compliance. Through empirical iterations the range of wind-speed values were obtained using PhiStack20K. It has been found that by keeping all other modeling parameters constant, H_2S concentrations are not in compliance if wind-speeds fall in the range of 2.4 m/s to 15.6 m/s.

Diurnal changes in wind speeds could include a decrease in the wind speeds to magnitudes below 2.4 m/s for a significant duration. Therefore, H_2S does not pose a significant impact at lower and at hurricane level wind-speeds.

b) Temperature

Significant fluctuations in atmospheric temperature are common in the Sonda de Campeche during a 24-hour cycle. A variation of +/- 5.0 °C has been considered and for all practical purposes, no variation in atmospheric temperature could bring about significant changes in the water-level concentrations of H_2S for stack effluents. It is also noted that PhiStack20K does not account for atmospheric inversions. Given the large thermal capacity of the seawater, inversions in the Sonda de Campeche are likely to occur and that should be indeed included in the model. The CALPUFF/CALMET simulations described in chapter five accounted for inversions and for the purpose of this study it is considered sufficient to conclude that even in this case, there is no significant impact on “Ciudad del Carmen” and that all adverse impact is localized at the vicinity of the flares. Non-compliance is shown to occur despite inversion periods and therefore modifications to PhiStack20k are not required.

c) Atmospheric stability

The worst-case scenario simulation for H_2S is based on the occurrence of atmospheric stability C. In the diurnal cycle, atmospheric stability is likely to change from category A (late morning) to category E (night-time). In the event of atmospheric stability A, the ground-level concentration of H_2S increases significantly and non-compliance still holds true. In the event of atmospheric stability E, there is a significant decrease in the ground-level concentration and therefore compliance can be induced. The following table 6.4 summarizes the findings described in this section concerning the variation of ground-level H_2S concentration (C max) and gives additional insight of the locations where maximum concentration occurs (X max) and the extent of the impact over the seawater (X touch ground and Y dispersion).

H_2S	C max *	X max **	X touch ground **	Y dispersion**
Modeling	53	870	160	1040
+ 2.0 m/s wind	64.8	690	140	1240
	22%	-21%	-13%	19%
- 2.0 m/s wind	3.3	2580	340	2000
	-94%	197%	113%	92%
+ 5.0 °C temp	53.1	870	160	1040
	0%	0%	0%	0%
- 5.0 °C temp	52.8	870	160	1040
	0%	0%	0%	0%
Stability A	161.7	250	100	1400
	205%	-71%	-38%	35%
Stability E	0.035	2650	840	1020
	-100%	205%	425%	-2%

* ($\mu g/m^3$) micrograms per cubic meter; ** (m) meters

Table 6.4 Sensitivity analysis for H_2S changing winds speed, temperature, and stability

6.2 Water pollution

Water during the installation and operation of a flare can be affected mainly in four different aspects. First the runoff water obtained from regular rains in the region, second the water used by workers for their regular activities i.e. taking a shower, using the toilets, or even from the kitchen, third seawater is used to clean the working areas, and finally the seawater utilized to run the hydrostatic test for pipelines.

Runoff water that has touched any part of the structure of the flare package is considered to have no significant impact on the surrounding environmental conditions, because the physical and chemical properties of this water has not been affected substantially to request for a separate treatment before being discharged to the ocean.

Moreover, waters utilized as mentioned for regular human activities do not represent a significant impact on the flora, fauna, or humans in the vicinity of the flares, because this water is treated before its final disposal into the ocean. To reinforce this stipulation, the MARPOL 73/78 (Annex IV) is followed in all the national waters belonging to Mexico.

With respect to seawater which is used to clean the working areas, it is treated in their corresponding vessels before being discharged. These discharges have to be in compliance with MARPOL 73/78 (Annex IV); for this reason, it is considered that this situation does not cause a significant impact in the actual environmental conditions observed in the area of concern.

Concerns about the seawater used for hydrostatic testing do not represent a significant impact for the actual conditions present in SDC. This is supported by the idea that the seawater properties are not drastically modified by the small particles removed from those pipes during the hydrostatic tests, therefore there is no realistic reason so far to give a pretreatment to this water before being released back into the ocean.

6.3 Waste management of residues

The managing of solid residues generated during the installation and operation of a flare in the Sonda de Campeche generated by workers (within working areas, vessels, or living quarters), has been done in what can be considered an appropriate manner in recent years. The fact is that all the solid waste (junk, burr, gloves, paints, used filters, etcetera) is classified as hazardous and not hazardous according to NOM-052-ECOL-93, and then they are sent for their recycling process or final disposal in adequate industrial plants onshore. Hence this solid waste does not represent a significant impact that could decrease, or negatively affect the current environmental conditions where these flares are installed. The same can be concluded, for residues generated in the kitchen. Because they have to be collected. A machine triturates them, which reduces them to less than 2.5 cm, as mentioned in MARPOL 73/78 (Annex V), and then they are disposed into the ocean.

Finally, the same assessment of no significant impact is applicable for combustible wastes (paper, cardboard, and wood), which are burned in the ship's incinerator respecting what is specified in MARPOL 73/78 (Annex VI). They do not provoke a negative effect in the existing quality of the air. The ashes produced by this process are collected in predestined barrels to be sent to "Ciudad del Carmen" for their final disposal.

Chapter Seven

Identification and incorporation of mitigation measures

After performing the assessment of impact significance of offshore flares in "Sonda de Campeche" it can be concluded that proper procedures have been followed to be in compliance with environmental laws (Mexican, and International) in the areas of water pollution and waste management of residues during the installation and operation of these structures. On the other hand, in the section of air pollution, the level of concentrations of three pollutants generated from offshore flares have been found to exceed their respective thresholds. For that reason, some mitigation measures are proposed in this chapter. The focus is mainly on the reduction of the following air contaminants:

a) Decrease the concentration of SO_2
b) Decrease the concentration of H_2S
c) Decrease the concentration of PM_{10}

7.1 Suggested actions

To obtain the most convenient solution to reduce the concentrations of these three air pollutants, some tentative actions are presented below.

1) Build two additional flares to comply with regulations for PM_{10}
2) Increase the height of flare by 15 meters to comply with regulations for H_2S
3) Use "Thiopaq process" to remove 99.99 % of H_2S from gas streams
4) Use the Mobil Oil SO_X Treatment (MOST) process to remove SO_2, and H_2S

5) Utilize chemical absorption with aqueous solution of 12-Molybdophosphoric acid to remove NO_X (92.9 %), SO_2 (99.9 %), and H_2S (99.7 %) from gas streams
6) Use a wire-to-cylinder-type nonthermal plasma reactor in a crossed DC magnetic field to remove SO_2 (100%), and CO (from 73% to 87%)
7) Use a bench-scale pulsed corona enhanced wet electrostatic precipitator (wESP) with the optional injection of ammonia and/or ozone to remove NO_X (80%), and SO_2 (100 %) from a flue gas
8) Use a floating storage and re-gasification unit (FSRU), to store Offshore Liquefied Natural Gas (LNG). In this way all the natural gas burned in the flares can be kept it for further re-use, reducing to a minimum for all air pollution (SO_2, NO_2, H_2S, CO, PM_{10}, CO_2, and CH_4) in the affected area
9) Construct an offshore LNG terminal to store natural gas coming from offshore flares. So as to decrease air pollution to minimum
10) Use a floating LNG structure to store natural gas, causing a reduction in the air emission of contaminants in the area

7.1.1 Construction of two additional flares

This consists of building another two flares in addition to the existing one for the worst case scenario (FL-02). Based on results from the PhiStack20k with this action the maximum concentration of PM_{10} at the sea level is reduced to 132.4 $\mu g/m^3$ for each flare. This value is lower than the applicable regulation (150 $\mu g/m^3$). Moreover, as long as the distance between flares is longer than 190 meters, the effect of overlapping is not representative (Cmax overlapping is 146.5 $\mu g/m^3$).

7.1.2 Increase the height of flare

Similar to the previous addition, based on results from PhiStack20k, if the height of the FL-02 is increased from 53.6 m to minimum 65.3 m (a difference of 11.7

m), then the maximum concentration of H_2S decreases to 38.8 μg/m^3 (corresponding threshold concentration is 42 μg/m^3). In this case, again the effect of overlapping is not significant because the concentration of FL-01 for this case is equal to 2.5 μg/m^3. The combined values from both flares yield a concentration of 41.3 μg/m^3. Hence, increasing the height of FL-02 by 15 meters is recommended to comply with H_2S.

7.1.3 Thiopaq process

"Thiopaq" is a biotechnological process for removing H_2S from gaseous streams by absorption into an alkaline solution followed by the oxidation of the absorbed sulfide to elemental sulfur by microorganisms. The "Thiopaq" process begins with the input of biogas or sour gas into an absorber unit (or scrubber). The scrubber is designed according to vessel size, construction specifications, gas type and solution flow capacities. System pH ranges from 8.2 to 9. The counter-current scrubber design washes the sour gas (or biogas) in a packed bed or packed beds containing 2-inch Pall rings. A total draw-off tray combined with a liquid redistribution tray in-between the packed beds ensures proper liquid redistribution. Treated gas (sweet gas) exits the scrubber top, enters a knockout drum, and is sent to the sales gas stream. After that the liquid stream is sent to the bioreactor (ambient pressure). A blower supplies air to a distribution header in the bottom section of the reactor, enhancing mixing. Some of the oxygen is consumed in reactions with sulfide to produce sulfur by the actions of the Thiobacillus bacteria. These nutrients are pumped into the bioreactor with a small metering pump. Next, regenerated solvent from the bioreactor is pumped back to the scrubber for reuse. A portion of the solvent from the bioreactor is also pumped to a settling tank where solids are separated from the solution and collected gravitationally. The solution is then recycled back to the bioreactor for reuse (Greenhouse Gas Technology Center, 2004). A general process flow diagram of the "Thiopaq" process is shown in figure 7.1.

