Petroleum Hydrocarbon Contamination Of Groundwater In Suez: Causes Severe Fire Risk

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Abstract. One of the major contributing causes to the fire that killed 8 persons in August 2000 at the Suez Petroleum region was the petroleum hydrocarbon releases to the subsurface groundwater at the SUEZ Geographical Region. The Suez petroleum geographic region is shared by several oil companies. Several of these companies have been in operation of oil refining, processing and petroleum products distribution activities for more than seventy years. The combined effects of petroleum related activities and war strikes have resulted in tremendous impacts on the safety and environmental conditions at the region. Hydrocarbon leaks and spills have resulted in serious contamination to shallow groundwater and became the major fire safety hazard in addition to posing serious environmental risk. Due to financial reasons and urge of immediate correction action, the conducted investigation focused on fire potential in order to minimize the risk.

To properly characterize and evaluate the impacted soils, an intensive site characterization was performed. Sixty-three (63) soil borings were drilled in different locations around the region. Soil samples were collected from different depths and then analyzed for total petroleum hydrocarbon (TPH) to determine its content in the soil. In order to assess the quantities and locations of free hydrocarbon product floating on top of the groundwater surface, fifty three (53) soil boring were converted to monitoring wells. Based on the detected levels of free product inside the installed monitoring wells network, the groundwater hydrocarbon plume varies in thickness from 6" to over 40". Free product samples were collected from selected monitoring wells. The samples were sent to SPL Labs in Houston to perform PIANO analysis (Paraffins, Isoparaffins, Aromatics, Napthenes, and Olefins) and give a complete breakdown of all the chemical components which comprise the hydrocarbons. Chemical analysis of the free product collected from the subsurface that several sources of petroleum hydrocarbon releases are responsible for the free product plume. Mazot, solar (diesel) and gasoline (benzene) range petroleum hydrocarbons all exist in the subsurface. Three different groundwater plumes have been identified.

Existing conditions at the site guarantee that upon an ignition source is present, the soils and free product on top of groundwater can and will maintain the fire to the furthest extent. Such conditions will be extremely dangerous and difficult for fire fighting teams. This paper presents the taken steps for investigating petroleum hydrocarbon contamination to minimize the fire risks. The presented procedures will assist scientists and professionals in the field when investigating similar conditions.

1.0 Introduction

The Suez Geographic region is shared by several oil companies namely: Exxon Mobil (Mobil and Esso), Caltex, PetroGas, CO-OP Petroleum, Misr Petroleum, Pipelines Petroleum Company (PPC), Petrojet, Sumid, Gasco, PetroMaint, Nasr Petroleum Company (NPC), Suez Oil Processing Company (SOPC), CityGas and Gastic. Few of these companies have been in operation for more than 80 years. Spills, leaks and sloppy operations have resulted in

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serious hydrocarbon contamination of the soils and shallow groundwater in the region. The center of the region has become very sensitive because of the shallow groundwater condition.

This area is underlain at a shallow depth by an extensive free product plume floating on the ground water table and oil soaked soils. Not necessarily the ignition source for the last fire incident at PetroGas, however, petroleum soaked soils have strongly maintained the occurred fire at the site which left a number of casualties and complete destruction of critical production unit. The complete abolishment of the hydrocarbon soaked yard next to the administration building at the time of fire is a clear evident of the last statement. In this area, clean-up activities need to be implemented as soon as possible to reduce the fire hazard danger. Prior to cleanup, a professional investigation and assessment for groundwater conditions needed to be performed.

2.0 Scope Of Work

This investigation involved the installation of numerous soil borings and monitoring wells throughout the Suez geographic region. Under supervision of Dr. James Warner of Colorado State University and during the progress of the investigation as data were collected, it became readily apparent that the most urgent area of concern for fire hazard danger was the central part of the region occupied by PetroGas, CalTex, CO-OP and Mobil companies. It should be emphasized that this area is not the only area of fire hazard concern at the Suez Geographical Area. Numerous petroleum releases have occurred throughout the Suez Geographical Area resulting in oil soaked soils and free product on the ground water table. However, conditions are most critical due to the very shallow ground water table at the PetroGas, CalTex, CO-OP and Mobil area. This area is underlain at a shallow depth by an extensive free product plume floating on the ground water table and oil soaked soils. In this area clean-up activities need to be implemented as soon as possible to reduce the fire hazard danger. In the process, the following was conducted:

- Reviewed available general layout maps of petroleum firms at the region.
- Drilled 63 boreholes to describe the soil condition at the region.
- Collection and identification of available topographic maps that best describes the topography of the region.
- Collected 180 soil samples to describe the vertical condition of the soil.
- Analyzed 180 soil samples for TPH to determine the hdyrocarbon content and accordingly identify the volume and location of high fire risk soils.

