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Total Emissions from Flaring in Kuwait Oilfields

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Abstract: Kuwait is a major oil producing country and its economy directly depends on its export of crude and refined products. Kuwait Oil Company (KOC) is responsible for all exploration and production of crude oil in Kuwait. These activities result in the emission of gaseous pollutants to the atmosphere, particularly from the flaring of undesirable product and excess gases. For environmental and resource conservation reasons, KOC is required to minimize the amount of gas flared in order to control and reduce the emissions of major pollutants in the State of Kuwait and neighbors countries. In the present study the total emissions of primary pollutants associated from flaring activities from Kuwait oil field have been estimated. An inventory records the annual emissions of air pollutants: NO_X, SO_2, CO, CO_2, Methane and non-methane, Volatile Organic Compounds (VOC): resulting from oil production operations in the Kuwait Oil Fields. The emissions are generated from various point sources and aggregated to have total pollutants load of ambient air. Emissions of flaring pollutants are associated with all operations in Oil fields, Gathering Centers (GC), Boaster Stations (BS), Tank areas and other oil production related activities. The objective of this work was to obtain an accurate estimation of the total flare emission from oil production activities thereby aiding the effective planning of mitigation strategies to control and reduce the pollution from crude related operation.

Key words: Kuwait oilfields, accurate estimation, total flare emission, oil production activities

INTRODUCTION

Kuwait is major oil exporting country and its economy, growth and prosperity is heavily dependent on oil production. This activity is carried out by KOC, which produces oil from 14 fields, including the oldest giant Burgan oil field. Crude is processed through a network of 21 gathering centres, where gas and water are separated. The processed oil is exported or refined at Kuwait's large refining Industries. Separated gas that cannot be utilised economically is flared. This flaring produces a number of undesirable atmospheric emissions, including CO, CO_2, SO_2, H_2S, NOx and particulates ($PM_{2.5}$ and PM_{10}). These pollutants are also released from other activities associated with the production of crude oil, such as local power generation (Gas Turbines, Diesel Turbines, Gas Engines, Gas/Diesel Engines,) and heating operation (Gas Boilers, Gas Heater Furnaces).

In practice, these other sources of emissions are small compared with emissions from flaring. This is largely due to relatively low energy requirement of upstream oil processing in Kuwait, where oil is currently produced largely by natural depletion and energy demand is limited for production and export.

Flaring is usual method for the safe disposal of excess hydrocarbons. By burning these hydrocarbons, thereby converting them largely to carbon dioxide and water, their environmental impact is greatly reduced. For example, the global warming potential of methane is about 21 times than of CO_2.

To safe guard the environment, one should have a thorough knowledge of gaseous emissions resulting from the flaring of associated gaseous mixture of known composition on daily basis through combustion activities under several operating conditions. This helps in the control of gaseous emission from flares and thus in the protection of immediate and distant environment against environmental degradation due to air pollution.

A detailed literature search has been conducted to collect the most relevant publications relating average annual emissions of various air pollutants; NO_X, SO_2, CO_2, particulate matter and hydrocarbons; from oil production operations facilities in the world.

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Smog, high ozone concentrations and health risk due to air pollution in mega cities have been focus of the research of many Environmental experts to quantify the nature of problem by determining the total organic load of ambient air. A detailed report[1] of emission characteristics of crude oil production operation in California showed that 18% of the CO, 3% of NOx, 2% of SO_2 and over 3% hydrocarbon and <1% of particulate emissions were accounted for oil production in the South Coast Air Basin alone based on 1979 statistics.

Dahl and Kuralbayeva[2] have presented the exploitation of the energy resources for Kazakhstan and their associated inherited environmental problems, methane emissions from aging gas infrastructure and coal mines, soil and Caspian Sea pollution due to oil products and thermal and particulate problem due to energy production. They have outlined the environmental laws for environmental protection and made recommendation technical and legal improvements to provide safer and clean environment in the country.

A comprehensive impact assessment report[3] has been published to account all emissions from the offshore operations of the oil and gas exploration and production by Mexico industry in the states of Tabasco and Compeche in southeast Mexico. The emission inventory include 174 offshore platforms, the compression station at Atasta, Dos Bocas Marine terminal for storage and treatment of crude oil and the transhipment station at Cayo Arcas. The total mass of air pollutants emitted into ambient air was calculated as nearly 660,000 tons per year. CALPUFF dispersion model was used to assess the impact of SO_2 emissions from offshore operations.

