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MEMOIRE

Pour obtenir le Diplôme de Master

Option : Production professionnel

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-THEME-

CONTROL SAND PRODUCTION

Soutenue le : 19 / 06 / 2021 devant la commission d'examen

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DEDICATION

The memory To of my mother, Salma the powerful and the gentle soul who raised me, supported me during my career and for her good reputation that she left after leaving this world, may Allah mercy her.

To my father Tidjani the kindest person in the world my hero and my ideal.

To my brothers and sisters for their eternal love, may Allah bless you all.

And finally to my supervisor thank you for your guidance and support.

DJIDOUR FAOUZI

DEDICATION

I dedicate this thesis:

-To my dear mother,

-To my dear father,

Who sacrificed a lot for me,

-To my brothers and to my dear sisters,

-To all my family,

-To my friends,

-At the end, I warmly dedicate this dissertation to my pairs.

KEDAID KAMEL

DEDICATION

"فال الله تعالى"وقل ربي زدني علما"

I would like to dedicate this thesis:

To the deceased grandparents Al-Mabrouk and Mohammad, may ALLAH have mercy on them, as a testament to their dedication and continuous support throughout my years of study and their limitless sacrifices and moral comfort during their lifetimes ;

Without forgetting Uncle Taher and Uncle Ahmed, may ALLAH have mercy on them, her goodness is still connected us until today ;

To my mom Amel, my dad Belgacem,my brother,my sisters specially IMAN ;

To all the family « ALL SOLTANI » near or far, here or there ;

My friends : A/ ENNOUR KH, CHETIOUI « SALIM, DJAMEL & KARIM », LAKHEDHER, AISSAM, RAMZI, A.EL-MALEK... !

To those who contributed, even with good and sincere intention.

BRAH!M SOLTAN!

ملخص:

لاشك آن إنتاج الرمال مشكلة مرتبطة بمعظم رواسب النفط في العالم. مما دفع ذلك شركات النفط إلى مواصلة البحث عن حلول لتقليل إنتاج الرمال في صناعة النفط والغاز بمرور الوقت. تم عرض مناقشة حول آلية التحكم في إنتاج الرمال (كيميائية وميكانيكية) مع إبراز العوامل الرئيسية المؤثرة في إنتاج الرمال. إن القدرة على التنبؤ بموعد فشل التكوين وإنتاج الرمال هي الأساس لنوع إستراتيجية إدارة الرمال المستخدمة. لذلك تم تطوير منهجية فعالة للتنبؤ بالرمال والتحكم فيها لتجنب المخاطر التي قد تنجم عن إنتاج الرمال.

الكلمات المفتاحية: إنتاج الرمال، استمرارية الإنتاج، التنبؤ، إدارة الرمال،المخاطر.

Résumé:

Il ne fait aucun doute que la production de sable est un problème associé à la plupart des gisements de pétrole dans le monde, ce qui a incité les compagnies pétrolières à continuer de rechercher des solutions pour réduire la production de sable dans l'industrie pétrolière et gazière au fil du temps. Une discussion sur le mécanisme de contrôle de la production de sable (chimique et mécanique) a été présentée, mettant en évidence les principaux facteurs affectant la production de sable. La capacité de prédire quand la formation et la production de sable échoueront est la base du type de stratégie de gestion du sable utilisée. Par conséquent, une méthodologie efficace de prévision et de contrôle du sable a été développée pour éviter les risques pouvant découler de la production de sable.

Mots clés: production de sable, continuité de production, prévision, gestion du sable, risques.

Abstract:

There is no doubt that sand production is a problem associated with most of the oil deposits in the world, which has prompted oil companies to continue to search for solutions to reduce sand production in the oil and gas industry over time. A discussion on the mechanism of controlling sand production (chemical and mechanical) was presented, highlighting the main factors affecting sand production. The ability to predict when formation and sand production will fail is the basis for the type of sand management strategy used. Therefore, an effective sand prediction and control methodology has been developed to avoid the risks that may arise from sand production.

Keywords: sand production, production continuity, forecasting, sand management, risks.

FIGURES LIST

TABLES LIST

Frac-and-pack: fracturing and packing.

DST: Drill stem tests.

Log: Logging.

µm: micrometre / micron.

UCS: unconfined compressive strength.

YM: Young's Modulus.

BHN: Brinell Hardness.

g: gram.

m: meter.

pptb: pounds per thousand barrels .

Lb: pound or pound-mass (US).

MMscf: million standard cubic feet.

Pa·s: pascal-second.

HCl: hydrogen chloride.

HF: hydrogen fluoride.

KCl: potassium chloride or potassium salt.

C_3H_8O: Isopropyl alcohol.

EGMBE: ethylene glycol mono-butyl ether.

n_s: number of slots per 1 m of the liner.

α_s: total external surface area of the liner.

F_s: external surface area per meter of the liner.

W_s: width of slotted aperture.

L_s: slot length.

m: the number of links between slots over the pipe cross section area.

D_f: is the final (expanded) pipe outer diameter.

D_i: is the initial outer diameter of the pipe.

w_s :is the sloth width before expansion.

π: 3.14159265359

%: percent sign.

HP: high pressure.

HT: high temperature.

H_2S: hydrogen sulfide.

C– factor: configuration factor.

V_p: fluid velocity.

ρ_m: mixture density.

ft: feet.

MEM : mechanical earth model.

DC : Datacom.

SN : Sample number.

KPa : kilo pascal.

PROSPER : PROduction and **S**ystems **PER**formance analysis software

IPM : Integrated Production Model.

SCAL: Special core Analysis Laboratory.

SEM : Scanning Electron Microscopy.

XRD : X-Ray Diffraction.

CL : Cathode-Luminescence Microscopy.

PSD : Particle (or grain) Size Distribution analyses.

TS : Thin Section analysis/ point counting (petrographic microscope).

PDF: probability distribution functions.

TABLE OF CONTENTS

Introduction:

Hydrocarbon serves as the key force to run the civilization since long. Production of oil and gas from the reservoir is not an easy process rather the scopes of uncertainty are always there. The route of these most valuable energy resources from the reservoir to the surface is followed by a supersensitive technical approach.

Generally, the fluid flows for the differences of pressure in different segments of the system. The pressure differential acts as the main driving force to lift them into the surface through production string. But there lies some problems to facilitate the oil or gas to come in the surface. It’s a very common scenario that wells are frequently producing solid particles along with oil or gas which not only cause serious distortion in the production profile of the well but also damage the equipment of the production system. It’s the most common and inevitable problems associated with hydrocarbon production. It’s a tough task to completely eradicate the issue but can be minimized at a greater extent.

As completion technology is getting matured day by day, the field of application continues to expand to increasingly challenging environments such as the poorly consolidated, high-permeability, high-productivity, classic reservoirs. The task of applying downhole go with the flow control to those areas is their propensity to provide full-size quantities of formation solids. At the great of times, sand production isn't correct for traditional completion device, and wise-crowning glory device is confronted with similar challenges. But the prime problem for the production experts lies on the adjustment of the strong production scenario to a minimal volume [1].

Problem Statement:

Sand production in unconsolidated formations has brought heavy injury for the petroleum industry moving into the next century. The history of sand production dates back to the 1900's. Sand production problems have presented major obstacles to well performance and have resulted in significant lost production potential.

Due to sand problems, this involves many challenges associated with drilling wells such as tubing erosion, mud losses, formation damage and wellbore instability. In terms of sand management, there are two main classes of techniques available; sand prevention by passive method and sand control using *mechanical exclusion* or *chemical consolidation.*

Objective of the study:

The objective of this thesis is limited to the literature study for various methods are available for treating sand production the main activities are:

- ✓ Learning about a problem in the petroleum fields, about which we do not have sufficient information locally.
- ✓ An attempt to approximate the effectiveness of treating some petroleum problems based on laboratory experiences and practical models.
- ✓ Review the state of the art of sand forecasting and techniques for controlling and managing sand.
- ✓ Development of an effective methodology for predicting, controlling and managing sand.

Methodology:

The methodology that we will follow to understand the correct pattern leading to the goals is as follows:

- ➢ Reviews of literature on the topic.
- ➢ A summary of these technical materials and highlighting the important factors (parameters) that affect sand prediction, control and management.
- ➢ Integrations. Sand forecasting and control to develop a new practical approach to sand production management.
- ➢ Highlighting the mechanisms that control sand production and their importance and effectiveness.

Structure of the thesis:

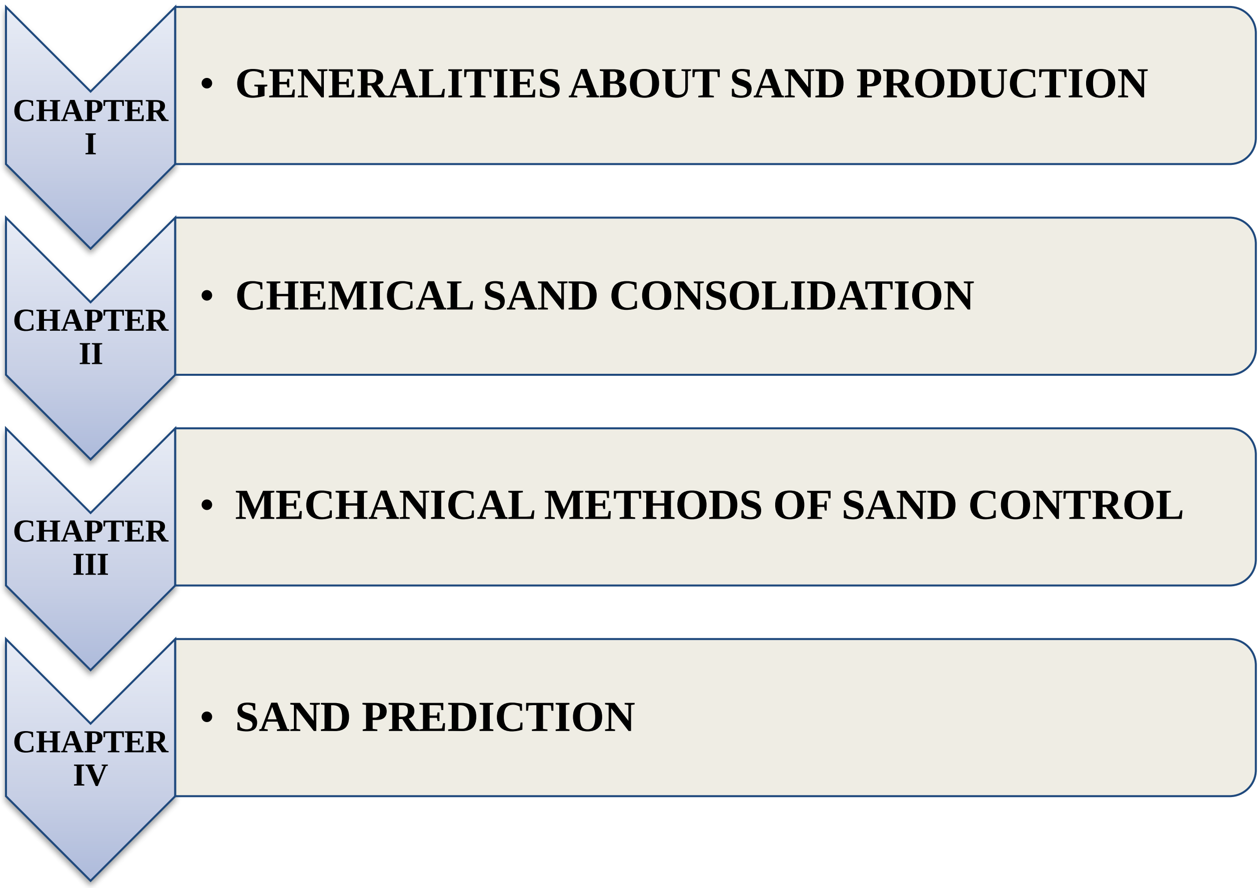
The thesis begins with a general introduction to the problem presented in advance, the problematic and the objectives of the work, subsequently we have:

CHAPTER I: Generalities about sand production: The chapter deals with general concepts to approximate the image of the topic to be discussed.

CHAPTER II: Chemical sand consolidation: Most of the chemical mechanisms used to raise the severity of the cohesion of sand grains in the reservoir to avoid their transfer from the reservoir to the well.

CHAPTER III: Mechanical Methods of Sand Control: Mechanical mechanisms implemented in the process of completing the well will help either control sand or not produce it according to the different treatment conditions for each field.

CHAPTER IV: Sand prediction: The backbone of the topic is embodied in this chapter, as it highlights the importance of forecasting by highlighting field and other laboratory experiments, as well as developing an effective methodology that enhances the level of confidence when confronting the problem and summarizing the burdens of suffering during treatment.



The study organization schematic diagram

CHAPTER I:

GENERALITIES ABOUT SAND PRODUCTION

1. Introduction:

Sustainable energy solution is the prime goal in the present world. Hydrocarbon production is serving as the key source of energy from the primitive time. Though the scenario is changing and the concentration is shifting towards renewable energy but the hydrocarbon based energy system still prevails mostly. So it's very important to ensure the sustainable production of oil and gas. But some problems may rise during this production phase of oil or gas; production of solid is one of them. Generally, the solids are termed as; 'sand' and excessive flow of sand can significantly deteriorate the production of hydrocarbon. Reservoirs with much solid production were declared abandoned previously. But later on, engineers have invented some techniques to curtail the rate of this sand production and found that worthy to apply practically [2].

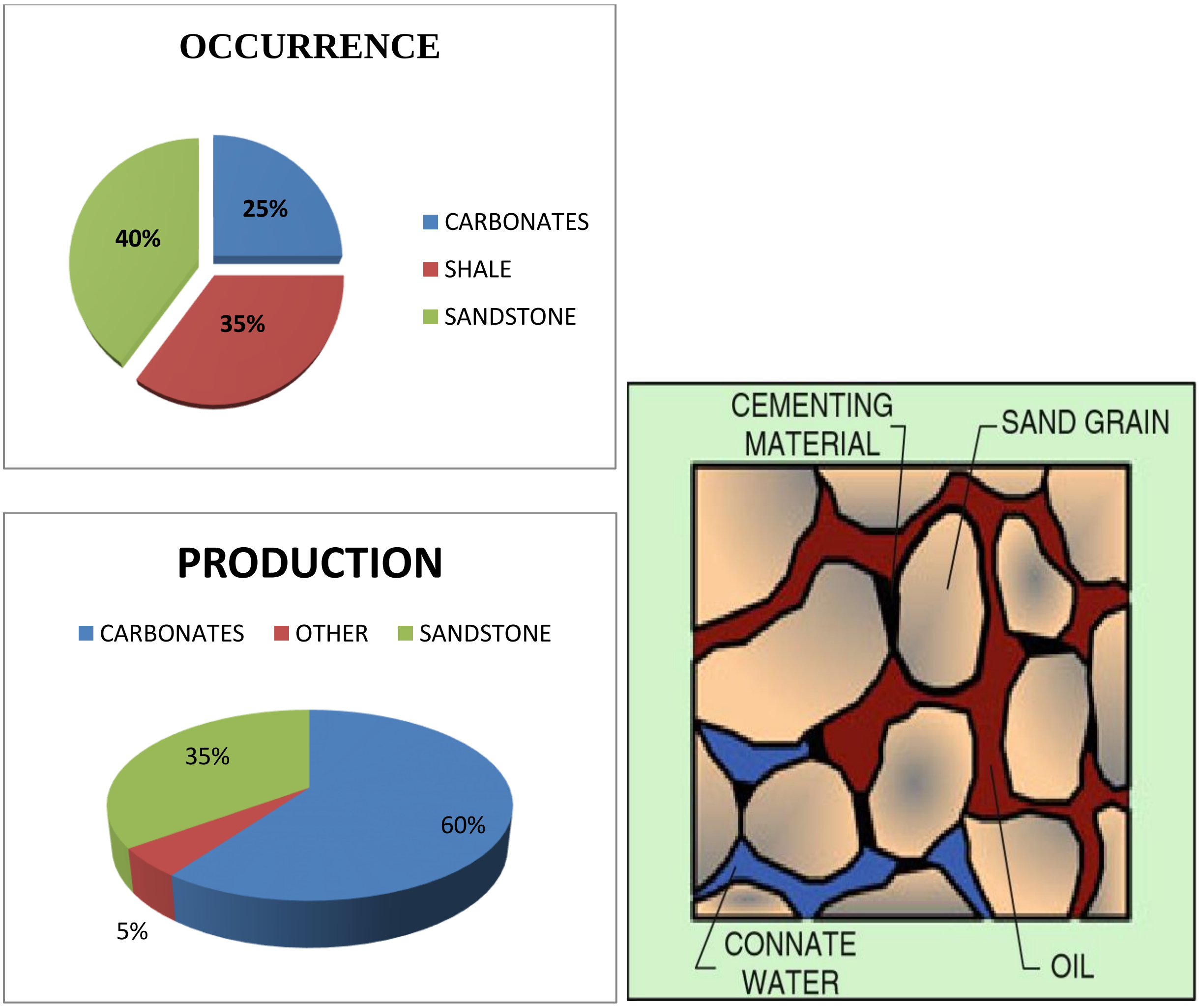


Figure I.1: Occurrence and production of oil and gas [3].

2. Definition and Mechanism:

2.1. Definition:

Sand control is a balance between letting a certain amount of sand pass through sand control solution, without blocking or corrosion of solution.

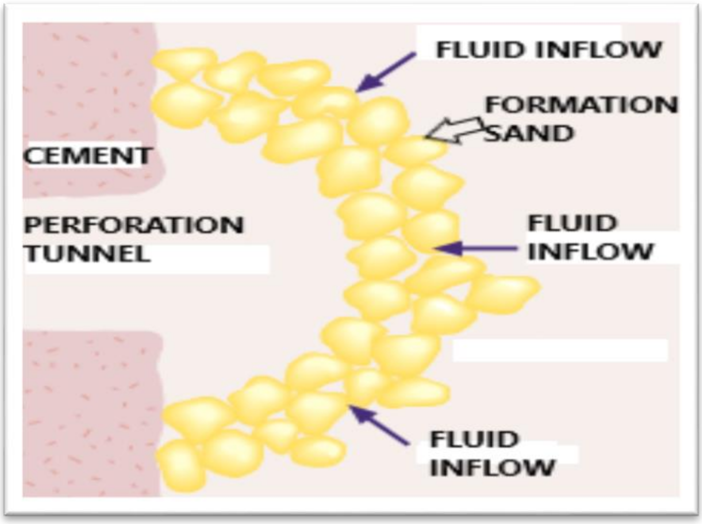


Figure I.2: Doorway to the wellbore. A stable arch is believed to form around the entrance to a perforation cavity.

2.2. Mechanism:

Sand is produced from the formation when the stress applied on the formation is greater than the formation compressive strength [3].

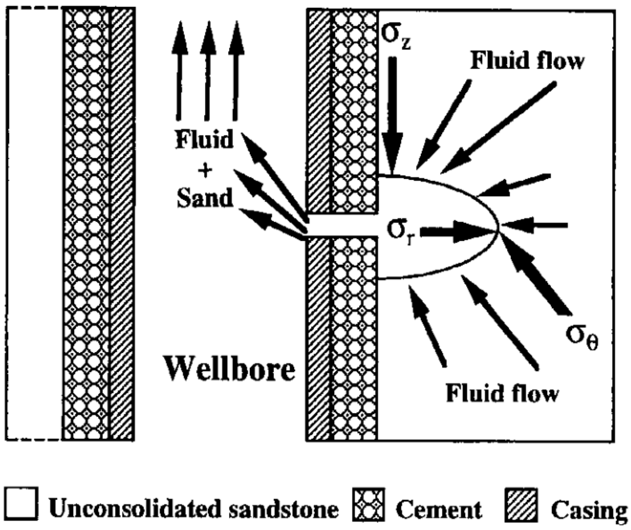


Figure I.3: Sand production mechanism with the flow

3. Historical approaches of sand production control:

Conventional sand control methods, such as chemical consolidation, wire wrapped screens, gravel packing, frac-and-pack, expandable screens, etc., are implemented based on a sand exclusion philosophy: definitely not any sand in the production equipments can be accepted. On the other hand, to avoid sand influx totally, the conventional method is to minimize the production rate to reduce the amount of sand entering the wellbore. The strategy to control or exclude the sand formation is based on the analysis of sand prediction. As a result, it has led to improvement of various numerical approaches to predict the sand production onset [5.6].

