EXPERIMENTAL APPLICATION OF CENTRIFUGAL SEPARATION TECHNIQUES “CST” ON RECLAIMING PRODUCED WASTEWATER FROM OIL REFINERY IN KHARTOUM STATE, SUDAN

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ABSTRACT

Purpose: The great amount of daily discharge wastewater from the oil refinery in Khartoum needs proper management as it contains high concentrations of oil that limits its use for any irrigation practices or human use.

Objective: The objective of this work is to implement and assess the application of the Centrifugal Separation Technique (CST) in separating oil from refinery wastewater.

Methodology: Wastewater samples were collected from the evaporation treatment ponds in different months and analysed for oil content and quality assessment. The wastewater samples (300l) were pumped into the CST system through a centrifugal filter for 12 hours. The separated samples were then collected in an outlet container and further analysed for total aromatic hydrocarbons (TRPHC) and total aliphatic petroleum hydrocarbons (TAPHC) concentrations.

Results: Analysis of the wastewater revealed a high concentration of oil that ranged between 1.70mg/l to 95.7mg/l. Other parameters, e.g. turbidity, pH, Ec, ammonia, sulphides and phenols, also showed high values.

Results also revealed that the concentrations of TRPHC, TAPHC and turbidity were reduced significantly after the CST method application.

Value: The CST method is recommended to be applied to remove the oil from wastewater for further uses.

Keywords: Oil removal; Wastewater management; CST

INTRODUCTION

The refinery is 2.5km east of the railway lines, and is 12.5km away from the River Nile. It is also located in an area that had been classified as an arid area at an altitude of 16o 09’ 17” N and longitude 32o 32’ 42” E. The annual amounts of rain range between 0.0-200mm: average rainfall is 127.5mm. Maximal rainfall of the day is 147.5mm. Maximum and minimum temperatures range from 33-22oC with annual average temperature 29oC. The normal wind direction is North, with an average speed of 3.9m/s. The water table is 30m (Faris, 2002). The natural flora of the area as has been described by Harrison and Jackson (1958) as desert scrub and sparse vegetation, characteristic of the semi-desert zone of the Sudan. The most common tree species of the area is mostly acacias.

The geomorphology of the area is generally flat with some isolated outcrop, and slopes gently towards the south-west. The drainage pattern of this area is characterised by dendrite upstream, and changes into straight wide shallow valleys through which the whole area is drained. The area between these valleys from the local water shed with different heights ranging between 0.5-2.0m.

The refinery area is part of the Sabaloga inliers, which are composed of a Precambrian-mesocene basement complexes unconformable, overlain by late cretaceous-quaternary sedimentary cover. The main rock type exposing the area is gneiss found in two different forms (Ossman et al., 2013).

The refinery consists of several production units and produces a mosaic of petroleum products of about 2.2587 metric tonnes; in addition to a substantial amount of water as a major waste by product, these products range from gasoline to liquefied gas. The amount of waste is estimated to about 20 million m3/annum. The idea was to get rid of the wastewater by an open pond evaporation system after preliminary pre-treatment. The refinery was designed with three evaporation ponds to treat the discharged wastewater. Each pond is 650m in length, 420m in width, and 2.2m in depth. The ponds were sealed downward with plastic sheets to ensure seepage prevention. The total evaporation area was estimated at 800,000m3, with a daily estimated evaporation loss of about 6800m3/day; however, the daily excess water was estimated at 4,200 m3 (KRC, 2005).

The great amount of the daily discharge wastewater from the refinery needs proper management and recycling. This is because the discharge water contains a high concentration of oil (Table 1) that limits its use for any irrigation practices or human use.

The refinery wastewater has been used to irrigate the trees and some fruit plantations around the refinery area; this adversely affected the soil quality (Saad et al., 2016). The problem of oil content still needs proper management to remove the oil and improve the water quality.

