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AIR EMISSIONS ASSESSMENT FROM OFFSHORE OIL ACTIVITIES IN SONDA DE CAMPECHE, MEXICO

I. SCHIFTER*, C. GONZÁLEZ-MACÍAS, A. MIRANDA and E. LÓPEZ-SALINAS
*Instituto Mexicano del Petróleo, Competencia de Estudios Ambientales, Eje Central 152, México, DF 07730, Mexico (*author for correspondence, e-mail: ishifter@imp.mx)*

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Abstract. Air emission data from offshore oil platforms, gas and oil processing installations and contribution of marine activities at the Sonda de Campeche, located at the Gulf of Mexico, were compiled and integrated to facilitate the study of long range transport of pollutants into the region. From this important region, roughly 76% of the total Mexican oil and gas production is obtained. It was estimated that the total air emissions of all contaminants are approximately 821,000 tons per year. Hydrocarbons are the largest pollutant emissions with 277,590 tons per year, generated during flaring activities, and SOx in second place with 185,907 tons per year. Marine and aviation activities contribute with less than 2% of total emissions. Mass of pollutants emitted per barrel of petroleum produced calculated in this work, are in the range reported by similar oil companies.

Keywords: air emission, Campeche, inventory, Mexico, offshore platforms

1. Introduction

Environmental impacts produced by the cycle of oil exploration and production and their effects in tropical environments at offshore sites in Mexico are not fully documented. Air emissions represent a continuous, potentially hazardous input supply, not only to the marine but also to the nearby coastal environment. The most important components of emissions to air include carbon dioxid, carbon dioxide, sulfur oxides (SOx), methane, non-methane volatile organic compounds and nitrogen oxides (NOx).

Offshore oil activities are an important source of emissions of all these gases. Emissions of CO_2 and NOx are mainly generated by combustion of natural gas in turbines for electricity production, and by flaring which is a safety system on the platforms. Off loading of oil, particularly at loading buoys on the oil fields, is the main source of hydrocarbon emissions. NOx emissions contribute to eutrophication, acidification, and the formation of ground-level ozone, and result in higher background concentrations of NO_2.

Non-methane hydrocarbons emissions combined with NOx result in the ozone formation, while CO_2 and CH_4 can contribute to global warming. It is particularly important to diagnose air quality on the marine environments, especially in regard to NOx and SO_2 emissions, because chemical reactions in the atmosphere generate several secondary contaminants, such as sulfuric and nitric acids. These contaminants dissolve in water, and are carried by rainwater into the soil and the ocean, thus affecting the fauna and flora of the region (US-EPA, 2001a).

The World Resources Institute reported that in 1995 the practice of burning off gas, released during the process of petroleum extraction, contributed with 1% of the total world emissions, estimated in 234 millions tons (WRI, 1998). In 1999, in Norway, the offshore oil and gas industry accounts for about 20% of total NOx emissions and, about 50% of the country's total non-methane volatile organic hydrocarbons (MPE, 2001).

According to British Petroleum, worldwide exploration and production of oil and gas were the main activities that contributed with 62% of the total atmospheric emissions generated by the company. On the other hand, the amount of greenhouse gas emissions was in the order of 77 million tons, 36% of them produced by exploration and production (BP, 2001). In year 2000, Shell Oil Company reported that, flaring activities amounted 9.3 million tons of hydrocarbons and 101 million tons of CO_2 equivalents from their worldwide operations (Shell, 2001).

The US-Environmental Protection Agency (USEPA) estimated in year 2000, 1 million tons of NOx due to mobile sources from which 7% were produced by marine sources and 1% by aircraft. In the same sense, of a total estimated of 22,000 tons of particulate, 6% were generated by marine vessels while 6% by aircraft (Revelt, 2001).

Along the coast of the state of Campeche, located in the south part of the Gulf of Mexico, the most important area of oil and gas production in the country is found (Santiago and Baro, 1992). Approximately 76% of the total oil and gas production is obtained by Pemex, the state owned oil company in this area known as the Sonda Campeche (SC). In a parallel way, an intense fishing activity is carried out along the coast of the state in view of the high biodiversity of the region (Soto *et al.*, 1982).

An estimate of the contribution from petroleum exploitation and processing in Mexico to the atmospheric environment is scarce. A non-exhaustive inventory provided by Pemex, calculate total air emissions as 979,000 tons per year in the year 2000, with 219,355 tons of SOx and 9558 of NOx, associated to oil exploration and exploitation (Pemex, 2000).

