Chapter 4
Drilling Waste Management Based on New Methods of Bioremediation and Solar Desalination

Amir Parnian, James N. Furze, and Amin Parnian

Abstract Drill cutting and mud waste management is the principal concern in gas and oil drilling operations. Waste management is usually based on engineering activities to reduce waste and its impact on the surrounding environment. Oil and gas drilling waste management has two operational parts which include water recovery and waste treatment. Traditional methods are costly and do not alleviate environmental concerns. A new method is proposed and organized to solve issues of pollution. The methods have been applied in Iran where there is particular demand due to high levels of pollution. The novel method is a complex of different processes that require optimization in order that they can be combined in an applied system of drilling waste management operations. Drill cuttings and mud waste are dumped into a newly designed corral/waste pit to separate water for purification and condense solids. Water is recovered by chemical treatments in cyclonic ponds and sent to the drilling rig. Solids remaining in the corral/waste pit are biologically dried by adding composted material, and the dried solid bioremediated material undergoes a process of co-composting. Waters of the treatments are sent to a solar desalination humidification-dehumidification (SDHDH) process which produces an improved purity of water and salt. The method was used to reduce the environmental impact of the oil well drilling operations in Iran and is approved by the Iranian Department

A. Parnian (✉)
National Salinity Research Center (NSRC), Agricultural Research Education and Extension Organization (AREEO), Yazd, Iran
e-mail: amir.parnian86@gmail.com

J. N. Furze
Royal Geographical Society (with the Institute of British Geographers), London, UK

Laboratory of Biotechnology and Valorization of Natural Resources,
Faculty of Sciences-Agadir, Department of Biology, Ibn Zohr University, Agadir, Morocco

Control and Systems Engineering Department, University of Technology-Iraq, Baghdad, Iraq
e-mail: james.n.furze@gmail.com; jamesfurze@hotmail.com

A. Parnian
Young Researchers Club, Masjed Soleyman Branch, Islamic Azad University,
Masjed Soleyman, Iran
e-mail: parnian.amin1988@gmail.com

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of Environment; functional results were verified by nationalized commercial groups of Iran. The method produces soil, salt, and fresh water and is shown to leave lower immediate adverse effects than conventional waste treatment in the local environment. Application of the methods in additional locations will offer generation of resources to enrich both human communities and ecosystem services in the face of global industrialization and pollution.

Keywords Drilling waste management · Organic absorbent · Biological drying · Composting · Bioremediation

4.1 Introduction: The Source and Impact of Petroleum Hydrocarbon on the Environment

Human industrial activity is the major source of petroleum hydrocarbons which cause disastrous contamination in the environment (Yi et al. 2016). Pollution with persistent contamination is reviled by all forms of life in all manner of ecosystems and has an enormous impact in reducing environmental diversity. Further, petroleum hydrocarbon contamination renders the ecosystem unstable and consequently dangerously vulnerable to normal changes and stresses imposed by biotic and abiotic complexes (Cheung and Kinkle 2001; Dojka et al. 1998; Kirk et al. 2005).

Petroleum hydrocarbon contamination is the result of human industrial and recreational activity. The operations related to oil and gas exploration, production, storage, refinery, and transportation lead to severe environmental pollution. Oil- and gas-related economical operations involving waste generation are associated with risks to the environment. Hazardous risks occur in the surrounding soil, air, and aquatic environments (Sharif et al. 2017). Petroleum hydrocarbon contamination has a carcinogenic effect for both humans and animals, and species diversity is being lost and prevented from regeneration (Singh and Shikha 2019; Sharif et al. 2017); further the pollution imposes some change in DNA of other forms of life (Das and Chandran 2011). The gravity of the problem is immense and justifies limiting the effects of petroleum hydrocarbon contamination. This kind of contamination puts humans in dangerous situations of environmental disorder. To avoid pollution of the environment and rectify all acts related to petroleum hydrocarbon contaminations, remediation is vital for the sustainability of the ecosystem, including that which surrounds human communities.