Therefore, the objective of this work is to implement the Centrifugal Separation Technique (CST) to reduce the oil concentration in the wastewater to suit quality measures for irrigation purposes.

MATERIALS AND METHODS

Reference samples

Samples from the evaporation ponds after final treatment were collected from a depth of 30cm and analysed for irrigation water quality assessment.

CST Treatment samples

Wastewater samples were collected from the evaporation ponds (P1, P2, P3) in the refinery in June, August and November and analysed for oil concentration.

The Centrifugal Separation Technique (CST), as described by Feedwater Ltd, UK:

The CST technique has the following specifications as produced by the manufacturer:

- The removal of specific unwanted solids from a pumped/pressurised fluid flow system shall be accomplished with a centrifugal-action vortex separator. Solids removal efficiency is principally predicated on the difference in specific gravity between the liquid and the solids. Fluid viscosity must be 100SSU or less. In a single pass through the separator, given solids with a specific gravity of 2.6 and water at 1.0, performance is predictably 98% of 74 microns and larger.
- Additionally, particles finer in size, heavier by specific gravity and some lighter by specific gravity will also be removed, resulting in an appreciable aggregate removal of particles (up to 75%) as fine as 5 microns.
- In a recirculating system, 98% performance is predictable to as fine as 40 microns (given solids with a specific gravity of 2.6), with correspondingly higher aggregate performance percentages (up to 90%) of solids as fine as 5 microns.

Performance Requirement

Separator performance must be supported by published independent test results from a recognised and identified test agency. Standard test protocol of upstream injection, downstream capture and separator purge recovery is allowed with 50-200 mesh particles to enable effective, repeatable results.

Single-Pass Test Performance

Must not be less than 95% removal. Model tested must be of the same flow-design series as specified unit.

Separator Design and Function

A tangential inlet and mutually tangential internal accelerating slots shall be employed to promote the proper velocity necessary for the removal of the separable solids. The internal accelerating slots shall be spiral-cut (Swirlex) for optimum flow transfer, laminar action and particle influence into the separation barrel.

The separator's internal vortex shall allow this process to occur without wear to the accelerating slots.

Separated Particle Matter

The separated particle matter will spiral downward along the perimeter of the inner separation barrel, in a manner that does not promote wear of the separation barrel, and into the solids collection chamber, located below the vortex deflector stool.

To ensure maximum particle removal characteristics, the separator should incorporate a vortex-induced pressure relief line (vortube), drawing specific pressure and fluid from the separator's solids collection chamber via the outlet flow's vortex/venturi effect. This will thereby efficiently encourage solids into the collection chamber without requiring a continuous underflow or excessive system fluid loss.

System fluid will exit the separator by following the centre vortex in the separation barrel and spiral upward to the separator outlet.

- Purging (as a specified option)

Evacuation of Separated Solids

The evacuation of separated solids will be accomplished automatically, employing a dedicated solid-state controller in a NEMA 4 housing, available for worldwide single-phase voltages of 24VAC to 250VAC. Programming options to include a purge frequency range of every 60 seconds to every 23 hours, 59 minutes.

- Purge duration: options range from 2 seconds to 59 minutes, 59 seconds. Non-volatile memory;
- Meets CSA requirements: this controller shall automatically operate one of the following techniques:
- Motorised Ball Valve - A full-port, electrically-actuated valve shall be programmed at appropriate intervals and duration in order to efficiently and regularly purge solids from the separator’s collection chamber. Valve body shall be bronze (optional stainless steel also available). Valve ball shall be stainless steel with Teflon seat.

