Chapter 17

Overview of Environmental Management by Drill Cutting Re-Injection Through Hydraulic Fracturing in Upstream Oil and Gas Industry

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Additional information is available at the end of the chapter

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1. Introduction

For the reason of worldwide increased activities of upstream oil and gas industry for future energy demands which will be associated with more waste generation, zero discharge is considered an environmentally friendly approach of complying with environmental legislations. Drilling is one of the major operations in upstream oil and gas industry that can potentially impact the environment through generation of different types of wastes. The drilling process generates millions of barrels of drilling waste each year; primarily used drilling fluids and drill cuttings especially oil-contaminated drill cuttings. In the early years of the oil industry, little attention was given to environmental management of drilling wastes. The rapid development of drilling operation in order to fulfill the global energy demands and so the drilling environmental regulatory requirements have become stricter, drilling and mud system technologies have advanced, and many companies have voluntarily adopted waste management options with more benign environmental impacts that those used in the past. Moreover, it is crucial to find out why drilling wastes are important nowadays, how they generated and by which means those waste could be disposed off with higher efficiency and acceptable HSE and economically concerns. Drill Cutting Re-Injection (DCRI) is one of the processes that developed as an environmentally friendly and zero discharge technology in upstream oil and gas industry.

A variety of oil field wastes are disposed of through injection, such as produced water that re-injected through tens of thousands of wells for enhanced recovery or disposal. Other oil field wastes that are injected at some sites include work over and completion fluids, sludge, sand, scale, contaminated soils, and storm water, among others. The focus of this chapter is injection of wastes related to the drilling process, which involve processing cuttings into small particles, mixing them with water and other additives to make slurry, and injecting it into a subsurface geological formation at pressure high enough to fracture the rock. DCRI has been given other terms by different authors such as fracture slurry injection, grind and inject, and drill cuttings injection.

The most critical aspect in waste injection through hydraulic fracturing (HF) in upstream oil and gas industry, which is DCRI, will be reviewed in this chapter. The subject of this chapter, DCRI, is a specialized area in upstream petroleum industry; even though many brilliant papers presented on various environmental areas, overview papers that present a context for those more specific studies are needed. This chapter will presents in an effort to review the environmental management of DCRI in upstream petroleum industry. The aims are firstly, to review the drilling process and different types of drilling fluid. Afterwards, because it's considered as a key in identifying containment formations to prevent waste migration to water resources and environment in DCRI operations, HF technology will be introduced in the second part of this chapter. Finally, after reviewing the essential parts of DCRI, drilling wastes and HF, the nature of DCRI and its role in environmental management will be presented in details.

2. Overview of drilling operation

Oil and gas wells are drilled to depths of several hundred to more than 5,000 meters. Figure 1 shows a schematic of typical drilling rig, which uses a rotating drill bit attached to the end of a drill pipe. Drilling fluids (muds) are pumped down through the hollow drill pipe, through the drill bit nozzles and up the annular space between the drill pipe and the hole. Drilling mud mixture is particularly related to site and hole condition; it used to lubricate and cool the drill bit, maintains pressure control of the well as it is being drilled, and helps to removes the cuttings from the hole to the surface, among other functions. In fact, the technology of mud mixing and treatment has been recognized as a source of pollutants.

Mud and drill cuttings are separated by circulating the mixture over vibrating screens called shale shakers. As the bit turns, it generates fragments of rock (cuttings), which will be separated from the mud by shale shakers that will moves the accumulated cuttings over the screen to a point for further treatment or management. Consequently, additional lengths of pipe are added to the drill string as necessary. As a common practice in drilling of oil and gas wells, when a target depth has been reached according to the drilling plan, the drill string is removed and the exposed section of the borehole is permanently stabilized and lined with casing that is slightly smaller than the diameter of the hole. The main function is to maintain well-bore stability and pressure integrity. (Three sizes of casing depicted in Figure 1). Cement is then is pumped into the space between the wall of the drilled hole and the outside of the casing to secure the casing and seal off the upper part of the borehole. Each new portion of casing is smaller in diameter than the previous portion through which it is installed. The final number of casing strings depends on the total depth of the well and the sensitivity of the formations through which the well passes. The process of drilling and adding sections of casing continues until final well depth is reached.

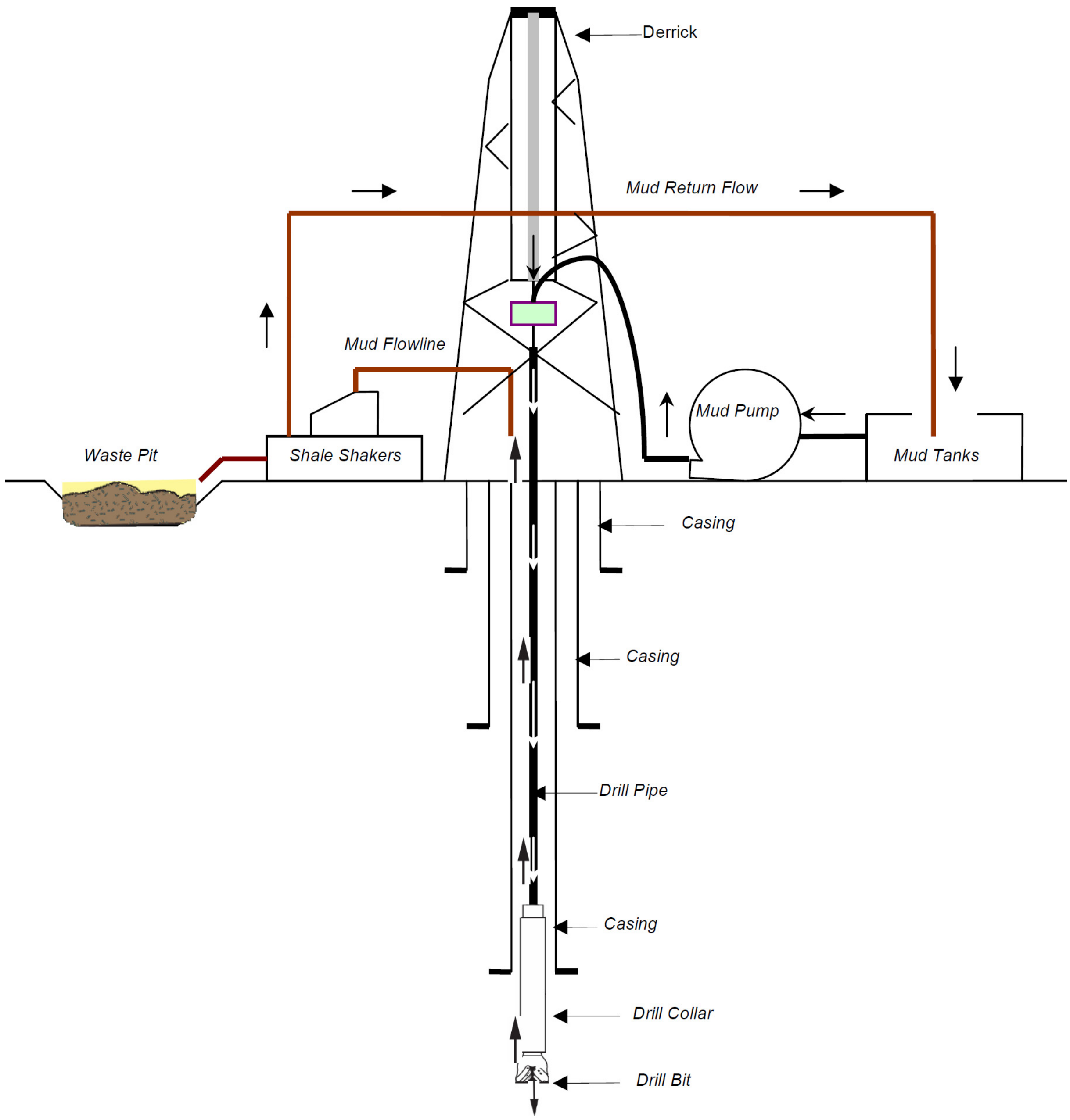


Figure 1. A schematic of a drilling rig (not to scale).

Two primary types of wastes are generated in drilling of oil and gas wells; drill cuttings and drilling fluids. Most drilling fluids contain bentonite clay, water, barite, specialized additives, and some types of muds also contain hydrocarbons. Large volumes of drilling muds are stored in aboveground tanks or pits. The liquid muds pass through the screen and are recycled into the mud system, which is continuously treated to maintain the desired properties for a successful drilling operation. Depending on the depth and diameter of the well bore, the volume of drilling wastes generated from each well varies; typically, several thousand barrels of drilling waste are generated per well. Figure 2 is a demonstration of the generated drilling waste from a 2400 meters well depth that comprises of four different borehole sizes.