Therefore, sand influx is frequently considered as a parameter that limits the production rate (and thereby effects the pay back of the project) through the induced production limitations set via mounted sand control techniques, flow rate losses due to equipment failures and workovers, and induced production restrictions that took place at low maximum sand-free rate limits. Nevertheless, sand influx is associated with a mechanical failure and formation rock dilation and the removal of damaged component [7.8].

The heavy produced oil wells are still to-date the common extensive field validation of the reliability and cost-effectiveness of sand management. This method is considered a modified combination of practices to describe the safety confines at which sanding can be well thought-out operatively tolerable. In this case, the expenditures of a too-traditional method should be avoided or delayed, and also at the same time improved well productivity from continuous well clean-up is succeeded.

4. Sand prediction:

Sand prediction is an essential step in the reservoir evaluation and analysis to predict the possibility of sand production and choose a proper control method. Some of the analytical techniques used for sand prediction include:

(1) Logging analysis,
(2) Core-based tests,
(3) Numerical simulators,
(4) Drill stem tests (**DST**).

4.1. Logging analysis:

The sonic log and porosity log are the two important log data, which are used in the formation evaluation for sand prediction. The sonic log records the transit time, which is the time necessary for the sound wave to travel within the reservoir formation.

(1) The shorter travel time less than 50 μm seconds indicates that the sand is hard, has low porosity and high density.

(2) On the other hand, the longer travel time more than 95 μm seconds indicates that the sand is soft, has high porosity and low density.

To utilize such method, calibration with specific geologic formations is required.

Formation porosity is utilized as a guideline to indicate whether if the sand control is required. If the porosity is higher than 30%, then the requirement of sand control is needed due to the lack of formation consolidation in contrast with the porosity smaller than 20%, which is unlikely to have sand control due to consolidation. Therefore, the porosity within the range of 20–30% is where ambiguity frequently presents [9].

Table I.1: Table of sand consolidation based on UCS Test.

Description	UCS(psi)	Porosity%	YM (psi)
Zero strength dry sand	0	<35	<50,000
Very weak damp sand	<200	<30	<300,000
Weakly cemented	<500	<25	<500,000
Weak more cemented	<1000	<22	<1,000,000
Gray area	<4000	<20	<50,000
Consolidated rock	<5000	<18	<3,500,000

4.2. Core-based analysis:

UCS test measures the resistance of a material to uniaxial deformation [10]. The classification of sand consolidation based on USC test is shown in (Table I.1).

BHN test measures the hardness and consolidation of the sand by pressing a spherical indenter into a material with a controlled force for 10–15 s to create indentation.BHN is calculated as a function of the applied force, indenter diameter and indentation diameter [11]. The classification of the sand consolidation based on the Brinell Hardness Test is shown in (Table I.2).

Table I.2: Sand consolidation based on Brinell Hardness (BHN) Test.

Classification	BHN (kg/mm²)	Geological Equivalent
Unconsolidated	<2	No cementing material
Partially Consolidated	2–5	Pieces easily crushed with fingers
Friable	5–10	Pieces crushed when rubbed between fingers
Consolidated	10–30	Pieces can only be crushed with forceps

4.3.Numerical simulators:

Experiment studies can only capable to predict the sand production onset [12]. Furthermore, as the experimental work is usually setup on a small scale, the results are usually affected via boundary effects. However, analytical models have the advantage of fast processing and easy to utilize, nevertheless they have their drawbacks. As numerical models are powerful tools where capable to predict the sand production and they also can be integrated with analytical correlations to determine proficient results.

4.4. Drill Stem Test (DST):

Is one of the most reliable prediction approaches as it consists of gradually increasing rate and drawdown until the maximum production rate or drawdown is achieved [13]. In the context of sand prediction, it allows the direct observation of sand particles being detected on the surface at the maximum pressure drawdown, also known as field observation of sanding.

Drill Stem Test (DST) consists of individual well testing through DST. When the production well produces a reservoir fluid under conventional completion, thus the potential sand production can be predicted [14].

5. Sand production type:

The classification of field measurements of sand production is considered an essential part of sand prediction as it defines the situation assessed. A classification is developed, based on field observations, to allow for a better comparison and interpretation of sand production events. Subsequently, changes in the downhole producing geometry are considered on the basis of the cumulative sand volumes produced.

5.1. Transient Sand Production:

Transient sand production refers to a sand concentration declining with time under constant well production conditions [15]. This phenomenon is frequently observed during clean-up after perforating or acidizing, after bean-up and after water breakthrough. The sand concentration, the cumulative sand volume and the decline period vary considerably.

5.2. Continuous Sand Production:

In a great number of fields, continuous levels of sand production are observed. The acceptable sand concentration depends on operational constraints with regard to erosion, separator capacity, sand disposal, artificial lift, well location. Typical tolerated sand cut levels are 6 -6006g/m (2.1-210 pptb) in oil producers and 16 kg/1 m (1lb/MMscf) in gas producers[15].The latter surface sand concentration is equivalent to a downhole sand concentration of about 4 g/m (1.5 pptb) (3900 m reservoir gas equivalent to 106 m^3 surface gas). Much higher acceptable sand cut levels of the order of 28, 000 g/m (10,000 pptb) have also been reported [17.18].

5.3. Catastrophic Sand Production:

Refers to the events where a high rate of sand influx causes the well to suddenly choke and/or die.

6. Reasons for sand production

The solid material produced from a well can consist of both formation fines and load bearing solids. The production of fines cannot normally be prevented and is actually beneficial. The critical factor to assessing the risk of sand production from a particular well is whether or not the production of load bearing particles can be maintained below an acceptable level at the anticipated flow rates and producing conditions which will make the well production acceptable. The following list summarizes many of the factors that influence the tendency of a well to produce sand [19]:

6.1. Degree of consolidation:

A mechanical characteristic of rock that is related to the degree of consolidation is called “compressive strength”. This shows how strong the individual sand grains are bound together. The cementation is typically a secondary geological process for consolidation. Poorly consolidated sandstone formations usually have a compressive strength that is less than 1,000 pounds per square inch. This indicates that sand production is normally a problem when producing from poorly consolidated sandstone.

6.2. Production rate:

The production of reservoir fluids creates pressure differential and frictional drag forces that can combine to exceed the formation compressive strength. This indicates that there is a critical flow rate for most wells below which pressure differential and frictional drag forces are not great enough to exceed the formation compressive strength and cause sand production. The critical flow rate of a well may be determined by slowly increasing the production rate until sand production is detected. One technique used to minimize the production of sand is to choke the flow rate down to the critical flow rate where sand production does not occur or has an acceptable level.

6.3. Drawdown:

An arch is a hemispherical cap of interlocking sand grains (figure 2 show the arch) like the stones in an arched doorway that is stable at constant drawdown and flow rate, preventing sand movement. Changes in flow rate or production shut-in may result in collapse of the arch, causing sand to be produced until a new arch forms.

6.4. Reduction of Pore Pressure:

The pressure in the reservoir supports some of the weight of the overlying rock. As the reservoir pressure is depleted throughout the producing life of a well, some of the support for the overlying rock is removed. Lowering the reservoir pressure creates an increasing amount of stress on the formation sand itself. At some point the formation sand grains may break loose from the matrix, or may be crushed, creating fines that are produced along with the well fluids. Compaction of the reservoir rock due to a reduction in pore pressure can result in surface subsidence.

6.5. Reservoir Fluid Viscosity:

The frictional drag force exerted on the formation sand grains is created by the flow of reservoir fluid. This frictional drag force is directly related to the velocity of fluid flow and the viscosity of the reservoir fluid being produced. High reservoir fluid viscosity will apply a greater frictional drag force to the formation sand grains than will a reservoir fluid with a low viscosity. The influence of viscous drag causes sand to be produced from heavy oil reservoirs, which contain low gravity, high viscosity oils even at low flow velocities.

6.6. Increasing Water Production:

Sand production may increase or begin as water begins to be produced or as water cut increases. Two possibilities may explain many of these occurrences. First, for a typical water-wet sandstone formation, some grain-to-grain cohesiveness is provided by the surface tension of the connate water surrounding each sand grain. At the onset of water production, the connate water tends to cohere to the produced water, resulting in a reduction of the surface tension forces and subsequent reduction in the grain-to-grain cohesiveness. Water production has been shown to severely limit the stability of the sand arch around a perforation resulting in the initiation of sand production. A second mechanism by which water production affects sand production is related to the effects of relative permeability. As the water cut increases, the relative permeability to oil decreases. These results in an increasing pressure differential being required to produce oil at the same rate. An increase in pressure differential near the wellbore creates a greater shear force across the formation sand grains. Once again, the higher stresses can lead to instability of the sand arch around each perforation and subsequent sand production.

Note; The acidification process can make the formation weak what does mean sand production indirectly.

7. Sand production consequences:

- Sand production can lead to one or more of the following problems[20]:

• Formation damage or collapse by the flowing sand grains.

• Wellbore instability. • Casing collapse.

• Impairment or failure of downhole and surface equipment.

• Lost production time due to well shut-in to change damage equipment or clean the sand filled wellbore.

• Work-overtime and expense to service the well and production equipment.

• Coiled tubing cost and possible complications.

• Cost of separating sand from the produced fluid.

• Environmental problems in the disposal of the produced contaminated sand.