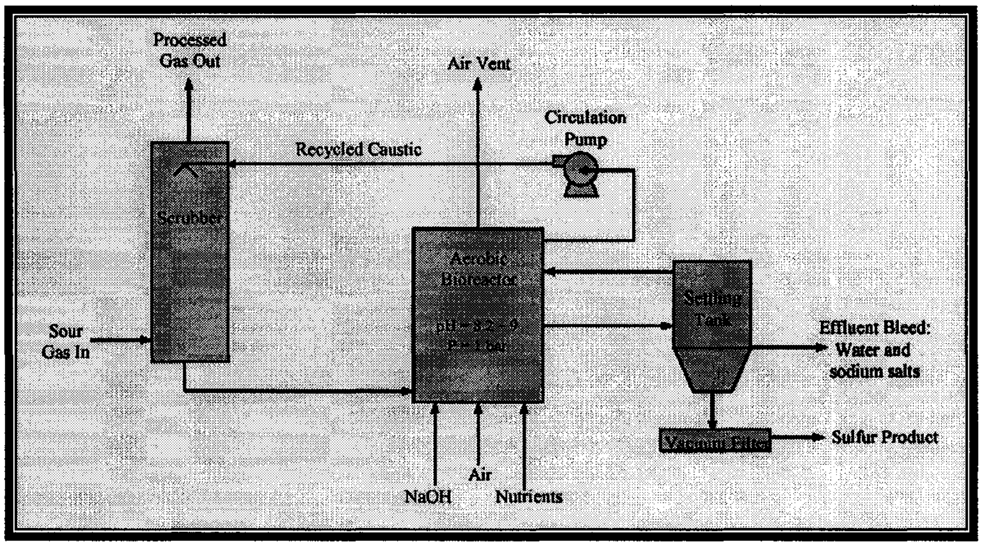


Fig. 7.1 Simplified Thiopaq process (Greenhouse, 2004)

7.1.4 Mobil oil SO_X Treatment (Buchanan, 1996)

The Mobil Oil SO_X Treatment (MOST) process, demonstrated here on the laboratory scale, consists of a unit for combusting the Claus tailgas with air, and converting all sulfur species to SO_2 and SO_3. The SO_X is then sorbed onto a solid sorbent, and in a separate step, the sulfur is reductively desorbed as a concentrated stream of mainly SO_2 and H_2S. These can then be recycled to the Claus plant for further processing.

A diagram of the MOST process is shown in figure 7.2. H_2S laden streams such as amine treater acid gas and sour water stripper effluent enter the Claus plant, along with air. Most of the sulfur is recovered as liquid sulfur. The tailgas goes to a burner, where the remaining H_2S is oxidized to SO_2 and SO_3. Excess air is used, such that the effluent from the burner contains from 1 % to 4 % of O_2. The burner effluent is shown going to sorbent bed "A", where the SO_X is adsorbed.

The cleansed tailgas then proceeds to the stack for release. The regeneration gas circuit is also shown in figure 7.2. Reducing gas, diluted with steam, flows through bed "B", to desorb the sulfur as a concentrated stream of H_2S and SO_2, which is fed back to the Claus unit. At the end of the cycle, bed "A" is loaded with sulfur, while bed "B" has had its sulfur removed. At this point, valve positions are changed, causing the tailgas to flow through bed "B", and regeneration gas to flow through bed "A" (Buchanan, 1996).

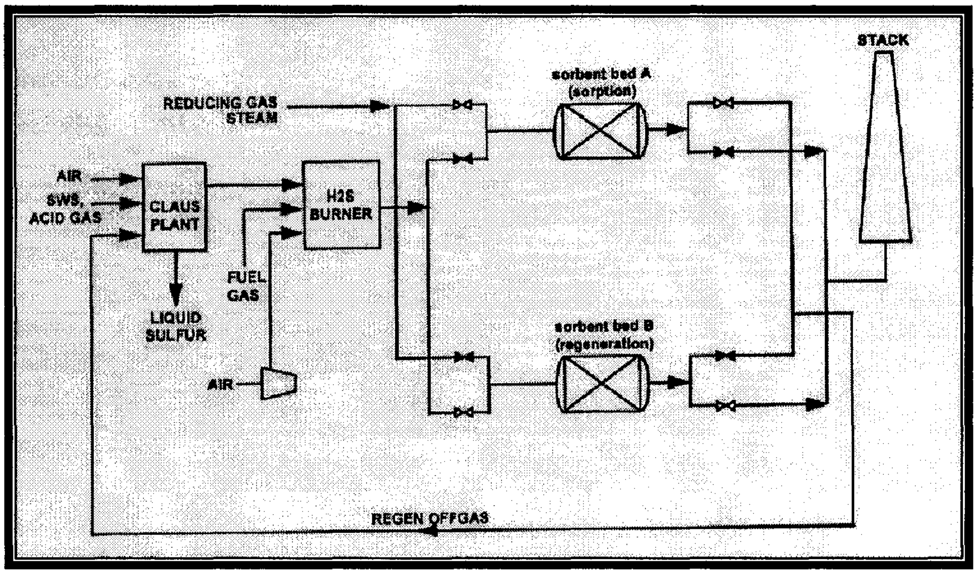


Fig. 7.2 MOST process flow diagram (Buchanan 1996)

7.1.5 Chemical absorption with aqueous solution of 12 Molybdophosphoric acid (Zhao, 1996)

Removal of SO_2, H_2S and NO_X from gas streams (air or towngas) was investigated using aqueous solutions of 12 molybdophosphoric acid and its reduced molybdenum blue species (Zhao, 1996). Results showed that H_2S and SO_2 in the gas streams can be removed quantitatively by yellow solution of 12 molybdophosphoric acid. The H_2S can be oxidized into recoverable elemental sulfur and SO_2 into H_2SO_4, while the yellow solution is reduced into blue species (reduced molybdenum blue). The reduced molybdenum blue solution can then be used for the quantitative removal of NO_X, which is reduced into N_2 and the blue solution is then oxidized back into yellow species. It is possible that the regeneration of scrubbing solution is not required and no chemical is consumed during absorption, when NO_X, SO_2 and/or H_2S coexisted in waste gases and the molar ratios of $NO_2/(SO_2 + H_2S)$ is just equal to 1/2, although, in most cases, the ratio in real practical waste gases is not always equal to that specific value. 12 molybdophosphoric acid used in this work is inexpensive, commercially available, can be regenerated easily, relatively nontoxic, and gives no secondary pollutant in the process. A diagram for the combined removal of the three pollutants is shown in figure 7.3, which displays (1) Common flow meters; (2) Micro-flow meters; (3) exit gas (for analysis); (4) Scrubbing solution; (5) D4 fritted glass disk (Zhao, 1996).

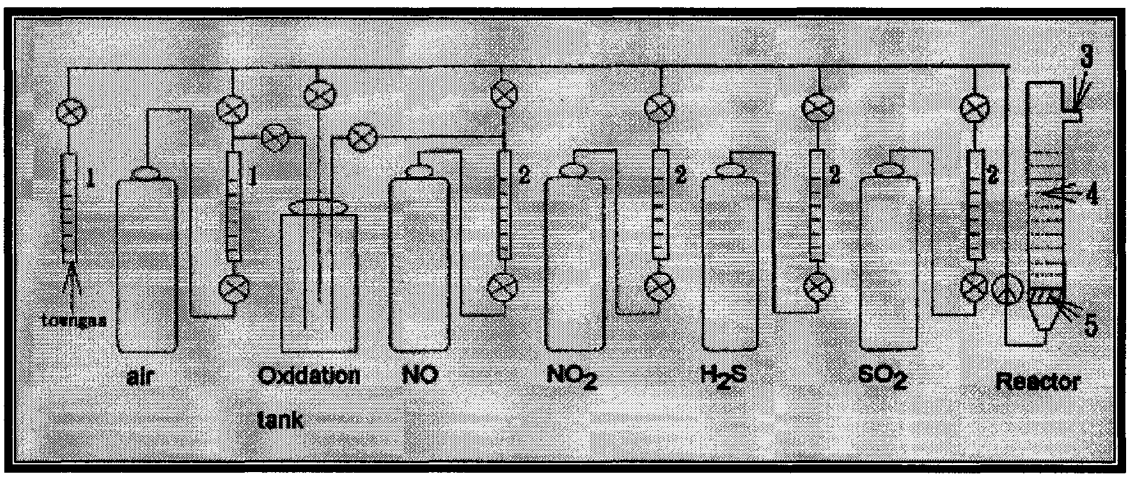


Fig. 7.3 Schematic diagram for the combined removal

of SO_2, H_2S, and NO_X (Zhao, 1996)

7.1.6 Wire-to-cylinder-type nonthermal plasma reactor in a crossed DC magnetic field (Moon, 1999).

Discharge and SO_2 and CO gas removal characteristics of a wire to cylinder type nonthermal plasma reactor in a crossed DC magnetic field have been investigated by Moon (1999). The experiment has been emphasized on the application of a crossed magnetic field, which would induce the cyclotron and drift motions of electrons making the residual time longer in the air-gap space. It also enhances the energy of electrons and the electro-physicochemical actions to remove pollutant gases effectively.

Figure 7.4 illustrates the schematic diagram of a horizontal wire to cylinder type nonthermal plasma reactor with and without a crossed DC current induced magnetic field to the electric field. The plasma reactor is made up of a wire electrode (Pt, 0.3 mm diameter, 20 cm long) and an outer cylinder electrode (SUS 304, 10 mesh, 0.1 mm thick). The outer cylinder electrode was adhered to the inner surface of the Pyrex glass tube (26 mm inner diameter), which makes it possible to see through the corona discharges in the wire to cylinder air gap. Diode-rectified DC sources were used as the power for the magnetic coil and the corona discharge. An exhausted gas consisting of SO_2, CO, NO_X, and CO_2 from an oil burner was used as the initial gas. Suitable SO_2 and CO concentrations for the test can be controlled by dry O_2 gas added to the initial gas. The temperature of the output gas was about 45 °C and the residence time of the reactor was 0.37 s. The total flow rate of initially fed gas was fixed at 2.0 L/min. The initial NO_X concentrations were about 150 ppm and 200 ppm. The applied voltage and the corona current were measured with a digital voltmeter (DVM) (Fluke 75) and a high-voltage probe (Tektronix P6015). The O_3, SO_2, and CO concentrations at the input and output of the reactor were measured with an ozone monitor (OM) (Dasibi DY-1500) and a gas analyzer (GM) (Chung Engineering CE22ASM-P). The analyses of the discharge products were carried out by using a Fourier transform infrared spectrometer (FTIR) (Galaxy Series FTIR7000) (Moon, 1999).