Data analysis: Kuwait had an estimated 94 billion barrels of proven oil reserves, more than 9% of the world total oil. The Neutral Zone area, which Kuwait shares with Saudi Arabia, holds an additional 5 billion barrels of reserves, half of which belong to Kuwait. Most of Kuwait's oil reserves are located in the Greater Burgan area, which comprises the Burgan, Magwa and Ahmadi formations. Greater Burgan is widely considered the world's second largest oil field and accounts to about 70 billion barrels.

The bulk of Kuwait's oil production occurs at the onshore Greater Burgan field, where Burgan, Magwa and Ahmadi structures produce roughly 1.6 million barrels per day (bbl/d) collectively. Most of Kuwait's other producing fields are relatively small and include the 250,000-bbl/d Raudhatain, 160,000-bbl/d Sabriya, 60,000-bbl/d Minagish and 60,000-bbl/d Umm Gudair fields.

Kuwait's oil reserves are located in to three productions area's as follows: Greater Burgan area located in South East Kuwait (SEK), which comprises the Burgan, Magwa and Ahmadi structures areas, which has 14 gathering centers (GCs) [GC01- 04, GC06 -11, GC19 -22] and 2 booster stations (BS).

* Minagish and Umm Gudair fields located in West Kuwait (WK) have 4 GCs [GC-16, GC-17, GC-27 and 28] and 2 booster stations (BS).
* Ratqa, Raudatin and Sabiriyah are located in North Kuwait (NK) have 3 GCs [GC-15, GC-23 and GC-25] and one booster stations (BS).

Fig. 1: Major oilfields in the state of Kuwait

Kuwait Oil Company (KOC) manages complex and extensive oil production operations including oil wells, gathering centers, booster stations and tank farms. The crude that is obtained from various wells is separated and stabilized at gathering stations. The stabilized oil fraction is pumped to tank farms while the gas fraction is retained for further separation. The water and crude in the low-pressure gas and high-pressure gas separators are separated. Gas and oil are pumped through booster stations for further refining or transported for marketing. The flare boxes at the site are used to burn the excess gas that is not liquefied by the compressors and excess oil resulting due to emergency shutdowns. Normal operating emissions are due to excess of fuel gas, fuel combustion in hot oil heater. The total emissions of hydrocarbons arise mainly from pipe network, pipe joints, flanges, valves fittings,

especially crude oil tank farm and also from open oil-water treatment pits or spills.

The present work covers all operational facilities and relevant sites where worker are exposed to ambient air quality that is effected by various pollutants emissions (e.g. apportioned emissions related to utilities production). The facilities that contribute to emission inventories are:

Production wells and interconnecting pipelines from 14 fields (covering the Burgan, Magwa/Ahmadi, Raudatin, Sabiriyah, Minagish and Umm Gudair fields)

* Gathering Centers
* Booster Stations

It is not practical to estimate or calculate the emissions of every substance which may be a potential hazardous compound, given the diverse range of chemical species encountered in oil production operations. Thus, a set of pollutants is proposed covering the most relevant and significant substances, based on known pollutants from the oil industry. The present study is insured on exact evaluation of inventories of the following pollutants:

* Carbon Dioxide (CO_2)
* Carbon Monoxide (CO)
* Sulphur Dioxide (SO_2)
* Nitrogen Oxides (NO_2 & NO & N_2O)
* Methane (CH_4)
* Volatile Organic Compounds (VOCs)

Emission inventory: It is rarely practical to directly measure emissions from all environmental sources continuously every year. Thus it is necessary to produce estimates of emissions that can be derived from other continuously monitored activity data, such as fuel usage or product throughput. With sufficient knowledge of the operational conditions and the level of activity, it is now accepted practice to apply emission factors.

For the exacted calculations, the latest Microsoft office Excel 2003 Software was used to host all of the input data, emission factors and estimates of the emissions using Chemical Mass Balance, (CMB). Excel workbooks were set up for every major KOC facility (e.g. gathering centers, booster stations, etc.).