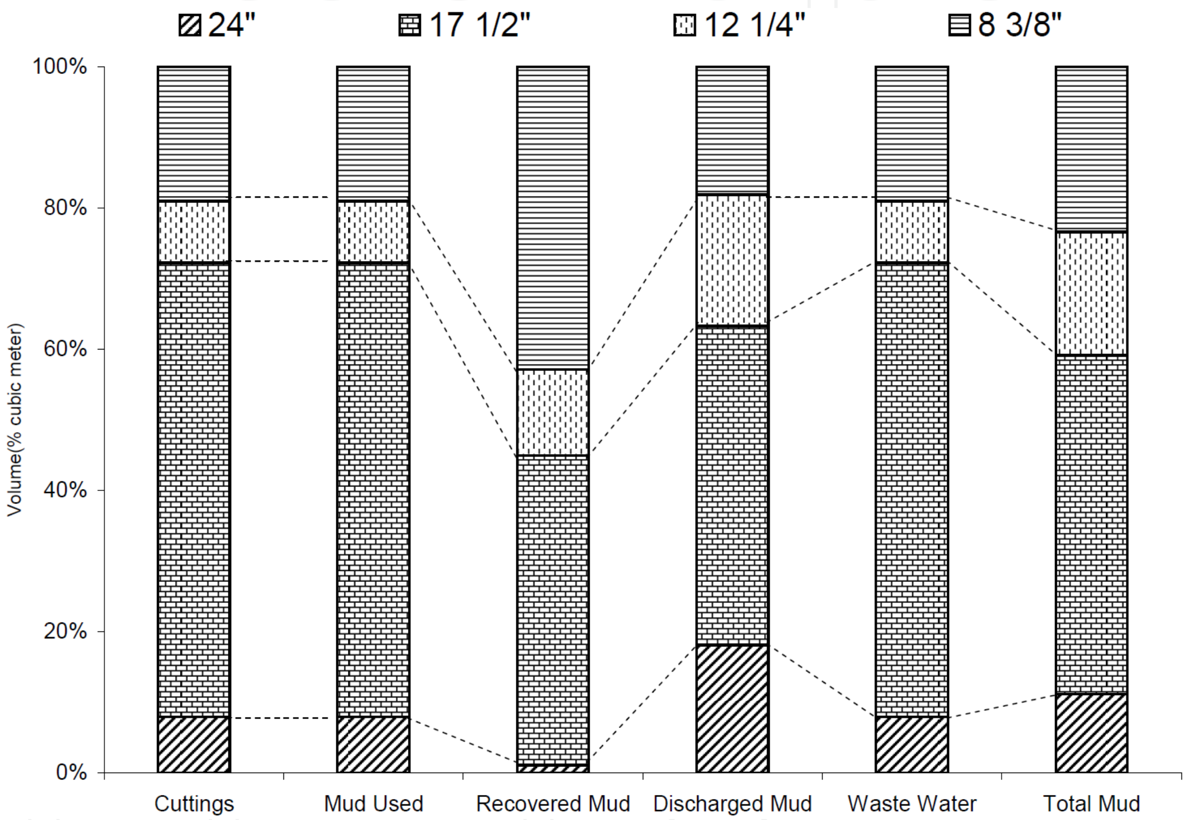


Figure 2. A typical drill cutting and mud volumes for a 2400 meters well depth.

The generation of wastes from drilling fluid and drill cuttings could be recognized at different stages of the drilling operation. When drilling at the first few hundred meters to run conductor casing or surface casing, higher quantities of cuttings are produced; that's because borehole diameter is the largest during this stage. Substantial waste fluid must be handled when drilling deep wells that encountered shale's and/or unstable formations. So, oil based muds (OBMs) is utilized to overcome those problems which will be mixed with other drilling fluids in waste pit and disposed to the environment. Furthermore, higher volume of wastes must be displaced in the completion phase of drilling operation which is replaced by completion fluids and equipment. Physical condition of a waste pit during and after drilling operation is illustrated in Figures 3 and 4, respectively. More details could be found by Shadizadeh and Zoveidavianpoor, (2008).

Figure 3. Mud pit condition during drilling operation.

Figure 4. Mud pit condition after drilling operation.

3. Environmental impacts of drilling muds

In upstream petroleum industry, drilling is the major operation that can potentially impact the environment. Drilling operation generates a significant volume of wastes. The composition of drilling fluid constituents is depicted in Table 1. Environmentally responsible actions require an understanding of the characteristics of these wastes and how they are generated in order to minimize their environmental impacts by known environmental protection methods. In this section, environmental impacts of a drilling mud will be presented along with a case study on mud pit samples for heavy metals (Cd, Cr, Ni, and Al) concentrations during and after the drilling operation. For more details please consult Shadizadeh and Zoveidavianpoor, 2008 and 2010.

Elements	Water	Cuttings	Barite	Clay	Chrome-lignosulfonate	Lignite	Caustic
Aluminum	0.3	40,400	40,400	88,600	6,700	6,700	0.013
Arsenic	0.0005	3.9	34	3.9	10.1	10.1	0.039
Barium	0.01	158	590,000	640	230	230	0.26
Cadmium	0.0001	0.08	6	0.5	0.2	0.2	0.0013
Chromium	0.001	183	183	8.02	40,030	65.3	0.00066
Cobalt	0.001	183	183	8.02	40,030	65.3	0.00066
Copper	0.0002	2.9	3.8	2.9	5	5	0.00053
Iron	0.003	22	49	8.18	22.9	22.9	0.039
Lead	0.5	21,900	12,950	37,500	7,220	7,220	0.04
Magnesium	0.003	37	685	27.1	5.4	5.4	0.004
Mercury	4	23,300	3,900	69,800	5,040	5,040	17,800
Nickel	0.0001	0.12	4.1	0.12	0.2	0.2	5
Potassium	0.0005	15	3	15	11.6	11.6	0.09
Silicon	2.2	13,500	660	2,400	3,000	460	51,400
Sodium	7	206,000	70,200	271,000	2,390	2,390	339
Strontium	6	3,040	3,040	11,000	71,000	2,400	500,000
Cobalt	0.07	312	540	60.5	1030	1030	105

Table 1. Elemental composition of drilling fluid constituents (ppm) (Bleier et al., 1993).

A potential source of heavy metals in drilling fluid is from crude itself. Crude oil naturally contains widely varying concentrations of various heavy metals. In the selected well a combination of water based muds (WBMs) and OBMs had used. As shown in Table 2, the major components of WBMs in the investigated site were barite, salt, starch, bentonite, and lime. The metals of greatest concern, because of their potential toxicity and/or abundance in drilling fluids, include chromium, cadmium, and nickel (Neff, 2002). Some of these metals are added intentionally to drilling muds as metal salts or organometallic compounds. Others are present as trace impurities in major mud ingredients, particularly barite and bentonite. One of the major drilling mud additives used in both WBMs and OBMs in the investigated well is barite. The amount of barite used in the investigated well as shown in Table 2 is 702 tonnes. Barite contains variable amounts of heavy metals and it is the main source of heavy metals in the investigated site. Metals concentrations in mud pit of selected well during and after drilling operation are presented in Figure 5. Chromium concentration was detected in the samples at 0–0.08 ppm. Other heavy metals were also at high levels and showed significantly higher values specially by using OBMs: cadmium 0–0.006 ppm, nickel 0–0.024 ppm, and aluminum 0–341 ppm. However, these heavy metal levels are generally above toxic levels. As shown in Figures 5, the concentrations of cadmium, chromium, and nickel increased progressively in the fourth sampling periods because of the contamination of the mud pit with OBMs that was initiated in the fourth sampling period. Concentration of aluminum increased from the first to the third sampling periods, whereas in the fourth period it shows decreased values from 0.05 ppm to 0.006 ppm. Aluminum was not observed in the fifth and sixth sampling periods but maintained an increased value from the seventh to the end of the sampling periods. In the entire study area, chromium levels ranged from 0 to 0.08 ppm but no concentration was observed after the seventh period of the sampling. This can be explained by the storm runoff water at the investigated well site that washes away all these wastes, especially in the mud pits to other locations or seepage from the discharge pits into the surrounding soils. The statistics of the investigated heavy metals are shown in Table 3.