Valve size

- Pneumatic Pinch Valve: Compressed air shall be provided to actuate this full-port valve at appropriate intervals and duration in order to efficiently and regularly purge solids from the separator's collection chamber. System shall include a pressure regulator for proper modulation of air pressure. Valve liner is natural gum rubber (other liner materials available);
- Pneumatic Ball Valve: A fail-safe valve will be programmed at appropriate intervals and duration in order to efficiently and regularly purge solids from the separator’s collection chamber. A spring-control will ensure that this full port valve closes in the event that compressed air or electricity is interrupted;

- The valve body will be bronze (optional stainless steel also available). The valve ball will be stainless steel with Teflon seat;
- Purge Liquid Concentrator: A dual pneumatic pinch valve package will be employed in order to effectively minimise the fluid loss when purging. The controller will provide proper sequential valve actuation at appropriate intervals and duration in order to efficiently and regularly evacuate solids from the separator's collection chamber. Liners for the pinch valves will be natural gum rubber (optional, at extra cost: neoprene, butyl, Buna-N and hypalon may also be specified). The system will also include a pressure regulator to modulate air pressure to the valves, a full-size sightglass for inspection of solids accumulation during operation, and a manual isolation valve for servicing requirements.

Solids Handling (as a specified option)

- An appropriate solids collection device will be provided with the separator; this will be suitable for capturing solids and returning all excess purged liquid to system use. The size and type of collection device will be determined according to the application requirements, selected from the following options (or custom, as specified):
- Solids Collection Drum: In conjunction with the appropriate automatic purge valve, this package will be employed to capture and concentrate separated solids (up to 90% solids by volume) from the separator directly into a standard 55-gallon drum, returning excess purged liquid to system use via an integral decant line on the drum shroud. Solids collection capacity: 12,700 cubic inches (200 litres). The package includes two shrouds, two shroud clamps, two drum carts for transporting the drums and a manual liquid evacuation pump.
- Recommended option: A purge diffuser will be installed on the discharge of the automatic purge valve in order to reduce the velocity of the purge flow and enhance the settling of solids within the drum.
- Solids Collection Hopper: In conjunction with the appropriate automatic purge valve, a one cubic yard (764 litre) hopper will be employed to capture and concentrate separated solids (up to 90% by volume) from the separator, returning excess purged liquid to system use via an integral decant line installed directly on the hopper. The hopper will feature a manually-actuated tilting mechanism for dumping accumulated solids as necessary.
- Recommended option: A purge diffuser will be installed on the discharge of the automatic purge valve in order to reduce the velocity of the purge flow and enhance the settling of solids within the hopper.
- Systemisation (as a specified option): The separator and its accessories will be

packaged as a complete system, with all componentry from a single source. In addition to the equipment already specified, the system will also include an appropriate support frame for positioning the separator accurately and effectively for solids purging/handling. If the specified purging technique is a pneumatic pinch valve, a spare pinch valve liner will also be included.

Separator Details

1. inlet and outlet will be grooved couplings;
2. purge outlet will be threaded with screw-on flange;
3. the separator will operate within a flow;
4. pressure loss will be between 3-12 psi (0.2 - 0.8 bar), remaining constant, varying only when the flow rate changes;
5. pressure gauges with petcock valves for both the inlet and outlet of the separator will be included, and an isolation valve at the purge outlet for servicing of the automatic valve as necessary without interrupting system flow.

Separator Construction

- The separator will feature the following access capabilities for either inspection or the removal of unusual solids/debris:
    1. an upper-chamber full-size grooved coupling, allowing complete access to the inlet chamber, acceleration slots and internal separation barrel;
    2. a hand-hole port at the collection chamber, with Neoprene gasket (low flow rate models to feature full-size coupling at collection chamber);
    3. an inspection port, located at the lowest point of the upper chamber.
    4. The separator will be of unishell construction with A-36, A-53B or equivalent quality carbon steel (with a minimum thickness of 0.25 inches/6mm). Maximum operating pressure will be 150 psi (10.3 bar), unless specified otherwise.
    5. paint coating will be acrylic urethane, spray-on, royal blue.
    6. as a specified option only: the separator will be constructed in accordance with the standards of the American Society of Mechanical Engineers (ASME), Section VIII, Division 1 for pressure vessels. Certification will be confirmed with the registered "U-stamp" on the body of the separator. Weld-on flanges are also available.