The combustion of hydrocarbons release many gases in to the atmosphere such gases as CO_2, CO and NO_X affect the natural balance that exists in the atmosphere. Upon combustion, each mole of carbon atoms is converted to one mole of CO_2. This means that one mole of CH_4 yields one mole of CO_2 when complete combustion is occurred and consequently one mole of C_2H_6 (ethane) resulted in to two moles of CO_2 and so on. Incomplete combustion can also occur if insufficient air is supplied. The following reactions are typical in the flaring system in Kuwait Oil Company (KOC);

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$
$$C_2H_6 + 3.5\ O_2 \rightarrow 2CO_2 + 3H_2O$$
$$C_3H_8 + 5\ O_2 \rightarrow 3CO_2 + 4H_2O$$
$$C_nH_{2n+2} + \frac{3n+1}{2} O_2 \rightarrow nCO_2 + (n+1)H_2O$$

Complete Combustión

$$CH_4 + 1.5\ O_2 \rightarrow CO + 2H_2O$$
$$C_2H_6 + 2.5\ O_2 \rightarrow 2CO + 3H_2O$$
$$C_3H_8 + 3.5\ O_2 \rightarrow 3CO + 4H_2O$$
$$C_nH_{2n+2} + \frac{2n+1}{2} O_2 \rightarrow nCO + (n+1)H_2O$$

Incomplete Combustión

Therefore, with known composition and amount of each hydrocarbon and the total moles of CO_2 can be calculated. Emission factors are well documented and well investigated to develop multipliers which are derived from large numbers of actual measurements. An emission factor would be applied as follows:

$$PE = LA \times EF \quad (1)$$

PE: Pollutant Emission in Tonnes
LA: Level of Activity
EF: Emission Factor

Emission factors have been derived for a large number of pollutants and industrial facilities, particularly those related to combustion processes. Thus, in general, emissions can be estimated provided the level of activity of an operation is known and there is an appropriate emission factor which can be used to calculate the total amount of that pollutant emitted. Emission factors should, whenever appropriate, take into account variations in fuel composition, crude oil properties, ambient air temperature and fuel/air ratio etc.

There are a number of established sets of emission factors applicable to oil exploration and production facilities, which are recognized internationally.

US EPA AP42 factors[4], which are applicable to a wide range of industries and thus must be used carefully to ensure applicability to the equipment and the planned use E&P Forum factors[5] which are based on AP42 or other international factors, based specifically on oil and gas production operations UKOOA factors[6], which have a similar basis to the E&P Forum factors but provide complimentary advice and quantification of different classification of typical North Sea production facilities. The factors employed in 1997 year for KOC oil related operations are based

on the E&P Forum protocols, with some input from the UKOOA guidelines.

E&P forum combustion emission factors: The Oil Industry International Exploration and Production Forum (E&P Forum) were approached by oil companies, governments and other organizations', to provide consistent guidance on methodologies for estimating gases emitted from E&P operations around the world. The environmental concerns at the time related to global warming as well as regional or local air quality. E&P Forum[5] in a study involving Brown and Root Environmental introduced a tiered approach to emissions estimation primarily based on emission factors. The factors were derived from previous measurement studies in a number of countries particularly the USA, Canada, Norway and the UK.

Table 1: E&P Forum Emission Factors

Factor Units = tonnes emission / tonne gas burned	Carbon Dioxide (CO_2)	Nitrogen Dioxide (NO_2)	Carbon Monoxide (CO)	Sulphur Dioxide (SO_2)	Methane (CH_4)	Non Methane VOCs
Flaring - Rich Gas	2.8595	0.0015	0.0087	0.0006	0.035	0.0015

It is assumed that most of the flares burn gas with negligible fine particulate emissions. In many countries, new smokeless flares are mandatory thus an emission factor for black smoke has not been recommended as part of the standard E&P Forum factors.

RESULTS AND DISCUSSION

The Environmental Pollution Inventory data for 1997- 2005 years have been collected for flaring events from all oil production facilities in Kuwait. The inventory focuses primarily on air emissions. The inventory estimates the amount of each of the flaring pollutants generated by KOC operations on an annual basis and the analysis is repeated for the next year and results are compared and validated with preceding year known emissions.

