Research Journal of Recent Sciences ISSN 2277-2502
Vol. 4(**ISC-2014**), 1-7 (**2015**) *Res. J. Recent. Sci.*

Hydraulic Fracturing for Oil and Gas and its Environmental Impacts

Chauhan Geetanjali*, Das Akashdeep, Agarwal Subham and Ojha Keka
Department of Petroleum Engineering, Indian School of Mines Dhanbad, INDIA

Available online at: www.isca.in, www.isca.me
Received 27th September 2014, revised 6th February 2015, accepted 5th March 2015

Abstract

Anywhere around the world, it is very difficult to imagine life, industrial process and private activity without oil and gas. Oil and gas resources are very limited and new technologies are being developed to extract more and more from these limited oil and gas reservoir. One such Technology to develop oil and gas fields is Hydraulic Fracturing, which is controversial due to its environmental footprints. Though implementation of hydraulic fracturing techniques has brought down the price of gas and electricity by increasing the natural gas production from unconventional reservoir like Tight gas, Shale Gas/Oil and CBM reservoirs, but this is on the cost of contamination of ground water resources, surface spills of chemicals causing soil pollution, noise pollution due to the large engines/pumps being used and the prolong contact with the chemical used can cause various health issues. In this paper, we will try to focus on the environmental impacts of chemicals used in hydraulic fracturing and well development and how huge water requirement for the hydraulic fracturing job can create problems for human water needs. In this paper the importance of realization of direct impact of fracturing fluids on environment and human health will be emphasized.

Keywords: Hydraulic fracturing, fracturing fluids, ground water contamination, spills, environmental laws, shale gas, CBM.

Introduction

Hydraulic fracturing has proved to be a promising game changer technique in countries with unconventional hot spots that not only met the present demand of energy, but also made the countries self-sufficient over the last few years and is creating considerable excitement globally. This has helped in gaining access to petroleum deposits which were earlier inaccessible to conventional drilling operations. Hydraulic fracturing is a stimulation technique to extract maximum natural gas from CBM, Shale gas reservoirs, which are 2000-8000 ft below the ground surface. This process is also used for oil wells for low to middle permeability reservoirs and for near well bore damage. It involves high pressure pumping of a mixture of water (about 95%), sand and chemicals, to fracture the surrounding rock formation. Sand is used as a proppant to keeps the fracture open to allow the flow of natural gas freely from the reservoir to production well. Once the process is completed, fracturing fluid flows back to the surface along with gas and oil. The flowback and produced waters are collectively called “HF water”. This flowback fluid and water that remains underground is a great threat to the environment and is estimated that only 5-60% of the fracturing fluid flows back to the surface and the rest remains underground[1]. The mixture remaining underground is the primary concern as it is the potential cause of contamination of water wells and the problem is intensified by the fact that this chemical mixture which remains underground is unknown to the knowledge of common person. Millions of gallons of toxic fluid is produced from each well containing the added chemicals, radioactive materials, heavy metals and brine water. The fracking process creates fissures which forms underground pathways for gases, radioactive materials and chemicals. The major drawback of this technique lies with the exploitation of vast amounts of water incorporated with over 600 chemicals known up to date consisting of toxins such as formaldehyde, ethylene glycol, methanol, etc and carcinogens. A multitude of environmental and health impacts by hydro racking is due to contamination of source . In this process due to the requirement of 8 million gallons of water with 40000 gallons of fracturing fluids, a well site may need upto 2000 water tankers per each frack (Earthworks- Hydraulic fracturing 101). The well contamination claims majorly involves methane, iron, manganese, etc. and physical properties such as, turbidity, odor and color. During this process, toxic chemicals and methane gas used during the operation contaminates nearby aquifer sources by leaching out from the system. Methane concentrations in domestic water sources are 17 times higher near fracturing sites than in normal conventional wells. Shale gas developments have the potential to cause hazardous situations to contaminate surfacial groundwater with methane. Methane being 23 times more powerful in entrapping heat in the atmosphere has also become one of the major causes for global warming and this process has also led to the release of pollutants due to limited technological developments in the waste disposal sectors. Iron and manganese oxides present in the casings of the wells and well bottom may get agitated into suspension due to vibration and pressure disturbance causing changes in color, odor and turbidity. Also, the well integrity failure leads to the leakage of annular fluids into the aquifers.

