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Dangerous Effects of Methane Gas in Atmosphere

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Abstract: *This paper discusses the effects of methane gas which causes sever global warming in the atmosphere. Global warming becomes main issue in economics in the 21st century. Because global climate change becomes more dangerous and every nation realized that this is due to greenhouse gas emissions. Methane is dangerous greenhouse gas, since it is 21 times more global warming potential than carbon dioxide. All the nations talk about the reduction of only carbon dioxide and no nation stress on methane reduction. Due to global warming the ocean levels are increasing, as a result most of the costal areas will submerge by 2050, and some insects and animals will extinct. In this paper an attempt has been taken to discuss the aspects of methane gas emissions and the importance of methane gas emissions reduction.*

Keywords: Fugitive methane emissions, Global warming potential, Shale gas, Climate change.

Introduction

The Kyoto protocol is given in 1997 but has activated in 2005. In this protocol 27 developed countries agreed that they are responsible for greenhouse gas (GHG) emissions but the USA refused to follow that protocol. At last the US government agreed that between 2008 and 2012 it would limit average annual emissions of GHGs to 7% below 1990 levels. But the US government have not expressed by which technology will apply to implement Kyoto Protocol. According International Energy Agency (IEA) data (IEA 2007), the USA and China are approximately tied and leading global emitters of GHG emissions. Together they emit approximately 40% of global carbon dioxide (CO_2) emissions, and about 35% of total GHGs. The USA is a developed country but China is yet a developing country (Mohajan 2011). Intergovernmental Panel on Climate Change (IPCC) in the 4th report in 2007 expressed that the main cause of GHGs is various human activities (IPCC 2007). If anthropogenic GHG emissions can not be reduced then the global worming will continually increase. The Bali Action Plan (2007) adopted United Nations climate conference recognizes that "deep cuts in global emissions" will be required to avoid dangerous climate change. Specifically, it acknowledges the need for industrialized nations to GHG emissions by 25% to 40% below 1990 levels by 2020 (Mohajan 2011). Five action plans are fixed in the conference as follows:

- How many aims the whole world will implement to control of global warming.
- To find out the efficient policies of mitigation.
- In how the procedure will be implemented.
- How the necessary financial supports will be managed.
- To fix the action plan for transferring technology and to acquire efficiencies for this.

In the Bali Action Plan it was hoped that within 2009 these five plans will be activated but yet in 2012 have no satisfactory advances. IPCC will express its fifth report in 2015. Environment analysts suspect that there will be no satisfactory progress in the reduction of GHG emissions up to 2015, because the USA and European developed countries are in financial crisis in 2011 and it is estimated that this crisis will not overcome very soon. In

December, COP/CMP7, UN Climate Change Consensus 2011, Durban, South Africa, all the nations of UN do not agree to reduce GHGs according to Kyoto protocol agreement. China shows willingness to the reduction of GHGs but some developed countries show opposite opinions. So that the mitigation policies of CO_2 equivalent reduction will not be fruitful in future if all the nations do not consent to the reduction of GHGs emissions (The Prothom Alo 2011).

Over the last two centuries methane (CH_4) concentrations in the atmosphere have more than doubled but in the last decade CH_4 concentration increases rapidly. The target of the 21st century is to keep the increase of global warming less than 2^0C. All the nations emphasized to the reduction of CO_2 emissions but no nation take CH_4 emissions seriously. But CH_4 is 21 times more potent than CO_2, so that all nations must take steps to reduce fugitive emissions of CH_4. In 1992 all the countries of the world implemented an international protocol to face the climate change and they promised to work together to control GHGs. Unfortunately they failed to implement it.