4.2 Drill Cuttings and Mud Waste Produced in Extractive Operations

The majority of waste generated from oil and gas well drilling operations come from exceeding or disqualified drilling fluids and drill cuttings (Onwukwe and Nwakaudu 2012). Drill cuttings are chips and particles, which become detached from the soil and geological structures during the drilling process and after drill sites are processed. Slack is removed from the drilling mud with special equipment in a physical process of solids control. Most of the mud is recirculated back to the drilling operation through the solids control process and drilling mud recycling system. Drill cuttings separated by solids control equipment are usually sent to a waste management process (Ball et al. 2012).

Drill cutting and mud waste characterization is dependent on the mud composition. There are two basic types of muds (fluids) produced in oil and gas drilling operations, water-based fluids and oil-based fluids (Caenn et al. 2011; Khodja et al. 2007); these are constituted as follows:

– Water-based systems (with freshwater and saltwater as the base for mud production) are water-based drilling fluids. These are the most widely used and are generally less expensive than other mud systems to process.
– Oil- or synthetic-based systems include the non-aqueous-based drilling fluids and have gasoline at the base. These have an oil or a synthetic base fluid in their fluid matrix phase and brine as the dispersed phase. These kinds of mud comprise 5–10% of the total composition of a common drilling operation well fluid composition.

4.3 Why Should We Manage Drill Cuttings and Mud Waste?

Drill cuttings and mud waste composition are dependent on mud composition and formation material composition. The wastes are often contaminated by harmful concentrations of trace elements and have an additional high concentration of petroleum hydrocarbons. Left unmanaged the drilling wastes flow to the surrounding environment and, as a consequence, pollute soil, surface water, and groundwater disabling the environments normal functions. As a result of public outcry, regional and national authorities and oil well drilling companies inevitably use some management techniques to reduce the drill cuttings and mud waste impacts on the environments (Caenn et al. 2011; Onwukwe and Nwakaudu 2012).

4.3.1 How Can Drilling Cutting and Mud Waste Be Managed?

Drilling operations of gas and oil wells are present in different environments. These are divided into onshore and offshore operations; produced wastes should be managed to avoid long-term environmental impacts (Bybee 2002; Veil 2002). Drilling waste management encompasses the following categories and parameterization: equipment, drilling operation and handling rates, costs, authorities, risks, and environmental impacts (Ball et al. 2012; Cripps et al. 1998).

Table 4.1 Drill cutting management operations

Number	Treatment	References
1	Leave the piles undisturbed	Gerrard et al. (1999) and Potts et al. (2019)
2	Bioremediation	Davis (2016)
3	Capping	Hess et al. (2013)
4	Gravel dumping	Cripps et al. (1998)
5	Spreading	Ball et al. (2012) and Ismail et al. (2017)
6	Retrieve with suction	Carpenter (2014)
7	Retrieve with dredging	Cripps et al. (1998)
8	Retrieve with a seafloor crawler	Cripps et al. (1998)
9	Subsea entombment in a pit	Paulsen et al. (2005)
10	Reinjection into a well	Bartko et al. (2009)
11	Bioreactor treatment	Interiano-López et al. (2019)
12	Super-critical treatment	Motamedimehr and Gitipour (2019)
13	Land-farming	Kogbara et al. (2018)
14	Mechanical treatment onshore	Mcintyre (2008)
15	Distillation	Winterbourne (2014)
16	Stabilization	Al-Ansary and Al-Tabbaa (2007)
17	Combustion and thermal treatments	Petri et al. (2015)
18	Landfill	Saeedi et al. (2020)
19	Either of treated or untreated wastes	Cripps et al. (1998), Phillips et al. (2018), and Sharif et al. (2017)

In oil extraction operations, water recovery is attempted from waste; fluids run out of the drilling rig and are recirculated to maintain the operation. Water recovery options involve physical separation by specialized equipment and may also be carried out in combination with chemicals to enhance the process. Thermal processes may also be engaged to get rid of the excess waters and fixed solids, with huge atmospheric pollution (Sharif et al. 2017).