Properties		**24″ hole ≅ 60 m**	**17½″ hole ≅ 1510 m**	**12¼″ hole ≅ 2158 m**	**8½″ hole ≅ 2330 m**
Mud Properties	Mud system	WBM	WBM	WBM	OBM
	pH	10-10.5	10.5-9.8	8-10	9-9.5
	Average salt concentration (mg/l)	2000	185600	297600	380100
	Average calcium concentration (mg/l)	464	2404	3320	231
	YP	11	4-7	6-78	19-27
	PV	35	5-10	8-58	8-12
	Initial Gel	22	3-6	1-13	2
	10 Min. Gel	30	4-8	2-6	3
	Mud lost @ unit (bbl)	0	2588	1252	802
	Density (pcf)	70-62	68-79	79-146	69.5
	Barite (t)	0	27	674.4	0
Mud Material	Salt (t)	2	166	168	15
	Starch (sx)	0	30	727	0
	Bentonite (t)	160	750	0	0
	Lime (sx)	123	69	222	130
	CMS H.V (sx)	0	0	0	17
	IRSATROL(sx)	0	0	0	140
	Diesel (bbl)	0	0	0	615

Note: YP=yield point; PV=plastic viscosity; bbl=barrel; pcf=pound per cubic feet; t=ton; sx=sacks

Table 2. Drilling fluid used in the selected well (Shadizadeh and Zoveidavianpoor, 2010).

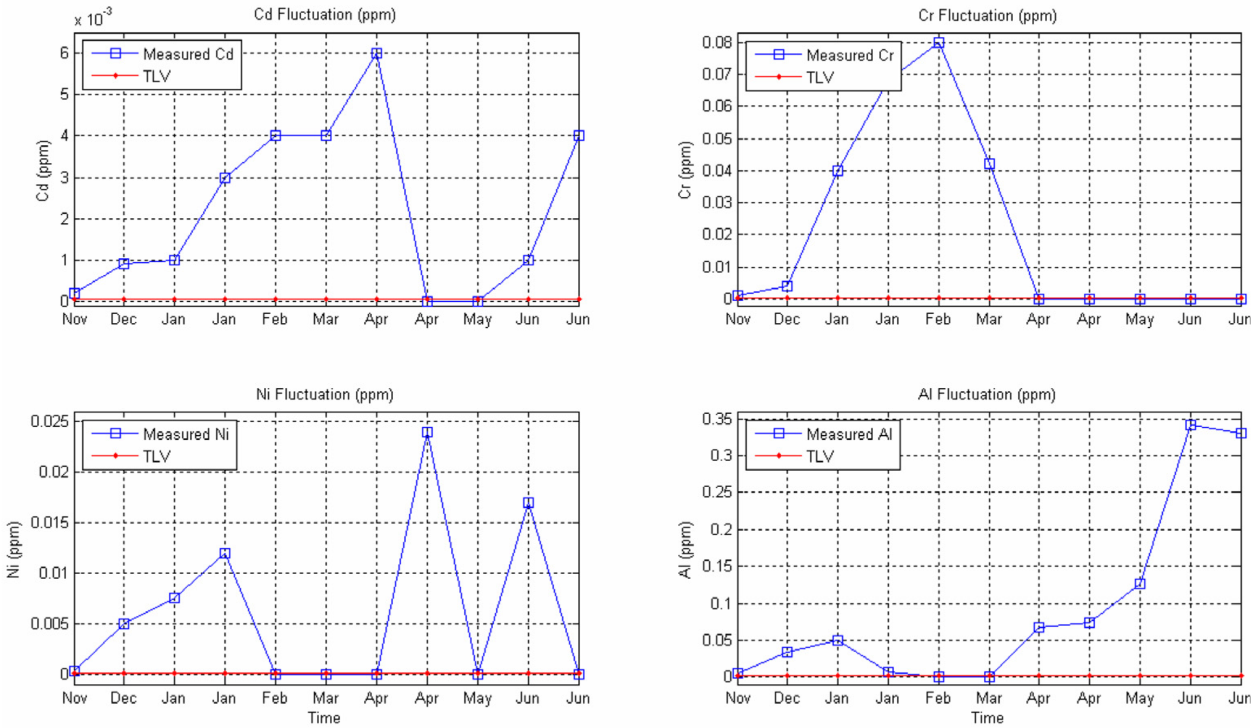


Figure 5. Heavy metals fluctuation during and after drilling operation.

Statistics	Heavy Metals (ppm)			
	Cd	Cr	Ni	Al
Max	0.0060	0.0800	0.024	0.341
Mean	0.0022	0.0214	0.005991	0.09396
Median	1.0000e-003	1.0000e-003	0.0003	0.05
Mode	0.0040	0	0	0
Std	0.0021	0.0306	0.008349	0.1255
Range	0.0060	0.0800	0.024	0.341

Table 3. Heavy metals statistics in the case study

4. Potential effects on natural resources, and minimization strategies

Drilling wastes can harm ecosystems, plants, and animals and cause health problems in humans. Many materials that are released into reserve mud pits also release drilling wastes into the environment, which calls for public awareness as well. When released heavy metals are discharged into unlined pits the toxic substances in the pits can leach directly into the soil and may contaminate groundwater. Additionally, there is no evidence of zero discharge in lined pits. In contrast to most organic pollutants, trace metals are not usually eliminated from aquatic ecosystems by natural processes due to their non-biodegradability. Both toxic and nontoxic heavy metals tend to accumulate in bottom sediments, from which they may be released by various processes of remobilization. Frequently, these metals can move up the biological chain, eventually reaching humans, where they can cause chronic and acute ailments (Ankley et al., 1993). As presented in the previous sections, routine drilling wastes such as drilling muds and cuttings contain a variety of toxic chemicals; they are known to be hazardous to wildlife, livestock, and human health. If pollutants from oil well drilling build up in the food chain, people who consume those natural resources from the contaminated drilled well area could be at risk of health problems such as genetic defects and cancer. For environmental protection, different strategies are considered; (1) restoring the well site to its natural state after drilling, (2) let the liquid to be evaporated, (3) Bioremediation, (4) multi-pit system, and (5) DCRI, which is the focus of this chapter. Because DCRI deal with the initiation and propagation of a fracture in a rock matrix by means of hydraulic pressure, HF will briefly be discussed in the next section.

5. Hydraulic fracturing

Initially, fracturing was a low technology operation consisting of the injection, at low temperature, of a few thousand gallons of napalm into low-pressure reservoirs. Substantially, HF has evolved into a highly engineering and complex procedure. As a technology has improved, so has the number of wells, formations, and fields that can be successfully fractured, increased. The development of high pressure pump units, high strength proppant, and sophisticated fracturing fluids, has meant that deep, low permeability, high temperature, reservoirs can now be fractured (Veatch et al., 1989). This technology is a well-known process, which was originally applied to overcome near wellbore skin damage (Smith, 2006). Since then, it has been expanded to such applications as (1) reservoir stimulation for increase hydrocarbon deliverability, (2) increase drainage area, and decrease pressure drop around the well to minimize problems with asphaltene and/or paraffin deposition, (3) geothermal reservoir recovery, (4) waste disposal, (5) control of sand production, (6) to measure the in-situ stress field and (7) heat extraction (geothermal energy) from deep formations. Obviously, there could be other uses of HF, but the majority of the treatments are performed for the mentioned reasons. HF has made significant contributions to the petroleum industry since its inception (Veatch et al., 1989). By 2009 HF activity has increased 5-fold compared to the investment of a decade earlier and has become the second largest outlay of petroleum companies after drilling (Economides, 2010).

HF is the pumping of fluids at high rates and pressures in order to break the rock. A typical chart of fracturing which shows the common treatment stages is shown in Figure 6. The operation begins with injection of a mixed acid and water named Pre-pad. A mixture of water and a polymer, named Pad, will follows. The fracture will initiated in this stage but contains no proppant. To make the fracture open for fluid flow, a mixture of proppant and the fracturing fluid, which called Slurry will have injected. For more details please consult Daneshy, 2010.

As it clear from section 2, the need has been arises to treat/manage the drill cuttings toward zero discharge by utilization of HF.