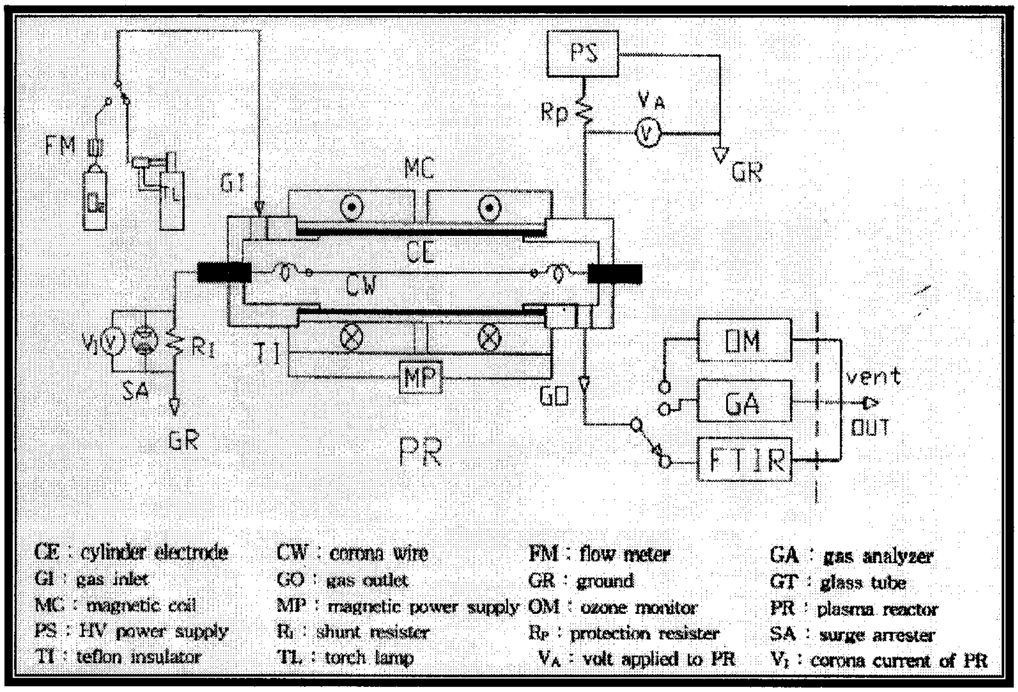


Fig. 7.4 Schematic of experimental setup and plasma reactor in a crossed DC magnetic field (Moon, 1999)

7.1.7 Bench-scale pulsed corona enhanced wet electrostatic precipitator (wESP) with the optional injection of ammonia and/or ozone (Tseng, 2001).

The combined removal of sulfur dioxide (up to 3000 ppm), and nitrogen oxides (up to 1200 ppm) has been investigated by Tseng (2001) in a bench scale pulsed corona enhanced wet electrostatic precipitator (wESP) with the optional injection of ammonia and/or ozone. The reaction of the ammonia with SO_2 produces submicron aerosol under certain conditions. Experiments have shown the feasibility of combined SO_2 and NO_X removal from simulated flue gases by the action of these in-situ generated aerosols. The mechanisms for NO_X removal include oxidation of NO to NO_2 and subsequent absorption of NO_2 into the water wall of the wESP.

A wESP system was used to measure SO_2 and NO_X removal in a continuous flow system as shown in figure 7.5. The wESP consisted of a mixing chamber, inlet and outlet ducts, a collecting area in the top section for NO_X removal studies, and a bottom section for the collection and sampling of the water. From an air pollution control standpoint, the wESP system combines the advantage of a wet flue gas desulphurization (FGD) system with the use of NH_3 reagent, while the electrostatic function efficiently collects ammonium aerosol and acid mist. In addition, the corona discharge aids in the oxidation of the SO_2 and NO to SO_X and NO_2, so more byproducts are in the stable sulfate and nitrate form rather than in the unstable sulfite form (Tseng, 2001).

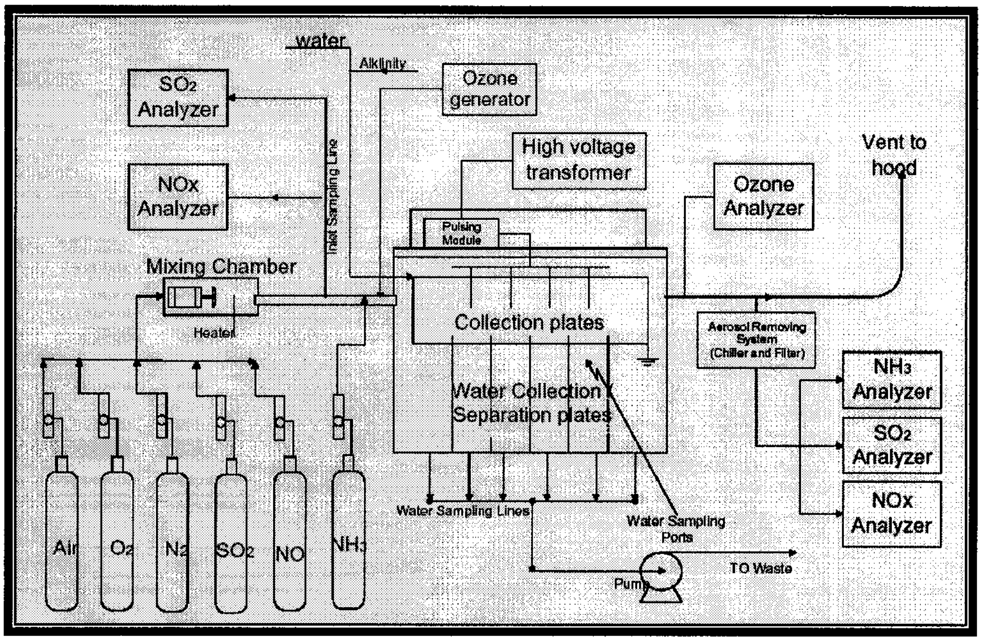


Fig. 7.5 Overview of the wESP system used to measure SO_2 and NO_X removal in a continuous flow (Tseng, 2001)

7.1.8 Floating storage and re-gasification unit (Miller, 2004)

The LNG supply process involves a complicated process, which begins at the production field, and ends with the consumption of natural gas. There are four main steps in the LNG supply chain, which are illustrated in figure 7.6.

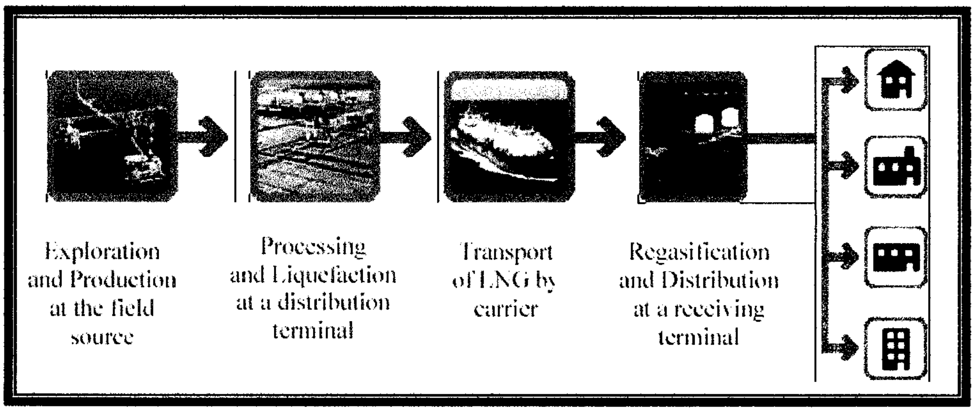


Fig. 7.6 LNG process (XIV)

A stationary FSRU will allow offshore side-by-side discharge of traditional LNG carriers. A FSRU will be classified as a vessel and will therefore require dry-docking within maximum 5 years intervals. After the positioning voyage, the FSRU shall be moored to and may stay on a turret buoy mooring system for an extended period of time up to 25 years. Although the size and cargo volume for a FSRU may vary, a typical FSRU may have the following dimensions (table 7.1).

This kind of vessel will be capable of disconnecting from the mooring buoy without assistance to move to a dry docking yard and also in case of hurricanes or extreme weather conditions within about 2 hours. It may also be relocated for commercial reasons to a new position, permanently or seasonally. The terminal can be constructed within 36 months. With 12 months permitting and design process and 2 months transit time from its construction site, a total of 50 months is foreseen from start to finish of such a project.

	Dimensions and characteristics
Size of vessel (l x b x d)	300 x 52 x 24 meters
Draft of vessel	12 m scantling, 11 m constant operation Compensation by water ballast
Deadweight	106 000 tons at 12 m, 94 000 tons at 11 m
Storage capacity	200 000 m^3 (alt. 240 000 m^3)
Containment system	Moss spherical tanks
Water Ballast Capacity	90 000 m^3
Re-gasification capacity	1 billion scf/day (1.2 bscf/day peak capacity) 5 vaporization units to be located on main deck
Propulsion	2 azimuth thrusters each 5.500 kW
Speed	11 knots
Power Generation	5 x 6 000 kW. Total 330 000 kW. 6,6 kV – 60 Hz
Power Consumption	About 14 500 kW normal operation
Water depth	From 20 to 25 meters
Mooring	Submerged turret buoy (APL)
Distance to shore	Outside territorial waters (>12 nautical miles)
Loading rate	Capable of receiving 150 000 m3 LNG cargo in 12 hrs Ship to FSRU side by side mooring LNG discharge by standard loading arms

Table 7.1 FSRU typical dimensions and characteristics (XV)

The FSRU will be very cost competitive compared with shore-based terminals and offshore Gravity Base Structures. The FSRU has a major environmental advantage compared to shore based and offshore fixed gravity based terminals. Another major advantage of the FSRU is the enhanced flexibility created by such a system. Figure 7.7 shows a typical FRSU.