Global warming potential of GHGs

The six gases; Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphurhexafluouride (SF_6), hydrofluourocarbon (HFC) and perfluourocarbon (PFC), together constitutes six GHG emissions. These six gases briefly called carbon dioxide equivalents (CO_2e). CH_4 is present in the atmosphere very low compared to CO_2 but it is 21 times more potent per unit as a GHG (EPA 2006a, Mohajan 2011). CO_2 emission in energy sector is more than 61% of total GHG emissions. CH_4 is the second most important GHG which emits 16% of global GHG emissions from anthropogenic and natural sources. In 2005, global GHG emissions calculated to over 44 Gt (gigaton) CO_2e and CH_4 accounted 7 Gt CO_2e. Approximately 60% of CH_4 emits from agricultural, coal mining, landfills, natural gas and oil activities, and the rest are from natural resources (IEA 2009).

The European Union (EU) Environment Council at its meeting on 30 October 2007 promised to decrease the global warming more than 2°C. It is expressed in the meeting that the sustainable concentration of CO_2e in atmosphere is 450ppm (parts per million) and substantial global emission reductions to at least 50% below the 1990 levels by 2050. The meeting also stresses that the group of developed countries and developing industrialized countries must reduce their emissions of GHGs in a range of 25-40% below 1990 levels by 2020. Each of the GHGs has its own particular properties in terms of infrared absorption and atmospheric lifetime after being emitted. The current concentrations of GHG in space have increased since 1750 from a CO_2e of 280ppm to 430ppm and pre-industrial period it increased up to 380ppm (Stern 2007). This increase of CO_2e is due to burning of fossil fuels and forests, and fugitive emissions of CH_4. Based on records from gas bubbles trapped in polar ice it is estimated that current concentration of CO_2e gases are the highest at least the last 650,000 years. Each GHG traps different amounts of heat and stays in atmosphere for different lengths of time. So that it is necessary to measures of global warming potential (GWP) to compare between gases. It is clear to us that if we do not take the effort to reduce the emissions of different GHGs by only considering the reduction of emissions of CO_2 then it is not possible to

keep the limit of global warming to 2^0C. The following table gives six GHGs global warming potential and atmospheric life in years (Sharma 2007, Mohajan 2011).

Table 1: The GWP of six GHGs, (IPCC 2001).

Gas	GWP	Atmospheric Life (years)
CO_2	1	5 to 200
CH_4	21	12
N_2O	310	114
HFC	140 to 11,700	1.4 to 260
PFC	6,500 to 9,200	10,000 to 50,000+
SF_6	23,900	3200

The potency of the greenhouse effect is radiative forcing which measures how much the gas affects the balance of heat coming in and going out of the atmosphere. Positive radiative forcing warms the surface of the earth while negative forcing cools it and which can be expressed in watts per square meter, Wm^{-2} (IPCC 2007). The combined radiative forcing of CO_2, CH_4 and N_2O is +2.30 Wm^{-2} compared to the radiative forcing of solar irradiance of +0.12 Wm^{-2}. Oceans have warmed from surface of the sea to up to a depth of at least 3km. It is estimated that absorbed 80% of the additional heat added to the climate. Warmer water taking more spaces of the sea than the colder water, as a result sea level is rising (Sharma 2007, Mohajan 2011).

Methane is 21 times more powerful than CO_2 to trapping heat. A vast expanse of permafrost in Siberia and Alaska has started to melt for the first time since it formed 11,000 years ago. It is caused by the recent 3°C rise in local temperature over the past 40 years which is more than four times the global average. Peat bogs cover an area of a million square miles (or almost a quarter of the earth's land surface) to a depth of 25 meters. This has the capacity to release billions of tons of methane trapped by ice below the surface. It is estimated that the west Siberian bog alone contains about 70 billion tons of CH_4, a quarter of all the CH_4 stored on the land surface of the world. This is equivalent to emitting 1.7 trillion tons of CO_2, which is more GHG than has been emitted by humans in the past 200 years. We can easily reduce our CO_2 emissions from fossil fuels if we try but we could not reduce methane emissions once if they started to emit (NAS 2010, Mohajan 2011).