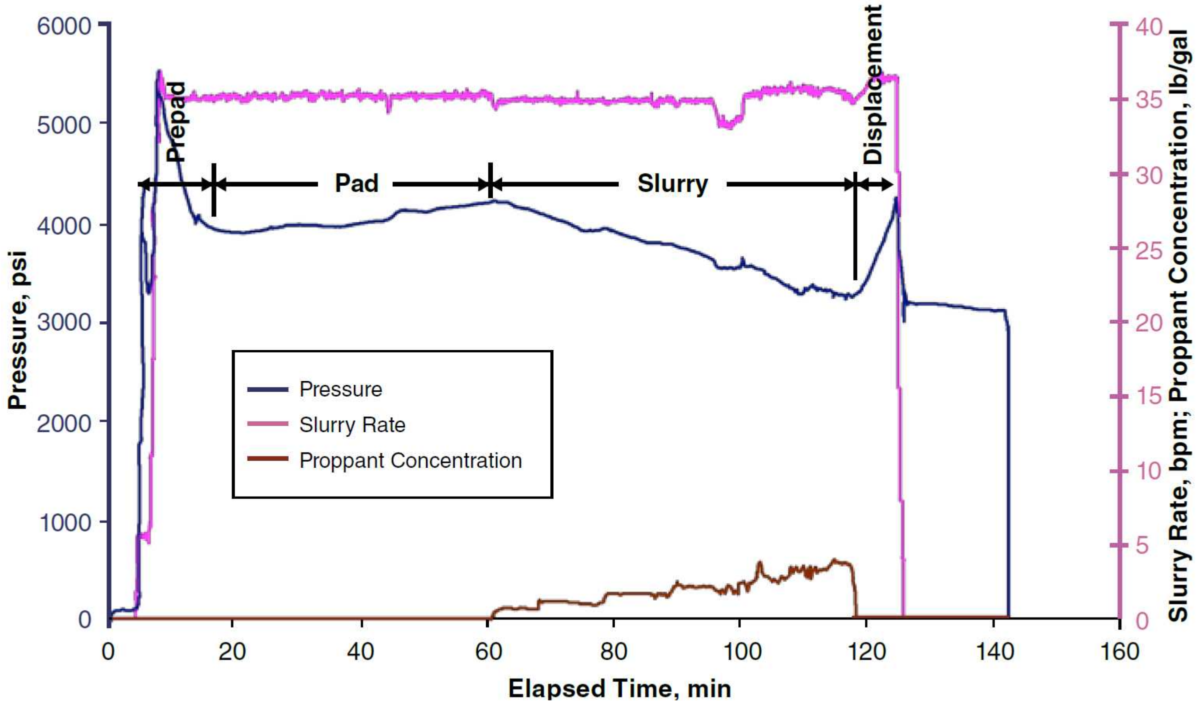


Figure 6. A typical fracturing chart illustrates the steps to HF a well (Daneshy, 2010).

There are both similarities and distinct differences between HF and DCRI which shown in Table 4. More details could be found from Arthur (2010).

Issue	Drill Cutting Re-injection	Hydraulic Fracturing
Target interval	Non Reservoir	Reservoir
Pumping period	Long-term	Short-term
Pumping pressure	Fracture	Fracture
Slurry mixture	Cuttings and fracturing fluids	Proppant and fracturing fluids
Fracture containment study	Essential	Essential

Table 4. Comparison between DCRI and HF.

6. Waste management by DCRI

6.1. An overview

Even though the generation of drill cuttings is a certain result of drilling, those wastes can be treated and/or managed in a number of ways. A summary chart on different drilling wastes management options are presented in Figure 7. As mentioned earlier, the focus of this chapter will be on DCRI.

Valuable literature available regarding the disposal options including: lessons learned concerning biotreating exploration and production wastes (McMillen et al. 2004), successful cases of fixation (Zimmerman and Robert, 1991), converting cuttings into a valuable sources by using vermicomposting (Paulse, 2004), and thermal treatment (Bansal and Sugiarto, 1999).

As summarized in Figure 7, environmental management of drilling wastes may be categorized in three options; waste minimization, recycle/reuse, and disposal. The first and second options are not addressed here. Table 5 shows a comparison among disposal methods which may classified into fixation, thermal treatment, DCRI, and bioremediation/composting. Among the four methods for disposal option that may be considered when deciding on waste management options, the focus of this chapter is on DCRI.

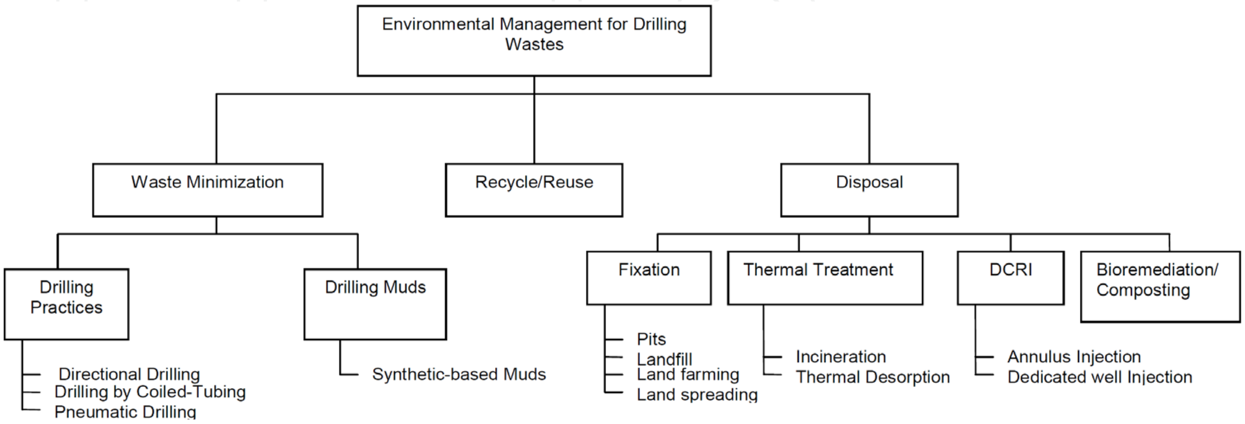


Figure 7. Different approaches in environmental management for drilling wastes

Comparative assessments on alternative disposal options are outlined in Table 5. As clearly shown, environmental impacts and safety risks, which are the most important factors among others, have low level degree and therefore its vulnerability as the best option increases to be adopted as the environmentally friendly drilling waste disposal process. in addition to zero discharge, other advantages of DCRI include; no transportation concerns, no future cleanup responsibilities by the operator, full control over the waste management process, world wide applicability, and its favorable economics. According to Reddoch, (2008): "DCRI is simply the lowest cost, easiest course of action for most drilling operations."

Comparison Factors	Fixation	Thermal Treatment	DCRI	Bioremediation/ Composting
Environmental Impact	Low	High	Low	Medium
Cost	$9-10/bbl [a]	$90/metric ton [a]	$5/bbl [b]	$500/cubic meter [c]
Safety Risks	High	High	Low	Medium
Technical	Low	Medium	High	Medium

$1m^3$=6.29 bbl (US bbl); 1 metric ton=7.1 bbl (for an oil with 0.88 specific gravity)
[a]Bansal and Sugiarto (1999); [b]Reddoch (2008); [c]McMillen and Gray (1994)

Table 5. Qualitative and quantitative comparison in disposal approaches

The question is raised that what is the relationship between environmental management and DCRI? It's clear that DCRI process will maintain waste containment in a target interval with zero discharge and consequently low HSE risks. Other goals such as cost management and asset management are not covered in this chapter. For more details please consult Bruno et al. (2000).

We can visualize DCRI to loss of circulation of drilling fluids in conventional under balanced drilling operation. Also, it's quite similar to HF operation, because we need to propagate the fractures in the selected horizon and this goal will be achieved by utilization of fracture propagation models which conventionally employed in HF treatment.

Cuttings may be re-injected into the annulus of a well being drilled or into a dedicated well. In annulus injection, cutting would be stored until the desired formation is reached. Whereas in dedicated disposal well, one or more dedicated disposal wells would be drilled and drill waste systems put in place in those wells. A schematic of both types of DCRI is shown in Figure 8.