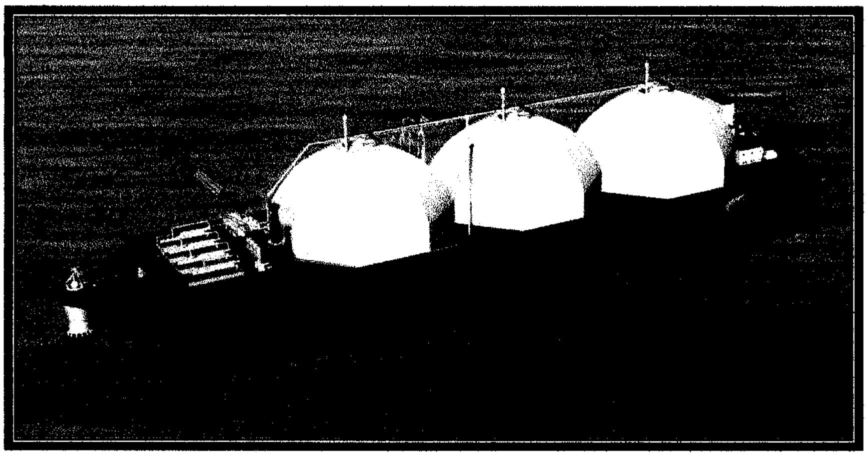


Fig. 7.7 Floating storage and re-gasification unit (FSRU) [XIII]

	Weight (m ton)	Japan	Korea	Spain
Hull Steel	50,579	$ 106	$ 96	$ 121
Hull Outfitting	7,500	$ 43	$ 39	$ 36
Hull Machinery	1,000	$ 1	$ 1	$< 1 *
Electric Outfitting	1,000	$ 2	$ 2	$< 1 *
Accommodations	800	$ 23	$ 21	$ 24
Cargo Fitting	2,000	$ 27	$ 24	$< 1 *
Topsides Module Supports	2,000	$ 2	$ 1	$ 2
SPB LNG Tanks	23,334	$ 93	$ 93	$ 93
Re-gasification Process & Engineering	NA	$ 184	$ 184	$ 176
Owners' Costs & Contingency	NA	$ 97	$ 92	$ 90
Transportation--Floater	NA	$ 15	$ 15	$ 5
Installation--Floater	NA	$ 15	$ 15	$ 15
	Total (millions)	$ 608	$ 585	$ 563

m ton = metric ton; NA = Not applicable; $< 1 * the addition of these three costs is equal to $ 1

Table 7.2 Cost Analysis for a FSRU located in the Niger delta region (XV)

A cost analysis for a FSRU has been estimated by Regan Miller and his colleagues from Texas A&M University in May 2004. As part of their work, they estimated the unit cost of each terminal component for three shipyards in Korea, Japan, and Spain respectively, see table 7.2. At market prices on that month, Spain was the least expensive option. The total cost for constructing the FSRU in Spain, including construction, transportation, and contingency, was US $563 million (Miller, 2004).

7.1.9 Offshore LNG terminal (Chevron-Texaco, 2003)

In some countries, natural gas is flared as an unwanted by-product of crude production or left stranded in the ground. Today, this gas is extracted and cooled until it condenses to a liquid. It can then be stored and shipped as safely as any other liquid fuel. The first offshore LNG receiving and re-gasification terminal will be built on the coast of Louisiana, United States. The proposed offshore LNG terminal can be constructed using a Gravity Based Structure (GBS) see figure 7.8, a freestanding concrete structure, along with mechanical facilities capable of offloading, storage and re-gasifying LNG.

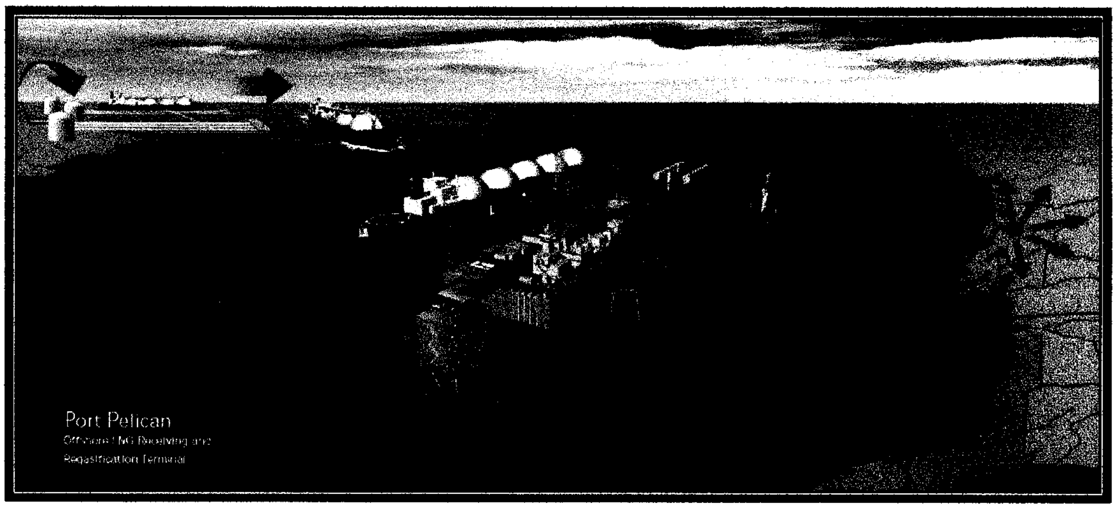


Fig. 7.8 Offshore LNG receiving and re-gasification terminal in Port Pelican (XVI)

The terminal features storage tanks within the concrete base, mechanical re-gasification facilities topside capable of initially processing 800 million cubic feet of gas per day. The environmental and economical benefits are listed below.

I. Diversifies energy supply – safely and securely
II. Helps meet growing demand for environmentally clean energy
III. Less impact on the environment than an onshore facility
IV. Reduces greenhouse gas emissions and conserves resources by eliminating flaring and enabling the development of stranded gas in remote regions
V. Removes LNG receiving/re-gasification operations from congested ports

Additionally, in December 2003 was released by Chevron Texaco Corporation in the magazine called “Filtration Industry Analyst” that they were planning to build an offshore LNG receiving and re-gasifying terminal, which should be located 13 km off the coast of Baja California Mexico. The total coast of this terminal was estimated in US$ 650 million (Chevron-Texaco, 2003).

7.1.10 Floating LNG structure (Raine, 2003)

Some governments are legislating to limit or prohibit the flaring or gas associated with oil offshore production. The result is an increasing interest into the development of offshore gas liquefaction installation, in particular the development of floating liquefied natural gas production facilities. The first focus of floating LNG proposals has been steel hulled Floating Production Storage and Offloading (FPSO); however Concrete Floating Production, Storage and Offloading (CFPSO) have certain advantages comparing with those made of steel.

The evaluation of concrete substructures for support of LNG production facilities and LNG storage reveals the following benefits:

i. Concrete is well suited to local construction
ii. Concrete substructures built in purpose built graving docks are not size constrained
iii. Concrete floating substructures realize superior motions compared to steel hulls
iv. Concrete substructures are well suited to the storage of LNG
v. Concrete substructures are resistant to LNG spill conditions
vi. Concrete is a durable material
vii. Concrete substructure OPEX is minimal
viii. Concrete floating substructures reduces operating cost
ix. Concrete floating substructures enhances safety for dropped objects and spills
x. Concrete floating substructures increases vessel impact capability
xi. Concrete floating substructures significantly increases mass to reduce facility motions
xii. Concrete floating substructures are better storage safety for possible tank leakage

Besides, CFPSO LNG installations (figure 7.9) are feasible and offer significant advantages by being able to locate the facility in close proximity to large, offshore stranded gas reserves. These advantages are the reduction of offshore pipelines, onshore facilities and marine jetty. In addition, the facility could ultimately be moved to another location in the future.

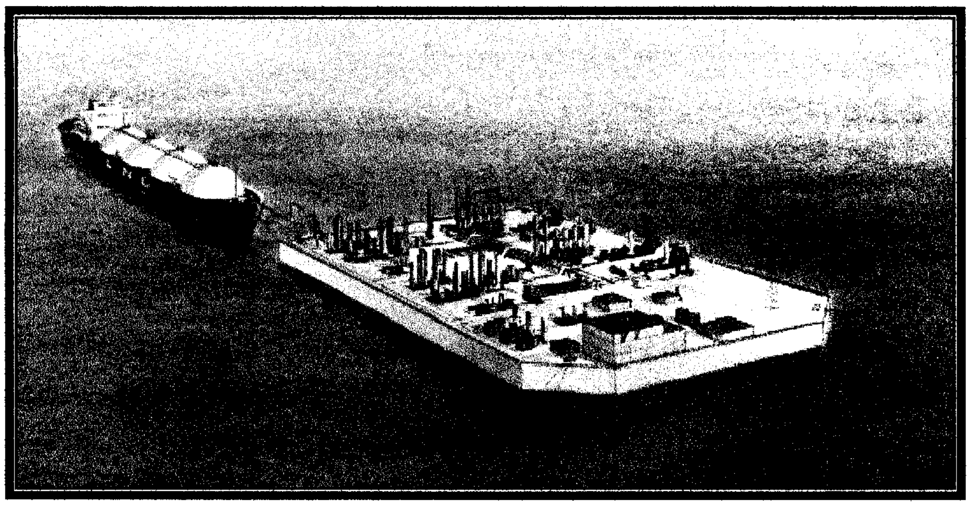


Fig. 7.9 Offshore CFPSO Facility (XVII)

An estimation of how much money could be involved in the construction of a CFPSO for a West African facility is summarized in table 7.3. This cost was publicized in the magazine "Offshore Engineer" by Brian Raine and his team in 2003. Their estimated cost was prepared considering that the construction could be done close to major population centers such as Lagos in Nigeria. They did not include additional cost as contingency, accommodation; flare quarters, and LNG/LPG (liquefied petroleum gas) loading systems, which should have been considered in their estimation. Therefore their level of accuracy was estimated in plus or minus 30 %.

Element	CFPSO with membrane tankage	CFPSO with prismatic tankage
CFPSO	$ 370 million	$ 380 million
Tankage	$90 million	$ 130 million
Mooring and installation	$ 40 million	$ 40 million
Total	**$ 500 million**	**$ 550 million**

Table 7.3 Cost Analysis for a CFPSO in West Africa (Raine, 2003)

7.2 Decision Factors

In order to compare these options (tentative actions) introduced in the section 7.1, different decision parameters have been identified (table 7.4). These are the parameters most relevant in this case study. The table below shows them as they appear in the following work sheets.