Figure I.4: Sand control installed by schlumberger in over 30 countries worldwide [21].

8. Conclusion:

The production of formation sand is a major problem encountered during the production of oil and gas from incompetent formations. Sand control techniques have the ability to exclude different sizes of particles depending on the type used. However, choosing the best sand control for wells poses a great challenge to the oil and gas industries

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CHAPTER II:

CHEMICAL SAND CONSOLIDATION

1. Introduction:

Damage to the formation in any form requires a chemical treatment design and pumping to remove the weak permeability. Formation and sand production is one such form, as it blocks and connects pore openings and corrosion of downhole equipment. The problem with sand production during hydrocarbon recovery is well known. When this occurs, production should be reduced to meet this. Local collapses near the wellbore may jeopardize many well operations. Several sand control technologies (mechanical or chemical) are applied worldwide. The more expensive mechanical alternatives are chemical technologies, such as on-site chemical incorporation of sand with agents (chemicals). Features of silicon organic chemicals technology include oil solubility, hydrophobic nature, and low bioaccumulation tendencies. Here, we will focus on polymer based sand standardization which mainly consists of pumping polymerized organic resins into the near well area when gravel bundles are not performing well.

The main idea is to merge grains of sand together without damaging the tank by reducing the oil permeability that occurs due to the oil's wettability of the resin that occupies the pores. The excess resin must be displaced from the over-fluid porous areas [22].Although difficult to accomplish both at the same time; operators do their best to properly integrate micro-formations, form a mass with better compressive strength, and keep the reservoir pores undamaged with resin. (FigureII.5) shows the porous voids and sand grains adhering to the resin which increases the compressive strength.

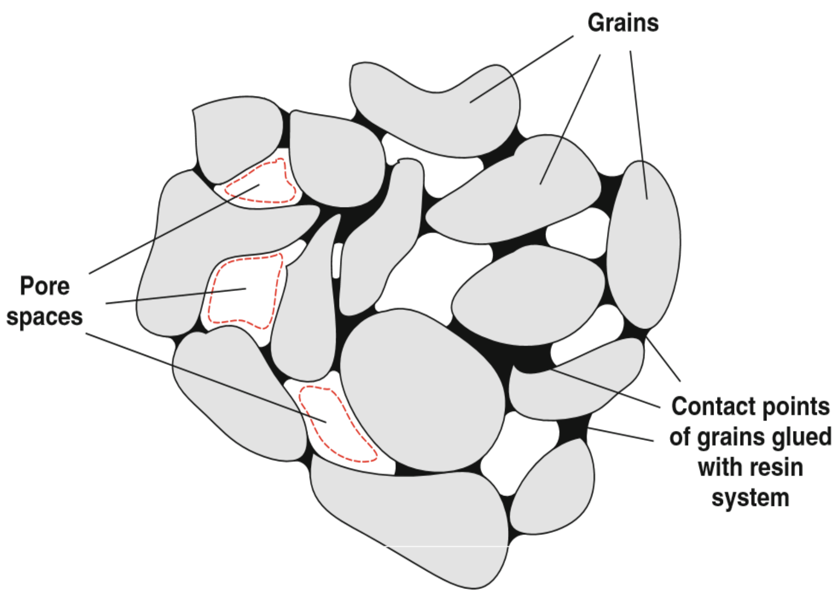


Figure II.5: Grains contact points after the resin consolidation treatment.

2. Resins:

In polymer chemistry and materials science, resin is a solid or highly viscous substance of plant or synthetic origin that is typically convertible into polymers.

Chemically composition, resins are solid, hard to soft, organic non crystalline polymers, brittle in the solid state. Molecular mass distribution of resins polymer network is very narrow. Flammable nature of resins requires an extra caution when handling and treating. In general, resins are raw materials for curable molding composition adhesives and coatings used in oil industry like in many others.

2.1. Thermosetting Resins:

When introduced to heat source, thermosetting resins change irreversibly from fusible and soluble to infusible and insoluble material through cross-linked polymer network. They have a pretty low molecular weight (<10,000). After the curing process, that is a transformation from liquid to solid network state, polymer chains link into one molecule.

The most utilized types of thermosetting resins are:

- ***Phenol resins,***
- ***Furan resins,***
- ***Amino resins,***
- ***Epoxy resins,***
- ***Unsaturated polyester resins,***
- ***Urethane foams,***
- ***Alkyl resins.***

Basically, thermosetting resins are very stable over a wide range of temperatures, chemically inert to wellbore fluids and rocks and environmentally safe. When thermosetting resins are cured and cross-linked, thermoset polymers are strong, hard and tough. When hot resin solidifies creating a hard mass between sand grains, it is able to withstand huge stresses.

2.2. Thermoplastic Resins:

Unlike thermosetting resins, thermoplastic ones are reversible, meaning that by applying different pressure and temperature their physical state changes. Thermoplastic polymers consist of linked monomers of very high molecular weight (>10,000). Molecular bonds can be easily broken by heating or dissolving the matter. Thermoplastic resins include:

- ***Polyethylene,***
- ***Polypropylene,***
- ***Polystyrene,***

- ***Polyvinyl chloride,***
- ***Furan resins:*** Furan resins can be fabricated to be thermosetting or thermoplastic.

2.3. Resins Curing Process:

The process of curing (also known as a cross linking process) relates to resin transformation from liquid to solid state. During that process monomers link into clusters until network is created forming a mass. As clusters become bigger and bigger their movement becomes restricted. After reaching a gelling point, clusters move no more due to very high viscosity of the system and the friction forces generated. If the resin is not properly placed inside the near wellbore zone before reaching the gelling point, it is not possible to pump and squeeze it further on [23].There are some important requirements resins must apply [24]:

- *The resin dynamic viscosity has to be moderately designed with values not more than 0.02 Pa·s. This will allow for good ability to pump the resin through all the restrictions without excessive pressure losses and to displace it with overflush fluid,*
- *The resin must wet formation solids to be able to bond them together, but only at certain points without over-occupying the pore spaces,*
- *When put in place, polymerized resin should have good compressive strength for sand movement prevention,*
- *Resin polymerization starting moment should be controlled with additives. Too short times may result in improper consolidation or even improper placement,*
- *Although polymerized resin is not water-wet, it should be able to tolerate long contacts with formation brines and must not be reactive with acids.*

3. Treatment Execution:

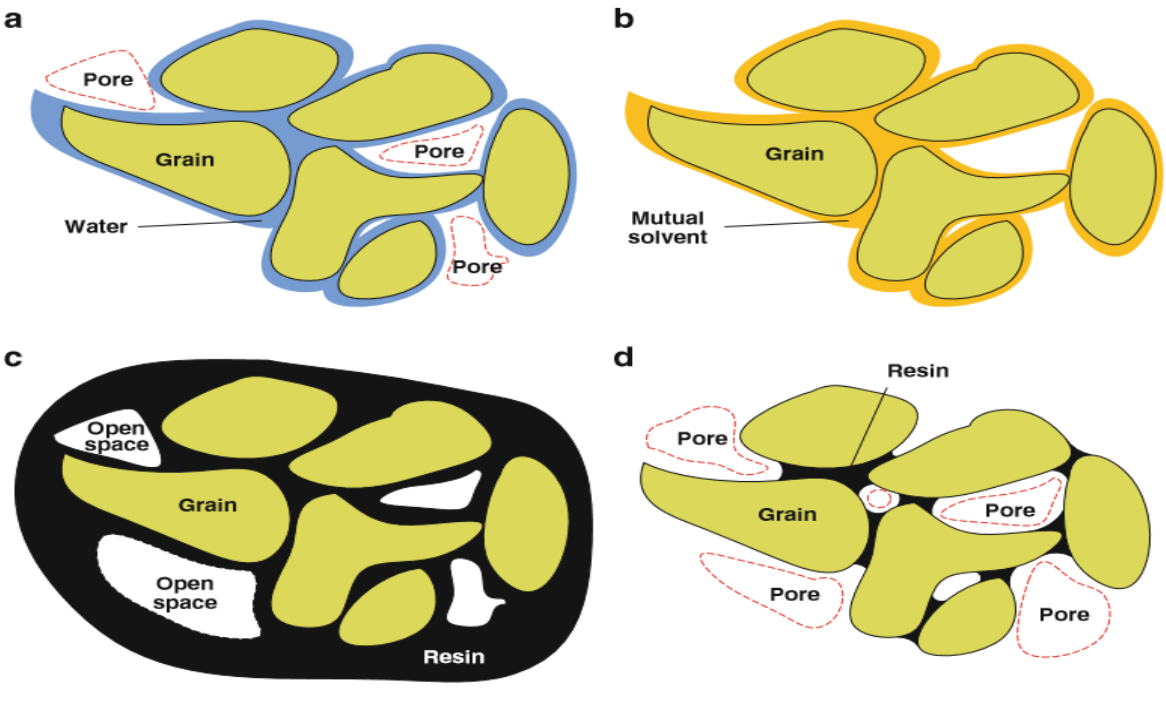
Working with resin systems necessitates the utmost job performance supervision and experience to be able to perform the treatment safely and technically correct. Interval to be treated with resins has to be isolated from the rest of the well to ensure effective injection into the perforations, prevent loss of process fluids and resins contamination. Mostly, the treatment execution embraces up to 1.5 m thick near wellbore zone. For the successful future hydrocarbon production it is better to treat the zone which has not produced sand before the resins treatment (sand production prediction is made). Thin layers treatment (<6.0 m) is recommended [25].It is possible to treat maximum 7 m thick zone in one stage [26].

Prior to treatment, perforation tunnels should be cleaned by pumping a cleansing fluid (HCl-HF conditioned acid system) to remove any unwanted particles capable of endangering the treatment process. Particles left inside the perforations will be solidified with resin after the treatment.

Appropriate workover fluids have to be used as well, and that is brine with sodium chloride (KCl) and diesel or lighter brine for placement above the treating zone (for prevention of resin system mixing with wellbore fluids).