Separator Source and Identification

The separator will be manufactured by LAKOS Filtration Systems, a division of Claude Laval Corporation in Fresno, California USA.

Oil separation from discharged wastewater:

A wastewater sample (300l) was pumped in the CST system, through a centrifugal filter for 12 hours. The separated samples were then collected in an outlet container and further analysed for total aromatic hydrocarbons (TRPHC), and total aliphatic petroleum hydrocarbons (TAPHC) concentrations, using the method of Total Petroleum Hydrocarbons TNRCC 1005 (2001).

RESULTS AND DISCUSSION

Reference wastewater sample analysis results:

As shown in Table 1, the amount of wastewater produced monthly is very high throughout the year, and its analysis showed a high concentration of oil that ranges between 1.70mg/l in the April sampling to 95.7mg/l in the September sampling. The turbidity is also high, the pH is in the alkaline range, and electric conductivity (EC) is relatively high. In addition, it contains sulphides, ammonia and phenols in different concentrations. Therefore; such water quality is not suitable for any further uses, e.g. as irrigation water or domestic use.

Table 1: Quality of wastewater from treatment evaporation ponds

Month	*pH*	*Turbidity NTU*	*EC dS/m*	*Oil Mg/1*	*Water discharge M^3/month*	*Sulfide mg/1*	*Ammonia mg/1*	*Phenol mg/1*
January	6.6	35234	6.3	2.40	163616.47	0.40	7.10	0.30
February	7.1	45233	4.3	1.90	143226.47	0.20	16.8	0.30
March	7.8	55235	5.6	14.1	133226.47	0.50	26.8	1.02
April	7.6	25231	5.7	1.70	153626.47	0.20	27.9	0.11
May	7.6	45231	5.6	23.7	143666.47	0.60	31.2	1.70
June	7.7	38234	5.8	40.9	123456.47	0.70	34.4	2.50
July	7.5	39204	5.7	71.5	113356.47	1.02	38.3	4.04
September	7.8	36204	5.8	95.7	103651.47	1.30	46.8	5.32

Source: KRC, 2015

Total petroleum hydrocarbons analysis of wastewater after CST application:

Figures 1-3 show the concentrations of total petroleum hydrocarbons before and after separation of oil in samples collected in June, August and November.

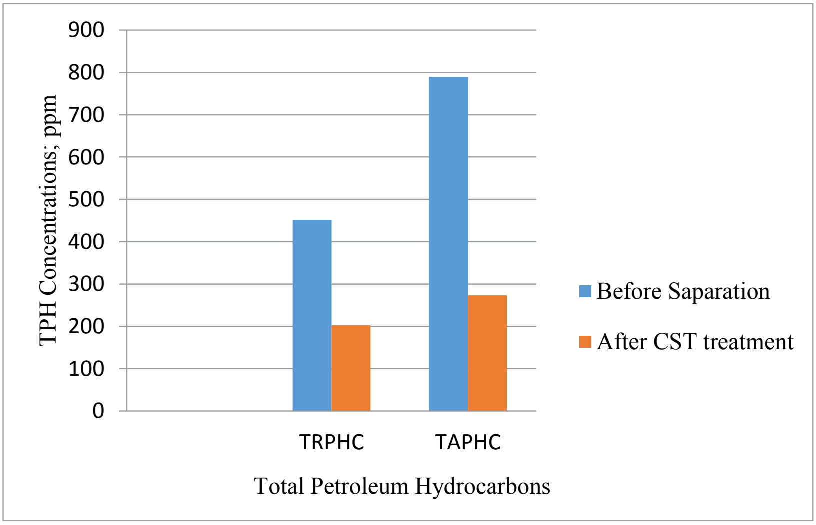

Figure 1: Concentration of total petroleum hydrocarbons after CST treatment, ppm June samples