While all the decision parameters mentioned above play an important role, they cannot be said to have the same importance. In order to quantify their relative importance, we have used the "Paired Comparison Technique for Importance Weight Assignment" as it is described by Canter (1996), see table 7.5.

In this technique the decision factors are compared in pairs, the pair selected is evaluated according to its importance, and based on the judgment of the person who is performing this assessment. The value of one is given to the factor that has a higher importance between the two, and zero to the other. Also there is a second alternative, which consists of providing 0.5 to both of the factors when it is considered that both options have the same importance. After the first pair is compared, another new couple is selected, and the same procedure is performed until all the decision factors are compared among themselves.

After this step, all the values obtained for each factor are added, and then these partial totals are added to obtain a final total. Each partial total is divided by the final total giving as result the factor importance coefficient (FIC) for each one of the decision factors involved in the evaluation.

Decision Factors
Initial Cost
Cost to implement
Time to implement
Cost to operate
Maintenance cost
Frequency of maintenance
Energy production efficiency
Performance reliability
Affected area
Concentration of SO2
Concentration of NO2

Decision Factors (cont.)
Concentration of H2S
Concentration of CO
Concentration of PM10
Concentration of CO2
Concentration of CH4
Health and safety of workers during installation
Health and safety of workers during process
Health and safety of workers during maintenance
Construction of flares
Number of flares and distances between them

Table 7.4 Decision factors

Decision Factors															
Initial Cost	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.5	0.5
Cost to implement	0.0														
Time to implement		0.0													
Cost to operate			1.0												
Maintenance cost				1.0											
Frequency of maintenance					1.0										
Energy production efficiency						1.0									
Performance reliability							1.0								
Affected area								1.0							
Concentration of SO_2									1.0						
Concentration of NO_2										0.5					
Concentration of H_2S											1.0				
Concentration of CO												0.5			
Concentration of PM_{10}													1.0		
Concentration of CO_2														0.5	
Concentration of CH_4															0.5
Health and safety of workers during installation															
Health and safety of workers during process															
Health and safety of workers during maintenance															
Construction of flares															
Number of flares and distances between them															
Dummy															

Table 7.5 Paired Comparison Technique for Importance Weight Assignment

Decision Factors															
Initial Cost	0.0	0.5	0.5	0.5	0.5	1.0									
Cost to implement							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Time to implement							1.0								
Cost to operate								1.0							
Maintenance cost									1.0						
Frequency of maintenance										1.0					
Energy production efficiency											1.0				
Performance reliability												1.0			
Affected area													1.0		
Concentration of SO_2														1.0	
Concentration of NO_2															0.5
Concentration of H_2S															
Concentration of CO															
Concentration of PM_{10}															
Concentration of CO_2															
Concentration of CH_4															
Health and safety of workers during installation	1.0														
Health and safety of workers during process		0.5													
Health and safety of workers during maintenance			0.5												
Construction of flares				0.5											
Number of flares and distances between them					0.5										
Dummy						0.0									

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement	0.0	0.5	0.0	0.5	0.5	0.0	0.5	0.5	0.5	0.5	1.0				
Time to implement												0.0	0.0	0.0	0.0
Cost to operate												1.0			
Maintenance cost													1.0		
Frequency of maintenance														1.0	
Energy production efficiency															1.0
Performance reliability															
Affected area															
Concentration of SO_2															
Concentration of NO_2															
Concentration of H_2S	1.0														
Concentration of CO		0.5													
Concentration of PM_{10}			1.0												
Concentration of CO_2				0.5											
Concentration of CH_4					0.5										
Health and safety of workers during installation						1.0									
Health and safety of workers during process							0.5								
Health and safety of workers during maintenance								0.5							
Construction of flares									0.5						
Number of flares and distances between them										0.5					
Dummy											0.0				

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.5	0.5	0.0	0.5	0.5	0.5	0.5	1.0
Cost to operate															
Maintenance cost															
Frequency of maintenance															
Energy production efficiency															
Performance reliability	1.0														
Affected area		1.0													
Concentration of SO_2			1.0												
Concentration of NO_2				0.5											
Concentration of H_2S					1.0										
Concentration of CO						0.5									
Concentration of PM_{10}							1.0								
Concentration of CO_2								0.5							
Concentration of CH_4									0.5						
Health and safety of workers during installation										1.0					
Health and safety of workers during process											0.5				
Health and safety of workers during maintenance												0.5			
Construction of flares													0.5		
Number of flares and distances between them														0.5	
Dummy															0.0

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate	1.0	1.0	0.5	0.5	0.0	0.0	0.5	0.0	0.5	0.0	0.5	0.5	0.0	1.0	1.0
Maintenance cost	0.0														
Frequency of maintenance		0.0													
Energy production efficiency			0.5												
Performance reliability				0.5											
Affected area					1.0										
Concentration of SO_2						1.0									
Concentration of NO_2							0.5								
Concentration of H_2S								1.0							
Concentration of CO									0.5						
Concentration of PM_{10}										1.0					
Concentration of CO_2											0.5				
Concentration of CH_4												0.5			
Health and safety of workers during installation													1.0		
Health and safety of workers during process														0.0	
Health and safety of workers during maintenance															0.0
Construction of flares															
Number of flares and distances between them															
Dummy															

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate	0.5	0.5	1.0												
Maintenance cost				1.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.5	0.5	0.0
Frequency of maintenance				0.0											
Energy production efficiency					1.0										
Performance reliability						1.0									
Affected area							1.0								
Concentration of SO_2								1.0							
Concentration of NO_2									0.5						
Concentration of H_2S										1.0					
Concentration of CO											0.5				
Concentration of PM_{10}												1.0			
Concentration of CO_2													0.5		
Concentration of CH_4														0.5	
Health and safety of workers during installation															1.0
Health and safety of workers during process															
Health and safety of workers during maintenance															
Construction of flares	0.5														
Number of flares and distances between them		0.5													
Dummy			0.0												

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate															
Maintenance cost	0.5	1.0	0.0	0.0	1.0										
Frequency of maintenance						0.0	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.5	0.5
Energy production efficiency						1.0									
Performance reliability							1.0								
Affected area								1.0							
Concentration of SO_2									1.0						
Concentration of NO_2										0.5					
Concentration of H_2S											1.0				
Concentration of CO												0.5			
Concentration of PM_{10}													1.0		
Concentration of CO_2														0.5	
Concentration of CH_4															0.5
Health and safety of workers during installation															
Health and safety of workers during process	0.5														
Health and safety of workers during maintenance		0.0													
Construction of flares			1.0												
Number of flares and distances between them				1.0											
Dummy					0.0										

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate															
Maintenance cost															
Frequency of maintenance	0.0	1.0	0.5	0.0	0.0	1.0									
Energy production efficiency							0.5	0.0	0.0	0.5	0.0	0.5	0.0	0.5	0.5
Performance reliability							0.5								
Affected area								1.0							
Concentration of SO_2									1.0						
Concentration of NO_2										0.5					
Concentration of H_2S											1.0				
Concentration of CO												0.5			
Concentration of PM_{10}													1.0		
Concentration of CO_2														0.5	
Concentration of CH_4															0.5
Health and safety of workers during installation	1.0														
Health and safety of workers during process		0.0													
Health and safety of workers during maintenance			0.5												
Construction of flares				1.0											
Number of flares and distances between them					1.0										
Dummy						0.0									

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate															
Maintenance cost															
Frequency of maintenance															
Energy production efficiency	0.0	1.0	1.0	0.5	0.5	1.0									
Performance reliability							0.5	0.5	1.0	0.5	1.0	0.5	1.0	1.0	0.5
Affected area							0.5								
Concentration of SO_2								0.5							
Concentration of NO_2									0.0						
Concentration of H_2S										0.5					
Concentration of CO											0.0				
Concentration of PM_{10}												0.5			
Concentration of CO_2													0.0		
Concentration of CH_4														0.0	
Health and safety of workers during installation	1.0														0.5
Health and safety of workers during process		0.0													
Health and safety of workers during maintenance			0.0												
Construction of flares				0.5											
Number of flares and distances between them					0.5										
Dummy						0.0									

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate															
Maintenance cost															
Frequency of maintenance															
Energy production efficiency															
Performance reliability	1.0	1.0	0.5	0.5	1.0										
Affected area						0.5	1.0	0.5	1.0	0.5	1.0	1.0	0.5	1.0	1.0
Concentration of SO_2						0.5									
Concentration of NO_2							0.0								
Concentration of H_2S								0.5							
Concentration of CO									0.0						
Concentration of PM_{10}										0.5					
Concentration of CO_2											0.0				
Concentration of CH_4												0.0			
Health and safety of workers during installation													0.5		
Health and safety of workers during process	0.0													0.0	
Health and safety of workers during maintenance		0.0													0.0
Construction of flares			0.5												
Number of flares and distances between them				0.5											
Dummy					0.0										

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate															
Maintenance cost															
Frequency of maintenance															
Energy production efficiency															
Performance reliability															
Affected area	0.5	0.5	1.0												
Concentration of SO_2				1.0	0.5	1.0	0.5	1.0	1.0	0.5	0.5	0.5	1.0	1.0	1.0
Concentration of NO_2				0.0											
Concentration of H_2S					0.5										
Concentration of CO						0.0									
Concentration of PM_{10}							0.5								
Concentration of CO_2								0.0							
Concentration of CH_4									0.0						
Health and safety of workers during installation										0.5					
Health and safety of workers during process											0.5				
Health and safety of workers during maintenance												0.5			
Construction of flares	0.5												0.0		
Number of flares and distances between them		0.5												0.0	
Dummy			0.0												0.0

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate															
Maintenance cost															
Frequency of maintenance															
Energy production efficiency															
Performance reliability															
Affected area															
Concentration of SO_2															
Concentration of NO_2	0.0	0.0	0.0	0.5	1.0	0.5	0.5	0.5	1.0	1.0	1.0				
Concentration of H_2S	1.0											1.0	0.5	1.0	1.0
Concentration of CO		1.0										0.0			
Concentration of PM_{10}			1.0										0.5		
Concentration of CO_2				0.5										0.0	
Concentration of CH_4					0.0										0.0
Health and safety of workers during installation						0.5									
Health and safety of workers during process							0.5								
Health and safety of workers during maintenance								0.5							
Construction of flares									0.0						
Number of flares and distances between them										0.0					
Dummy											0.0				