The first inventory has been completed for 1997 and is therefore an appropriate baseline for the incoming year's inventories. The inventory is based on the best estimates of actual operational data but where operational data is not available, typical industry values are substituted.

The Excel spreadsheet used to collate the input data and calculate the estimated emissions has been greatly improved and updated for the later years. The gathering centers are all fairly similar in size in terms of throughput and power consumption, which are emphasized by the lack of variation in combustion gas emissions such as NO_x. The gathering centers in West and North Kuwait are generally larger, with greater capacity and hence have larger power consumption. This is further increase due to further expansion of drilling activities in these 2 areas which gives rise to much higher levels of emissions in these regions than in South East Kuwait.

1997 Flare Inventory: Figures 2, 3a and 3b depict a breakdown mainly in 3 major production areas of KOC. With the exception of SO_2 exclusively in West Kuwait, it can be observed that there is a fairly even spread of emissions across the operations. The larger number of facilities present in SEK as explained in accounts for the slightly higher NO_x emissions, whilst the proportionately higher North and West emissions of CO_2 result from higher levels of flaring of excess gas.

The quantity of gas flared for each area in year 1997 is shown graphically in Fig. 2. Very high levels of gas flaring occurred in North and West Kuwait, together accounting for over 70% of the total emissions in the state of Kuwait in this year.

The results of total emissions from flaring at each area are represented graphically in Fig. 3a and 3b. Very high levels of gas flaring occurred in North and West Kuwait.

Total emissions to air from flaring: Figure 4 shows overall total crude and gas production and Fig. 5 presents quantity of gas flare for 1997-2005 years. It is clear that there is an obvious decrease in atmospheric emissions since 1997 to 1999. This reduction is mainly due to apparent decrease in production over the same period providing less excess gas/oil to be flared.

Figures 6a and 6b provided graphically the results of the total emissions from flaring at each area in KOC for years 1997-2005. Very high levels of gas flaring occurred in North and West Kuwait for year 1998, although these were substantial reduction on the following year. The major reasons for the increased flare per KOC Area's during 1998 are as follows:

* Condensate Recovery Unit frequent shutdowns
* Shortage of gas compression facilities
* Booster Station's malfunction

The percentage of gas flared has increased in 1998 due to the above mentioned reasons and the subsequent increased volume of flared gas in West Kuwait.

In line with the KOC flaring reduction goals, emissions from flared gas have reduced in 1999 below

1997 levels, despite a significant increase in 1998. Flaring emissions increased during 1998 but have decreased by about 10% over the 3 year period.

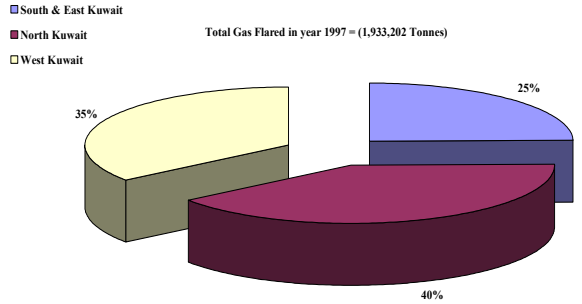

Fig. 2: Total gas flared from different oilfields in the state of Kuwait in year 1997

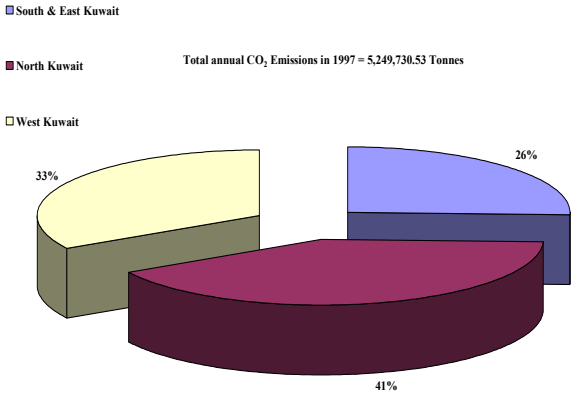

Fig. 3a: Percentage of Total annual CO_2 emissions from various Oilfields in Kuwait in Year 1997