- Completed 52 of soil borings into monitoring wells to monitor the subsurface free product plume.
- Used advanced electronic probes to detect free product in monitoring wells.
- Analyzed free product samples for PIANO analysis to identify the composition of hydrocarbon plumes and their approximate age
- Using extensive experience, determined the extent of subsurface free product plume
- Using extensive experience, identified the most potential sources
- Identified the types of different subsurface plumes in the region
- Proposed the most appropriate remediation system for the existing conditions

3.0 Groundwater Investigation

In order to assess the quantities and locations of free hydrocarbon product floating on top of the groundwater surface, fifty three (53) soil borings were converted to monitoring wells. The well construction details for each monitoring well are presented in the following sections. Using advanced electronic oil/water probes, the top level of free product surface and that of groundwater were detected. Accordingly, the thickness of free product was determined in each monitoring well.

Figure 1 shows the locations of the constructed monitoring wells. Red color indicates monitoring wells where free product (oil) thickness was detected. Blue color indicates monitoring wells where NO free product was detected.

Table 1 lists the oil thickness floating on top of ground water table in each monitoring well. The depth to free product from the ground surface is also listed for each well.

Based on the detected levels of free product inside the installed monitoring wells network, Figure 4 shows the layout of hydrocarbon free product floating on top of the shallow groundwater underneath the ground surface. The plume varies in thickness from 6" to over 40". Huge layers of free product exist underneath the ground surface at the Suez Geographic region. Free product layers exist on top of the shallow groundwater surface. Free product layers reach over four (i.e. about 1.2 meter) feet in thickness in some locations and are present as shallow as few inches from the ground surface. These layers are mobile and move from one location to the next depending on the groundwater gradient and seasonal changes. Thus, it is not uncommon that free product which is detected in one facility could have resulted from another outside source. Because the companies are closely adjacent to each other at the Suez geographic region, interaction and extension of free product layers from one company to the next is highly encountered.

Table 1. Free Product Thickness and Depth

Monitoring Well ID	Oil Depth	Oil Thickness
MW 01	ND	ND
MW 02	ND	ND
MW 03	0' 09"	0' 06"
MW 04	2' 03"	2' 11"
MW 05	1' 09"	3' 03"
MW 06	3' 02"	3' 06"
MW 08	1' 11"	3' 01"
MW 09	1' 02"	2' 02"
MW 10	2' 09"	2' 06"
MW 12	2' 03"	2' 02"
MW 15	1' 07"	0' 03.5"
MW 16	0' 08"	2' 0"
MW 17	1' 11"	0' 11"
MW 20	5' 0"	0' 01"
MW 23	4' 04"	0' 08"
MW 24	2' 04"	1' 02"
MW 25	1' 07"	6' 06"
MW 26	1' 01"	4' 04"
MW 27	1' 02"	2' 01"
MW 28	ND	ND
MW 29	ND	ND
MW 30	0' 09"	2' 11"
MW 31	ND	ND
MW 32	0' 11"	4' 02"
MW 33	3' 0"	1' 11"
MW 34	2' 03"	1' 00"
MW 35	ND	ND
MW 36	ND	ND
MW 37	ND	ND
MW 38	1' 09"	0' 01"
MW 39	ND	ND
MW 40	ND	ND
MW 41	ND	ND
MW 42	ND	ND
MW 43	ND	ND
MW 44	ND	ND
MW 45	3' 00"	1' 00"
MW 47	ND	ND
MW 50	1' 07"	3' 08"
MW 53	ND	ND
MW 54	2' 09"	1' 06"
MW 55	1' 10"	4' 07"
MW 56	1' 07"	4' 05"
MW 57	4' 05"	0' 05"
MW 58	2' 08"	3' 06"
MW 59	ND	ND
MW 60	ND	ND
MW 61	1' 06"	3' 08"
MW 62	4' 03"	0' 08"
MW 63	ND	ND

ND: Non Detect

Occurrence of free product is not evident by surface stained soils. In numerous cases during investigation, free product was detected in monitoring wells which were drilled in apparent clean soil. Thus, the appearance of location is not indicative of free product existence. Addition of clean soil layers to the previously contaminated sites and off site migration of free product contribute to the complexity of the problem.