In this work, we conduct a study of the SC operational parameters aiming to evaluate the environmental impacts related to SC operations due to air emission of pollutants as well as the contribution of the fishery industry.

In order to approach to this analysis, an inventory of pollutants emitted from stationary and mobile sources related to the upstream sector of the oil industry as well as those of the fishery activities at the SC was performed. The results of this study were compared with those obtained by similar oil companies in the world.

2. Experimental Section

A "screening" approach was undertaken following USEPA guidance for conducting studies for hazardous waste releases for limited site investigations, and those of the American Society for Testing and Materials Standard for corrective actions at sites where emissions caused by oil activities are taking place (EPA-Australia, 1993; ASTM, 2001).

2.1. Layout description

A schematic layout of the SC site is shown in Figure 1. A Seven platforms complex produce oil and gas that are associated with two different oil fields connected by 2000 km of pipelines. Two grades of crude oil are produced in the fields: Maya at the northeastern platforms and Istmo at the southwestern platforms, some physico-chemical properties of these crude oils are shown in Table I. Crude oil is exported worldwide by approximately 500 oil-tanquers at Cayo de Arcas buoy and 450 oil-tanquers at the Dos Bocas marine terminal. The Dos Bocas Marine terminal, located near the city of Paraiso in the state of Tabasco, is the primary storage and treatment facility for crude oil from the offshore area (Pemex Exploración/Producción, 2000).

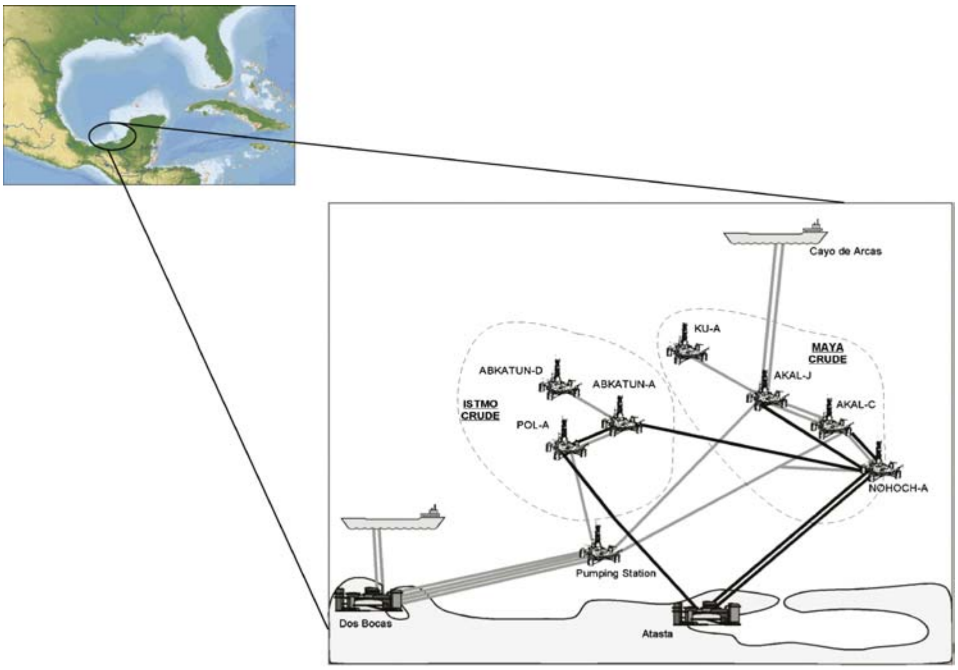

Figure 1. Schematic layout of the offshore and coastal facilities in the Sonda de Campeche region.

TABLE I
Physicochemical properties of Mexican crude oils at Sonda de Campeche

Crude oil	Water (vol.%)	API	Sulfur (wt.%)	Specific gravity (60/60 °F)	Ni (ppm)	V (ppm)
Maya	<1	20.73	3.79	0.9295	8.3	38.3
Istmo	5	32.9	1.32	0.8604	54.3	301.3

The Marine terminal is also home of drilling and maintenance activities of oil wells unit (UPMP). Gas from the offshore platforms arrives at the Atasta gas processing and transport center. The main task of this site is gas recompression between the offshore platforms and the inland gas processing centers. Approximately 5.1×10^5 m^3 per day is pumped inland petrochemical centers via compressors on site (Pemex Exploración/Producción, 2000).