Nineteen operation options for managing drill cutting piles are described in Table 4.1.

4.4 Solids Control: The First Step and Inevitable Part of Drilling Operations

The first/initial step in waste management of drilling operations is carried out in the solids control system. Solids control is directly attached to the drilling rig and is essential due to its reducing act in the operation's mud demand. Solid control systems include shale shakers, degassers, desanders, and desilters. These processes physically remove the outcome fluids of the coarse particles and make the mud ready for reuse. In effect drill cuttings are removed from the drilling mud at the surface, and muds are prepared for recirculation and pumping (Bybee 2002; Sharif et al. 2017). Moreover, remnants remain after the solids control step; all fluids run out of the rig operational area, which are to be managed by waste management operations. Management depends on the local situation, local law, and the decision of the drilling operations manager.

4.4.1 New Methods of Drilling Waste Management Following Solids Control

Generally, waste management steps are based on reduction, reuse, and recycling of everything disposed of by the drilling rig. The three main steps classify waste management strategies according to their desirability in terms of waste minimization. Proper management of wastes begins with pollution prevention which truly eliminates, changes, or reduces operating practices resultant discharges to the environment. Given waste elimination is not possible, minimizing the generated waste should be investigated (Arshad et al. 2018; Phillips et al. 2018).

In the majority of oil extraction methods, after solids control in consideration of waste minimization goals, water is recovered by the addition of chemicals and remaining solids are stabilized or remediated for reuse (Ball et al. 2012). In 2019, a new method was newly designed and developed for cost reduction and better remediation; the method was trialed in Naft Sefid, Shushtar County, Khuzestan province, Iran, supporting an oil well drilling operated by National Iranian Drilling Company (NIDC). The creative method reduces the environmental impact of the oil well drilling for one of Iran's oil and gas production companies.

In this method, water of the drill cuttings and mud wastes are recovered by a physical and chemical process; floated oil is removed from waters by organic oil absorbent or line-up procedure; remaining solids are bioremediated by co-composting, with super saline waters evaporated and desalinated by a new humidification-dehumidification (SDHDH); the process flow is shown in Fig. 4.1.

4.4.2 Water Recovery by Physical and Chemical Processes

In most drilling operations, after solids control, drilling, cutting, and mud wastes flow as slurry to a corral (Veil 2002). In the corral/waste pit, slurry shape materials settle to TSS (total suspended solids) and are physically reduced in time. This chapter shows a development of the corral where the corral and the waste pit are merged. Further divisions are created by cement blocks, partitioning the area into three parts, staggered with the ground slope/gradient. This new waste pit design helps to separate muddy outcomes by the water suspended solid levels, as seen in Fig. 4.2. The slurry flows to the middle part of the waste pit which is equipped with 20