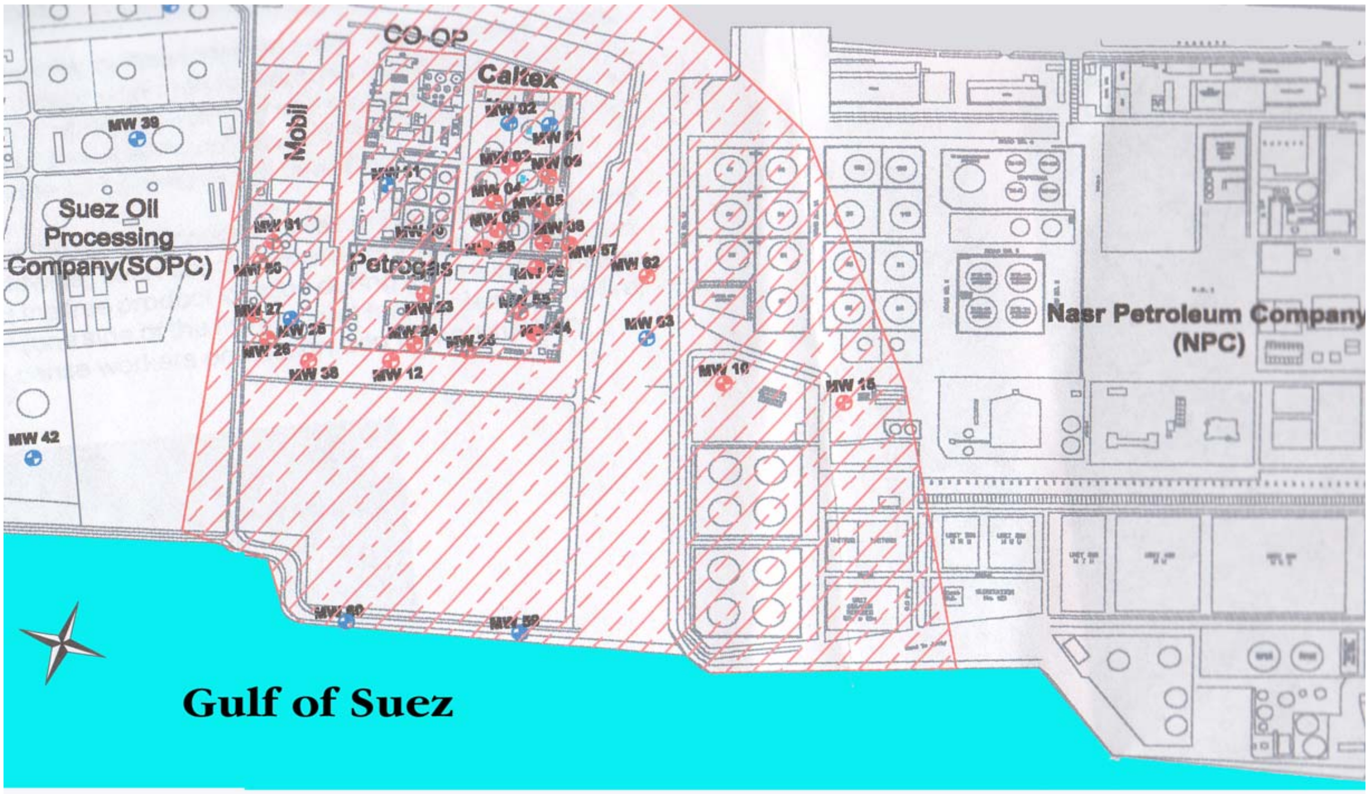

Figure 1 : Area of Primary Fire Hazard Concern with Free Product

Existence of free product layers under the current conditions resemble a very likely time bomb for the next fire incident. Worldwide, such conditions are very hard to face when fires occurs. Fire fighters can't predict the free product location during the fire incident and thus find it very hard to isolate the fuel (one side of the fire triangle) for maintaining the fire. Condensed capital installations and dense workers population add to the situation.