The commercial marine vessel category includes vessels that transport goods through the SC along with ships associated with exploratory drilling (crew boats, tugs and barges that transport heavy equipment). The fishing industry contributes to emissions in region through a combined fleet of vessels operating on the high seas and in the rivers and lagoons of the states of Tabasco and Campeche. Additionally, helicopter traffic to the platforms from Ciudad del Carmen and Dos Bocas that taxi between the marine terminals offshore is another source of contaminants.

2.2. Air emission data

This study covers the major categories of emission sources: process fugitives, tank storage, combustion sources and those related to coastal traffic and fishing. Emissions data obtained reflect year 2000 current processes at each facility. A processes and equipment census was made with the aid of location maps, process flux diagrams, construction drawings, pipelines and combustion equipment. Sources were grouped as flares, combustion equipment, fugitives and evaporative hydrocarbon emissions from equipment components and tanks, and those due to marine and support activities.

2.2.1. *Flares*

Agregate emissions were calculated as kilogram pollutant per kilogram of gas flared, using the emissions factors reported by the United Kingdom Offshore Operators Association (UKOOA, 1993). The uncertainty in estimation may be between 5 and 30%, even if the gas is metered (CPPI, 2001).

2.2.2. *Internal Combustion*

Fuels used in the region were fully characterized in their physical and chemical properties in our laboratories. Boilers, heaters and burners that provide process heat and steam as well as diesel engines used to run generators, pumps, compressors and well-drilling equipment were inventoried. Emissions were estimated by combined monthly activity data collected from operators with emissions factors reported by US-EPA (2002). Emission factors were calculated in grams per cubic meter of fuel burned (STP), while CO_2 and SOx by mass balance.

In the case of emission factors for diesel engines, values were converted to grams per liter of burn fuel based on a calorific power for diesel of 44,851 kJ kg^{-1} and a density of 851.6 kg m^{-3}. In order to obtain carbon mass balance for the combustion of sour and sweet gas, a 99% conversion into CO_2 was considered, but for liquid fuels, it was 99.5% (US-EPA, 2001). For sulfur, a 100% conversion of both, liquids and gases, was considered.

2.2.3. *Evaporative Emissions*

Crude oil stabilization involves the removal of the most volatile components of the crude oil. Although the process has the potential to cause emissions of volatile organic compounds, the UKOOA claim that emissions are in fact small since the volatiles are generally either used as fuel or are sent to flare rather than being vented directly to the atmosphere. Storage tank emissions were evaluated for tanks in crude service. Emissions were calculated by using the latest versions of EPA AP-42 (US-EPA, 1996), using the actual number of tank turnovers/year.

2.2.4. *Fugitive Emissions*

Fugitive emissions from all process units that handle hydrocarbons were calculated as part of the inventory process. Fugitive emissions were estimated from the following components in gas/vapor, light liquid or heavy hiquid service: valves, flanges/connectors, pump seals, compressor seals, pressure relief valves to atmosphere, and drains. An actual count was based on an equipment list for the unit with the aid of operating manuals. For component counts, estimated emission factors reported by the European Environmental Agency were employed (EMEP/CORINAIR, 2003).

2.2.5. *Marine and Support Activities*

The ENTEC study (ENTEC, 2002) used detailed emission factors for different operational modes based on the fuel type. The study differentiated between slow-, medium- and high-speed marine diesel engines, gas turbines and steam turbines. Overall, numerous sources indicate a strong correlation between emission factors and engine speed and engine type (Corbett and Fischbeck, 1998).

As such, engine type specific emission factors continue to be the most appropriate for preparing emission inventories. After engine type, the second largest factor, influencing emissions, is fuel type. On average, residual fuel has higher nitrogen content and lower heat value. Thus, fuel consumption and NOx emissions are likely to be higher for engines using residual fuel as compared with engines using distillate fuel.

Data provided by the Campeche Harbor authorities were used in characterizing engine type and fuel used in ships, harbor facilities, traffic activity records, and commercial fishing practices (Gobierno del Estado de Campeche, 2001). The source of our support helicopter activity data was Pemex reports. Emissions factors for marine vessels and helicopters, estimated assuming short landing and takeoff cycles, were those reported in Radian International (1997).