In the 2007 meeting of EU only CO_2 emission reduction efforts are cited. But not mentions emissions of non-CO_2 GHGs such as CH_4, N_2O, HFC, PFC and SF_6 at all. CH_4 is one of the dangerous level GHGs but no nation mention about the reduction of CH_4. The GHG, CH_4 is present in the atmosphere very low compared to CO_2 but it is 21 times more potent per unit as a GHG (EPA 2006a). In the pre-industrial period CH_4 was 715ppb (parts per billion) but in 2005 it increased 148% to reach 1774ppb (IPCC 2007). About half of this increase is due to decomposition of wastes in landfills, natural gas systems, and enteric fermentation (EPA 2006a, Mohajan 2011). Since the atmospheric lifetime of CH_4 is short compared to that of the CO_2, the GWP of CH_4 varies considerably depending on the period of time chosen.

It is also needed to calculate impact of emissions each GHG as global warming compared to that of CO_2 for a period, 100 years. IPCC forwarded the concept of GWP,

which indicates the relative contribution to global warming over 100 years of a pulse emission at the start of the period of 1 kg of a specific GHG in comparison to the contribution, over the same period, of an emission of 1 kg of CO_2. Let the integral (at t = 0 to $t = T$) of the function of the decline in CH_4 over time = $I(M)$ and the integral of the function of the decline in CO_2 over the same time = $I(C)$. Let the radiative efficiency of CH_4 = $R(M)$ and the radiative efficiency of CO_2 = $R(C)$. The GWP of CH_4 at the time horizon ($t = T$) for emissions at the start ($t = 0$) is as follows:

$$\text{GWP (at } t = 0 \text{ to } t = T) = \frac{I(M) \times R(M)}{I(C) \times R(C)}. \qquad (1)$$

Here, $I(M) \times R(M)$ = Absolute global warming potential (AGWP) for CH_4 and $I(C) \times R(C)$ = AGWP for CO_2. Hence we can write (1) as;

$$\text{GWP (at } t = 0 \text{ to } t = T) = \frac{\text{AGWP for } CH_4}{\text{AGWP for } CO_2}. \qquad (2)$$

The GWP of CH_4 over a 100 year period is 21, which means that the emission of 1 unit of mass of CH_4 has a climate impact equivalent to that of the emission of 21 units of mass of CO_2 over the 100 year period following these emissions. As a result the reduction of CH_4 emission must be taken into account (Dessus et al. 2008).

The pulse emission of 1 ton of CH_4 in 2000 is counted as 21 tons CO_2 on the basis of the cumulative effects respectively of CH_4 and CO_2 between 2000 and 2100 which implies that the impacts of a CH_4 emission compared to those of an emission of the same volume of CO_2 are each year put back 100 years.

From table-1 we see that the lifetime of CH_4 (12 years) is short compared to that of CO_2 (5 to 200 years), so that the GWP of CH_4 varies considerably depending on the period of time chosen. Although the GWP of CH_4 over a 100 year period is 21 but it is impossible to estimate effects at a given time horizon (such as 2020, 2050, 2100 etc.) of CH_4 emission. Hence for measuring the impact of CH_4 it is of course necessary to take into account the difference between the year of the emission and the year of time horizon. Because the GWP rapidly varies depending on the time period chosen to measure the respective impacts of CO_2 and CH_4 on global warming (Dessus et al. 2008).

Calculation of GWP

The GWP calculation for CH_4 at different time horizons was made on the basis of IPCC (2007) as follows:

- By reconstituting the CO_2 and CH_4 decline table in the period 0 to 500 years.
- By calculating the AGWPs of CO_2 and CH_4 using values of the radiative efficiency of these two GHGs provided by the IPCC which is for the same unit of mass present in the atmosphere, the radiative efficiency of CH_4 is equal to 73 times that of CO_2.
- Calculating the GWP of CH_4 to the AGWP for example for 1 kg (the AGWPs for a 1 kg emission can calculate for every gas).