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate															
Maintenance cost															
Frequency of maintenance															
Energy production efficiency															
Performance reliability															
Affected area															
Concentration of SO_2															
Concentration of NO_2															
Concentration of H_2S	0.5	0.5	0.5	1.0	1.0	1.0									
Concentration of CO							0.0	1.0	0.5	0.5	0.5	0.5	1.0	1.0	1.0
Concentration of PM_{10}							1.0								
Concentration of CO_2								0.0							
Concentration of CH_4									0.5						
Health and safety of workers during installation	0.5									0.5					
Health and safety of workers during process		0.5									0.5				
Health and safety of workers during maintenance			0.5									0.5			
Construction of flares				0.0									0.0		
Number of flares and distances between them					0.0									0.0	
Dummy						0.0									0.0

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate															
Maintenance cost															
Frequency of maintenance															
Energy production efficiency															
Performance reliability															
Affected area															
Concentration of SO_2															
Concentration of NO_2															
Concentration of H_2S															
Concentration of CO															
Concentration of PM_{10}	1.0	1.0	0.5	0.5	0.5	0.5	0.5	1.0							
Concentration of CO_2	0.0								0.5	0.5	0.5	0.5	1.0	1.0	1.0
Concentration of CH_4		0.0							0.5						
Health and safety of workers during installation			0.5							0.5					
Health and safety of workers during process				0.5							0.5				
Health and safety of workers during maintenance					0.5							0.5			
Construction of flares						0.5							0.0		
Number of flares and distances between them															
Dummy															

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors															
Initial Cost															
Cost to implement															
Time to implement															
Cost to operate															
Maintenance cost															
Frequency of maintenance															
Energy production efficiency															
Performance reliability															
Affected area															
Concentration of SO_2															
Concentration of NO_2															
Concentration of H_2S															
Concentration of CO															
Concentration of PM_{10}															
Concentration of CO_2															
Concentration of CH_4	0.5	0.5	0.5	1.0	1.0	1.0									
Health and safety of workers during installation	0.5						1.0	1.0	0.5	0.5	1.0				
Health and safety of workers during process		0.5					0.0					0.0	0.5	0.5	1.0
Health and safety of workers during maintenance			0.5					0.0				1.0			
Construction of flares				0.0					0.5				0.5		
Number of flares and distances between them					0.0					0.5				0.5	
Dummy						0.0					0.0				0.0

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

Decision Factors							SUM	FIC
Initial Cost							7.0	0.030
Cost to implement							5.0	0.022
Time to implement							6.0	0.026
Cost to operate							12.0	0.052
Maintenance cost							8.5	0.037
Frequency of maintenance							7.5	0.032
Energy production efficiency							12.0	0.052
Performance reliability							16.5	0.071
Affected area							17.5	0.076
Concentration of SO_2							17.5	0.076
Concentration of NO_2							9.5	0.041
Concentration of H_2S							17.5	0.076
Concentration of CO							10.5	0.045
Concentration of PM_{10}							16.5	0.071
Concentration of CO_2							9.0	0.039
Concentration of CH_4							9.0	0.039
Health and safety of workers during installation							15.5	0.067
Health and safety of workers during process							7.5	0.032
Health and safety of workers during maintenance	0.5	0.5	1.0				8.5	0.037
Construction of flares	0.5			0.5	1.0		9.0	0.039
Number of flares and distances between them		0.5		0.5		1.0	9.0	0.039
Dummy			0.0		0.0	0.0	0.0	0.000
							231.0	1.000

Table 7.5 Paired Comparison Technique for Importance Weight Assignment (cont.)

7.3 Alternatives

The next step consists of considering different alternatives based on the tentative actions that have been mentioned before. For this case six have been identified as being representatives of the desired changes at the "Sonda de Campeche". Each alternative is a combination of each one of the tentative actions. The six alternatives are listed in the table 7.6.

Alternative	
A1	Increase height of flare
	Chemical absorption
	FSRU
A2	THIOPAQ
	Nonthermal plasma reactor
	Offshore LNG terminal
A3	Build two extra flares
	MOST
	Bench-scale pulsed corona
	CFPSO

Alternative	
A4	Build two extra flares
	MOST
	Nonthermal plasma reactor
	FSRU
A5	THIOPAQ
	Chemical absorption
	CFPSO
A6	Increase high of flare
	Bench-scale pulsed corona
	Offshore LNG terminal

Table 7.6 Proposed alternatives

These six alternatives must be compared among themselves, and the best one must be proposed as the most suitable action for this case study.

The next step is to systematically grade each one of the alternatives according to a pre-determined scale. The table 7.7 shows that numerical value range from 1 to 5. The lowest value (1) is attributed to the alternative that is known to act in the worse manner in relation to the parameter in question. On the other hand, following the same principle, the larger numerical value (5) is assigned to the alternative that acts in the best possible way to each given parameter.

1	Worse
2	Below Average
3	Average
4	Above Average
5	Best Possibility

Table 7.7 Scale for the decision making process

The scoring process was carried out with the straightforward multiplication of each alternative grade (scale for the decision making process), and the respective weight importance factor (factor importance coefficient) of the decision factor. This can be seen in the two work sheets presented in table 7.8.

Decision Factors	FIC	A1	A2	A3	A4	A5	A6
Initial Cost	0.030	3	1	4	2	5	2
Cost to implement	0.022	3	1	4	2	5	2
Time to implement	0.026	5	1	2	4	3	1
Cost to operate	0.052	5	1	2	4	3	2
Maintenance cost	0.037	5	1	2	4	3	2
Frequency of maintenance	0.032	5	1	2	4	3	2
Energy production efficiency	0.052	2	5	2	1	3	4
Performance reliability	0.071	5	3	1	4	2	3
Affected area	0.076	3	5	1	1	5	3
Concentration of SO_2	0.076	5	2	3	2	5	3
Concentration of NO_2	0.041	5	2	3	2	5	3
Concentration of H_2S	0.076	3	4	2	2	5	2
Concentration of CO	0.045	3	5	2	4	2	3
Concentration of PM_{10}	0.071	3	2	5	5	2	3
Concentration of CO_2	0.039	5	3	4	4	3	5
Concentration of CH_4	0.039	5	3	4	4	3	5
Health and safety of workers during installation	0.067	5	1	2	4	3	1
Health and safety of workers during process	0.032	5	3	1	4	1	3
Health and safety of workers during maintenance	0.037	5	3	1	5	1	3
Construction of flares	0.039	3	1	5	5	1	3
Number of flares and distances between them	0.039	3	1	5	5	1	3

FIC = factor importance coefficient

Table 7.8 Scoring process

Decision Factors	FIC	A1	A2	A3	A4	A5	A6
Initial Cost	0.030	0.091	0.030	0.121	0.061	0.152	0.061
Cost to implement	0.022	0.065	0.022	0.087	0.043	0.108	0.043
Time to implement	0.026	0.130	0.026	0.052	0.104	0.078	0.026
Cost to operate	0.052	0.260	0.052	0.104	0.208	0.156	0.104
Maintenance cost	0.037	0.184	0.037	0.074	0.147	0.110	0.074
Frequency of maintenance	0.032	0.162	0.032	0.065	0.130	0.097	0.065
Energy production efficiency	0.052	0.104	0.260	0.104	0.052	0.156	0.208
Performance reliability	0.071	0.357	0.214	0.071	0.286	0.143	0.214
Affected area	0.076	0.227	0.379	0.076	0.076	0.379	0.227
Concentration of SO_2	0.076	0.379	0.152	0.227	0.152	0.379	0.227
Concentration of NO_2	0.041	0.206	0.082	0.123	0.082	0.206	0.123
Concentration of H_2S	0.076	0.227	0.303	0.152	0.152	0.379	0.152
Concentration of CO	0.045	0.136	0.227	0.091	0.182	0.091	0.136
Concentration of PM_{10}	0.071	0.214	0.143	0.357	0.357	0.143	0.214
Concentration of CO_2	0.039	0.195	0.117	0.156	0.156	0.117	0.195
Concentration of CH_4	0.039	0.195	0.117	0.156	0.156	0.117	0.195
Health and safety of workers during installation	0.067	0.335	0.067	0.134	0.268	0.201	0.067
Health and safety of workers during process	0.032	0.162	0.097	0.032	0.130	0.032	0.097
Health and safety of workers during maintenance	0.037	0.184	0.110	0.037	0.184	0.037	0.110
Construction of flares	0.039	0.117	0.039	0.195	0.195	0.039	0.117
Number of flares and distances between them	0.039	0.117	0.039	0.195	0.195	0.039	0.117
	Scores	4.048	2.545	2.608	3.314	3.158	2.773
	Ranking	1	6	5	2	3	4

FIC = factor importance coefficient

Table 7.8 Scoring process (cont.)

Table 7.9 shows the ranking of the six alternatives. One should note that the first alternative (A1) obtained the highest score (4.048) and that the second alternative (A4) obtained the second higher score.

Alternative Ranking	1	A1	4.048
	2	A4	3.314
	3	A5	3.158
	4	A6	2.773
	5	A3	2.608
	6	A2	2.545

Table 7.9 Ranking of the alternatives and their respective scores

It is to be noted also that the scores (the numerical value) of each alternative are not close to one another. This gives grounds to propose, with some degree of certitude, that A1 is indeed the best alternative to be adopted.

7.4 Mitigation measures

The alternative A1 was estimated to be the best one solution for the conditions exposed for "Sonda de Campeche" and the impact caused by offshore flares. This means that the three options are recommended to be adopted (Increase height of flare, Chemical absorption, and FSRU).

It is recognized, however, that the changes cannot be achieved all at once. The best sequence scheme appears to be is the following one:

Step 1: Use chemical absorption
Step 2: Increase height of flare
Step 3: Use FSRU

The mitigation measures stated here are based on the best alternative determined by the decision-making process, and the foreseeable problems that could arise from the implementation of these options.