3. Results

Thirty-four flares are located on the platforms system, six more at Atasta, and two at Dos Bocas Marine terminal. The inventory includes flaring from offshore platforms and onshore terminals. Emissions of pollutants from flaring are either unburned fuel or by products of the combustion process and were estimated using the reported flaring volume, given that SC flares are not equipped with metering systems.

It was found that the total amount of pollutants is in the order of 673,977 tons per year, hydrocarbons being the greatest contributor with 278,015 tons per year. Accordingly, in the Norwegian platforms, the percent of the gas production flared varied from 0.04 to 15.9 (The Norwegian Oil Industry Association, 1994), while Exxon Mobil Corporation reported that, globally, approximately 4.6% of all the gas product is flared (Exxon Mobil, 2003). In the case of the total flares of SC, we found that 27 of them burn less than 10% of the total gas, 9 between 10 and 25%, and 6 more than 25%.

Volatile organic compounds uncontrolled fugitive emissions factors and inventory at the SC are shown in Table II. Approximately 1359 thousands tons of hydrocarbons per year were emitted in the year 2000. The Norwegian data in general have estimated an uncertainty of +55%/−35% of the sum of vent and fugitive losses (The Norwegian Oil Industry Association, 1994).

Internal combustion emission factors and their inventory are presented in Table III. Sour gas contain large amounts of hydrogen sulfide or sulfur, which

TABLE II
Volatile organic compounds uncontrolled fugitive emissions

Source	Service type	Emission factors (kg h^{-1} source)	Sonda Campeche (10^3 tons per year)
Valves	Gas/vapor	0.0055842	281
	Light liquid	0.0070824	173
	Heavy liquid	0.000227	3
Pumps	Light liquid	0.0493498	147
	Heavy liquid	0.0213834	56
Compression seals	Gas/vapor	0.2277264	334
Relief valves	Gas/vapor	0.1038752	303
Flanges	All	0.0008172	59
Open ended lines	All	0.0016798	2
Total			1359

TABLE III
Internal combustion emission factors and inventory

Emission factor	NOx	SOx	CO	HC	Particulate
Sweet gas (g m^{-3} STP)	15.000	Mass balance	24.500	115.000	2.300
Sour gas (g m^{-3} STP)	1.600	Mass balance	21.600	67.300	2.100
Diesel (g l^{-1} STP)	52.570	Mass balance	13.970	1.480	1.64
Pollutants emissions (10^3 tons per year)	34.869	6.493	61.710	10.585	6.177

in order to become sweet gas, sulfur compounds must be removed. Total amount of emitted pollutants was 119.83 thousand ton per year, CO emissions being the major contributor.

Marine and support activities emission factors and their inventory are collected on Table IV. Total amount of emitted pollutants was 12,898 tons per year, NOx and SOx being the major contributors.

Total emissions inventory of pollutants at the Sonda de Campeche by source is presented in Table V. From the audit, it was estimated that global air emissions of all contaminants were approximately 821,709 tons per year. As expected, flares were the major supplier of pollutants with almost 85% of the total emissions by activity, as it is shown in Figure 2.

In the Table V we have include reported values of total emissions published by the Mexican state oil company (Pemex, 2000), where it can be noted similar

TABLE IV
Marine and support activities emission factors and inventory

	Fuel consumption	NOx (tons per year)	SOx (tons per year)	CO (tons per year)	NMHC (tons per year)	Particulates (tons per year)
Commercial fishing (number of ships (tonnage))						
51 (50)	17.850 (10^3 l per day)	262	6	32	34	7
1956 (5)	29.340 (10^3 l per day)	431	9	52	57	11
549 (70)	192.150 (10^3 l per day)	2824	61	343	370	73
2278 (5)	34.170 (10^3 l per day)	502	11	61	66	13
Commercial marine vessels						
Type of emission						
Active sailing	257.770 (l per day)	1821	4045	404	196	177
Docked	39.855 (l per day)	180	772	16	25	17
Support helicopters Trips per year and (km per fly)						
4725 (120)	145 (kg of fuel per trip)	10.33	1.17	7.24	3.11	0.00
Total		6030	4904	915	751	297