We have calculated the GWP for CH_4 to the AGWP of CO_2 for an emission of 1 kg of each gas at year 0. Because the value of GWP for CH_4 and for an emission of 1 kg of

both gases is equal to the ratio of the AGWPs per ppm multiplied by $\frac{44}{16}$. Since molecular mass of CO_2 = 12+16×2 = 44 and molecular mass of CH_4 = 12+1×4 = 16. The calculated GWP values are obtained by IPCC (2007) for 20, 100, 150 years be 72, 25 and 18 respectively which are given in table-2.

Table 2: The value of GWP of CH_4 depending on time horizon (year of emission: 0).

Year	5	10	15	20	25	30	35	40	45	50
GWP	**101**	**90**	**80**	**72**	**64**	**58**	**53**	**49**	**45**	**42**
Year	55	60	65	70	75	80	85	90	95	100
GWP	**39**	**37**	**35**	**33**	**31**	**30**	**28**	**27**	**26**	**25**
Year	105	110	115	120	125	130	135	140	145	150
GWP	**24**	**23**	**23**	**22**	**21**	**21**	**20**	**19**	**19**	**18**

From the above table-2 we see that the effect on global warming due to the emission of 1 kg of CH_4 in year 0 is the same over a period of 100 years. As the effect of the emission of 25 kg of CO_2 in year 0; over a period of 20 years of emission of 72 kg of CO_2 in year 0; and over a 100 years of the emission of 25 kg of CO_2 in year 0 (IPCC (2007) measures the GWP of CH_4 is 25 times than CO_2).

The above procedure is given with the basis of using the 100 years equivalence. Now we consider another type of measurement as follows (Dessus et al. 2008): In the year 0, annual emission of 1 kg of CH_4 is equivalent according to current methodology of 21 kg of CO_2. Here it is avoided emission of 1 kg of CH_4 each year. Similarly, the measurement avoided emission of CO_2 each year also. We need cumulative effects of each emission avoided during the whole of the period between the years in which the measurement was implemented and the horizon year is obtained by adding together the AGWPs of CH_4 and CO_2. The ratio of the cumulative effects gives a comparison between a permanent CH_4 emission reduction measure and a permanent CO_2 emission reduction measure (table-3).

Table 3: Value of the CO_2 measure with the same effect as the CH_4 measure at different time horizons.

Year of horizon	20	50	100	250	500
CO_2 (kg)	81	57	39	21	13

From table-3 we see that at 20 and 50 year time horizons the under estimated impacts of using the GWP of 21 a factor of 3.9, (81÷21≈ 3.9) and 2.7 respectively and reach the factor 1 after the time elapse of 250 years.

Methane Gas Emissions in Oil and Gas Sector

The oil and gas sector is the second largest anthropogenic methane source worldwide which release annually about 85 billion cubic meter (≈ 1200 Mt CO_2e) methane in the atmosphere (M2M 2008a). The major of these emissions come from oil and natural gas production, processing, transitions and distribution. Since gas moves through the pipe with extreme pressure, CH_4 can emit into the atmosphere through the worn valves, joints, pump seals and connections of pipelines. Usually emissions of CH_4 are happen from venting the gas from compressors or pipelines when they are taken out of services. The

emissions vary from country to country depending on operation maintenance procedures, and equipment conditions. At present 17% of the total global CH_4 emissions result from oil and natural gas. Brazil and China are the largest growth of CH_4 due to their rapid expanding economies (EPA 2006a).

Methane Gas Emissions when Drill Wells

Shale gas is extracted by large amount hydraulic fracturing (fracking). Huge water is forced under pressure into the shale to fracture and re-fracture the rock to boost gas flow. A large amount of this water returns to the surface of the earth as back flow within the first few days after injection. Also a large quantity of CH_4 comes out with return water (EPA 2010). Howarth et al. (2011) collected data from 2 shale gas formations and 3 tight-stand gas formations in the USA which are given in table-4.

Table 4: CH_4 emissions during the flow-back period following hydraulic fracturing for five unconventional wells in the USA (Howarth et al. 2011).