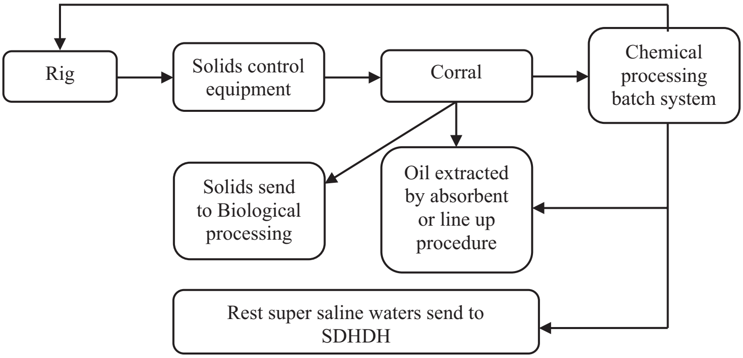

Fig. 4.1 Novel approach used to process oil extraction waste

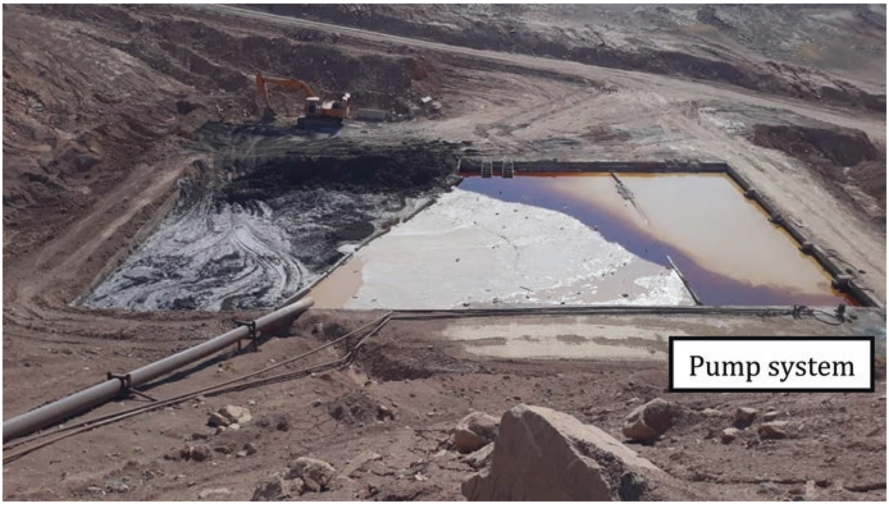

Fig. 4.2 Combining waste pits and corrals. (Nafte Sefid, ShuShtar County, Khuzestan province, Iran, 2019)

centimeters diameter PVC agricultural drainage pipe tubes. Water flowing to the lowest elevation part of the waste pit is pumped to the batch chemical water processing ponds; solids elute from the water and are moved to the upper elevation part of the waste pit by a loader. Solids in the upper part of the pit remain and are stored for biological treatments.

In Fig. 4.2, three partitions are created by cement blocks, the large pipe transfers wastes to the middle part; the pump system and pipeline in the right side of the pit move the water to the batch chemical water processing unit. The upper left part of the image shows storage of the settled solids and a place for the waste's biological drying process.

Water treatments were established to reach three goals: avoiding problems of water source reduction, wastewater treatment, and water recycling. Chemical water treatment is a rapid method for water purification using chemicals (Gupta et al. 2012). Batch chemical water processing ponds are composed of three 80 cubic meters round ponds, shown in Fig. 4.3; the cyclonic series of ponds have the following features:

1. Production of a free vortex (for faster treatment and lower chemical use).
2. Full acid and alkali resistance as they are mainly constructed of high-density polyethylene sheets (Fig. 5.4).
3. Easy to fill and clean up due to possession of a central outlet. Hence they produce a free vortex that allows the solids to settle in the center of the pond.
4. The ponds are easy to set up and cheaper than other ponds or reservoirs used (Davarpanah et al. 2018).
5. Adding chemicals is facilitated with a pipe system due to the height and low pH of the water (around 2.5).
6. Shower systems operate over the pond and compressed air is vented into the ponds, allowing users to apply heavy aeration for odor control and biological water treatments in the system (Figs 4.3 and 4.4).

Figure 4.3 shows the pond design capable of producing a free vortex flow. Heavy aeration of waters achieves effective water treatment performance.

In the chemical water treatments, coagulation, flocculation, hardness removal, and pH setting are accomplished by adding chemicals (lime, soda, soda ash, PAC (polyaluminum chloride), PAM (polyacrylamide)) into the treatment ponds regarding a user's needs and permission, pending water properties (Davis 2010).

In Fig. 4.4 the ponds have a 7.7 m diameter and a capacity of 80 m^3.

Submersible pumps relay water to the shower, producing a free vortex flow and aeration as seen in Fig. 4.5.

The following section describes processes of oil absorption and recovery.