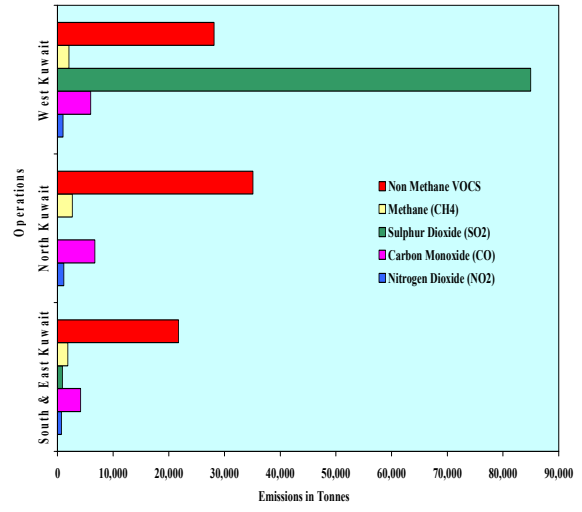

Fig. 3b: Total emissions of different pollutants from various Oilfields in year 1997

All KOC assets have introduced measures to reduce the quantity of gas flared in year 2000. These include:

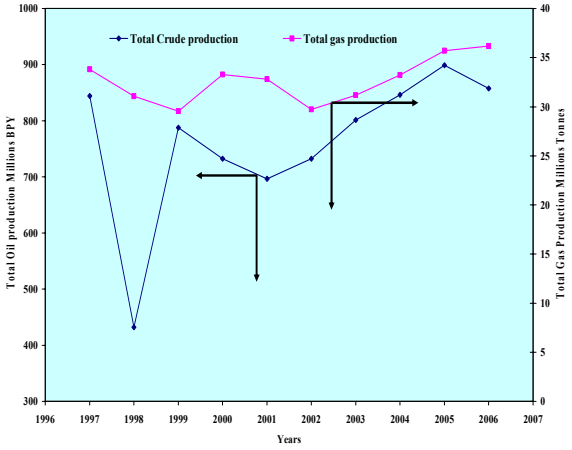

Fig. 4: Total annual oil and gas production in the state of Kuwait

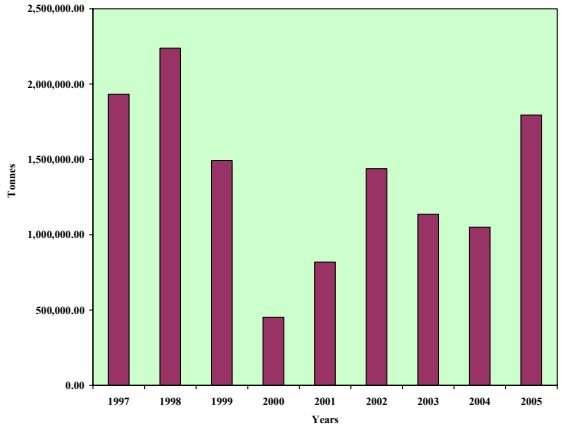

Fig. 5: Total annual amount of gas flared from the state of Kuwait

* The compression of vapors from the storage tanks, enabling them to be fed into the gas export line.
* The installation of new high pressure separators at Burgan and Magwa.
* Linking drilling sites to gathering centers so that any gas produced during drilling operations can be further processed. Therefore, emissions from flared gas have reduced significantly in years 2000 and 2001 even less than the 1999 levels.

The quantity of gas flared has increased slightly in 2002 due to the frequent shutdowns of Condensate Recovery Unit and Shortage of gas compression facilities and the subsequent increased volume of flared gas in North Kuwait.