	CH_4 emitted during flow-back (10^3 m^3)	CH_4 emitted per day during flow-back (10^3 m^3 /day)	Initial gas production at well completion (10^3 m^3 /day)	Life-time production of well (10^6 m^3)	Methane emitted during flow-back as % of life-time production
Haynesville (Louisiana, shale)	6,800	680	640	210	3.2
Barnett (Texas, shale)	370	41	37	35	1.1
Piceance (Colorado, tight sand)	710	79	57	55	1.3
Uinta (Utah, tight sand)	255	51	42	40	0.6
Den-Jules (Colorado, tight sand)	140	12	11	?	?

From table-4 we see that production of gas from wells is emitted as methane during the flow-back period between 0.6% and 3.2% of the life-time. The highest CH_4 emissions during flow-back were in Haynesville, where the initial pressures and initial production were very high. On the other hand the lowest emissions were in the Uinta, where the flow-back period was the shortest. Huge CH_4 is released when drill out the stage in developing unconventional gas in which the plugs set to separate fracturing. EPA (2007) estimated that drill-out emissions at 142×10^3 to 425×10^3 m^3 per well. Wood et al. (2011) used the average life-time production for a larger set of data on 12 formations as 45×10^6 m^3, which estimate a percentage emission of 0.62% but Howarth et al. (2011) obtained that value of 0.33% from table-4. Again from table-4 gas losses from flow-back fluid as the mean value is 1.6%. The conventional wells have no flow-back and no drill-out, so that emissions of CH_4 are very lower for conventional natural gas wells during completion. An average of 1.04×10^3 m^3 of CH_4 is released per well completed for conventional gas corresponding to 1.32×10^3 m^3 natural gas (EPA 2010). In 2007, about 19,819 conventional wells were completed in the USA (EPA 2010), so that it was estimated a total national emission of 26×10^6 m^3 natural gas. The total national production of onshore conventional gas in 2007 was 384×10^9 m^3 (EIA 2010).

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Fugitive Emissions of Methane gases

A typical well has 55 to 150 connections in the equipment of heaters, meters, dehydrators, compressors and vapor-recovery apparatus. Unfortunately many of them are leaks and vent gases. Among them pneumatic pumps and dehydrators are major parts of leakage (GAO 2010). On the other hand venting is visible during the liquid unloading. GAO (2010) estimated that 0.02 to 0.26% of total life-time. Sometimes CH_4 releases during "pipeline ready" without further processing. Also fugitive emission occurs during transport, storage and distribution of natural gas. It is estimated that in USA this type of emission is 0.53% and in Russia is 0.7% (Lelieveld et al. 2005). Howarth et al. (2011) estimated that a total loss during life cycle of an average shale-gas well, 3.6% to 7.9% of the total production of the well is estimated to atmosphere as CH_4. It is at least 30% more than conventional gas.

Methane leakages are usually difficult to detect. By infrared cameras CH_4 emissions can be visible as black smoke (figure-1). Russia and USA apply direct inspection and maintenance programmes both for substantial CH_4 emissions reductions and gas savings. In 2007, US domestic partners reduced CH_4 emissions by 92.5 billion cubic feet, which saved approximately $ 650 million to natural gas sales. CH_4 is produced and emitted during the anaerobic decomposition of organic material in livestock manure mainly from swine, cattle and poultry operations. In 2008, US farm digester system produced an estimated 290,000 MWh equivalents of energy generation. CH_4 management contributes approximately 4% of the total anthropogenic CH_4 emissions. Global CH_4 emissions from manure management are projected to increase 21% between 1990 and 2020 (EPA 2006b). CH_4 from manure can be recovered using anaerobic digesters, including covered lagoons, plug flow digesters, complete mix digesters and small scale digesters (M2M 2008b). These types of CH_4 mitigation technologies are costly and most countries do not aware of these. So that proper education needed with financial support to CH_4 mitigation in manure preparation projects.

Figure 1: Photographs by the U.S. Environmental Protection Agency (EPA). To the naked eye, no emissions from an oil storage tank are visible. But viewed with an infrared lens, escaping methane is evident.