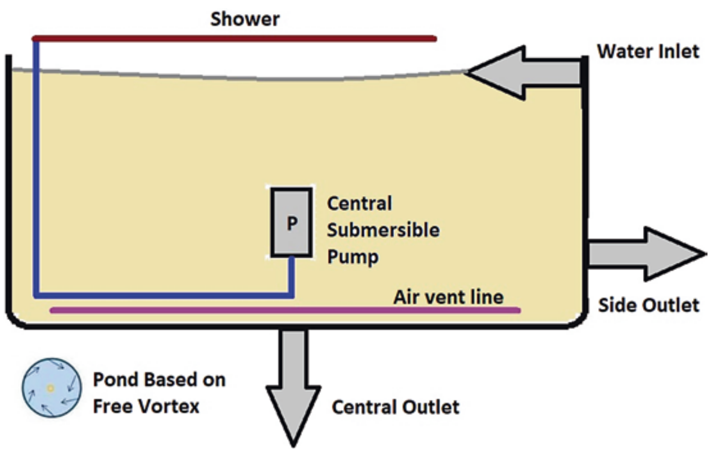

Fig. 4.3 Cyclonic pond systems

Fig. 4.4 Polyethylene cyclonic series of ponds mounted with iron structures. (Naft Sefid, Shushtar County, Khuzestan province, Iran, 2019)

Fig. 4.5 Shower operation over ponds. (Naft Sefid, Shushtar County, Khuzestan province, Iran, 2019)

4.4.3 Organic Oil Absorbent and Lineup Procedure for Oil Recovery and Removal

Oil pollution appears on water bodies through human activities (Kim et al. 2010). Drill cuttings, mud wastes, and drilling rig effluents contain different amounts of petroleum hydrocarbons. These contaminants are considered hazardous to ecosystems in close proximity or within the flow of polluted materials, which creates environmental concerns. As oil has a lower density than water, contamination stays rest on the water surface and form an oily layer mixed with water. In lineup procedures, the top oily part of the water source is pumped into a reservoir; water partitions in lower layers and drains from the tank. During this procedure, the tank fills with petroleum materials and the oil-contaminated water source be cleared. At the end of the lineup procedure, recovered petroleum materials may be reused for operational intentions, for example, as fuel for heating purposes.

Use of skimmer and lineup procedures are the most common oil removal methods; both are based on differences between water and oil density. These methods are inefficient when oil thickness on the water is low. In such scenarios, oil absorbents are made use of to enable efficient water cleanup. Commercial oil absorbents are made from different materials including cotton fibers, synthetic material, polymers, and agricultural wastes (Chai et al. 2015; Teas et al. 2001; Wang et al. 2012). In operations documented in the current chapter, to make the oil absorbent, sugarcane was used and bagasse was de-pithed/extracted by a mechanical process (Ranjbar Jafarabadi et al. 2019). Subsequently, sugarcane pith is processed in a pyrolysis reactor, during a 4-h anaerobic thermal treatment of between 170 and 210 °C (Awasthi et al. 2019). Through this process the materials obtain greater hydrophobicity properties and show oil absorption capability of seven to nine times more than their dry weight. Finally, treated sugarcane coir pith fills fluid permeable bags which are used as an oil absorbent. Figure 4.6 shows absorbents used in "low thickness" oil absorption operations.

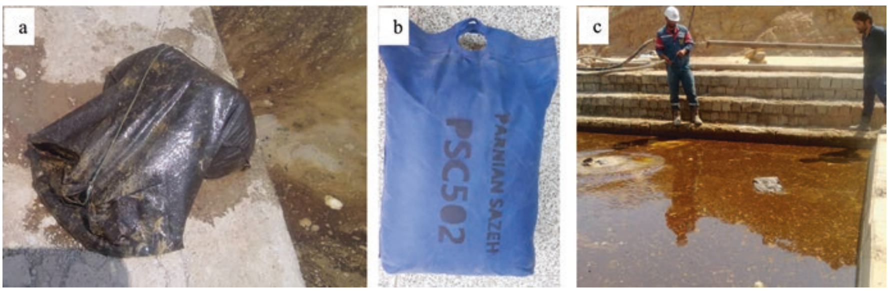

Fig. 4.6 Organic oil absorbent made by anaerobic thermal treatment of sugarcane bagasse coir (Naft Sefid, Shushtar County, Khuzestan province, Iran, 2019). (**a**) Absorbent after oil absorption is extracted out of the water; (**b**) clean absorbent before the oil absorption process; (**c**) the organic absorbent floats on the contaminated water and absorbs the oil pollution

The following section details the composting processes which may be engaged to remediate and create/restore displaced soil resources.