Source: Devised by authors

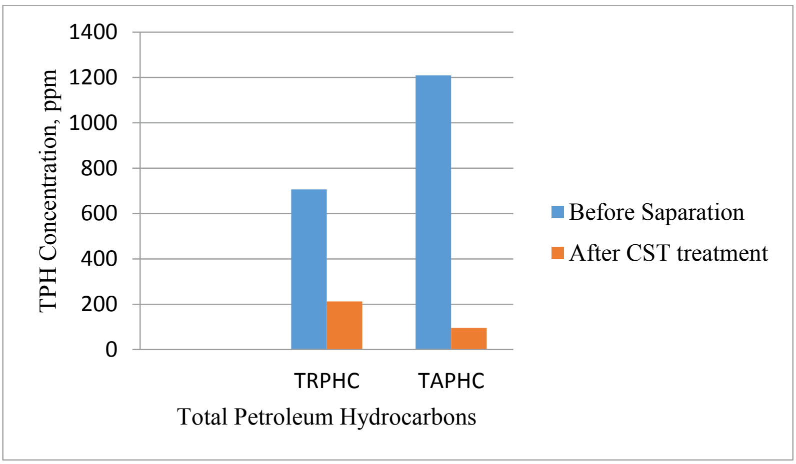

Figure 2: Concentration of total petroleum hydrocarbons after CST treatment, ppm, August samples

Source: Devised by authors

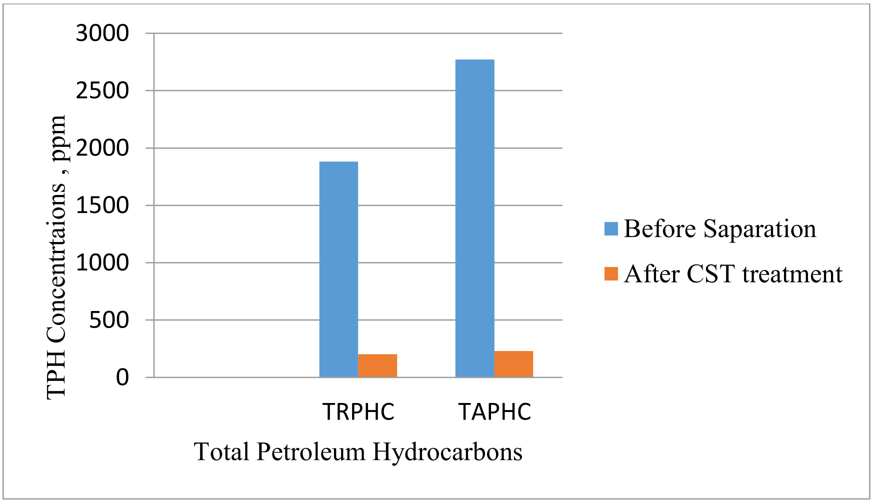

Figure 3: Concentration of total petroleum hydrocarbons after CST treatment, ppm, November samples

Source: Devised by authors

Results revealed that the concentrations of TRPHC and TAPHC were reduced significantly before and after the CST application, as shown in Figures 4 and 5.