Preflush operation's primary intention is to remove reservoir fluids (water specifically) not compatible with resin system and capable of contaminating it (see Figure II.6 a, b). Since resin has to affix the grains, which is possible only in oil wet conditions without the residual water, the major concern here is weather the reservoir grains surface is water or oil wet.

According to that preflush fluid has to be chosen carefully depending on the resin system type used. In some cases diesel with surfactants is used. Other preflush systems contain isopropyl alcohol or mutual solvents like EGMBE (Ethylene glycol mono-butyl ether) for water removal [27.28].



FigureII.6: Chemical sand consolidation sequences

(a) Before the treatment water wet conditions are met with residual water surrounding the grains.

(b) By preflushing, mutual solvents successfully displace the residual water and maintain the permeability.

(c) Main treatment fluid is pumped entering the pores by capillary pressure.

(d) All but residual resin is displaced with overflush connecting the grains at the contact points.

Treatment fluid normally consists of some type of resin, solvent, curing agent (catalyst), activator and accelerator (optional). Depending on the near wellbore zone cleanliness, pressure, temperature and other properties, diverse resin systems with different additives are used.

When preparing resin treatment fluid, one of the most important factors is formation temperature. It dictates resin hardening time and thus needed concentrations of some additives like accelerators and curing agent. Injection itself must be done below fracture initiation pressure at low rates to provide uniform coverage of formation to be treated (Figure II.6 c).

In phase separation process polymerizing resin separates from the solvent after some time as a second liquid phase. Capillary forces draw resin into intergranular spaces to the grain-to-grain contact points where it solidifies and interconnects the grains. Permeability is preserved by limiting the volume fraction of the separate resin phase.

Overflush or displacement fluid is used to displace all but residual resin saturation at the grains contact points and to control thickness of the plastic film and compressive strength (Figure II.6 d). It establishes desired permeability and resin cure time as well. High yield furan or epoxy solutions are used in these applications commingled with surfactants that help resin adhere to the grains.

Overflushes are mostly hydrocarbon based fluids but it is also possible to be water based. Overflush hardener solution for initiating polymerization containing very reactive acid components and hardeners is also sometimes pumped as a second phase overflush. These systems may contain accelerators and curing agents being quite viscous for sweep efficiency improvement.

Spacers are sometimes pumped to separate different types of fluids pumped in a row [29.30].

4 .Additives:

Desired treatment fluids in chemical consolidation are on the rare occasion ready to use without additives since they help them to achieve wanted properties required for proper placement, resin curing and other. Some of these important additives and their main purposes are presented below.

Activators, as very essential additives, are used in treatment fluids to prolong resin placement time and to minimize curing time. It can also be added to second overflush fluid to speed up the curing time. When the activator is already added to the treatment fluid, overflush to retain permeability may be needful, but a plastic set up procurement is not needed, so there is no need for activator addition into the second overflush. Activators require a careful addition to the resin system as the reaction time with resin can lessen considerably.

Accelerators are used to minimize resin curing time (for speeding up the reaction time). In accordance with it, as used in treatment fluids, treatment placement time will be reduced. When pumping and curing time operations are expected to last considerably shorter time than usual, accelerators are introduced to the system.

Surfactants, or surface active agents, are used to lower the surface tension between two liquids or liquid and solid. They can be very effective in removing connate water in preflushing the reservoir. Basically, they are organic compounds acting like dispersants, foaming agents, wetting agents, emulsifiers or detergents.

Isopropyl alcohol (C3H8O) is a flammable chemical able to dissolve wide range of compounds. That is the reason why is it used in preflushes for water removal. It evaporates quickly and is not very toxic, unlike other solvents.

EGMBE, or *ethylene glycol mono-butyl ether,* is a mutual solvent which has solvency for both aqueous and non aqueous liquids. It effectively cleans sand and miscible displaces residual water. The end result of such treatment is better accessibility of resin to intergranular spaces.

5. Resin-Coated Proppant Packs:

As an alternative to regular chemical consolidation with resins, there is a formation sand exclusion method which incorporates gravel packing and afore-mentioned technique. Principally, it is a gravel packing method with proppant coated with thin layer of resin [31.32.33].Resin layers can be applied to any kind of commercially available proppant. One has to differentiate pre-coated proppant in the factory which is then taken to location and proppant coated on-the-fly during the treatment. Resin coat is usually curable and after the treatment when the well is shut in, due to high temperature values downhole, resin dissolves and consolidates grains procreating stable packed boundary leaving the formation sand behind it. Stability and permeability of packed zone done with resin-coated proppant depends mainly on resin polymer properties, so the formation temperature awareness and polymer chemical properties are crucial for the job success.

Resins used in these applications are mostly thermosetting epoxy and phenol. As mentioned earlier, curable proppant can be pre-coated or coated on-the-fly. There is also a pre-cured type of proppant that is already heated and cured in the factory where it is mixed with melted resin. The cure is achieved under certain conditions by mixing those two with sufficient mechanical shearing action. Proppant grains end up coated with thermoset resin layer [34.35].

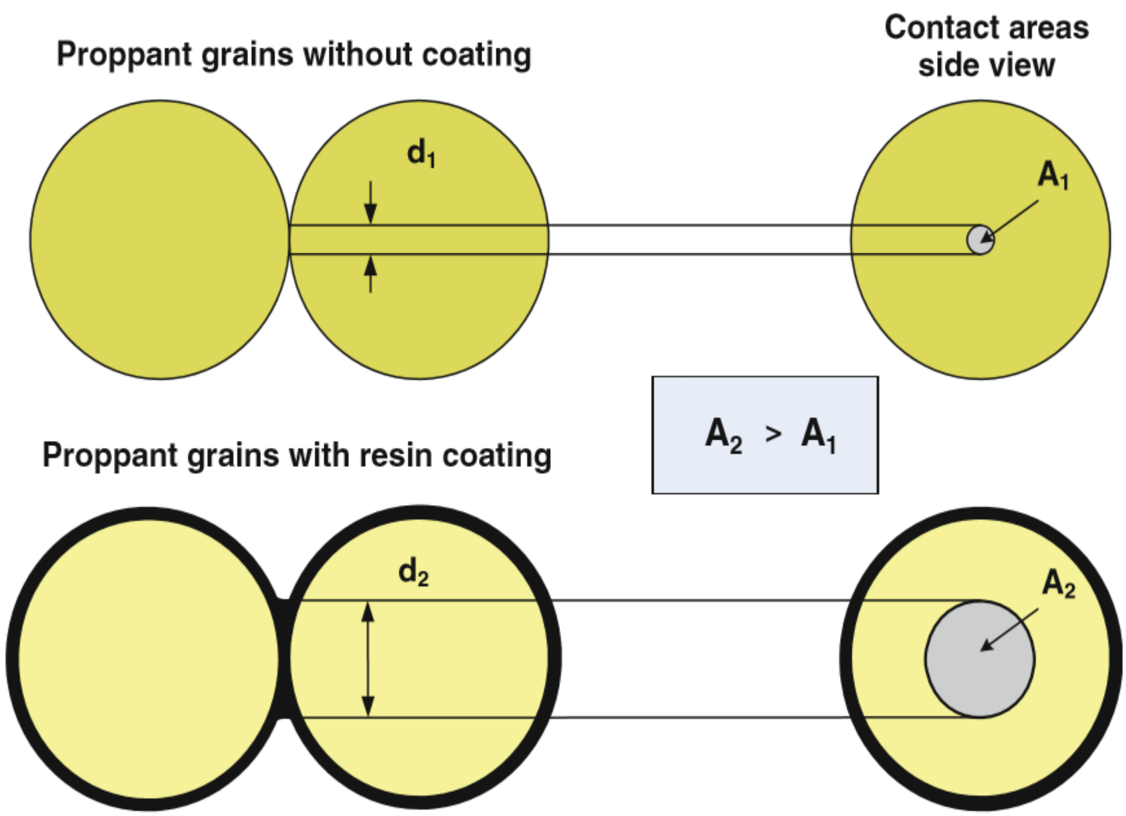


Figure II.7: Comparison of proppant grains with and without resin coating

Resin-coated proppant packs are also effectively implemented in frac packing operations where they prevent sand influx at extremely high fracture closing pressures and it's embedding into formation is reduced to minimum. For better understanding (Figure II.7) depicts comparison of grains interaction in case of resin coated proppant and proppant without coatings. On resin-coated proppant stress is allocated over a greater area so a greater breaking resistance of detached grains is achieved.

6. Advantages and Disadvantages:

Chemical consolidation *advantages* with resins over other sand control methods are numerous. Some of them are listed below:

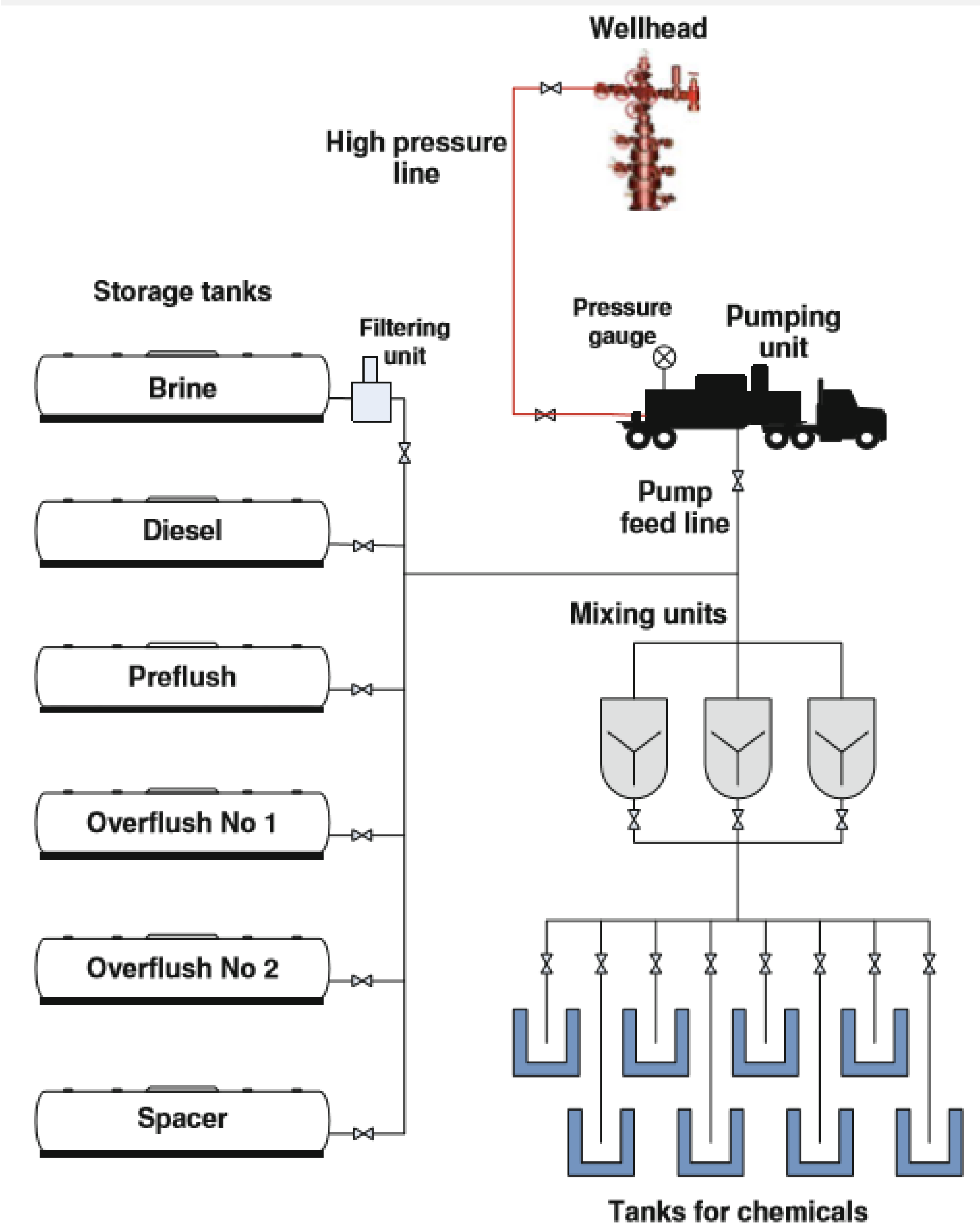
- *Gravel is not required in perforations, so a severe production reduction is not introduced like in case of gravel packing method,*
- *Screens are not used, so mechanical risks caused by installation of such hardware do not exist,*
- *No rig is required, and therefore additional funds for its rent,*
- *Chemical consolidation can be done through existing completion or coiled tubing,*
- *It is quite cheap comparing to gravel packing and frac packing methods,*
- *Convenient and ready for through tubing applications,*
- *Application possible in abnormal pressure wells,*
- *Good compressive strength in near wellbore zone with 60–90% of original permeability retention. It is possible to retain more than 90% of original productivity.*
- *Can be also used to repair an unsuccessful sand control treatment.*

Basic chemical consolidation *disadvantages* with resins are:

- *Chemicals handling always poses a threat to safe job performance so they have to be treated with ultimate care,*
- *Formation damage imposed in near wellbore zone by chemical treatment can be substantial. That means a reduced porosity and permeability leading to reduced productivity,*
- *Placement of the whole chemicals volume through all perforations is critical to success.*

7. Surface Equipment:

Consolidation treatment operation may be sometimes very complex. This is due to the need to prepare the grain surfaces for treatment fluid (preflushes), treat the grains with resin system and flush it afterwards with overflush fluid to preserve



FigureII.8: Surface equipment layout for chemical consolidation mixing and pumping process.

Permeability and flush away undesirable excess chemicals. A series of chemical treatments to be pumped inside the reservoir (preflushes, spacers, resin systems, Overflushes) require a huge number of logistical units. Separated storage tanks, manifolds, mixers, high pressure lines, pumps etc. (Figure II.8) – they all have to be correctly affixed and connected to be able to perform smooth fluid pumping operations.

8. Conclusions:

We have demonstrated a number of effective techniques for treating mass sand formation. With highlighted the advantages and limitations of the methods. We have attempted segmentation in this way to improve readability readability to make it comprehensible. From the above discussion we can conclude that a lot of work has been done on the resin system, such as phenolic resins, furan resins, amino resins, polyethylene, polystyrene, etc., and it has been proven that these systems are effective and can provide the desired results. New chemicals and technologies have been developed to achieve better results. Resins are usually sticky, and putting these chemicals into the desired configuration through all the holes is critical to achieving success.

Difficult to pump in a reasonable amount of time. Currently, sand control was the key to economically recovering hydrocarbons from unconsolidated formations. Each technology has its own advantages and limitations. Hence, the methods have to be chosen based on the requirements and conditions of the tank, such as temperature, pressure, fluid presence, pH etc. The development of new chemicals, new technologies, fluid dynamics and geological theories will promote further improvements in chemicals and sand standardization methods. Therefore, more research is needed

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CHAPTER III:

MECHANICAL METHODS OF SAND CONTROL

1. Introduction:

Usually, sand production problems occur in shallow formations that have a very low degree of cohesion between sand grains, but in some oil fields, sand production may occur at very high depths as well [36].Sand control requirements come when the compressive strength (cohesion force) of the formation becomes so low that it is not possible to hold sand grains together during the useful life of the well.

Control of sand production involves maximizing production and maintaining it at acceptable production rates. A great deal of revenue is invested each year to prevent sand production and other problems related to it, which greatly affect the economic profit of the industry [37.38]. In the oil fields, mechanical and chemical methods have been used to control sand production. The mechanical method involves the use of sand screens, filters, perforated and slotted liners, which are placed inside the wellbore to prevent loose sand grains from escaping into the wellbore. Mechanical devices, “Downhole Filter**”** such as Slotted Liner, Screens and Gravel Pack; the bushings fail to completely block the flow of sand particles in the production equipments.

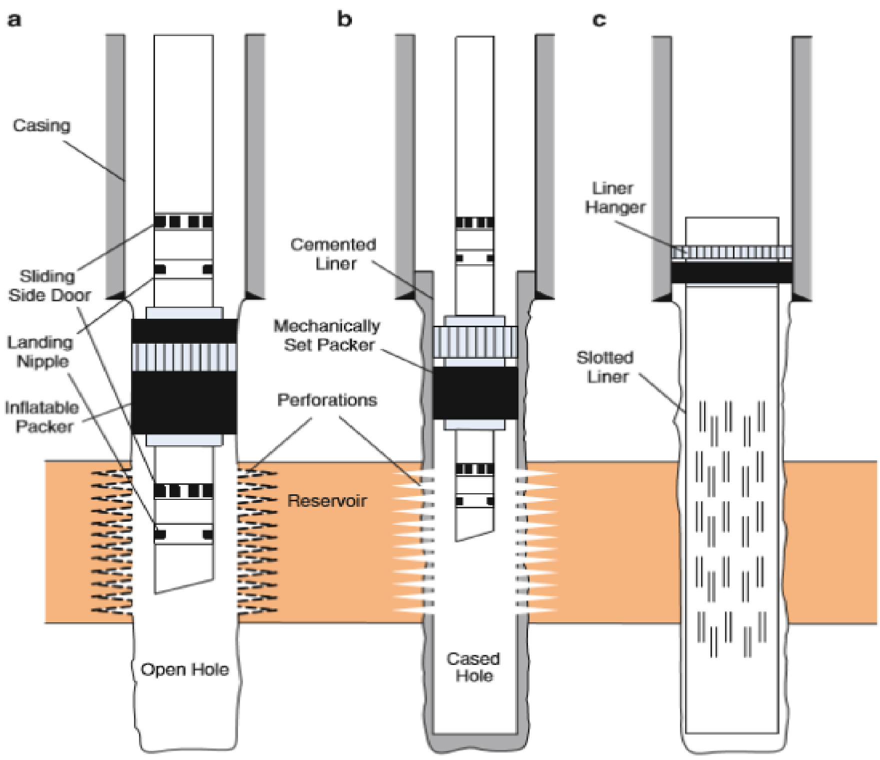


Figure III.9: Basic well completion designs: (a) Open hole completion, (b) Cased hole completion, (c) Slotted liner completion.

2. Slotted Liners:

Sometimes, slotted liners are used without gravel pack placement to control formation sand production. One of the common applications is in reservoirs that produce high-viscosity oil from horizontal wells drilled through unconsolidated, high permeability sands [39].In this case formation has to be well consolidated and sand grains well sorted. If the formation is not well sorted and the produced sand not clean with large grain sizes, this type of completion has fairly short producing life before liner plugs with sand. That is because in long horizontal sections accompanied with low inflow rates, fluid cannot transport even small formation grains through the well out to the surface. Due the low economics of such wells they are usually completed with low-cost sand control system, such as slotted liners. Slotted liners should provide the sand control based on bridging or are used to restrain gravel. So, the main reason for gravel packed liners installation would be better sand management by obtaining an additional sand filtering zone (Figure III.10). Usually, when gravel packing open hole; it is preferable to ream the wellbore across the reservoir with under reamer for greater gravel thickness around the liner providing for productivity increase.