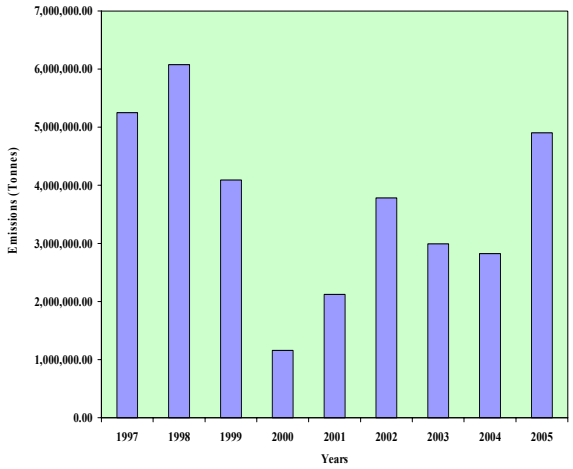

Fig. 6a: Total annual CO_2 emissions (Tonnes) from all oilfields in Kuwait

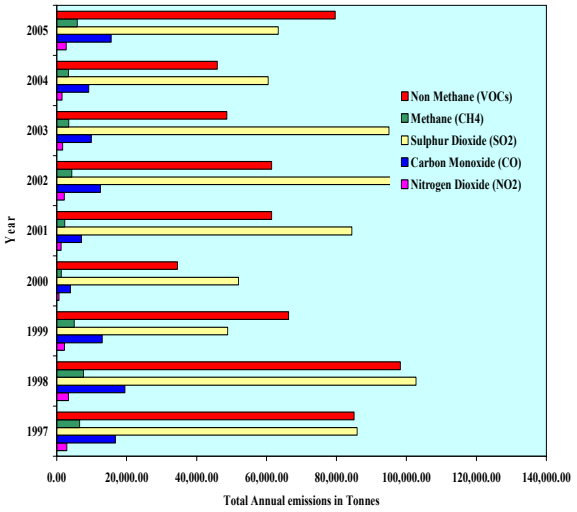

Fig. 6b: Total annual emissions of different Pollutants (Tonnes) from all oilfields in Kuwait

Monitoring carried out in between 2003 and 2004 showed that emissions from flared gas have reduced to below 2002 levels and the primary pollutants levels were generally within local EPA limits.

The quantity of gas being flared in KOC was about 14% of the total gas produced in 2002 that flared fraction reduced to 0.1 (10%) in 2003, despite substantial increase in the amount of gas being produced as shown in Fig. 4.

As in the case of CO_2 emissions, releases of all other pollutants have fallen gradually from 2002 to 2003 and 2004 in line with the decrease in the quantity of gas flared as shown in Fig. 6a.

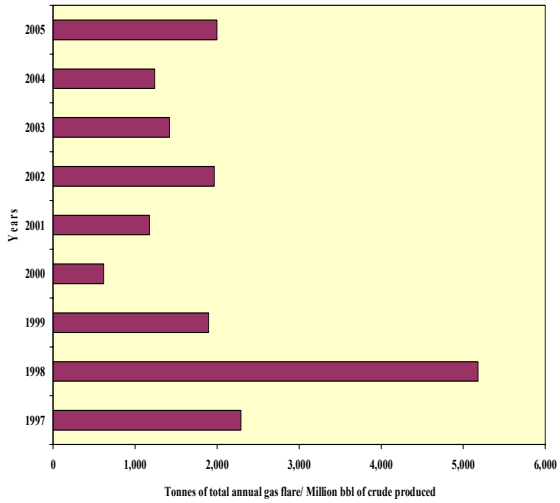

Fig. 7a: Total annual amount of Gas flared per million tones of crude produced from all Oilfields in Kuwait

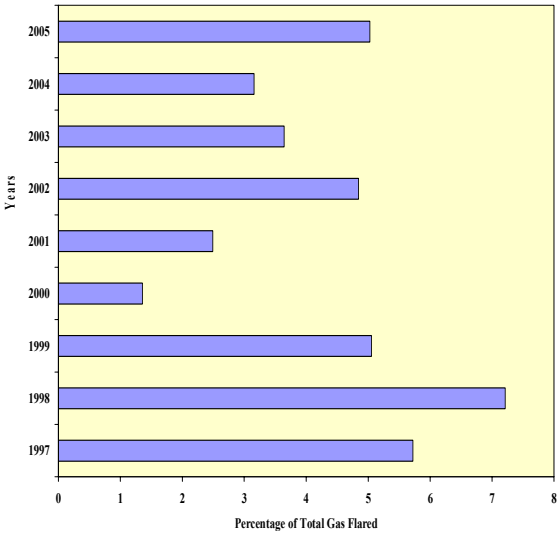

Fig. 7b: Percentage of total gas flared annually from all oilfields in Kuwait

Efforts continued to reduce the quantity of gas flared. Although the amount of gas produced increased substantially from previous years, the amount of gas flared or lost only increased slightly from 2003 and quantified to 8% of the total gas production compared with 14% in 2002 and 10% in 2003.