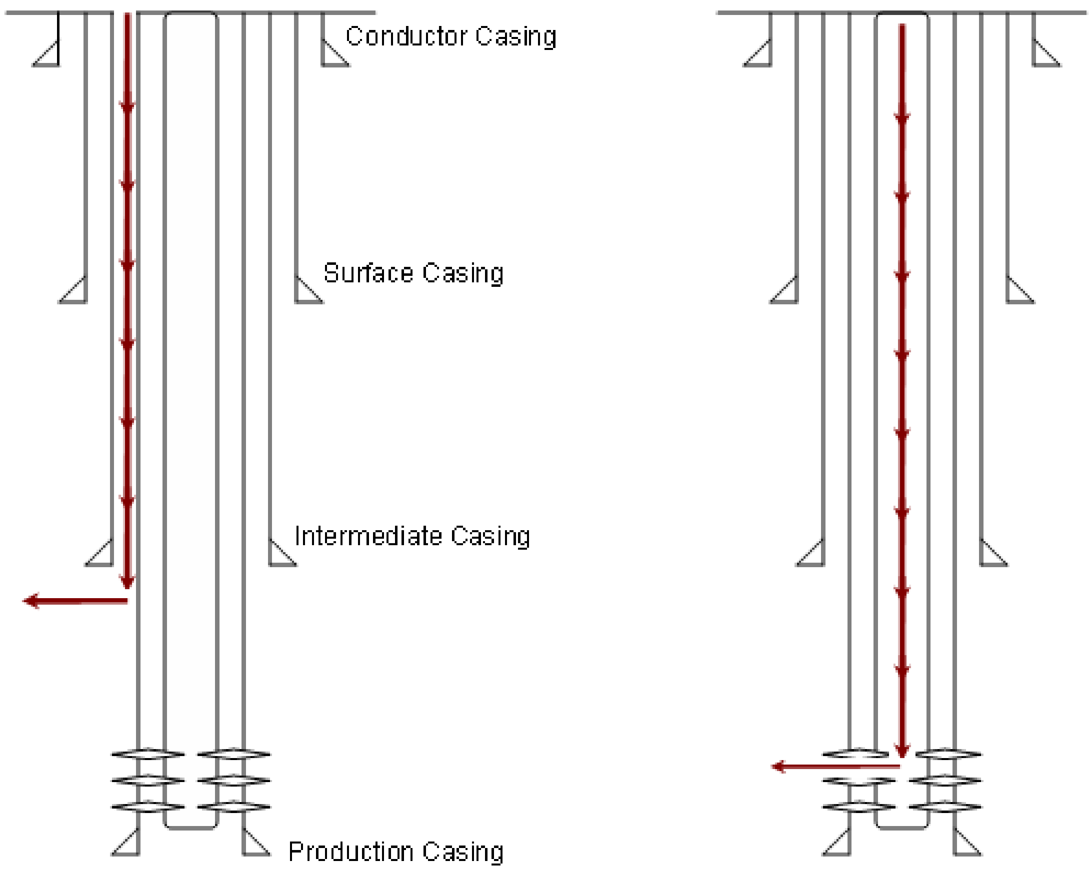


Figure 8. Two major types of DCRI; annulus injection (left) and dedicated well (right).

Drill cuttings may be injected into subsurface geological formations at the drilling site, offshore or onshore and would provide a complete disposal solution. Its worth to note that onshore operations have a wider range of options than offshore operations.

Readers may be asks why this process is called drill cutting re-injection? That's because drill cuttings will be returned back to their origin, deep beneath the Earth's surface.

A sketch of basic setup and flow of DCRI process is shown in Figure 9. Drill cuttings and other oilfield wastes are slurried by being milled and sheared in the presence of water. The resulting slurry is then disposed of by pumping it into a dedicated disposal well, or through the open annulus of a previous well into a fracture created at the casing shoe set in a suitable formation.

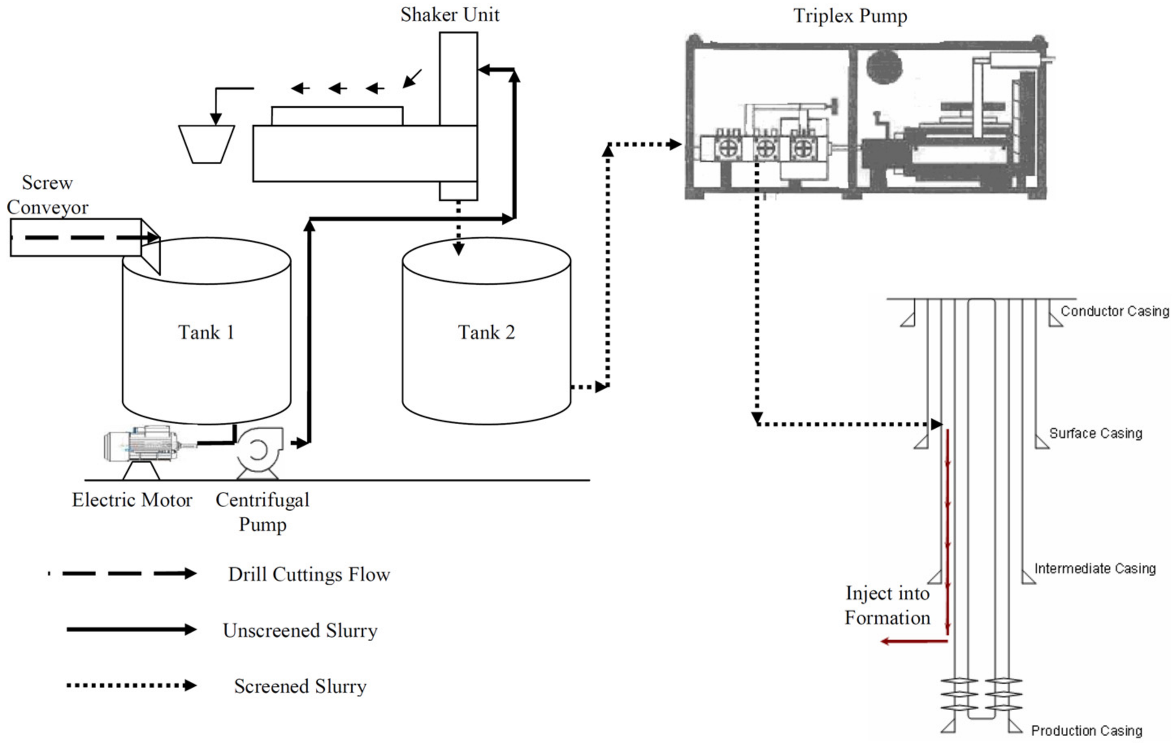


Figure 9. A sketch of basic setup and flow of DCRI

6.2. A case study

In addition to the drill cuttings and drilling fluids, various waste streams need to be handled and disposed of properly include: produced water, contaminated rainwater, scales, and produced sand. DCRI provides a secure operation by injecting cuttings and associated fluids up to several thousand meters below the surface into hydraulically created fractures. In order to guarantee containment within the selected underground formation and perform sufficient design of surface facilities, simulations are performed for the anticipated downhole waste domain.

In this regard, a feasibility study was performed to show the possibility of DCRI in Ahwaz oilfield located in southern Iranian oilfields. The possibility of annular injection and dedicated injection wells was investigated in this study. The objectives were to (1) estimate the volume of drilling waste produced from drilling of each wellbore of the field, (2) select the most appropriate disposal formation in the field, and (3) determine whether the drill wastes can be safely injected into a dedicated well or annular space. Numerous scenarios were considered in the feasibility studies to ensure safe containment of any injected drilling waste. More details could be found by Shadizadeh and Zoveidavianpoor, (2011).

The volumes of drill cuttings and muds, type of utilized mud, and geological information are shown in Table 6. The required data to conduct this study is depicted in Table 7.

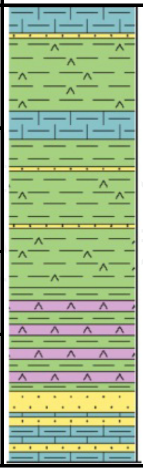
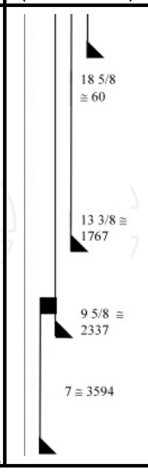
Depth (m)	Formation Name	Column	Setting depth (inch≅m)	Lithology	Hole Size (inch)	Cutting volume (bbl)	Mud volume (bbl)	Mud type
1550	Aghajari			Marl with Sandston bonds	26	132	4400	WBM
1660	Mishan			Marl with Limestone basement	17 1/2	2040	2800	WBM
2332	Gachsaran			Marl, Salt, Anhydrate.	9 5/8	219	3500	WBM
3590	Asmari			Limestone with Sandstone	8 1/2	73	800+400	WBM+ OBM

Table 6. Generalized geologic data along with drill cuttings and mud volumes.

Required data	Description
Injection batch volumes and injection rates	Injection of the slurry is often conducted intermittently in batches into the selected disposal formation, followed by a period of shut-in. depending upon the batch volume and the injection rate, each batch injection may last from less than an hour to several days or even longer.
Minimum in situ stress	Most important in fracture simulation that controls fracture-height growth, fracture azimuth and vertical and horizontal orientation, fracture width, treatment pressures, fracture conductivity, and wastes containment in disposal horizon.
Pore pressure	Very critical parameter to planning and carrying out successful DCRI, because the stress state of the poroelastic medium is directly influenced by pore pressure or reservoir pressure.
Young's modulus	Is the ration of longitudinal stress to longitudinal strain, which has significant effect on fracture geometry, especially on fracture width
Poisson's ratio	Is a measure of the compressibility of material perpendicular to applied stress that has significant effect on fracture geometry
Casing setting depths and injection point	The target which the slurry has to be injected via annulus or dedicated well.
Fluid leak-off data	Means the leaking of fluid from the surface of a fracture into the surrounding rock formation. It's an important parameter controlling the size and geometry of the hydraulically induced fracture.
Slurry rheology	The study of the deformation and flow of matter, that crucial for maintaining zonal isolation.
Fracture toughness	Is an important parameter in fracture modeling and is a measure of a material's resistance to fracture propagation

Table 7. Explanation of required data for DCRI simulation.

In particular, the expense of DCRI requires that the operator knows how the formation will respond to treatment, and whether the treatment design such as selection of pump rates, fluid rheology, accurate rock mechanic properties, pumping schedule and fracture propagation model, will create the intended fracture.