These issues due to well integrity failure results in leakage that are annular flow and leak flow. The leakages in which the fluids flow move up the wellbore, travelling between the cement and the casing or rock formation and cement, are under annular flow while leak flow is due to radial locomotion of leakage out of the well and into the formations, resulting into a greater concern for natural gas and is suspected to cause contamination of water wells. This contaminated well water, if consumed as drinking water may lead to sensory, respiratory and neurological anomalies in human beings and over 1000 cases have been documented till this day[2].

The waste fluid is left in open air pits to evaporate, releasing harmful VOC's (volatile organic compounds) into the atmosphere, creating contaminated air, acid rain, and ground level ozone. The 600 chemicals that were identified from the fracturing fluids used in drilling operations has been found that 75% of the chemicals could affect the skin, eyes and other vital sensory organs and also affect the respiratory and gastrointestinal systems. 40-50% of the chemicals affect the brain, nervous, immune, urinary and cardiovascular systems, while 37% of these toxic chemicals are presumed to affect the endocrine system and 25% of them are found to cause cancer and mutations in human bodies[3]. These toxic chemicals even if exposed to humans at lower levels can cause terrible ill effects to their endocrine systems due to its sensitivity to chemical exposures even in less than parts per billion. These health risks due to the fracturing fluids do not manifest its ill effects immediately and needs to be taken under long-term analysis in order to comprehend its future effects on the human population. Researchers have found out that the injection of fracturing fluids underground causes seismic activity of low order, known as induced seismic events that has reported in many areas near the fracturing sites.

The huge amounts of fresh water exploited in this process has led to limit this technique to water-abundant regions and has become a global concern as the quality of 'flowback' water released during this process is toxic and is in disposable in the surroundings. The wastewater that comes to the surface can pollute surface water if the pits on which it will be stored are inadequately constructed, leading to the risk of leaking or overflowing. Due to its non-biodegradable nature, this has led the concerned authorities to develop the resources required to check the hydraulic fracturing plays. The geologic fractures formed during this process may lead to fresh water sources through fissures formed in the shale rock, thus providing a path for the fracturing fluids to contaminate the underground water table.

Hydraulic Fracturing Fluids Composition

For the preparation of Hydraulic Fracturing fluid, water is mixed with sand and chemicals are added. The composition may vary from 90-99% water, 1-9% sand and 1-2% chemicals such as acids, salts and organic compounds[4,5]. The composition and number of chemical additives depends on the type of well being fractured, the service company performing the fracturing job and the chemical suppliers[6]. The table below gives an idea about the typical composition of fracturing fluids.

Around 150 different organic compounds are used in hydraulic fracturing like soap, surfactants and fatty acids, but all are not used at a time. In a specific well 4-10 of these organic compounds are used as an ingredients and the most commonly used are glycols, methanol and hydrotreated distillates[5,7]. Figure 1, lists some of the organic compounds that are used in the preparation of hydraulic fracturing fluid. A number of these compounds are unknown due to proprietary formulations protected by property laws making it very difficult to completely evaluate risk assessment.

Table-1
Typical fracturing fluid Composition

Total Fracturing Fluid	Composition	Others i.e. 0.44% Include	
Water	90.60%	Acid	0.11%
Sand	8.96%	Breaker	0.01%
Other	0.44%	Bactericide/Biocide	0.00%
		Clay Stabilizer/Controller	0.05%
		Corrosion Inhibitor	0.00%
		Crosslinker	0.01%
		Friction Reducer	0.08%
		Gelling Agent	0.05%
		Iron Control	0.00%
		Scale Inhibitor	0.04%
		Surfactant	0.08%
		pH adjusting Agent	0.01%

Environmental impacts of Hydraulic fracturing on the broader level includes: Water pollution, Air pollution, soil pollution, health risk, noise pollution.