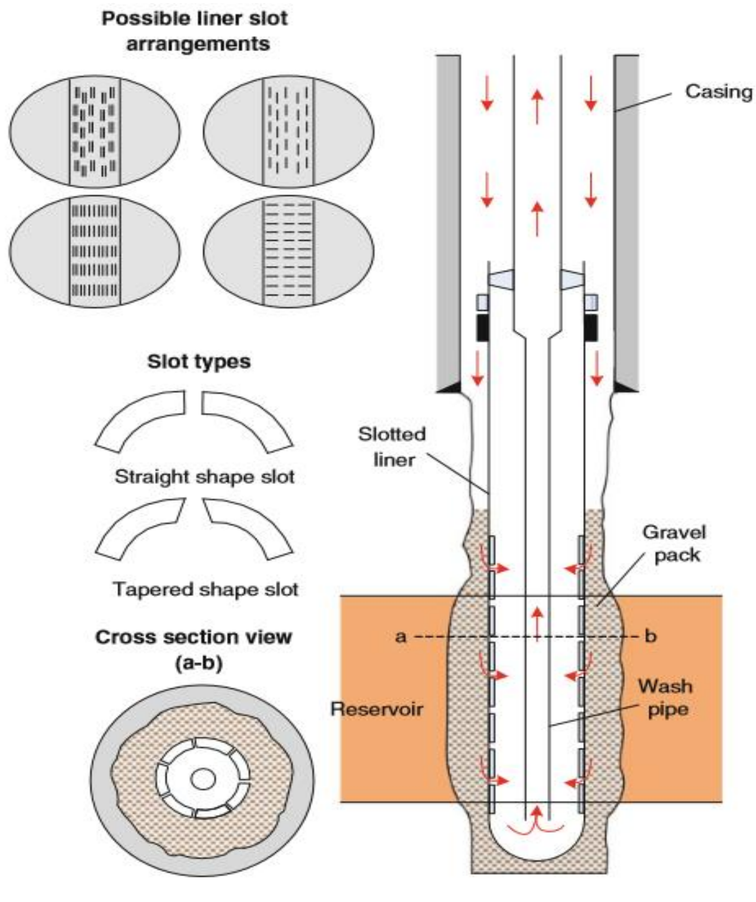


Figure III.10: Slotted liner completion

Slotted liners for gravel packing have slots specially machined in workshop. Their orientation can be perpendicular or horizontal along the liner with different arrangement and sizes. Quantity of slots depends on the flow area of the slotted liner. Generally speaking, 2–3% of total external surface area of the liner is taken as the total area of the slots. Slots number can be determined from the following equation:

$$n_s = \frac{\alpha_s F_s}{W_s L_s} \qquad \textbf{(III.1)}$$

Number of slots per 1 m of the liner (n_s), is determined according to the total slot area of total external surface area of the liner (α_s), external surface area per meter of the liner (F_s), width of slotted aperture (W_s), and slot length (L_s) [40].

According to slot shape, there are normal straight slots and tapered shape slots, providing a non-plugging mechanism. (Figure III.10) also shows the difference between straight slots often having problems with plugging by sand particles and tapered slots which do not allow for clogging.

2. 1. Expandable Slotted Tubular:

Expandable slotted liners have been developed to improve well production and reduce sand production with reduction of well costs at the same time. The main concern when using such pipes (liner, casing or screen) for sand control purpose should be about slot size based on deformation after expansion. For the purpose of post-deformation determination the study has been conducted [41].that has provided the industry with the analytical model for calculation of slot deformation, axial tension and compression slotted pipe ratings.

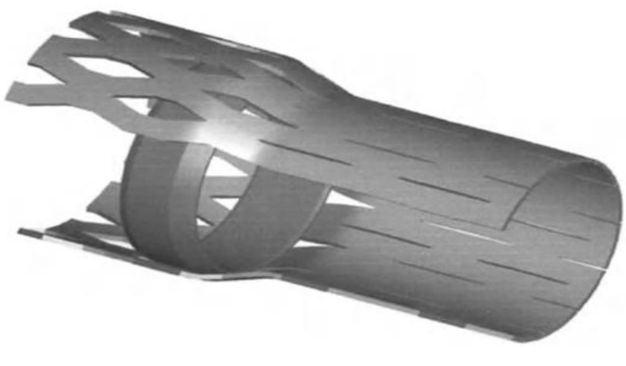


Figure III.11: Slotted pipe expansion [42].

Slots on expanded tubular are always done along the length of the pipe. In the well, slotted-expandable liner is lowered to the desired depth on the drill pipes or tubing. The expansion is done by the use of a cone (Figure III.11) that can be hydraulically expanded to the desired diameter. Expansion starts at the bottom of the slotted liner by lifting the cone up to the top of the slotted pipe. Releasing the pressure allows the cone to shrink back to smaller size. That is because the tubular joints are not slotted and cannot be expanded. The process is repeated according to the number of slotted pipes in the string. If there is the need to retrieve slotted-expanded pipes, the drill string and the pulling force should be applied to collapse back the expanded slots. Originally slots are rectangular. After expansion their shape is octagonal as shown in (Figure III.12).

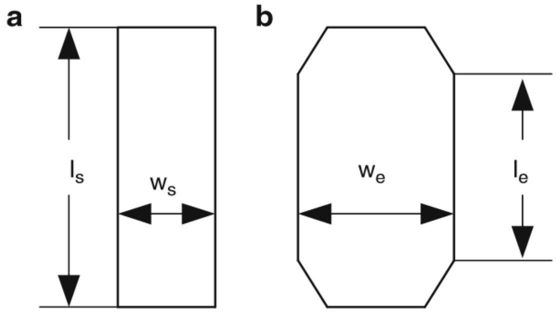


Figure III.12: Slot shape: (**a**) original; (**b**) after expansion.

The assumption used to calculate the change in slot width is that after the deformation the width and wall thickness of steel strips between two slots do not change the dimension. Then the slot width on the expanded pipe (w_e) is expressed as:

$$w_e = \frac{2\pi}{m}(D_f - D_i) + w_s \qquad \textbf{(III.1)}$$

where m determines the number of links between slots over the pipe cross section area, (D_f)is the final (expanded) pipe outer diameter, (D_i) is the initial outer diameter of the pipe, and w_s is the sloth width before expansion.

3. Screens:

Screens are more efficient and reliable sand control in unconsolidated formations, which contain fine sand. This control mechanics is better than using slotted liners. There are three main screen types available and used in horizontal completions. These are wire wrap screens, meshed screens (premium) and expandable screens. In horizontal well, screen lies on the low side of the well. This is as a result makes open spaces on the topside and may leads to unstable/unsupported topside of the wellbore. For this problem, an expandable screen reduces/eliminates annular space as illustrated on (Figure III.13) [43].

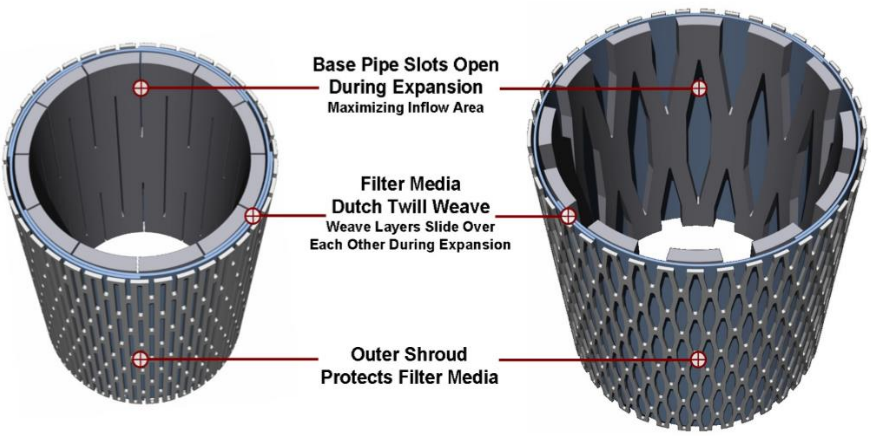


Figure III.13: Expandable sand screens construction.

3.1. Wire wrapped screens:

This screen consists of an outer jacket that is produced on special wrapping machines. The shaped wire is wrapped and welded to longitudinal rods to form a single helical slot with any desired width. The jacket is then placed over and welded at each end to a base pipe containing drilled holes to provide structural support. This is a standard-commodity design manufactured by several companies. A schematic of the screen construction is shown in (Figure III.14).

Another method of producing the wire wrapped screen is direct wrap on pie screens. These screens are produced with a wire jacket shrink-wrapped directly to the base pipe. This type of screen is commonly used in long horizontal gravel packed wells [44].

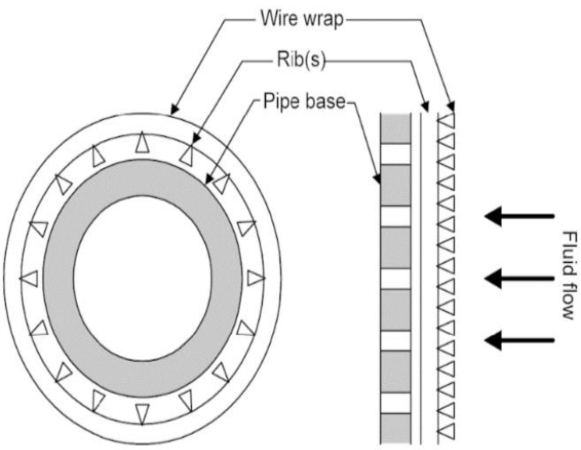


Figure III.14: Wire wrapped screen. [45].

3.2. Premium screens:

Premium screens were originally developed for stand-alone installations in horizontal wells rather than a gravel-packed completion; however, this type of screen has been installed in several wells worldwide in combination with a grave pack. Proprietary designs are premium designs that surpass the performance of either a standard wire-wrapped screen or a prepacked screen in their ability to resist plugging and erosion and are equipped with torque-shouldered connections to permit rotation.

Mesh screens maintain their strength during installation without altering the filter pore openings. With drainage layers, and an optimized design of base pipe perforations, these screens evenly distribute flow across the full area of mesh and reduce the risk of plugging at the screen face. These types of screens have increased inflow areas to as much as 30% of the surface area of the screens [46].

Figure III.15: Premium screen [47].

3.3. Pre-packed Screens:

This type of screens is mainly designed for application in inclined wells of special requirements. A wide array of pre-packed screens is available today. Double layered wire wrapped screens are gravel packed between the inner and outer wire layer while single wire pre-packed screens are gravel packed between the wrapped wire and the outer perforated shroud. Some types of double layered pre-packed screens have a micro screen instead of wire [48].