Most 2D models are based on three common models entitles Perkins-Kern-Nordgren (PKN), Khristianovic-Geertsma de Klerk (KGD), and Radial models. The first and second models which assume constant height, are appropriate when the stress contrasts are high between the pay layer and neighboring formations and these contrasts follow lithologic boundaries. For Radial model, its better works in a setting where the fracture grows in a formation of homogeneous stress and mechanical properties so that fracture height is small compared to formation layer thickness. A brief comparison among 2D models is listed in Table 8.

The main advantage of a more advanced method such as pseudo 3D (P3D) over 2D models is that it does not require estimating fracture height, but it does require input of the magnitude of minimum horizontal stress in the zone to be fractured and in the zones immediately above and below.

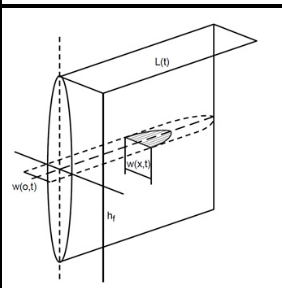
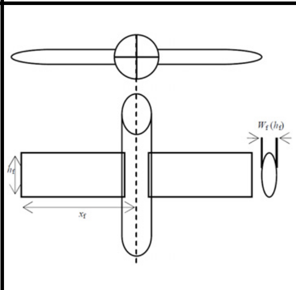
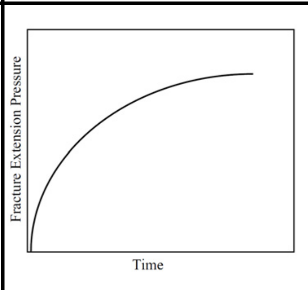
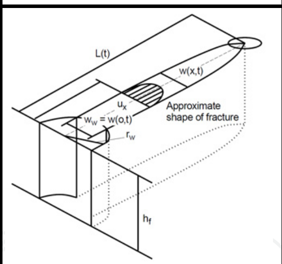
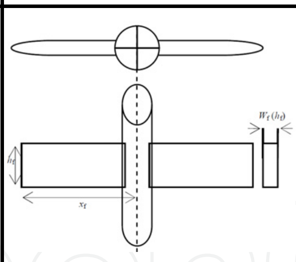
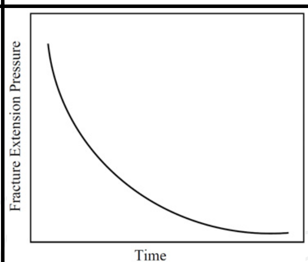
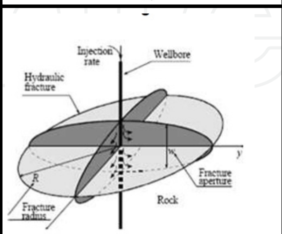
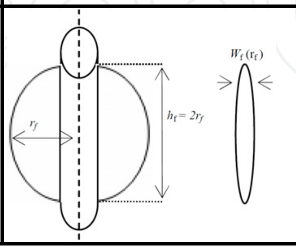
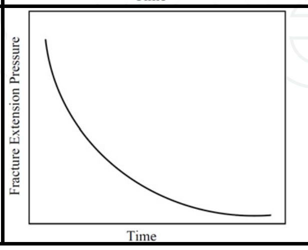
Model Name	Plan View	Cross Section View	Pressure-Time Trend	Description
PKN				Cross section= Elliptical Width ∝ height Width < KGD Length > KGD Suitable when: length>height
KGD				Cross section: Rectangular Width ∝ height Suitable when: length<height
Radial				Cross section= Elliptical Suitable when: length=height

Table 8. Comparison of 2D fracture models

6.2.1. Simulation study

Based on the petrophysical logs, from lithological point of view, the relevant formations are fairly marl, sandstone and limestone with an average rock density 2.33gr/cm3. The vertical stress was calculated by integrating the available bulk density with respect to depth. Vertical stress gradient is calculated as Eq. (1):

$$\sigma_v = 0.433\rho_{OB} = 0.433 \times 2.33 = 1 psi / ft \tag{1}$$

The values of minimum horizontal stress of Aghajari, Mishan, and Gachsaran formations were 1693, 3847, and 4489, respectively which calculated from Eq. (2) is:

$$\sigma = \frac{\upsilon(\sigma_v D - 2p) + p}{1 - F\upsilon} \tag{2}$$

Elasticity of the formations is determined with the sonic log. Table 9 lists the values of the static elastic Young's modulus, Poisson's ration, leak-off coefficient for the different formation zones shown in Table 5. These values are based on the dynamic elastic Young's module obtained from sonic and density logs. Static elastic Young's module values are often two times smaller than dynamic values derived from sonic logs. The elastic Young's module values that are listed in Table 9 are arbitrarily one-half of their dynamic equivalents. The larger than usual values were used in the analysis for these shallower formations.

Zone Name	Zone Height (ft)	Poission's Ratio*	Pore Pressure* (psi)	Fracture Gradient* (psi/ft)	In-situ Stress (psi)	Young's Modulus (MM psi)	Leak-off Coefficient (ft.min $^{-0.5}$)	Toughness (psi.min $^{0.5}$)
Aghajari	5250	0.29	1050	0.650	1693	2	0.00081	1000
Mishan	330	0.31	2567	0.714	3847	2	0.00087	1000
Gachsaran	330	0.36	2878	0.780	4489	2	0.00089	1000

Table 9. Formation properties used in fracture simulations.

Slurry rheology design did not performed in this paper and is beyond the scope of this article; however by considering the cuttings brought out of the wellbore and the drilling muds used in Ahwaz oil field, a reasonable result was earned of rheology characteristics of the injection slurry. It was assumed that the cuttings slurry with final rheological condition would behave in a manner similar to the drilling muds used in Ahwaz oil field. Slurry and solid properties are selected from past DCRI operation in literature (Abou-Sayed et al., 2002), which is also near the nature of selected drilling fluids and cuttings lithology of the Ahwaz oilfield and are presented in Table 10.

Density	1.26 SG
Particle Loading	80/100 mesh proppant at a consternation of 2 PPG
Apparent Viscosity	161 cp ≅ 170 1/S
Non-Newtonian power law indices	N=0.26; k=0.15

Table 10. Physical properties of injected cuttings slurry.

For the scenario of casing injection into a dedicated injection well, the intermediate casing can be set on top of Gachsaran formation. The casing is assumed to perforate at a depth about 50 m under the Aghajari formation and the center of the Mishan formation. The initial fracture is assumed to be at the center of the perforated interval.

6.2.2: Simulation results

After determining all required data, a fracture geometry model was selected for use in the simulation. As described previously, the dedicated injection mechanism is more suitable for the Mishan formation because it is deep enough and consists of limestone lithology in a base that is appropriate for reinjection. In each case, the geometry reported indicates the maximum fracture achieved when slurry is pumped continuously. The simulation study is represented for both dedicated wells that consist of two cases and annulus injection well mechanisms.

Dedicated Well Injection Mechanism

Two cases will be presented in this section, which differs in the magnitude of two parameters; Young's modulus and leak-off coefficient.

Case 1: For a case like Ahwaz oilfield in which the vertical distribution of the minimum in situ stress is uniform, a circular fracture is expected. The formations had Young's modulus and leak-off coefficients as shown in Table 9. For this simulation, the fracturing would initiate from the Mishan formation and broke through the Aghajari formation but was still 4,700 ft. below the surface when 50,000 bbl of slurry had been injected continuously. Table 11 summarizes the results of this simulation. Figures 10 and 11 show predicted the fracture shape plot after injection of 50,000 bbl continuously at 5 bbl/min.