TABLE V
Emission inventory of pollutants at the Sonda de Campeche by source

Source	Site	NOx (tons per year)	SOx (tons per year)	CO (tons per year)	HC (tons per year)	Particulates (tons per year)	H_2S (tons per year)
Flares	Maya fields	132397	164908	78173	247015	7708	1028
	Istmo fields	9389	9601	5622	17516	547	73
Internal combustion	Maya fields	13237	937	37497	3802	3603	–
	Istmo fields	15332	648	23226	6007	2268	–
	Coastal traffic and fishing	6032	4905	917	767	297	12917
	UPMP	268	4	70	9	9	361
Evaporatives	Releases from storage tanks				364		
Uncontrolled fugitives emissions	All sites				1359		
Coastal traffic and fishing	All sites	6030	4904	915	751	297	
Total		182685	185907	146420	277590	14729	14379
Pemex		9558	219355		5543	432	

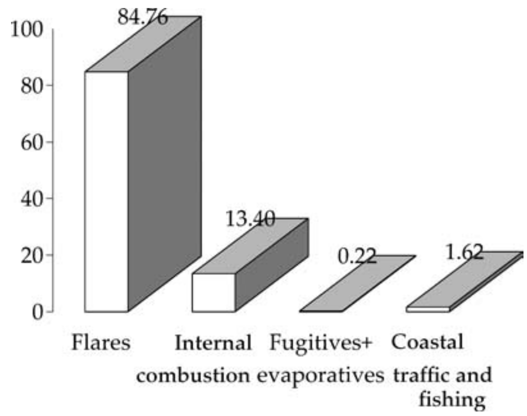

Figure 2. Percentage contribution to total emissions by activity in the Sonda de Campeche region.

estimates for SOx total emissions, but striking differences in NOx and HC estimates. In view that the agreement in the SOx estimates are related to sulfur content of the fuel burned, we are confident that estimates of the amount of fuel are in general in agreement with the company values, but differences in the other pollutants must be related to lower emission factors used to estimate them.

Data reported by oil companies of the worldwide air emissions generated exclusively by their exploration and production activities, were compared with the results of this work for the Sonda de Campeche and they are shown in Table VI. The units in this table are expressed in thousands of tons of petroleum equivalents

TABLE VI
Flaring during exploration/exploitation activities: Comparison among companies

Company	Oil and gas production (10^6 ton hydrocarbons per year)	Ton emissions ton throughput^{-1}		
		NOx	SOx	VOCs
British Petroleum[a]	6.596	0.1221	0.1184	0.1857
Shell[b]	9.300	0.0217	0.0298	0.0578
Exxon[c]	1.981	0.0380	0.0230	0.0470
Pemex SC (this work)	4.480	0.0381	0.0393	0.0612

BOE: barrels oil equivalent.
[a]BP, 2000.
[b]Shell, 2000.
[c]ExxonMobil, 2003.

flared per tons of pollutants emitted to the atmosphere. Clearly in this comparison, SC ranks second in the three types of pollutants among companies.

Concerning the emissions of greenhouse gases, Table VII shows the results of this study compared with carbon dioxide and methane emissions reported by other oil companies. According to our data, 19.08 million tons of carbon dioxide, and 39.73 thousand tons of methane are emitted per year by all sources in the SC. This table presents also the amount of both gases emitted by thousands of barrels of oil equivalents produced by year. In the SC less carbon dioxide is generated in comparison with that of the other oil companies; an indication of lower efficiency in combustion processes.

The key limitation and source of uncertainty associated with this inventory effort pertains to the completeness of the activity data gathered and used to develop emission estimates. It is difficult to confirm that all affected lessees and operators

TABLE VII
Greenhouse emissions during oil and gas production: Comparison among companies

Company	Oil and gas production (10^3 BOE per year)	CO_2		CH_4	
		10^6 tons per year	Tons per BOE	10^6 tons per year	Tons per BOE
British Petroleum[a]	1182600	76.6	64.77	0.33	0.2790
Shell[b]	1346485	92	68.33	0.398	0.2956
Exxon[c]	1547965	132[d]	–	–	–
Pemex Sonda Campeche	1441020	19.08	13.18	0.0397	0.0276

[a]BP, 2000.
[b]Shell, 2000.
[c]ExxonMobil, 2003.
[d]CO_2+CH_4.

provided accurate information as required, nevertheless one may conclude that flaring is the major contributor to emissions of pollutants in the Sonda de Campeche and the highest in the estimation of uncertainty in the values that could be in the order of ±20% following the report of ExxonMobil (2003).

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