Water contamination

There are five stages in water cycle of hydraulic fracturing fluid that can contaminate drinking water resources. These include i. Water Acquisition, ii. Chemical Mixing, iii. Well Injection, iv. Flow Back and Produced Water and v. Wastewater treatment and water disposal. It is estimated that, to fracture 35,000 wells each year in United States, 70-140 billion gallons of water is used. The same water could have fulfilled the annual requirement of water of 40-80 cities with a population of 50,000. Coal Bed Methane wells used 50,000 to 35000 gallons of water per well for fracturing treatment while deep shale reservoir required 2 to 10 million gallons of water to fracture individual well. The use of water for Hydraulic Fracturing can divert the water from stream flow, ground water, surface water, can be driven from municipalities, industries like power generation. Such large amount of water withdrawals is an area of concern as it may impact local drinking water availability and quality. Also, the chemical used during the fracturing get injected to groundwater sources, the injection of these chemicals have long term impact, as 20 to 80% of these chemicals remain may remain in formation. Groundwater methane contamination has an adverse effect on drinking water quality and in worst case it may even lead to explosion. When fracturing fluid flow back to the surface, sometimes it contains not only the chemical used for fracturing but also heavy metals, radioactive materials (like uranium, thorium, radium, radon), volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) such as benzene, toluene, ethylbenzene and xylene (BTEX). On site mixing, storage and pumping of fracturing fluid may cause accidental leaks onto the surface may cause release of leaked fluids into the surface water sources or may filtrate into the soil contaminating ground water resources. It may also occur due to equipment failure or improper pit containment which may lead to surface water pollution. There has been a continuous increase in levels of radium, uranium and benzene in rivers and stream due to improper treatment of wastewater before discharging into surface water