4.0 Plumes And Source Identification

Free product samples were collected from selected monitoring wells. The samples were sent to SPL Labs in Houston. The chemical analysis performed is referred to as PIANO analysis (Paraffin, Isoparaffin, Aromatic, Naphtene,

TABLE 2
PIANO ANALYSIS

Compound	Sample ID MW – 3(Caltex)	Sample ID MW – 10 (Nasr)	Sample ID MW – 24 (PetroGas)	Sample ID MW – 27 (Mobil)	Sample ID MW – 30 (CO –OP)	Sample ID MW – 49 (Mobil)
Paraffin , wt % {tc "Paraffin , wt % " \l 4}	32.263	89.020	64.698	56.729	57.888	64.359
Isoparaffin , wt %	18.274	1.113	9.529	9.382	11.033	8.044
Naphthenics , wt %	11.451	0.195	3.468	5.496	4.560	7.305
Aromatics , wt %	27.136	3.933	14.680	17.639	17.541	10.676
Olefins , wt %	0.931	0.036	0.258	0.589	0.313	0.609
Unknowns , wt %	9.940	4.626	7.158	10.164	8.665	9.007
2,2,4 – Trimethylpentane , wt %	ND	ND	ND	0.033	ND	ND
Research Octane	88.44	90.00	89.46	89.30	88.88	89.56
Lead	N / A	N / A	N / A	N / A	N / A	N / A
MTBE	N / A	N / A	N / A	N / A	N / A	N / A
N – Hexane , wt %	ND	ND	ND	ND	ND	ND
Benzene , wt %	ND	ND	ND	ND	ND	0.024
Ethyl Benzene , wt %	0.096	ND	0.015	0.128	0.092	0.123
Toluene , wt %	0.017	ND	ND	0.039	0.018	ND
Meta –Xylene , wt %	0.132	ND	0.150	0.179	0.052	0.116
Para – Xylene , wt % {tc "Para – Xylene , wt % " \l 5}	0.418	ND	ND	ND	ND	0.439
Ortho – Xylene wt %	0.096	ND	0.151	0.038	0.012	0.040
Total Xylenes , wt %	0.646	ND	0.281	0.217	0.064	0.595
EDB	N / A	N / A	N / A	N / A	N / A	N / A
EDC	N / A	N / A	N / A	N / A	N / A	N / A
Ethanol	N / A	N / A	N / A	N / A	N / A	N / A
Specific Gravity @ 60 F.	0.08699	0.8693	0.8479	0.8935	0.8969	0.8849
API Gravity @ 60 F.	31.15	31.28	35.38	30.48	26.26	28.40
Color	Very Dark Crude	Very Dark Crude	Very Dark Crude	Very Dark Crude	Very Dark Crude	Very Dark Crude
Odor	Gasoline	Crude	Crude	Crude	Crude	Crude
Carbon Range	C6 – C20+	C6 – C2+6	C7 – C25+	C5 – C25+	C6 – C25+	C6 – C25+
Major Range	C9 – C11	C14 – C10	C10 – C15	C10 – C16	C10 – C19	C11 – C16
Naphthalene , wt %	0.227	0.216	0.383	0.398	0.377	0.204
2 – Methyl Naphthalene , wt %	0.649	0.289	0.411	0.534	0.344	0.429
1 – Methyl Naphthalene , wt %	1.590	0.666	1.105	1.798	1.573	2.130

and Olefin) and gives a complete breakdown of all the chemical components which comprise the hydrocarbons. The analysis assisted in identifying samples belong to same hydrocarbon plume. The analysis also referred (in a broad fashion) to the approximate age of the hydrocarbon sample. Accordingly, the number of existing plumes and their locations were identified. A summary of the PIANO analysis is presented in **Table 2.**

The analytical results from PIANO analysis (Table 2) suggests the existence of three main hydrocarbon plumes floating on top of the ground water table beneath the ground surface in the geographic region. These plumes can be described as follows:

- Plume I

Plume I is mainly composed of heavy range crude oil (C6-C25) and exists extends at the western part of NPC. The plume is characterized to have low napthenics, low aromatics and olefins. The hydrocarbon is more towards heavy crude range C6 to C25 with strong normal paraffins.

The hydrocarbon characterization of the plume suggests that the plume has NOT resulted from old spills and practices, instead it is recently new source. This suits the likely hood of recent (within the last few years) tank spill and pipeline oil leak in the western side of NPC.

- Plume II

Plume II extends south of Caltex to Petrogas. The plume is characterized to have gasoline odor mixed with heavy oil. This suggest that plume II overlaps with plume III in some locations. The plume is in the gasoline range with lighter carbon range.

The hydrocarbon characterization of the plume suggests that a recent leak from gasoline source is present in the area. This suits an identified source of broken underground pipeline that runs across the street from NPC to Caltex. Drilling of monitoring wells MW63 south (downstream) of the pipeline (facing PetroGas gate), and MW62 north (upstream) of the pipeline (facing Caltex gate) confirmed that free product was detected in MW63 and non at MW62.