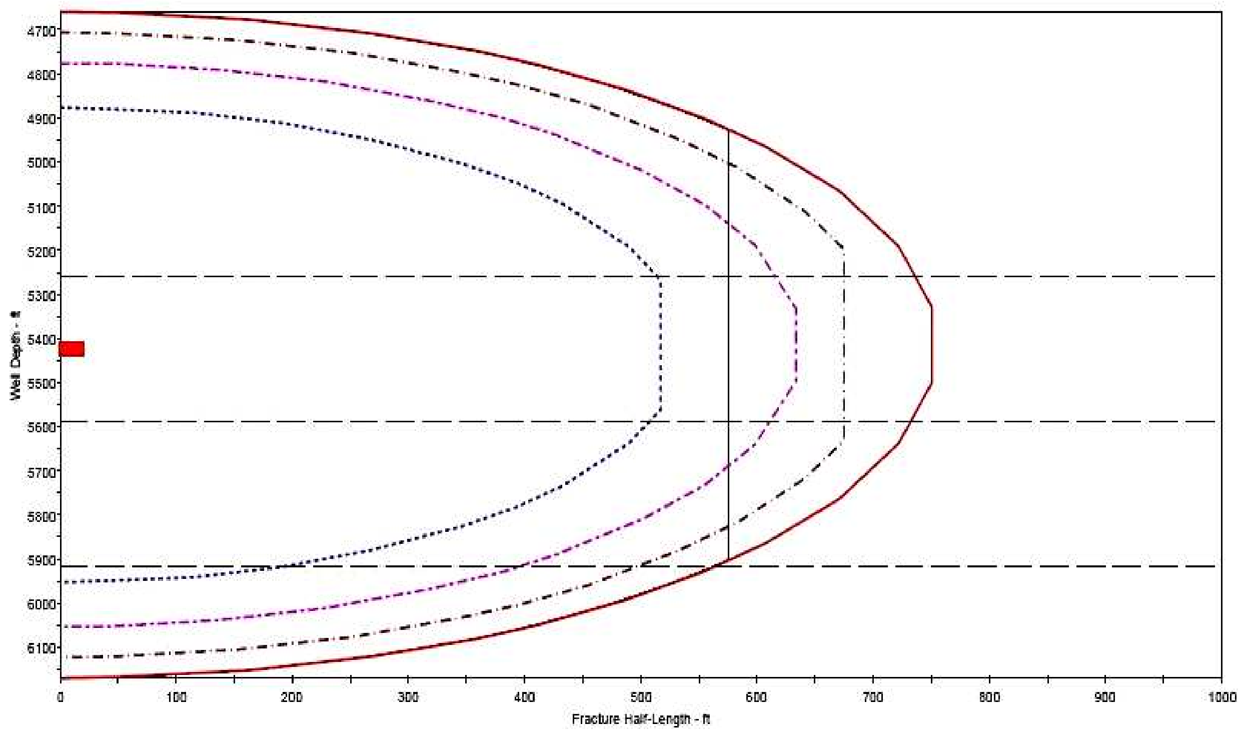


Figure 10. Fracture geometry history- Radial model (case 1).

Case 2: The formations were assumed to have Young's modulus that was twice those listed in Table 9. Also, the leak-off coefficient for formations used was specified as one half of the value listed in Table 9. This extremely large modulus and small leak-off resulted in a much larger fracture. Consequently, this is a very conservative analysis. Even for this very conservative case, the fracture that broke through the Aghajari formation was still 4,550 ft. below the surface when almost 50,000 bbl of slurry had been injected continuously at 5 bbl/min. Table 11 summarizes the results of the fractures created.

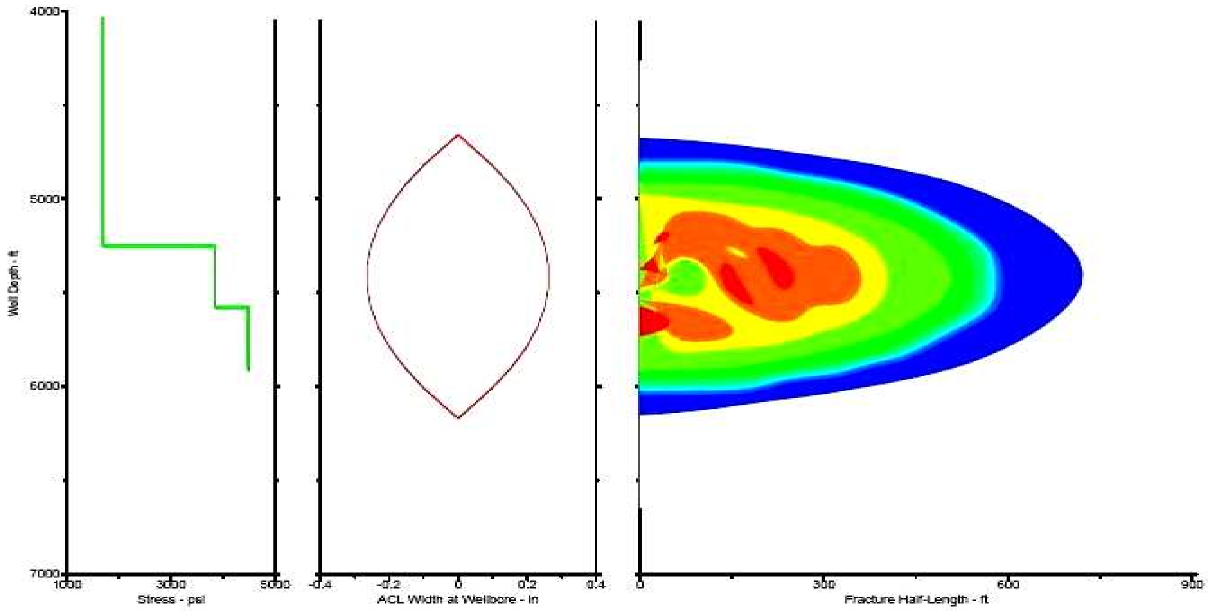


Figure 11. Fracture profile and cuttings concentration- Radial model (Case 2).

Parameters	Case 1	Case 2
Slurry volume (bbls)	50000	50000
Fracture half-length (ft)	576	795
Fracture width at well (in)	0.276	0.237
Net pressure (psi)	71	89
Max surface pressure (psi)	1755	1807
Shut-in time (hrs)	13	26

Table 11. Simulation's results of dedicated well injection.

Annulus Well Injection Mechanism

Annulus injection is only possible if the annulus of an intermediate casing string in an existing well is open to a suitable subsurface formation and this well satisfies a range of screening criteria. The allowable injection pressures for annulus injectors are often lower than the allowable pressures for dedicated wells because of casing burst and collapse limitations for annulus injectors. By considering the lithology and casing design of Ahwaz oilfield, it is concluded that the planned slurry injection would occur in an 18 5/8-in./13 3/8-in. annulus. Other annuli are not possible for injection because they are open to unsuitable subsurface formations. To prevent the upward migration of injected wastes to the surface, the 18 5/8-in. casing string should set at about 1,000 ft. and cement back to the surface, and the 13 3/8-in. string should cement back to 1,500 ft. below the previous casing shoe. This provides a window across the Upper Miocene marl and sandstone of Aghajari formation. For this simulation, the fracturing initiated from the Aghajari formation and grew toward the surface but was still 500 ft. below the surface when 15,000 bbl of slurry had been injected continuously. Table 12 presents the different parameters of the fracture created. Figure 12 shows the predicted fracture shape plot after injection of 15,000 bbl continuously at 5 bbl/min.

Parameters	Radial Model
Slurry volume (bbls)	15000
Fracture half-length (ft)	230
Fracture width at well (in)	643
Net pressure (psi)	2.39
Max surface pressure (psi)	968

Table 12. Simulation results of annular well injection.

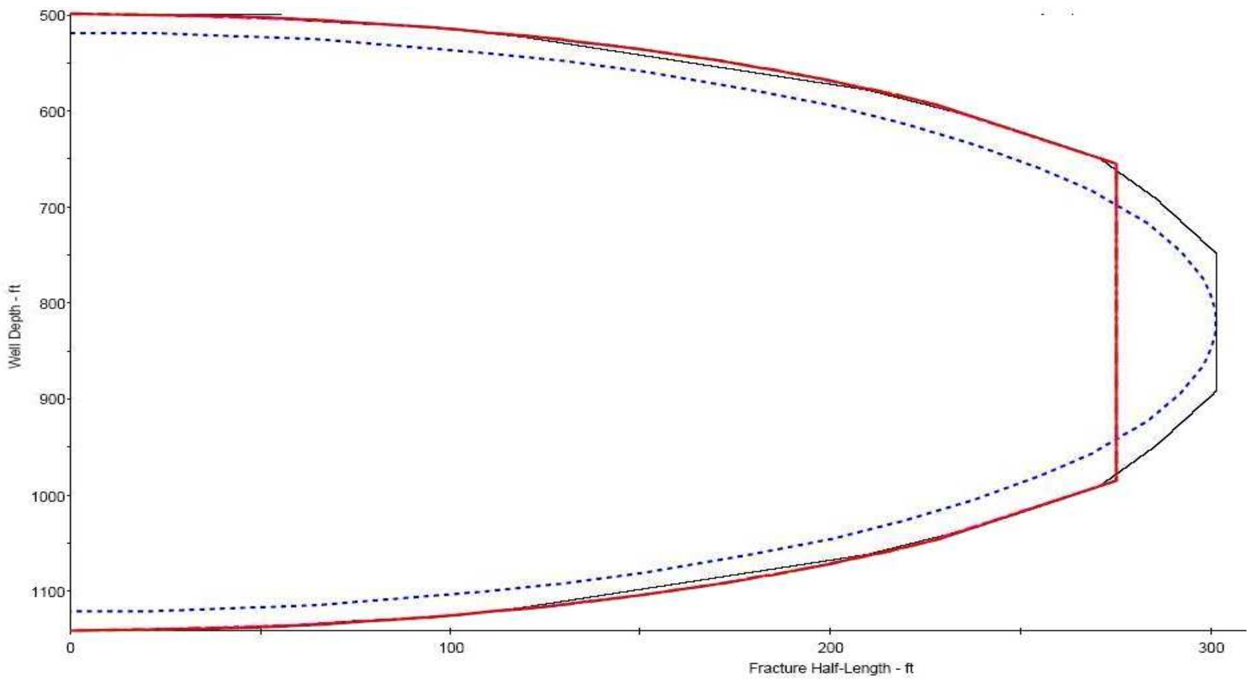


Figure 12. Fracture geometry history- annular injection well (Radial model)