4.5 Co-composting of Solids and Remediated Soil Production

Oil and gas well drilling processes primarily generate two types of wastes – spent drilling fluids (muds) and a large amount of drill cuttings (solids). The fluid phase of wastes can be water, synthetic or natural oils, air, gas, or a mixture of these components (Onwukwe and Nwakaudu 2012). Due to environmental concerns, different management procedures have been detailed for the treatment of the solids remediation and fixation depending on the amount of waste and the type of contamination, authorities, and operational/financial concerns (Liden et al. 2017). The management procedures used in drilling oil and gas well waste management include thermal treatments (incineration and thermal desorption), biological treatments (composting, bioreactors, bio-slurry, and land-farming), and landfill and deep-well injection (Morillon et al. 2002; Onwukwe and Nwakaudu 2012; Paladino et al. 2016).

Biological treatment or bioremediation processes make use of living organisms to remediate or neutralize contaminant concentration to specific levels (Steliga et al. 2012). Moreover, in the matter of solid waste management, composting involves mixing drilling waste with bulking agents. Materials such as wood chips, straw, rice hulls, or husks provide increased porosity and aeration potential for biological degradation (Davis 2016; Paladino et al. 2016). Methods of treatment aim to maintain objectives toward increased time or efficiency of remediation and can be summarized in the following three steps.

1. Organic Semi-composted Material Production

To aid the process of bioremediation, agricultural waste (sugarcane wastes) and microorganisms are prepared in semi-composted heaps (Fig. 4.7). The process is similar to normal composting of agricultural waste (Zhang and Sun 2016) though materials obtained by biological drying and co-composting of solids are not fully composted; the carbon-nitrogen ratio is around 30:40 $g.g^{-1}$.

2. Biological Dehydration of Cuttings and Solids

Biological drying of cuttings and solids is the act of microorganisms. In Fig. 4.8 Organic material is mixed with wet solids; breakdown of the material leads to increased temperature and drying (Zhang et al. 2008).

3. Co-composting of Solids

After reaching the optimum material's moisture, by addition of microorganisms, nutrients (N and P, depending on the mixture composition C-N and C-P ratio) and

Fig. 4.7 Pile composting of agricultural waste (sugarcane bagasse) to produce semi-composted materials. (Amirkabir Sugarcane Cultivation and Industry Company, Ahvaz County, Khuzestan province, Iran, 2019)

Fig. 4.8 Biological drying of cuttings and solids (Naft Sefid, Shushtar County, Khuzestan province, Iran, 2019) : (**a**) Absorbing water by organic materials; (**b**) evaporation of water

Fig. 4.9 Pile composting of drilling oil and gas well solid wastes. (Naft Sefid, Shushtar County, Khuzestan province, Iran, 2019)

sugarcane molasses, the process of material mixing commences (Fig. 4.9). Davis (2016) and Paladino et al. (2016) detailed that composting of drilling oil and gas well waste has the following benefits: fixation of trace elements by $CaCO_3$ (organic Ca and CO_2) decreases metal and metalloid element bioavailability; microbial removal of petroleum hydrocarbon and other organic pollutants; and reduction of elements by dilution with organic material.