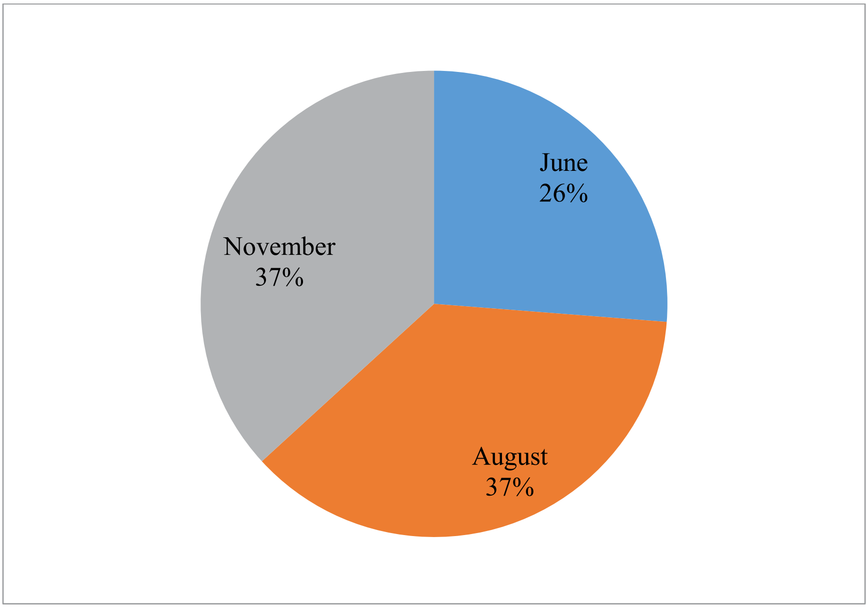

Figure 4: Reduction of TRPHC concentration after CST application, %

Source: Devised by authors

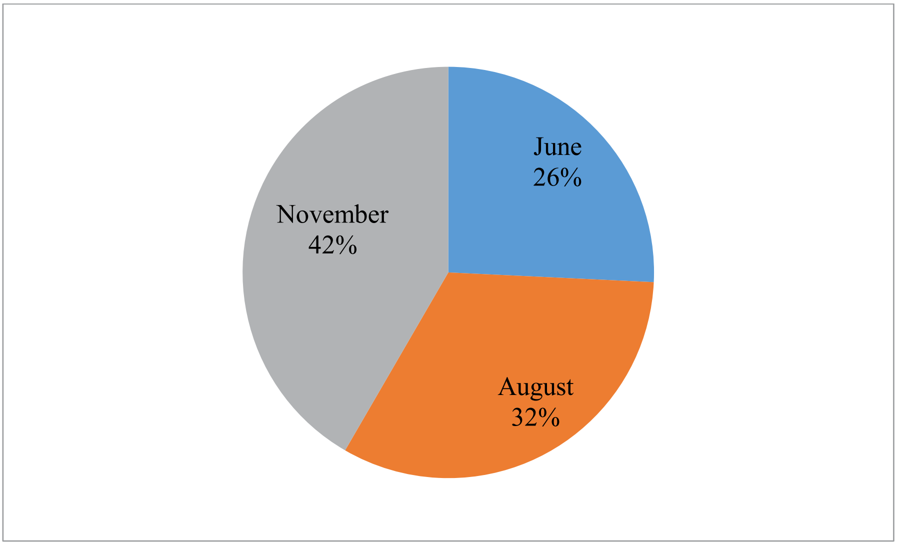

Figure 5: Reduction of TAPHC concentration after CST application, %

Source: Devised by authors

Also the turbidity of the wastewater samples showed a significant difference, as shown in Figure 6.

Therefore, separation using the CST method reduced the turbidity of wastewater and concentrations; this indicates the use of such water for further purposes, e.g. irrigation of crops.