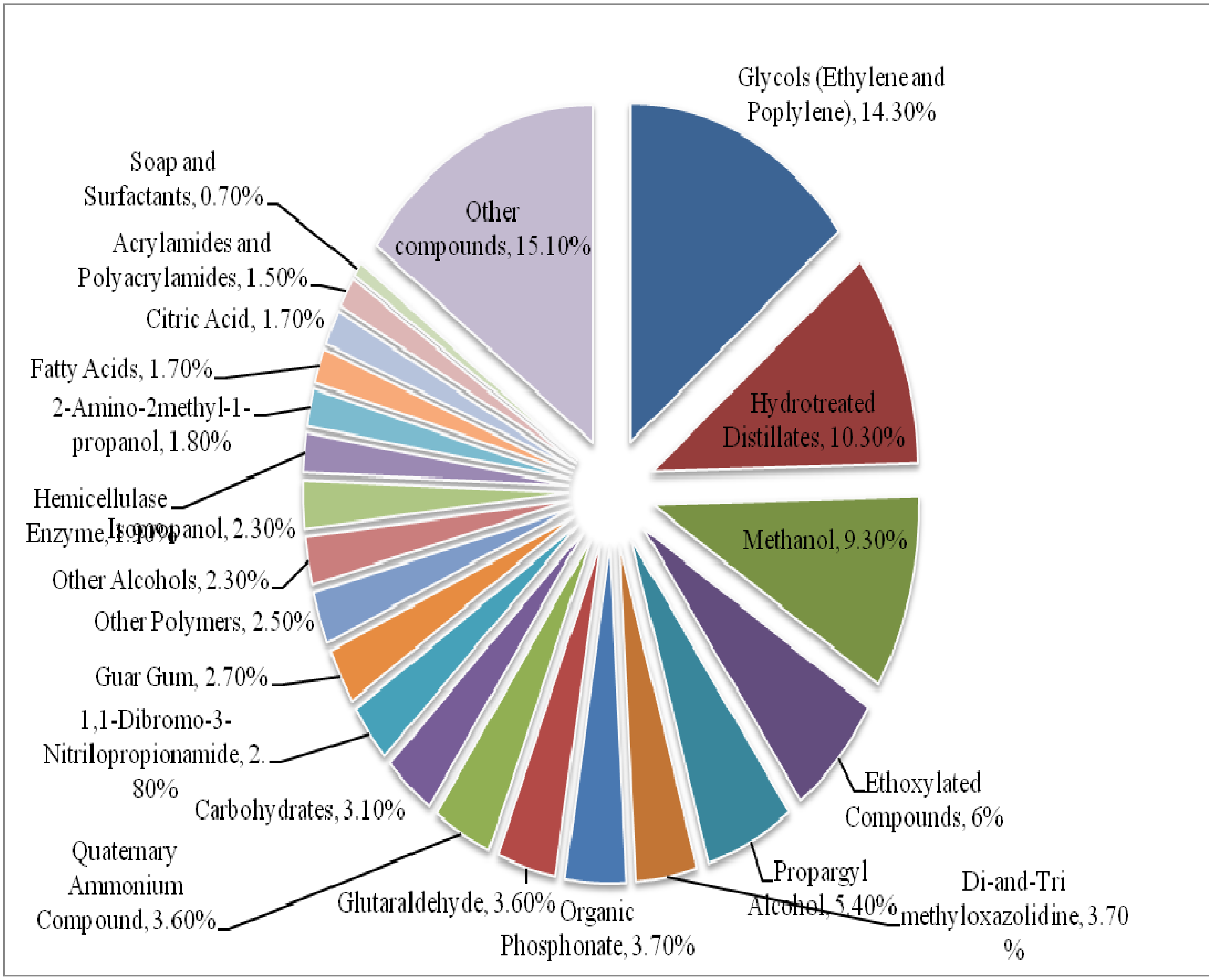

Figure-1
Organic Compounds used in Fracturing Fluid Composition

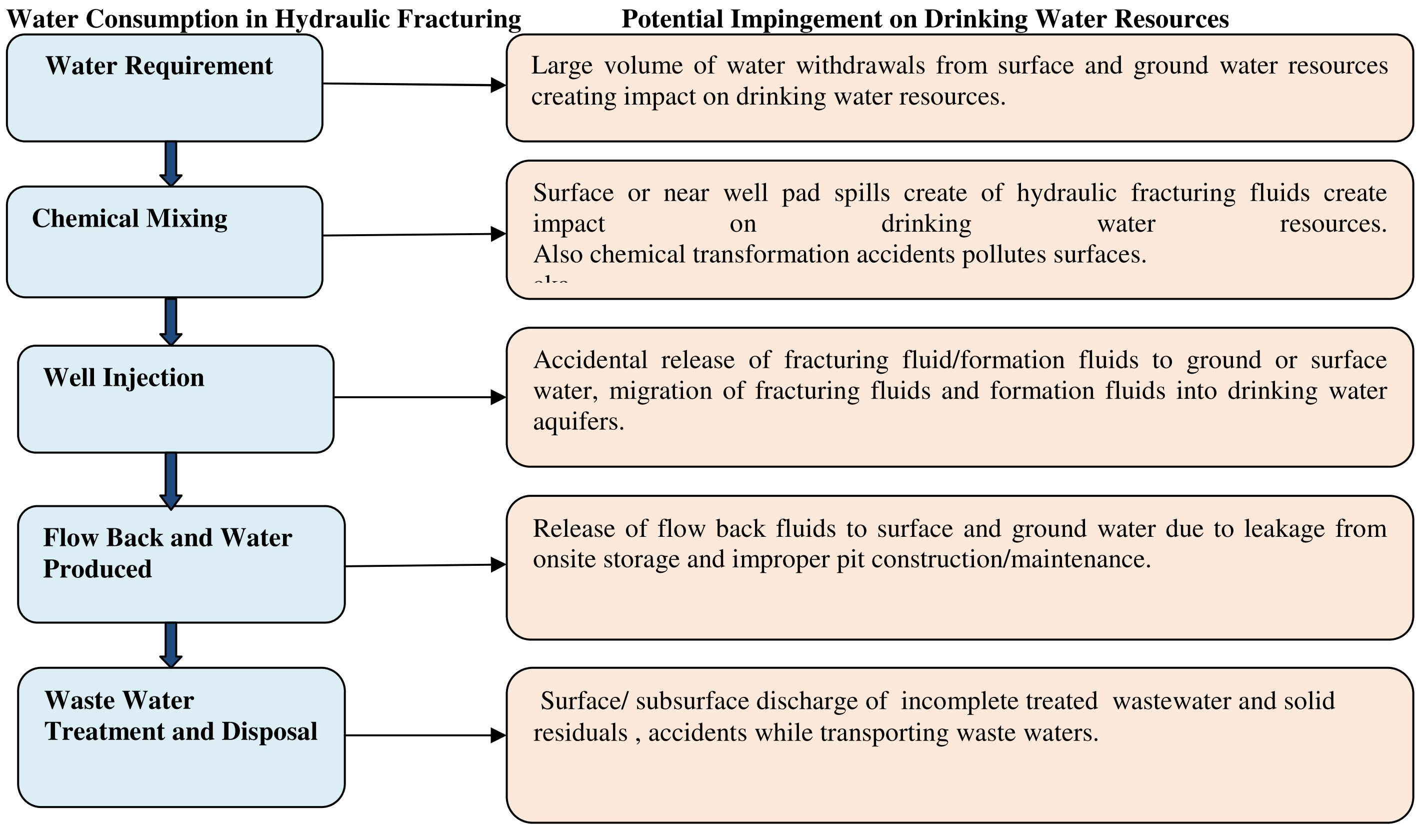

Figure-2
Water Cycle in Hydraulic fracturing Process

Air pollution

Many oil and gas region has degraded air quality. Methane is a major greenhouse effect gas, which has 25 times potent to trap the heat than carbon monoxide. Around 4% of methane produced by the well is escaped to the atmosphere. Shales contain many organic hydrocarbons, these hydrocarbons are brought to the surface in flowback which may enter into impoundment where the waste water off gas its organic compounds into the air which results to air pollution. Emission of volatile organic compound (VOC) like methanol from open pits, tanks, or impoundments which accept flowback waste from wells also leads to air pollution. After fracturing, a mixture of gas and flowback fluid return to surface for several weeks and it is uneconomical to separate them out, so, gas is either vented- released directly into the atmosphere or flared- burned on release. The amount of VOCs and HAPs released in case of flaring is almost one-fourth of venting but releases more nitrogen oxides and carbon-monoxide. Engines which are used to operate pumps and condenser also releases nitrogen oxides, carbon monoxide etc. Trucks which are used to transport water, chemicals and fluids required, are the largest emitters of nitrogen oxides, carbon monoxide and hydrocarbons. Some of the pollutants released during drilling include BTEX i.e. benzene, toluene, xylene and ethyl benzene, particulate matter, dust, ground level ozone, nitrogen oxides, carbon monoxide and metals contained in combustion of diesel fuel.

Health risks

Chemicals which are used for fracking (like methanol) has adverse long and short term health effects. These chemicals could affect the skin, eyes, and other sensory organs, respiratory and gastrointestinal system, brain and nervous system, immune and cardiovascular systems, kidneys and may even cause cancer. Such problem can occur by ingesting chemicals that have spilled and enter water resources, through direct skin contact with chemicals or wastes, by breathing from vapors from flowback wastes stored in pits and tanks. They affect not only to workers of drilling operation, but also to the nearby residents.

Due to complicated water cycle and organic compounds during fracturing and produced water treatment, the ability to identify and quantify chemicals independently is very challenging. Not all the chemicals injected return back to surface; some are adsorbed/desorbed within the formation. Some chemicals has been identified by Environmental Protection Agency on the basis of information publically available on hazards and frequency of use. Tables 2 contains list of chemicals used in hydraulic fracturing fluids.