- Plume III

Plume III extends in the western part of the distribution companies, through Caltex, Mobil, CO-OP and part of PetroGas. The plume is characterized to have medium aromatics, lownapthenics and little olefins. The hydrocarbon characterization of the plume suggests that a considerable amount of the plume is old aged hydrocarbons. This suits the likely hood of old spills/leaks resulted from poor past practices and war eras. In addition, the filling operations of rail road trucks are very poorly managed. Evidence of Mazot spill is apparent everywhere. A big contribution of this source to the plume is expected. Unacceptable practices such as trucks changing lube oil and dumping in the street are also taking place in the region.

Very broadly, the hydrocarbon components of petroleum compounds may be categorized as either saturated hydrocarbons (Alkanes) and unsaturated hydrocarbons (Alkenes)or alternatively categorized as Aromatic and non-Aromatic (Aliphatic) hydrocarbons. Paraffins are the straight-chain Alkanes, Isoparaffins are the branch-chain Alkanes and the Naphthenes are the saturated hydrocarbons that are arranged in one or more rings (Cycloalkanes or Cycloparaffins). Paraffins and Isoparaffins follow the general chemical formula C(n)H(2n+2) while Naphthenes follow the general chemical formula C(n)H(2n). Paraffins, Isoparaffins and Naphthenes are Aliphatic (non-aromatic) hydrocarbons. The PIANO analysis (Table 3) indicates that the hydrocarbons in the plumes are:

- Plume I: predominately Paraffins (Total Paraffins = 89% = Paraffins + Isoparaffins + Naphthenes).

- Plume II: low Paraffins (Total Paraffins = 32.63% = Paraffins + Isoparaffins + Naphthenes).

- Plume III: low Paraffins (Total Paraffins = 60% (average) = Paraffins + Isoparaffins + Naphthenes).

Paraffin hydrocarbons are not very soluble in water and will biodegrade rapidly under the proper environmental conditions.

Olefins are the Aliphatic (non-aromatic) Alkenes (unsaturated hydrocarbons). The Olefins are mono-unsaturated (single double bond between carbon atoms) and follow the general chemical formula C(n)H(2n). Olefins are usually formed by thermal and catalytic cracking and rarely occur naturally in unprocessed crude oil. The PIANO analysis (Table 3) found essentially zero Olefins in the hydrocarbons from the three plumes which is characteristic of a big portion of unprocessed crude oil mixed in the plume.

The Aromatic compounds are cyclic (ring-type) unsaturated hydrocarbons containing one or more Benzene rings. In general Aromatic hydrocarbons are more soluble in water, more toxic and are more resistant to biodegradation than the corresponding Paraffins, Isoparaffins, Naphthenes and Olefins. The PIANO analysis (Table 3) had a total Aromatic hydrocarbon concentration of:

- Plume I: 4%

- Plume II: over 35% (counting unknowns as Aromatics based on boiling point)
- Plume III: 17% average

The Polycyclic Aromatic Hydrocarbons (PAHs) contain multiple benzene rings. PAHs are known potent human carcinogens and are not easily biodegraded. The PAHs include Naphthalene (C10H10), Anthracene (C14H10), Phenanthrene (C14H10) and Pyrene (C16H10). Of these PAH compounds, Naphthalene was found in the hydrocarbons from the waste ponds. These include Naphthalene (0.3% by weight), 1-methylnaphthalene (1.5%) and 2-methylnaphthalene (0.6%). Naphthalene compounds contain a double Benzene ring and are not to be confused with Naphthenes (Cycloparaffins). Naphthalene is a potent carcinogen versus the relatively less toxic Naphthenes. These Naphthalene compounds represent a potential health hazard.

5.0 Recommendations

Existing conditions at the site guarantee that upon an ignition source is present, the soils and free product on top of groundwater can and will maintain the fire to the furthest extent. Such conditions will be extremely dangerous and difficult for fire fighting teams. Surrounding residential areas add to the sensitivity of the situation. Capital costs of condensed installations of two refineries in addition to several major oil distribution companies make the financial liability in question. Fire hazards have to be eliminated from Suez Geographic region before another fire accident take place.

The standard recommended steps for such conditions are handled as follows:

Determine cleanup standards based on acceptable TPH concentration for the soil that does not pose fire hazard. This will set target levels for clean up technique.

Conduct remediation activities as soon as possible to eliminate the fire hazards explained in details in this report. This will include:

- Top soil treatment; and
- Groundwater treatment.
- Stop any contributing hydrocarbon source.