4.6 Water Evaporation and Desalination by a New Solar Desalination Humidification Dehumidification (SDHDH) System

Water desalination is a process that removes salt from the water and also demands a large amount of energy (Karagiannis and Soldatos 2008). Solar desalination methods are techniques which desalinate water using solar energy. Humidification dehumidification (HDH) systems are a type of desalination system, which are broken into an air humidifier and air dehumidifier (Giwa et al. 2016). Further a seawater greenhouse is a form of HDH system that grows plants using the sun's energy, seawater, and airflow to produce freshwater and cool air (Zarei and Behyad 2019).

To develop the seawater greenhouse in Fig. 4.10 with the aim of producing more water, a dehumidification system may be added, and purified water passes to a separate water reservoir as shown in Fig. 4.11.

In Fig. 4.11 saline water flows into the base pool that is covered by a double clear plastic curtain as a greenhouse; water is sprayed into the air by vortex nuzzles. The

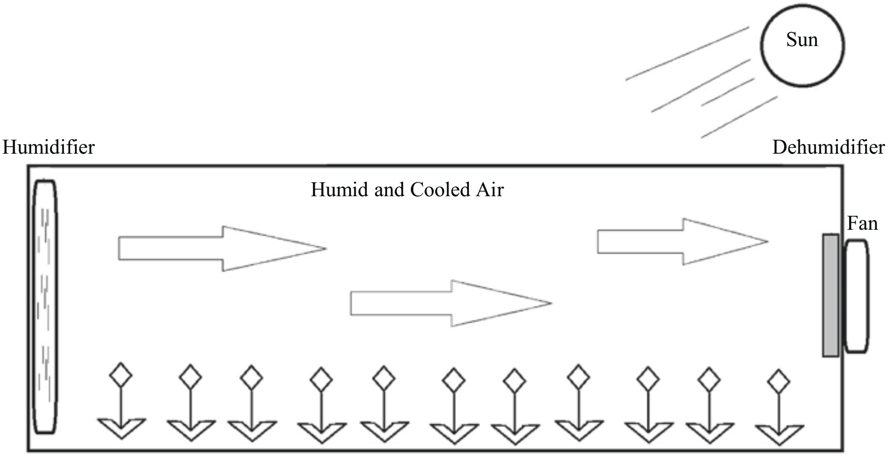

Fig. 4.10 Seawater greenhouse

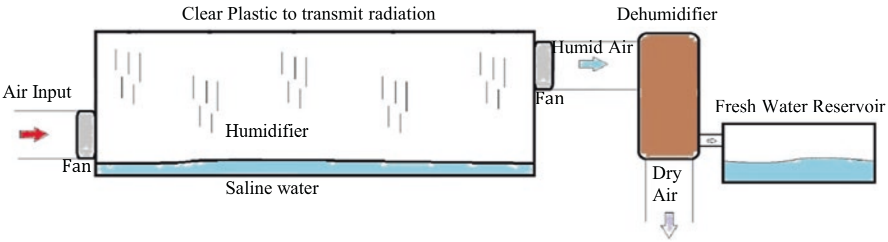

Fig. 4.11 New solar desalination humidification dehumidification (SDHDH) based on seawater greenhouse**.** (Parnian et al. 2020)

water and atmosphere of the semi-greenhouse (humidifier) part is warmed by solar radiation, causing the atmospheric humidity to increase. Fans push the humid air to a ground dehumidifier section and freshwater flows to the reservoir.

This technology has been used for desalination of oil and gas drilling wastewater in Iran in private oil operations; the seawater greenhouse in Fig. 4.12 of the integrated desalination plant produces 10 liters of freshwater per day.

The SDHDH is seen in Fig. 4.13(a) and pile composting is indicated in Fig 4.13(b). Bioremediation processing is seen in the heaps above the SDHDH on the right, and the waste corral is indicated (c) on the left.

This new approach developed the HDH of Fig. 4.10 into a low-cost and more efficient system; developments of the new design are mentioned below following Parnian et al. (2020).