Table-2
List of Chemicals identified as carcinogens or classified as hazardous air pollutants (HAP) and the number of products formed from each chemical between 2005 and 2009[2]

Chemicals	Category	No. of Products
Methanol	Hazardous Air Pollutant	342
Isopropanol	Hazardous Air Pollutant	274
Crystalline silica	Hazardous Air Pollutant	207
2-Butoxyethanol	Hazardous Air Pollutant	126
Ethylene glycol	Hazardous Air Pollutant	119
Hydrotreated light petroleum distillates	Regulated under Safe Drinking Water Act	89
Sodium hydroxide	Carcinogen, Hazardous Air Pollutant	80
Naphthalene	Carcinogen, Hazardous Air Pollutant	44
Xylene	Regulated under Safe Drinking Water Act, Hazardous Air Pollutant	44
Hydrochloric acid	Hazardous Air Pollutant	42
Toluene	Regulated under Safe Drinking Water Act, Hazardous Air Pollutant	29
Ethylbenzene	Regulated under Safe Drinking Water Act, Hazardous Air Pollutant	28
Diethanolamine	Hazardous Air Pollutant	14
Formaldehyde	Carcinogen, Hazardous Air Pollutant	12
Thiourea	Carcinogen,	9
Benzyl Chloride	Carcinogen, Hazardous Air Pollutant	8
Cumene	Hazardous Air Pollutant	6
Nitrilotriacetic acid	Carcinogen	6
Dimethyl formamide	Hazardous Air Pollutant	5
Phenol	Hazardous Air Pollutant	5
Benzene	Carcinogen, Hazardous Air Pollutant, Regulated under Safe Drinking Water Act	3
Di (2-enthyhexyl) Phthalate	Carcinogen, Hazardous Air Pollutant,Regulated under Safe Drinking Water Act	3
Acrylamide	Carcinogen, Hazardous Air Pollutant, Regulated under Safe Drinking Water Act	2
Hydrofluoric acid	Hazardous Air Pollutant	2
Phthalic anhydride	Hazardous Air Pollutant	2
Acetaldehyde	Carcinogen, Hazardous Air Pollutant	1
Acetophenone	Hazardous Air Pollutant	1
Copper	Regulated under Safe Drinking Water Act	1
Ethylene oxide	Carcinogen, Hazardous Air Pollutant	1
Lead	Carcinogen, Hazardous Air Pollutant, Regulated under Safe Drinking Water Act	1
Propylene oxide	Carcinogen, Hazardous Air Pollutant	1
p-Xylene	Hazardous Air Pollutant	1

Worldwide the hydraulic fracturing jobs are typically performed by a service provider company under a contract with the National Oil or Gas production company. Like in India, hydraulic fracturing jobs are being performed by Schlumberger, Baker Hughes, Halliburton etc., for National Oil Companies like Oil and Natural Gas Corporation (ONGC), Oil India Limited (OIL). Therefore the service companies have complete information regarding the implementation and designing of the hydraulic fracturing job. The Environmental Protection Agency in the United States requested service provider companies for providing information on the standard operating procedures (SOPs) and the composition of hydraulic fracturing fluids used between 2005 to 2010 to measure the impacts of chemicals on human health and the environment, the locations of oil and gas wells. Under the Toxic Substances Control Act (TSCA), most of the data received by the Environmental Protection Agency was under confidential business information (CBI). Five of the nine companies, however, provided non-confidential information. These service companies have hydraulically fractured around 25k wells in United States between 2009 and 2010.

Table-3
Shows the number of formulations, products, and chemicals reported by each of the nine service companies, the total product and chemical constituents[2]

Company	Formulations	Products	Chemical Constituents
BJ Services	37	401	118
Key Energy Services	16	180	119
Halliburton	15	450	304
RPC	13	182	128
Schlumberger	11	110	61
Patterson-UTI Energy	10	67	67
Weatherford International	6	214	180
Complete Production Services	3	122	92
Superior Well Services	3	312	117
Total	114	1,858	1,186 (677 unique chemicals)

The health effect information has identified 353 chemicals with CAS numbers, and created a profile of 12 health effect categories as shown in figure-3. More than 75% of the chemicals affect the skin, eyes, respiratory system and other sensory organs. More than 50% of chemicals show effect on brain and nervous system. Chronic and long term organ affecting health categories comes in the middle portion, which include the nervous system (52%), the cardiovascular system and blood (46%), immune system and kidney (40%). The "other" category includes the effect on teeth, bone, weight and the ability of a chemical to cause death. Ecological effect (40%) can harm aquatic and other wildlife[3].