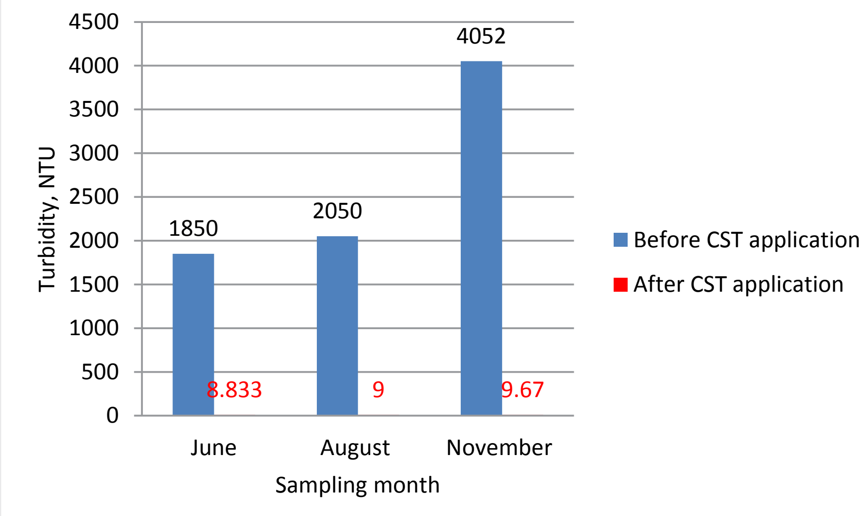

Figure 6: Turbidity of wastewater before and after CST application

Source: Devised by authors

CONCLUSIONS AND RECOMMENDATIONS

The study concludes the following:

- The CST method could be implemented for wastewater treatment as it plays a significant role in separating organic pollutants and reduces the turbidity of water.
- Further research work is needed to test the efficiency of the CST method in treating wastewater from municipal areas, especially the treatment of microbes and pathogens.

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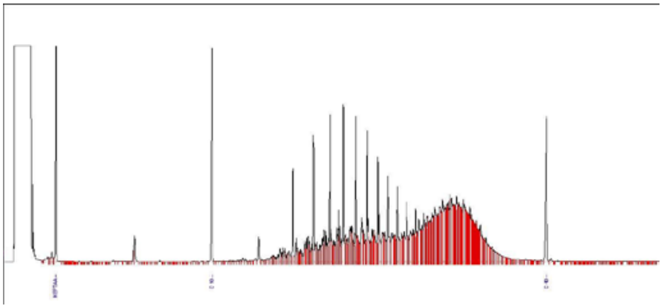
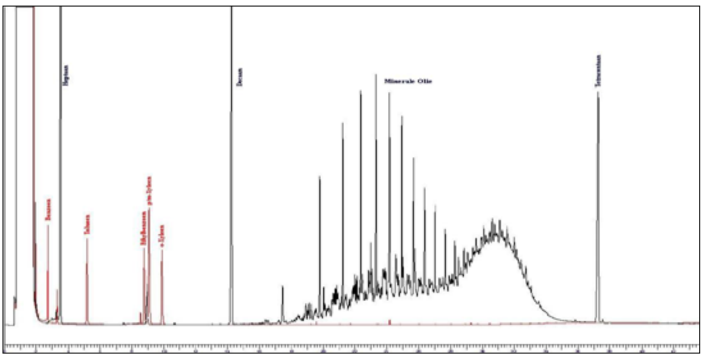
APPENDIX

TPH standard chromatograms:

1) TAPHC:



2) TRPHC:



BIOGRAPHIES

Dr. Sarra Ahmed Mohamed Saad was awarded her PhD in Soil Science in 2002 from the University of Goettingen, Germany. She graduated from the Faculty of Agriculture, University of Khartoum, majoring in Soil Science. She is currently working as a senior researcher of Soil Science at the National Center for Research, Department of Environment, and has led many research projects dealing with the problem of food security, soil productivity and climate change. She has supervised many postgraduate students at both MSc and PhD level, and has offered consultancy to governmental and private sectors about organic food production and fertilisation strategies especially in poor fertile soils.

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Sufyan Abd Elrazig Mohammed Ossman is currently working as Head of Agricultural Unit in Khartoum Refinery Company in Khartoum-Sudan. He was awarded the BSc in Forestry and Range Sciences, and an MSc in Environment and Forestry from Sudan University of Science and Technology in 2002 and 2013, respectively. He has participated in many workshops inside and outside Sudan related to disaster management; quality control of water and wastewater; management of petroleum installation; compost production and uses; proliferation of orchards, production of medicinal and aromatic plants; Cop 21 in France 2015 and in Morocco 2016.