There was a large increase in gas flaring in 2005 compared with previous years as shown in Fig. 6a and 6b. This was almost entirely due to events in North Kuwait. These included:

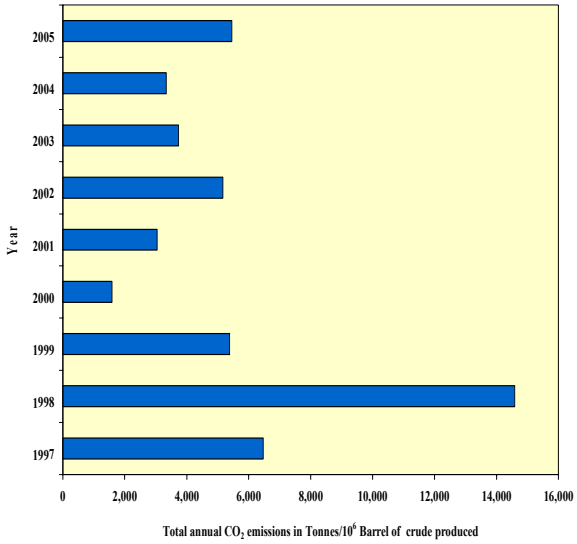

Fig. 8: Total Annual CO_2 emission (Tonnes) per million barrels of crude produced

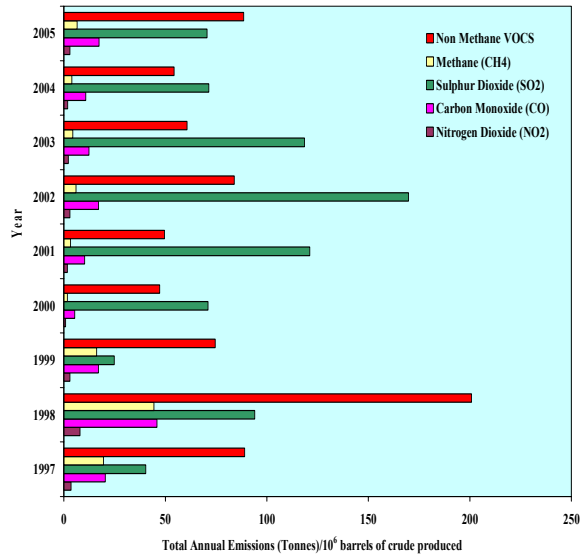

Fig. 9: Total annual emissions (Tonnes) per million barrels of crude produced

* A breakdown of the condensate pump in North Kuwait.
* A major survey of the Condensate Recovery Unit in North Kuwait.
* The complete shutdown of the compressor in North Kuwait.

The cumulative effect of these events resulted in very high levels of flaring at the respective gathering centers. Because of the problems in North Kuwait, the amount of gas flared, as a percentage of production,

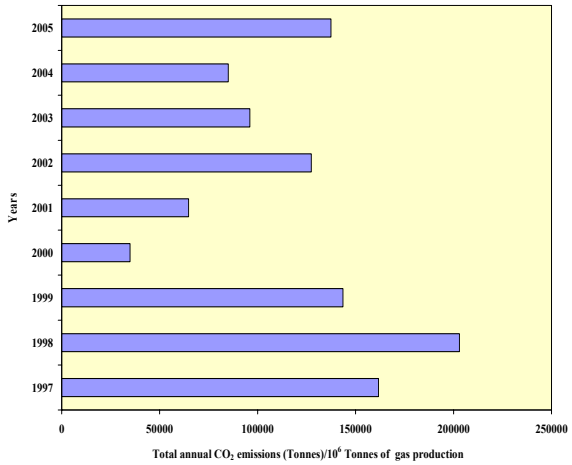

Fig. 10: Total annual CO_2 emission (Tonnes) based on million tonnes of total gas produced