Indian Energy Scenario

In recent years, shale gas has gained widespread popularity due to the technological advancement that makes it commercially viable. The United States is the most common example where the production has increased from 0.3 trillion cubic feet in 2000 to 9.6 trillion cubic feet in 2012. This increased production has reduced gas prices to about one-fourth of past levels and has even reduced electricity prices to half. India, the world's fourth largest consumer of oil and gas products, imports three-fourth of its requirement.

Since India needs to limit its increasing oil, gas and electricity prices, which are creating adverse effects on its manufacturing sector and the economy as a whole, it should tap its Shale gas and CBM reserves on a war footing. India has much potential of shale and CBM development. Though identification of prospective areas of shale gas and oil has only just begun, initial estimates are encouraging. They show that technically recoverable shale oil resources are 3,800 million barrels while that of shale gas is 96 trillion cubic feet and that of CBM reserves are 3.4 trillion cubic meters[8].

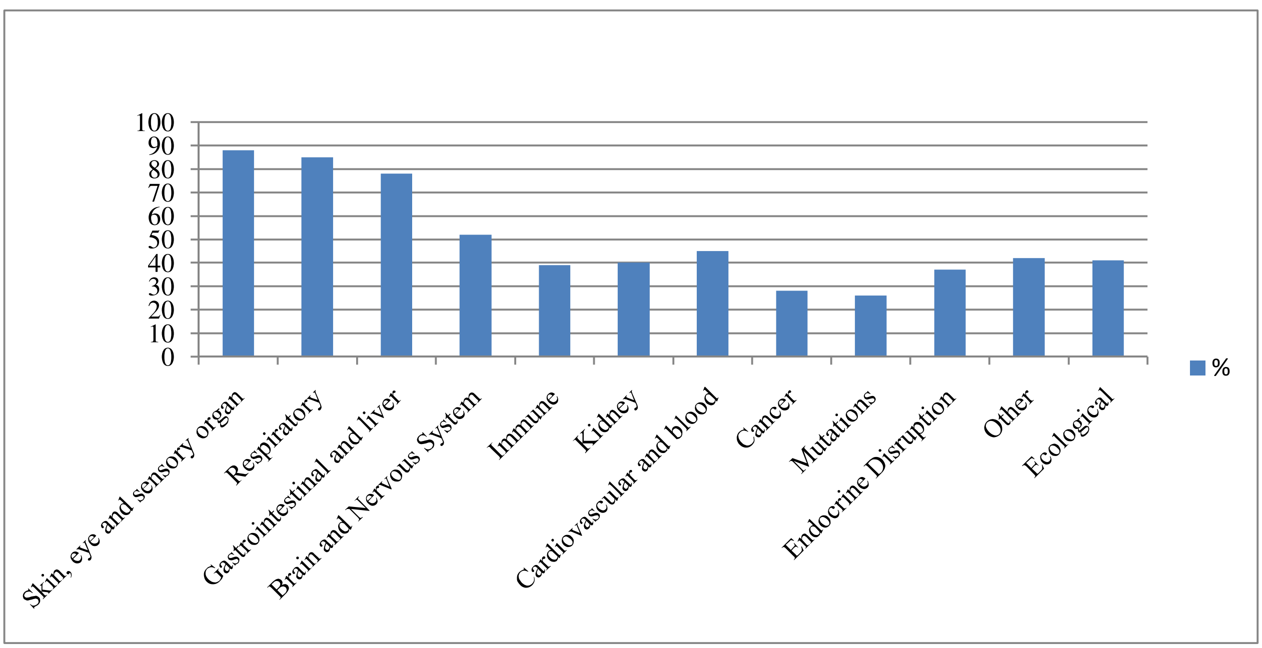

Figure-3
Possible health effect of chemicals used in Oil and Gas Operations [3](Colborn et. al)

This constitutes about two-third of India's current oil reserves and double its natural gas reserves. Though questions are being raised about the environmental consequences of the fracking technology used for producing these CBM and Shale gas, but the natural gas from these sources will bring down the consumption of coal, which is the worst polluter. Moreover, improvements in fracking technology will also reduce its environmental impact in the long run. Large-scale CBM and Shale oil and gas production would cut trade imbalances and the current deficit, and will also reduce our dependence on Middle Eastern oil.