Fig. 4.12 New humidification dehumidification (HDH) based on seawater greenhouse. (Naft Sefid, Shushtar, Khuzestan, Iran, 2019)

Fig. 4.13 Drilling solid waste bioremediation with an integrated solar desalination humidification dehumidification (SDHDH) system at Naft Sefid, Shushtar, Khuzestan, Iran, 2019

1. Merging the Solar Water Heater and the Humidifier

Inspired by greenhouses, we merged the solar water heater and the humidifier to make a low-cost SDHDH system. Saline water flows into a room covered by a clear plastic membrane, and air is pushed out to the dehumidifier by a fan. Solar radiations crossed into the heater-humidifier room, allowing the saline water temperature to rise.

2. Using Vortex Spray Nozzles to Spray Water

Spraying water into the air humidification chamber in the SDHDH system raises humidity and drives the system akin to that of a transpiration flow in plant systems. Raising humidity and extracting the air via fans maximize the growth of plants in the system and lower the super critical salt concentration in the chamber; consequently the humid air is extracted to the de-humidification chamber by fans.

3. Using a Ground Dehumidifier

The soil has a lower temperature than the air during the day in warm seasons. Inspired by house-ground heat extractors (Ali et al. 2017), a prototype of the ground dehumidifier was designed, which can be used to dehumidify air and produce fresh water. A 50 m length of a 20 cm diameter PVC tube was placed underground at a 2 m depth as the dehumidifier and water was collected in a plastic reservoir.

4. Possibility of Salt Production

The use of vortex nozzles for spraying water into the heater-humidifier room makes salt production possible as saline water may be sprayed up to the edge of salt super-saturation.

4.7 Discussion

Common methods for drilling waste management have advantages; however pollutants remain (Sharif et al. 2017; Siddique et al. 2017). After years of observation and many laboratory pilot-scale tests aiming to minimize problems at each stage, the combinatorial introduced method shown in this chapter was invented as an innovative response. Disadvantages of previous methods are as follows: requiring a place to dump/dispose solids, the cost of recovery of brines; overall high capital investment required for setup and running costs, requirement of engineering operations before running the process, and a major problem in application in high gradients of sloping topology (Ismail et al. 2017; Morillon et al. 2002; Onwukwe and Nwakaudu 2012; Saeedi et al. 2020; Veil, 2002).

Many methods have been developed to solve the problems of drilling waste (Ball et al. 2012; Jewesimi et al. 2019; Khodja et al. 2007; Napp et al. 2018; Phillips et al. 2018); demand for a new complex solution for all problems has not as yet been considered. The current chapter details a new method which has a solution for oil recovery/remediation from water (lineup procedure/oil absorbent), solid remains remediation (bioremediation through co-composting), and brine recovery/management (a new SDHDH). Additionally the current chapter created a parallel system for water recovery and treatment, making the method cheaper and more flexible than others which use high-cost equipment and extra resources.

4.8 Conclusion

This chapter introduces drilling waste management based on new methods of bioremediation and solar desalination as a new method with huge application potential. The combined method was developed with the aim to make a solution for solid waste and brine remains and meet the requirement of a flexible and low-cost waste management system for drilling oil/gas operations. The method has been successfully applied to manage oil well-drilling waste in Naft Sefid, Shushtar County, Khuzestan province, Iran in 2019. The method reduces the environmental impact of oil well drilling. Authors suggest the future application of methods documented in this chapter in alternative locations and environmental settings, although it is stated that the methods may be optimized within different biotic and abiotic parameters.

Finally, the current chapter contains innovative approaches for huge environmental problems. Out of extractive methods, new resources are generated, namely, water and soil. The authors wish to be clear that the current chapter in no way condones extractive industrial activity – "prevention is better than cure" appears to be an appropriate proverb from the Greek Goddess of Health, Sanitation and Hygiene as stated by philosopher Desiderius Erasmus in around 1566. However we do advocate soil bioremediation and recommend the use of processed materials for agricultural use, ecosystem services, and cleanup. Water reuse, recovery, and production are achieved from an unconventional source and may find uses from increasing urban water supply, to enriching droughted areas; thus increasing productivity and rehabilitation of the Earth following approximately 300 000 years of human onslaught.

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