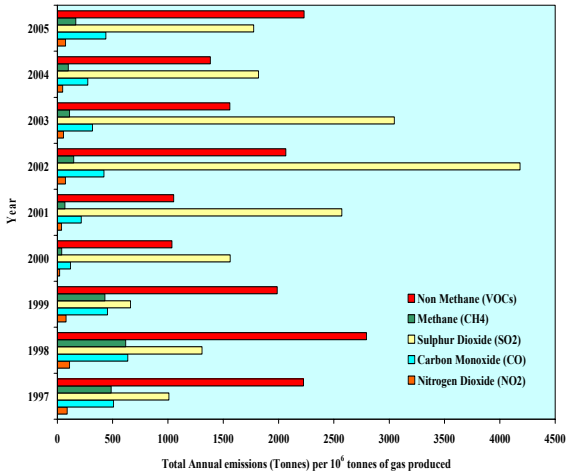

Fig. 11: Total annual emissions (Tonnes) based on 10^6 tonnes of gas produced

was about double that of the previous year as shown in Fig. 7a and 7b.

The increase in gas flared in 2005 inevitably resulted in a similar increase in most atmospheric emissions. The exception to this was sulphur dioxide emissions, which remained almost unchanged from the previous year as show in Fig. 6b. This was mainly due to flaring of sour gas (rich in H_2S and mercaptans) at West Kuwait contributing to high levels of sulphur dioxide emissions.

To observe the influence of crude production to the associated gas and fraction being flared, total annual Emissions (Tonnes) of different pollutants per Millions barrel of crude produced are shown in Fig. 8 and 9.

There has been a general decrease in flaring volumes 1997 to 1999 with the exception of year 1998 and the least emissions in year 2000 followed by slight gradual to 2005.

The influence of crude production and associated gas depends on Gas-Oil ratio of the characteristic of the crude. The influence of gas production was assessed and shown in Fig. 10 and 11.

Figures 10, 11 show the total emissions (Tonnes) per million tonnes of annual gas produced. There has been a general decrease in flaring volumes from 1997 to 1999 and further decrease in year 2000. There was gradual increase in coming years 2002 to 2005.

CONCLUSION

The flaring of excess gas is the largest single source of atmospheric emissions arising from KOC operations. However, flaring produces carbon dioxide, oxides of sulphur and nitrogen (NOx) and other chemical species that are produced due to incomplete combustion, such as carbon monoxide, aldehydes, ketones and other organic compounds known as VOCs (Volatile Organic Compounds). From the first three years, it is shown that flaring emissions are reduced by 10% against 1997 baseline levels, although there was sudden increase in 1998 due to certain malfunctions of the gas handling equipments. There was decrease in production but still atmospheric emissions from fuel use have increased in 1998.

In line with the KOC flaring reduction goals emissions from flared gas have reduced in years 2000 to the minimum and continued further lower than 1999 levels. But the quantity of gas flared has increased slightly in 2002 due to the frequent shutdowns of Condensate Recovery Unit and Shortage of gas compression facilities and the subsequent increased volume of flared gas in North Kuwait.

From the Monitoring results that were carried out in year 2003 and 2004, it is obvious that the emissions from flared gas have reduced to below 2002 levels and the primary pollutants concentrations were generally within EPA limits. The quantity of gas being flared in KOC has been reduced from 14% of total production in 2002 to 10% in 2003, despite an increase in the total amount of gas being produced. There were unexpected problems in North Kuwait oilfields in year 2005, the amount of gas flared, as a percentage of production, was about double that of the previous year

In the long term, KOC has the goal of eliminating all routine flaring entirely. Only emergency flaring would occur, with a target that this should not exceed 1% of the amount of gas produced. To help KOC in its environmental health operation, it is important to develop long-term strategies for environmental control, for the incoming years KOC plan to reduce the "normal production" flaring to 1%. This requires the execution of many capital projects such as:

* Replacement of Existing Condensate Recovery Unit in several Gathering Centers
* Installation of new Booster station in North Kuwait
* Upgrade of Gas Networks

In addition, new clean burning flares have to be installed at the gathering centers. Each major project is subject to a detailed Environmental Impact Assessment (EIA), to ensure that it incorporates the best environmental engineering practice. Looking further ahead, KOC have to investigate other potential technologies for reducing emissions by implementing new and right technology for measurement of flared gases and conduct research, internally and with partners for the benefit of KOC and for the State of Kuwait in general. Also, further work is planned to monitor comprehensively VOCs to identify sources and determine the contribution of each source for planning the mitigation strategies.

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