The problem associated with the controversial extraction of shale gas have been flagged by the Ministry of Environment of India recently and cannot be ignored as the process pollutes nearby environments when the poisonous mixture of chemicals and carcinogens seeps into the groundwater. For the country like India, which is notorious for the weak implementation of environmental laws and regulations, fracking can be extremely harmful. Another problem associated with fracking operations in India is heavy use of water and discharge of waste water as India has only 4% of world water resources but 16% of world population. India cannot afford this high level use of water that millions within the country thirst for.

Conclusion

Clearly there are inescapable social and environmental costs which call into question the wisdom of using hydraulic fracturing technology. There has been increase in public awareness in the east, like in the US, EPA is working to identify potential impact of hydraulic fracturing on drinking water resources so that the extraction of natural gas and oil does not come at the expense of the environment and public health. Likewise in India also, the Ministry of Environment should take such steps to provide guidance, laws, and rules for the protection of air, water and land. Although there are many environmental laws in India, but weak enforcement, lack of manpower and funds are the stumbling blocks for controlling pollution[9]. The situation is like, hydraulic fracturing is must for development of oil and gas resources in India, but the failure of Environmental agencies to strictly enforce environmental laws is challenging. There is a need for act like FRAC Act (Fracturing Responsibility and Awareness of Chemicals Act) as proposed by Congress in the US , which make energy industry compulsory to disclose all chemicals which has been protected by trade secrets policy. Fracturing fluids technology should be made advance that does not damage underground water resources and create less pollution at the surface. Improvements in fracking technology over the years will also reduce its environmental impact in the long run.

Private and Public companies should understand their responsibility towards sustainable development i.e. development but not on the cost of environment. Most often these oil and gas development activities are run in remote areas where it is very difficult for regulatory agencies to conduct frequent inspections. Therefore companies should understand it's their liability also to work without leaving environmental footprints. On regulatory agency part, there is a need to improve scientific understanding of hydraulic fracturing and providing regulatory clarity with respect to existing laws to enhance health and environment safeguards. There is a need to amend old laws as per the scientific understanding of hydraulic fracturing, as the technology is not the same as it was in 60's.

Nomenclature: EPA: Environmental Protecting Agency, HAP: Hazardous Air Pollutants, VOC: Volatile Organic Compounds, SDWA: Safe Drinking Water Act

References

1. Carter K.E., Hydraulic *Fracturing and Organic Compounds-Uses, Disposal and Challenges*, **SPE 165692 (2013)**
2. United States Enviornmental Protection Agency Progress Report on Study of Potential Impacts of Hydraulic fracturing on drinking water resources, **(2012)**
3. Colborn Theo, Kwaitkowski Carol, Schultz Kim and Bachran Mary, *Natural Gas Operation from a public health perspective*, *Human and Ecological Risk Assessment: International Journal,* **17(5),** 1039-1056, **(2011)**
4. Lee, D.S., J.D. Herman, et al, A critical evaluation of unconventional gas recovery from the Marcellus Shale, Northeastern United States, *KSCE Journal of Civil Engineering,* **15(4),** 679-686 **(2011)**
5. Spellman T. and J.E. Valle, et al, Environmental Impacts of Hydraulic Fracturing. London GBR, *Engineering,* **(2012)**
6. Rahim Z. and S.A. Holditch, Effect of fracture fluid degradation on underground fracture dimentions and production increase, *Journal of Petroleum Science and Policy,* **17,** 12-23**, (2003)**
7. Jenner S. and Lamadrid A.J., Shale gas vs.coal: Policy implications from environmental impact comparisions of shale gas, and coal on air, water and land in the United States, *Energy Policy,* **53,** 442-453 **(2013)**
8. Directorate General of Hydrocarbon report Hydrocarbon Exploration and Production Activities India, **(2013)**
9. Saheb S.U., Seshaiah S. and Viswanath B., Environment and their legal issues in India, *International Research Journal of Environment Sciences,* **1(3), 44-51, (2012)**