7.4.1 Chemical absorption

According to the study Zhao (1996), the H_2S was oxidized into Sulfur (S), and SO_2 into Sulfuric Acid (H_2SO_4), while the yellow solution (12-Molybdophosphoric acid) was reduced into blue species (reduced molybdenum blue). This last product was used for the removal on NO_2, which was reduced to Nitrogen gas (N_2), and finally the blue solution was oxidized back to yellow solution to start over the same procedure.

Moreover, as part of his investigation Zhao (1996) detected some possible inconveniences. For example, the particles of sulfur generated by the oxidation of H_2S are very small and may take two or three days to settle. Also, the sulfur generated may get attached to the inner walls of the scrubbing tower. This requires a tower designed for an easy collection of sulfur, and washing. It was suggested that 12-Molybdophosphoric acid which is not completely pure could also be used, since large quantities of scrubbing solution are needed. Summarizing, in the implementation of this alternative is imperative to consider procedures that will establish safety measures for the storage and transportation of the following hazardous materials: 12-Molybdophosphoric acid, Sulfur, Sulfuric Acid, and Nitrogen gas.

In the case of 12-Molybdophosphoric acid, its handling and storage is recommended to keep it in a tightly closed container, stored in a cool, dry, ventilated area. It has to be protected against physical damage, and isolated from incompatible substances (strong bases), for instance sodium hydroxide (NaOH), potassium hydroxide (KOH), barium hydroxide [$Ba(OH)_2$], sodium hydride (NaH), or sodium amide ($NaNH_2$).

For the transportation of 12-Molybdophosphoric acid, it is labeled according to United Nations with the number UN3260, and as packing group III, in its label hazardous warning must be displayed as: "Danger! Corrosive. Causes burns to any area of contact. Harmful if swallowed or inhaled. Vapors cause irritation to eyes and respiratory tract. May affect liver and kidneys." In case of spill, clean it up immediately, cover with sand, dry lime or soda ash and place in a closed container for disposal. All sources of ignition are to be removed. Ventilation has to be provided.

For the last three hazardous materials, information about their emergency responses and potential hazards is presented from table 7.10 to 7.12. This information is based in the 2000 Emergency Response Guidebook (ERG2000), which is applicable in Mexico, USA, and Canada. It was created to be used by fire fighters, police, and other emergency services personnel who may be the first to arrive at the scene of a transportation incident involving these materials.

	Sulfuric acid
Guide number	Guide 137 substances-water reactive-corrosive
Small Fires	When material is not involved in fire, do not use water on material itself. Dry chemical or CO2. Move containers from fire area if you can do it without risk

Table 7.10 Sulfuric acid its emergency responses and potential hazards (ERG2000) [XVIII]

	Sulfuric acid
Large Fires	When material is not involved in fire, do not use water on material itself. Flood fire area with large quantities of water, while knocking down vapors with water fog. If insufficient water supply: knock down vapors only.
Fire involving Tanks or Car/Trailer Loads	Cool containers with flooding quantities of water until well after fire is out. Do not get water inside containers. Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank. Always stay away from tanks engulfed in fire.
Spill or leak	Fully encapsulating, vapor protective clothing should be worn for spills and leaks with no fire. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Stop leak if you can do it without risk. Use water spray to reduce vapors; do not put water directly on leak, spill area or inside container. Keep combustibles (wood, paper, oil, etc.) away from spilled material.
Small spills	Cover with dry earth, dry sand, or other non-combustible material followed with plastic sheet to minimize spreading or contact with rain. Use clean non-sparking tools to collect material and place it into loosely covered plastic containers for later disposal. Prevent entry into waterways, sewers, basements or confined areas.
Fire or explosion	Some of these materials may burn, but none ignite readily. May ignite combustibles (wood, paper, oil, clothing, etc.). Substance will react with water, releasing corrosive and/or toxic gases. Flammable-toxic gases may accumulate in confined areas. Contact with metals may evolve flammable hydrogen gas. Containers may explode when heated or if contaminated with water. Substance may be transported in a molten form.

Table 7.10 Sulfuric acid its emergency responses and potential hazards (ERG2000) cont. [XVIII]

	Sulfur
Guide number	Guide 133 flammable solids
Small Fires	Dry chemical, CO_2, sand, earth, water spray or regular foam.
Large Fires	Water spray, fog or regular foam. Move containers from fire area if you can do it without risk.
Fire involving Tanks or Car/Trailer Loads	Cool containers with flooding quantities of water until well after fire is out. For massive fire, use unmanned hose holders or monitor nozzles; if this is impossible, withdraw from area and let fire burn. Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank. Always stay away from tanks engulfed in fire.
Spill or leak	Eliminate all ignition sources (no smoking, flares, sparks or flames in immediate area). Do not touch or walk through spilled material.
Small dry spills	With clean shovel place material into clean, dry container and cover loosely; move containers from spill area.
Large Spills	Wet down with water and dike for later disposal. Prevent entry into waterways, sewers, basements or confined areas.
Fire or explosion	Flammable-combustible material. May be ignited by friction, heat, sparks or flames. Some may burn rapidly with flare burning effect. Powders, dusts, shavings, borings, turnings or cuttings may explode or burn with explosive violence. Substance may be transported in a molten form. May re-ignite after fire is extinguished.

Table 7.11 Sulfur its emergency responses and potential hazards (ERG2000) [XVIII]

	Nitrogen
Guide number	Guide 121 Gases-inert
Fires	Use extinguishing agent suitable for type of surrounding fire. Move containers from fire area if you can do it without risk. Damaged cylinders should be handled only by specialists.
Fire involving Tanks or Car/Trailer Loads	Fight fire from maximum distance or use unmanned hose holders or monitor nozzles. Cool containers with flooding quantities of water until well after fire is out. Do not direct water at source of leak or safety devices; icing may occur. Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank. Always stay away from tanks engulfed in fire.
Spill or leak	Do not touch or walk through spilled material. Stop leak if you can do it without risk. Use water spray to reduce vapors or divert vapor cloud drift. Avoid allowing water runoff to contact spilled material. Do not direct water at spill or source of leak. If possible, turn leaking containers so that gas escapes rather than liquid. Prevent entry into waterways, sewers, basements or confined areas. Allow substance to evaporate. Ventilate the area.
Fire or explosion	Non-flammable gas. Containers may explode when heated. Ruptured cylinders may rocket.

Table 7.12 Nitrogen its emergency responses and potential hazards (ERG2000) [XVIII]

7.4.2 Increase height of flare

It is expected that the increased height of flares most likely will provoke the same effects in "Sonda de Campeche" as the installation of a flare. It might cause similar negative conditions, but their magnitude will be quantitatively smaller compared with the entire flare. Therefore materials, manpower, and time to perform these increases will be required in smaller quantities. However, the mitigation measures will be the same as those applicable for the installation of a flare for the reasons expressed before.

For instance, it is recommended to use sacs made of "Ixtle" to collect residues from sand blast, paper, cardboard, Styrofoam cups, and ropes from working areas. Moreover, collection of residues generated from working areas or vessel must be classified, and deposited in their corresponding metallic or plastic containers of 200 liters, as it was described in chapter two (Identification of pollutants), and then the containers shall be kept in the designated area (hazardous, and not hazardous) in the vessel as it was proposed in the referred chapter. Moreover, combustible waste would be burned in the vessel's incinerator to save space, and the obtained ashes would be deposited in container "A". As a last step all these containers must be shipped to "Ciudad del Carmen" for their final disposal.

Seawater utilized to clean the working areas should be sent to the vessel's treatment system before being discharged into the ocean. Similarly, the seawater used for the hydrostatic tests in pipelines would be sent to the plant designed to treat produced water.

7.4.3 Floating Storage Re-gasification Unit (FSRU)

BHP Billition LNG International, Inc. in 2003 submitted an environmental impact report to obtain a lease from the California State Lands Commission (CSLC) to own, construct and operate Cabrillo Port LNG deepwater Port, which includes a FSRU, offshore and onshore natural gas pipelines. This report has been used as a guideline to propose the applicable mitigation measures related to the proposed FSRU to install in "Sonda de Campeche", obviously pertinent consideration and adjustment have been done to suit this case of study. The tables below (from table 7.13 to table 7.17) summarize the main possible impacts and their corresponding mitigation measures that have been considered as highly probable of occurring in "Sonda de Campeche".

Impact	Mitigation measures
Potential release of LNG due to operational incident (human error, upsets, or equipment failure) or natural phenomena (tsunami, high winds, etc)	Obtain certification (through the International Marine Organization) and a safety management certificate (ISO-9000, or ISO-14000)
	Periodic inspections by classification societies
	Designate safety exclusion are to be avoided. For instance 500 m radius as safety zone, and an area to be avoided of 3.7 kilometers, around the FSRU
	Patrol safety zone by marine forces
	Safety engineering as HAZIDs, HAZOPs, and QRA in all of them include cases where cargo tank insulation could fail in event of a fire
	Conduct post-operational HAZOPs
	Emergency procedures as, the use of tug to maintain the FSRU in position in case of failure of the mooring system or to maintain the carrier in position in the event of losing propulsion or control

Table 7.13 Potential release of LNG due to operational incident or natural phenomena (XIX)

Impact	Mitigation measures
Potential release of natural gas due to accidental damage of sub-sea pipelines	The pipelines would be concrete-coated, this would provide them with additional mass and it would increase the possibility that the fishing gear would detach from the vessel before it damages the pipeline
	The pipelines would be designed and installed to meet seismic criteria according to the area where they will be located
	Comply with the design, maintenance, inspection, and testing requirements of pipelines
	Cathodic protection systems shall be installed during the construction of pipelines

Table 7.14 Potential release of natural gas due to accidental damage to sub-sea pipelines (XIX)

Impact	Mitigation measures
Long term disruption of local marine traffic and increased risk of vessel collisions	Establish that no project vessels (including LNG carriers) would use anchorages. If there is a delay in docking, LNG carriers would slow their speed to arrive at suitable time or stop, or drift between 185 and 370 km offshore
	Procedures that mandate early notification of possible delays shall be incorporated into the facility operations manuals. If the LNG carrier is not able to meet this criteria, it shall remain at least 22 km from land
	The number of LNG carriers at the FSRU shall be limited to one

Table 7.15 Long term disruption of local marine traffic (XIX)

Impact	Mitigation measures
Potential hazardous material spills due to offshore construction	Develop and implement a reduction plan. This plan would specify the appropriate wind and sea conditions for operation of the vessel refer to appropriate personnel and evaluation procedures.
	The vessel would have sufficient quantities of adsorbent materials stored onboard to contain and clean up small spill
	Material safety data sheets shall be available for all hazardous material stored onboard and accessible to the crew

Table 7.16 Potential hazardous material spills (XIX)

Impact	Mitigation measures
Degradation of water quality due to release of treated discharges during offshore operation	Sewage from FSRU would be treated according to an approved system from the International Marine Organization
	The gray-water shall be treated using filtration to separate particulate matter and ultraviolet oxidation to destroy dissolved organic materials
Potential release of LNG due to high marine collision with another vessel, or intentional attack	Provide FSRU and carriers with AIS, with real time radar, and marine VHF radiotelephone capabilities
Collision between project vessels and marine mammals	Avoid offshore installation during migrations season

Table 7.17 Degradation of water quality, and marine collision with another vessel or a marine mammal (XIX)

7.5 Anticipated improvement of air quality

Upon implementing the alternative (A1), and the suggested mitigation measures, what is expected to happen is to observe a significant improvement of the environment conditions in the air of “Sonda de Campeche”.