7. Discussion and conclusions

Assessment of environmental impacts of drilling operations and searching for the methodologies to protect nature and resources against negative impacts has become an interesting topic during the last thirty years in upstream petroleum industry. The necessity of environmental management in drilling operation, lessons learned, and a brief list of mitigation options from wastes generated by drilling operations in a southern Iranian oilfield were documented previously (Shadizadeh and Zoveidavianpoor, 2008, 2010). Most of the drilling wastes sources in the oilfields are OMBs and oily cuttings associated with them. Unfortunately, lack of demanding regulations regarding drilling waste discharge leaves room for drilling companies to leave the waste in the nature without treating them (Shadizadeh and Zoveidavianpoor, 2008, 2010). This chapter tried to study the possibilities of waste prevention and zero discharge by utilization of serviceable methods in drilling well sites. So, the feseability study of DCRI at Ahwaz oilfield was initiated and conducted to fulfill the needs of growing upstream petroleum industry in Iran. This article focuses on the design aspect of the technology. Design guidelines are given to include data required for project planning, injection scheme (annulus versus dedicated well) selection, injection well and disposal formation identification, subsurface fracturing simulation, and waste containment. Operational procedures such as slurry rheology were the area of investigation in this study; however, it was determined as input data for simulation that has conformity with the nature of selected drilling fluids and cuttings lithology of the Ahwaz oilfield. Well design requirements and estimation of disposal capacity in each of the injection schemes was performed. This study shows that the DCRI study at Ahwaz oilfield is practical by considering some potential risks involved in any DCRI job. It was determined that by using HF technology, drilling wastes could be reinjected to the Mishan formation or even a shallow formation such as the Aghajari formation without propagation of the fractures to the surface or near wellbores. The thickness of the Aghajari formation provides an appropriate barrier to upward growth of DCRI at the Mishan formation through a dedicated injection well. A dedicated injection well is more typical of longer-term, permanent injection operations and is more common onshore (Keck, 2002). It is simulated that a large amount of drilling waste can be safely injected to Mishan formation. The maximum surface pressure required to inject the slurry is in a range of 1,500 to 2,000 psi, which is completely reasonable with the current surface facilities. The propagation of the fracture to the surface showed to be efficient and safe in the two cases performed in the dedicated well injection scheme. The simulation results confirm that the drilling wastes produced from each wellbore could be injected through annulus of the same wellbore while drilling. The selected annulus for annular reinjection in Ahwaz oilfield is not very favorable because the injection point is close to the surface. As described before, other annuli are not suitable due to abnormal pressure or hydrocarbon bearing. The annular reinjection at Ahwaz oilfield has many serious risks that need a careful job planning. However, the amount of drilling wastes from a typical wellbore is not high and the simulations confirm that 15,000 bbl wastes from a typical wellbore can be injected without serious danger. Advantages and disadvantages of annular and dedicated well injectors are presented in Abou-Sayed and Guo (2001).

It should be noted that the simulations represent upper-bound predictions of the fracture geometry because low leak-off and high Young's modulus is assumed in different formations. In reality, even a very limited change in the amount of fluid leak-off, coupled with intermittent batch injection of slurry, would result in a significantly reduced fracture area. The analyses confirm the integrity and suitability of the injection operations and ensure safe application of this technology at Ahwaz oilfield.

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8. References

Abou-Sayed, A. S., Quanxin G., McLennan, J. D. and Hagan, J. T. (2000). Case studies of waste disposal through hydraulic fracturing. Presented at the Workshop on Three Dimensional and Advanced Hydraulic Fracture Modeling, held in conjunction with the Fourth North American Rock Mechanics Symposium, July 29, 2000, Seattle.

Abou-Sayed, A. S., and Guo, Q. (2001). Design considerations in drill cuttings re-injection through downhole fracturing. Paper IADC/SPE 72308 presented at the IADC/SPE Middle East Drilling Technology, Bahrain. October 22–24.

Ankley, G. T., Mattson, V. R., Leonard, E. N., West, C. W., and Bennett, J. L. (1993). Predicting the acute toxicity of copper in freshwater sediments: Evaluating the role of acid-volatile sulfide. Environ. Toxic Chem. 12:315–320.

Arthur, J.D., "A Comparative Analysis of Hydraulic Fracturing and Underground Injection", Presented at the GWPC Water/Energy Symposium, Pittsburgh, Pennsylvania. September 25-29, 2010.

Bansal, K. M. and Sugiarto, (1999). Exploration and Production Operations-Waste Management A Comparative Overview: U.S. and Indonesia Cases. Paper SPE 54345 presented at the SPE Asia Pacific Oil and Gas Conference, Jakarta, Indonesia, April 20-22.

Bleier, R., Leuterman, A. J. J., and Stark, C. (1993). Drilling fluids making peace with the environment. J. Petrol. Tech. 45:6–10.

Bruno, M., Reed, A. and Olmstead, S. (2000). Environmental Management, Cost Management, and Asset Management for High-Volume Oil Field Waste Injection Projects. Paper SPE 51119 presented at the IADC/SPE Drilling Conference held in New Orleans, Louisiana, 23–25 February 2000.

Daneshy, A. (2010). Hydraulic Fracturing to Improve Production. The Way Ahead: Tech 101. 6(3), 14-17.

Economides, M. J. (2010). Design Flaws in Hydraulic Fracturing. Paper SPE 127870 presented at the SPE International Symposium and Exhibition on Formation Damage Control. 10-12 February. Lafayette, Louisiana, USA.

Keck, R. G. (2002). Drill cuttings injection: A review of major operations and technical issues. Paper SPE 77553 presented at the SPE Annual Technical Conference and Exhibition, San Antonio, TX, September 29–October 2.

McMillen, S. J. and Gray, N. R. (1994). Biotreatment of Exploration and Production Wastes. Paper SPE 27135 presented at the Second International Conference on Health, Safety & Environment in Oil & Gas Exploration and Production, Jakarta, Indonesia, January 25-27.

McMillen, S. J., Smart, R. and Bernier, R. (2004). Biotreating E&P Wastes: Lessons Learned from 1992-2003. Paper SPE 86794 presented at the 7th SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Calgary, Alberta, Canada, 29-31 March 2004.

Neff, J. M. (2002). Bioaccumulation in Marine Organisms. Effects of Contaminants from Oil Well Produced Water. Amsterdam: Elsevier Science Publishers. ISBN: 978-0-08-043716-3. 452 pages

Paulse, J. E., Getliff, J. and Sørheim, R. (2004). Vermicomposting and Best Available Technique for Oily Drilling Waste Management in Environmentally Sensitive Areas. Paper SPE 86730 presented at the 7th SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Calgary, Alberta, Canada, 29-31 March 2004.

Reddoch, J. (2008). Why cuttings reinjection doesn’t work everywhere—or does it? World Oil, January 2008, 69-70.

Shadizadeh, S. R. and Zoveidavianpoor, M. (2010) 'A Drilling Reserve Mud Pit Assessment in Iran: Environmental Impacts and Awareness', Petroleum Science and Technology, 28: 14, 1513-1526. ISSN: 1091-6466 print/1532-2459 online

Shadizadeh, S. R., and Zoveidavianpoor, M. (2008). Environmental Impact Assessment of Onshore Drilling Operation in Iran, Abadan, Iran: Petroleum University of Technology.

Shadizadeh, S. R., Majidaie, S. and Zoveidavianpoor, M. (2011) 'Investigation of Drill Cuttings Reinjection: Environmental Management in Iranian Ahwaz Oilfield', Petroleum Science and Technology, 29: 11, 1093-1103. ISSN: 1091-6466 print/1532-2459 online.

Veatch, Jr. R. W. Moschovidis, Z. A. (1989). An Overview of Recent Advances in Hydraulic Fracturing Technology. Paper SPE 14085 presented at the International Meeting on Petroleum Engineering. 17-20 March. Beijing, China.

Zimmerman, P. K. and Robert, J. D. (1991). Oil-Based Drill Cuttings Treated by Landfarming. Oil & Gas Journal, 89(32): 81-84.