It is estimated that green technologies can reduce gas-industry CH_4 emission by 40% (GAO 2010). Liquid-unloading emissions can be greatly reduced with plunger lifts (EPA

2006b, GAO 2010). The use of flash-tank separators or vapor recovery units can reduce dehydrator emissions by 90% (Fernandez et al. 2005). The emissions during transmission, share and distribution can be reduced by the use of better storage tanks and compressors and through improved monitoring for leaks. But unfortunately the industry has very little interest to reduce these emission sources (Percival 2010).

Contamination of Methane in Drinking Water

The natural gas extraction increases due to rising of energy demands, mandates of cleaner burning fuels, and the economics of energy use. Recently the natural gas extraction is performed by directional drilling and hydraulic fracturing technologies. When shale-gas is extracted from organic-rich shales in USA and elsewhere in such processes, methane is contaminated in drinking water. No doubt we find benefits for such extraction (Osborn et al. 2011) but contaminated drinking water with CH_4, which is harmful for health. If there are one or more gas wells within 1 km then average and maximum concentrations of methane in drinking water wells increased and it reaches about 19.2 and 64 mgL^{-1} respectively. In Susquehanna County, Pennsylvania alone, approved gas-well permits in the Marcellus formation increased 27-fold from 2007 to 2009 (Pennsylvania Department of Environmental Protection, Bureau of Oil and Gas Management 2010).

A huge amount of water is used in fracking which may deplete local ecosystems. In fracking process chemicals and water are used, the mixture eventually returns to the surface which may contaminate both land and water. The mixture consists of carbon dioxide, hydrogen sulphide, mercury, arsenic and lead, naturally occurring radioactive materials such as radium, thorium, uranium and the BTEX compounds-benzene, toluene, ethylbenzene and xylene. Due to the contamination of these chemicals drinking water turn to be brown and people become sick which sometimes strongly suspected to cancer. Domestic animals may lose their hair by drinking this type of contamination water.

Benefits from the Reduction of Methane Gas Emissions

Reduction of CH_4 gives various benefits such as safety of energy, decrease environment pollutions. On the other hand CH_4 decreases global warming which mitigate global climate change. Global emission of methane in 2000 is 352 million tons. This calculation would accurately be applied for a fifteen year period (1995-2010). Hence in 15 years total emissions of methane = 32 million×15 tons = 35 billion tons. The total cost of 15 years global methane emissions is $ 600 billion. So that the mean benefit = 600 billion ÷ 5.3 billion = $110 per ton of methane reduction. We can compare this with cutbacks of CO_2 which gives benefits of between $10 and $50 per ton of CO_2, with a mean value of $20. All values are calculated in 1990 dollars (Plambeck and Hope 1996). Only 5% of the benefits are in the EU, and 8% in the USA; the rest are benefited the developing countries. These benefits will continue the 21st century (Hope 2001). As like methane ozone (O_3) is also a greenhouse gas. Tropospheric O_3 is formed from photochemical reactions involving nitrogen oxides (NO_x) and volatile organic compound in the global troposphere. So that CH_4 mitigation reduces O_3 concentration in the troposphere. Tropospheric O_3 damages agriculture, ecosystems, public health. Although O_3 concentration increased in pre-industrial period but recently the process of O_3

concentration increases alarmingly due to increase of GHGs. By abatement of CH_4 emissions both reduces surface O_3 concentrations and slows greenhouse warming (West et al. 2006).

Concluding Remarks

In this paper we have discussed the methane emissions, the effects of it in the atmosphere and the mitigation policies of this gas. Although CH_4 is 21 times more potent than CO_2 but lifetime of CH_4 is shorter than CO_2. We show the comparison of global warming potential of CO_2 and CH_4 up to 500 years. Since CH_4 is a dangerous gas in atmosphere we have to take immediate steps to reduce this gas emission. We have discussed all the sections of the paper with some detail and easier processes. Methane mitigation provides opportunity to improve air quality globally, which can be a cost-effective component of international ozone management, bringing multiple benefits for air quality, climate, agriculture and human health.

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