This estimated improvement is shown in table 7.18. This table shows that the implementation of “A1” could improve air quality in the area. For instance, in column two the values of the seven main air pollutants in thousand tons per year are shown. Then in column three some improvements are detected with the implementation of chemical absorption with aqueous solution of 12-Molybdophosphoric, which is anticipated to remove NO_X (92.9 %), SO_2 (99.9 %), and H_2S (99.7 %) from the natural gas, here is observed an improvement of 1.12% in the air quality, it could be considered as small improvement, nevertheless it is important to keep in mind that the purpose of this alternative is to comply with regulations for H_2S and NO_2, and both are completely accomplished with this step.

In the next column shows the values obtained after the increase in the height of flare by 15 meters to comply with regulations for H_2S as a consequence the values are the same as in the column before; obviously implementing this action will improve the dispersion of all the pollutants, but this is not quite significant in value to be observed as a numerical value in the table.

Finally in the last column is shown the possible benefits to obtain from using a floating storage and re-gasification unit (FSRU) to store Offshore Liquefied Natural Gas (LNG), with this action the emission of pollutants are reduced to zero, which would be the optimal expected condition.

Contaminant	Sonda de Campeche	Chemical absorption	Increase the height of flare	FSRU
NO_X (tt/y)	41.16	2.92	2.92	0.0
SO_X (tt/y)	181.00	0.18	0.18	0.0
H_2S (tt/y)	1.10	0.003	0.003	0.0
CO (tt/y)	145.51	145.51	145.51	0.0
HC (tt/y)	276.84	276.84	276.84	0.0
PM (tt/y)	14.43	14.43	14.43	0.0
CO_2 (tt/y)	19041.20	19041.20	19041.20	0.0
CH_4 (tt/y)	39.70	39.70	39.70	0.0
Total (tt/y)	19740.94	19520.783	19520.783	0.0
Percentage	100 %	98.88 %	98.88 %	0 %

tt/y = thousand of ton per year

Table 7.18 Improvement of air quality in “Sonda de Campeche”

Chapter Eight
Conclusions and recommendations

8.1 Conclusions

1) The results of the study indicate that there is no significant impact on the flora or fauna of the area caused by water pollution or waste management of residues during the installation or production phase of flares.
2) The study indicates that four air contaminants (NO_2, CO, CO_2, and CH_4) comply with environmental laws (Mexican, or International). On the contrary, three other air pollutants (SO_2, H_2S, and PM_{10}) are not in compliance with the standards.
3) The study also suggests the following actions to reduce these three pollutants. The use of chemical absorption is desirable to remove NO_X, SO_2, and H_2S. It is beneficial to increase the height of flares by 15 meters. Lastly, the installation of a Floating Storage Re-gasification Unit in a relatively isolated region will ensure a drastic reduction of air pollution and will also provide a reservoir for natural gas. The natural gas can be purchased by a Pemex's customer or can be consumed by the Mexican Industry.

8.2 Recommendations for future work

Although the implementation of the conclusions of this study will contribute to the improvement of environmental quality in "Sonda de Campeche", future work is recommended to study other options to the solutions proposed in this study. The following recommendations have to be studied and can contribute to reduce the adverse impact of air pollution due to flares.

1) One should assess the number of FSRU that will be required according to actual production of natural gas and its prediction in the future.
2) It is desirable to provide complementary cost analysis related to the implementation of the suggested actions.
3) It is important to create laws applicable to discharges of offshore pollutants (air, water, solid waste, noise, etcetera), following the laws issued in other nations (Canada, and USA), especially for the three contaminates (H_2S, CO_2, and CH_4).
4) It is important to remove wastewater related contaminating materials from the sea floor, and to assess the impact of the fate of contaminants coming from water discharges.

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VIII	http://biblioweb.dgsca.unam.mx/cienciasdelmar/instituto/1990-2/articulo365.html
IX	http://www.gov.nl.ca/hoa/regulations/rc040039.htm#schedule1
X	http://www.gov.ns.ca/just/regulations/regs/envairqt.htm
XI	http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=474f779beade290997e4611971d078f4&rgn=div5&view=text&node=40:2.0.1.1.1&idno=40#40:2.0.1.1.1.0.1.11
XII	http://www.tnrcc.state.tx.us/oprd/rules/index.html
XIII	http://fiesta.bren.ucsb.edu/~lng/fsru-merlin.jpg
XIV	http://www2.bren.ucsb.edu/~keller/courses/GP_reports/LNG_final.pdf
XV	http://www.hoeghlng.no/hoeghlng/midstream/fsru/
XVI	http://www.chevrontexaco.com/about/our_businesses/docs/2003_Port_Pelican_brochure.pdf
XVII	http://www.fwc.com/publications/tech_papers2/files/ALKAPLAN.pdf
XVIII	http://www.tc.gc.ca/canutec/erg_gmu/erg2000_menu.htm
XIX	http://www.cabrilloport.ene.com/files/eiseir/6%20-%20Conclusions%20and%20Recommendations.pdf

Appendix A
Overview of the PhiStack20K

PhiStack20K is an interactive computer code used to model the dispersion of air pollutants emitted to the atmosphere from a smokestack. It was created by Mr. Edouard-Philippe Martin, a fellow graduate environmental engineering student at Concordia University. The original PhiStack20K code has been adopted and adapted, with the permission and collaboration of Mr. Martin, in order to suit the needs of this present study. The information that follows is intended to give the reader a better appreciation of the rationale, input data and the logistic behind PhiStack20K.

Given the appropriate modeling parameters (Q, H, u, σy, σz) the Pasquill-Gifford plume dispersion equation yields the concentration (C) of a pollutant at any given point P(x, y, z) downwind from an emitting source. To model the three-dimensional air dispersion of a pollutant requires the computation of the concentration values of a large number of points. The manual computation of a large number of concentration values is unreasonable, thus it is desirable to resort to a computer software to perform repeating calculations.

The user is required to use the "Data entry" spreadsheet to input the modeling parameters. These include:

1)	The overall stack emission rate	(Qs)	[g/s]
2)	The pollutant emission rate	(Qp)	[g/s]
3)	The stack height	(h)	[m]
4)	The stack diameter	(d)	[m]
5)	Stack effluent temperature	(Ts)	[°C]
6)	Ambient temperature	(Ta)	[°C]

7) Wind speed (u) [m/s]
8) Atmospheric Stability (Ast)
9) Class (urban or rural) (U or R)

Phistack20K then:

1) Computes the buoyancy flux parameter (constant over the modeling volume)
2) Computes the plume rise (as a function of the buoyancy flux parameter and the downwind distance at 10 meters intervals)
3) Calculates the effective stack height (as a function of plume rise)
4) Computes the dispersion coefficients (using the Briggs equations as a function of the downwind distance at 10 meters intervals)
5) Models the x-axis ground-level concentration ($y = z = 0$), and yields the distance along the centerline where the pollutant first touches the ground (XtouchGround) by means of a numerical method based on $\{C(x, 0, 0) \neq 0\}$
6) Finds the distance where the maximum ground-level concentration (XmaxGround) occurs by a numerical method based on the realization that the maximum ground concentration is at the point where $\{C'(x, 0, 0) = 0\}$
7) Models the y-axis ground-level concentration at the point of maximum x-axis concentration C(XmaxGround, y, 0), and yields the y-dispersion (m) by a numerical method based on the realization that the affected region is that one where {C(XmaxGround y, 0) ≠ 0}
8) All concentration values are given in $\mu g/m^3$

PhiStack20K calculates all changeable parameters at 10 meters intervals from the origin. The boundaries are 20 000 meters on the x-axis, 2 000 meters on the y-axis and 1 000 meters on the z-axis. The modeling volume is therefore 40 km^3.

PhiStack20K can be used for any gaseous pollutant and for an approximate representation of the particle dispersion for particle below about 30 μm in diameter, since they behave in similar manner with gas molecules. Larger particles are subject to deposition forces, and additional terms are needed in more advanced models to account for this feature.

If the low level inversions occur above the physical height of the stack, the effluent may not disperse along the vertical axis. In this case, ground level concentration may increase considerably. The PhiStack20K will yield erroneous results with ground level concentrations values significantly below the actual values. On the other hand, if the temperature inversion comes about below the physical height of the stack, the plume will not likely reach the ground near the source and the surface concentrations will be considerably lower then those obtained trough the standard Gaussian model. High level inversions form in a plane of air at some distance above the ground. These inversions are typically more widespread and more persistent. If they are found at heights elevated enough, their influence would only minimally compromise the Gaussian model results. An estimation of ground level concentration under an inversion has been proposed in the literature (Hemond and Fechner-Levy, 2000) as follows:

$$C(x,0,0) = \frac{Q}{\sqrt{2\pi}\, u \sigma_y} \frac{1}{L} \qquad \text{Eq. 10.1}$$

Disadvantages of PhiStack20K also include spatial variability in the meteorological parameters which are in practice difficult to incorporate. Difficulties are specially encountered when the wind speed is light and wind direction is poorly defined. Also, the wind properties are only considered in one direction. A program capable of handling the three dimensional fluid motion of wind and inversions would be more accurate and would yield considerably more precise values.

References of appendix A

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