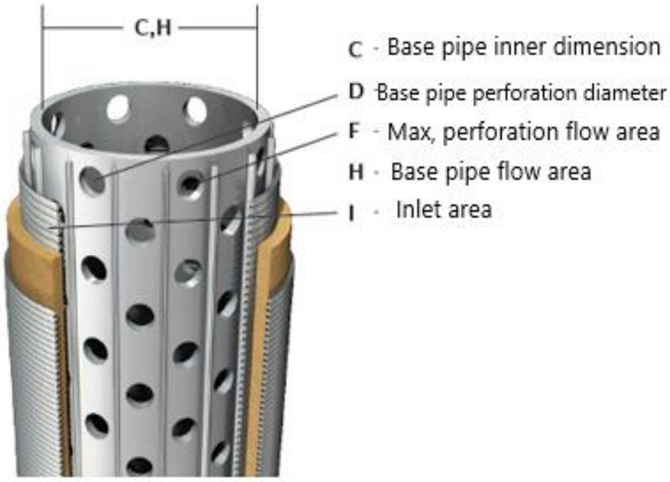


Figure III.16: Pre-packed Screens

3.4. Special Design Screens:

This screen type, made mainly for standalone applications, includes different wool wrapped screens and various high grade alloy and chrome screens resistant to corrosion with excellent mechanical integrity. Like through tubing screens, wool wrapped screens are designed to retain all sand grain sizes as well. High permeability of the screen indicates a high flow performance without losing too much of reservoir pressure. High grade alloy and chrome screens are designed to apply in high pressure/high temperature wellbore conditions. Being resistive to sour gases like hydrogen sulfide and carbon dioxide, these screens are fit for harsh downhole environment [49].

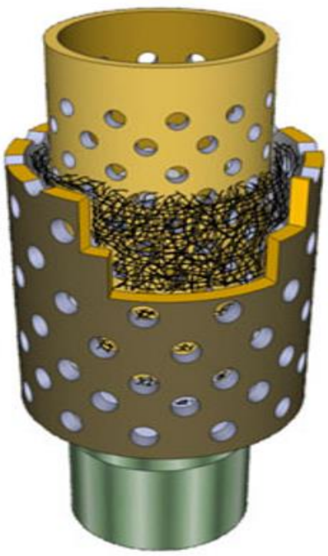


Figure III.17: Special Design Screens.

3.5. Alternate Path Screens:

During the gravel pack operation execution, proppant laden slurry might dehydrate inside screen/casing annulus at the early stage of operation, so a blockage may occur due to high proppant concentration as the slurry becomes non-pumpable. To be able to pump proppant laden slurry, it has to have good rheological properties, and that is an optimum viscosity, density and proper fluid loss additives addition [50].

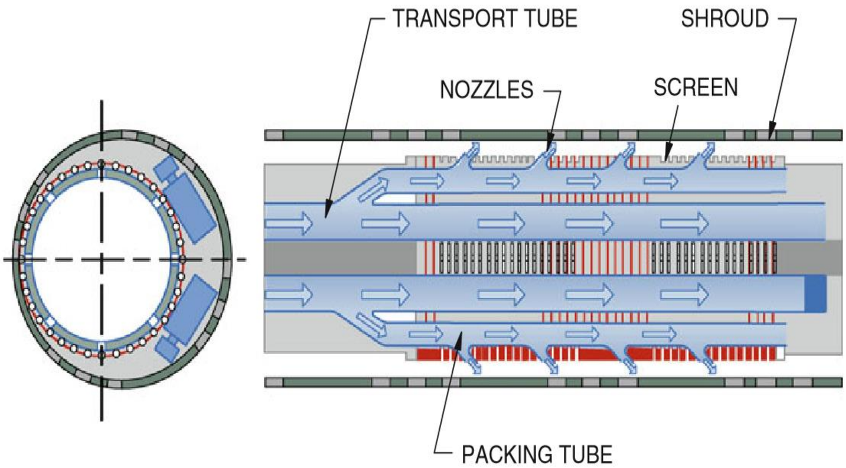


Figure III.18: Alternate path screen with shunt tubes.

Premature screen-out and proppant pack-off issue is easily solved by using an alternate path screens consisting of few rectangular or round tubes (Shunt tubes) welded on the outside of screen body with or without protective perforated shroud (Figure III.18).

3.6. Through Tubing Small Diameter Screens:

When designing such a screen special attention should be given to screen inner diameter which has to be the largest possible, so very thin layers surround the base pipe (0.8–2.0 mm). They are made by wrapping a special stainless steel fiber around the base pipe and compressed to form apertures. The weave is pressed against the outer and inner screen layers and does not utilize welding connection.

Figure III.19 shows a small diameter screen cross section views showing different inner and outer layers not thicker than 2.0 mm. Outer protecting layer/shroud is press-fit against the inner layers to provide complete entrapment ensuring maximum protection from pressure fluctuations [51.52].

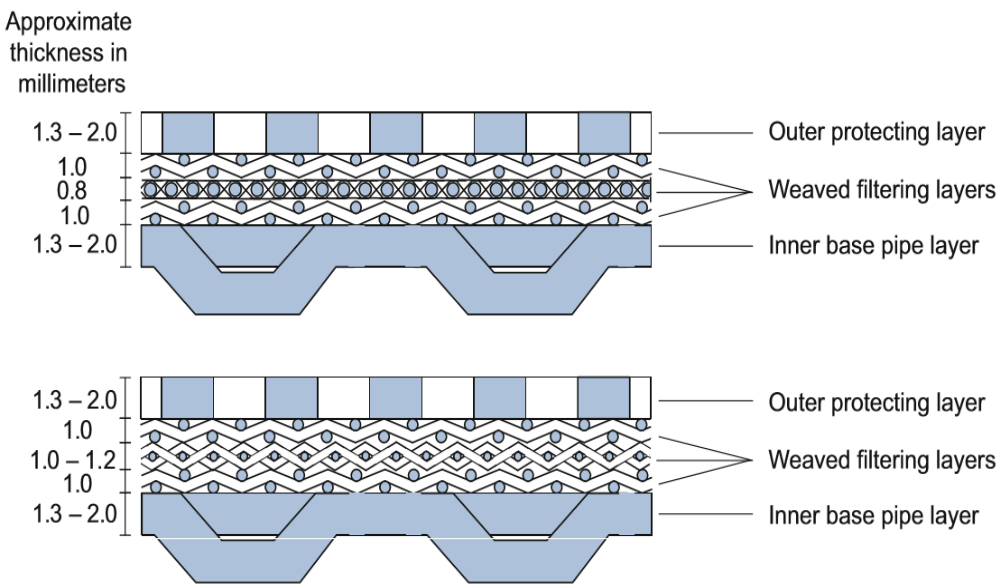


Figure III.19: Through tubing small diameter screen cross section [53].

3.7. Expandable Screens:

Expandable screens usage eliminates the annulus allowing greater space for downhole tools manipulation and supporting the borehole. That way sand exclusion is achieved without gravel packing. Base pipe is an expandable pre-slotted tubular capable of widening to wellbore wall interface with other layers. Hydraulic expansion is applied when large forces are needed to expand the screen.

Outer protective layer keeps filtering layer in place and protects it from aggressive abrasive downhole conditions. Screen expansion is accomplished by forcing a widening device downwards through the string. Popular methods to do that are depicted in (Figure III.20).The screen usually expand a bit more over the wedge diameter (2–3%) for safe trip out of the hole. Rollers expansion is done by pressure activating the pistons, pushing the rollers against the screen and thus expanding it. This type of expansion is done quite fast comparing to others [54.55].

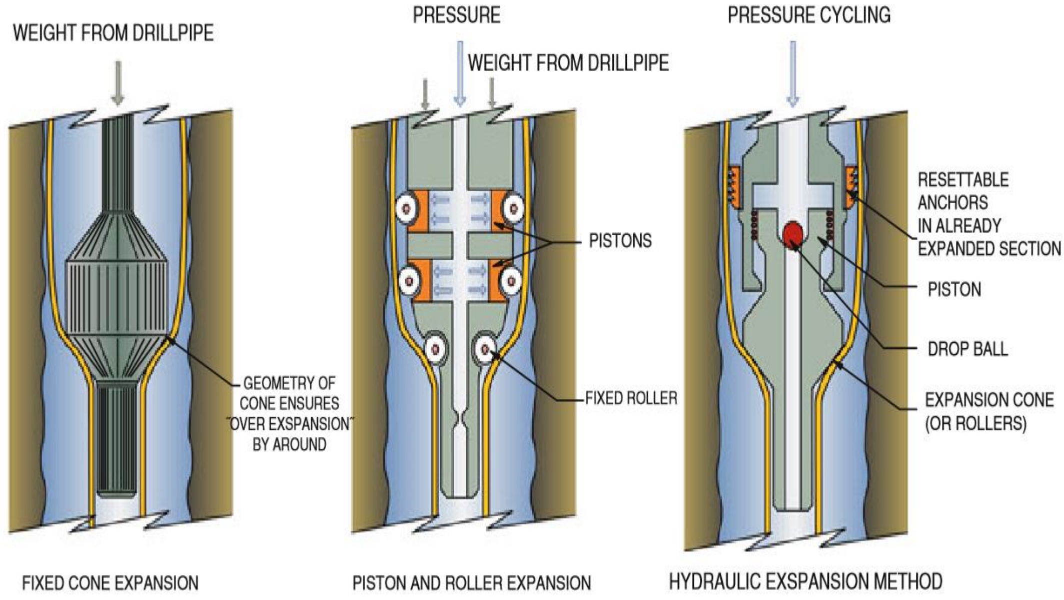


Figure III.20: Expandable screen expansion methods [56].

Notice:

Nowadays, expandable screen joints are very often used in tandem with solid expandable tubular and swelling packers (zonal isolation). Solid expandable provide for zonal isolation by expanding to the wellbore wall interface. They have an elastomeric cloths bonded to the pipe which ensure a good seal between the formation and the pipe. Swelling packers start to swell when they are emerged into the wellbore fluid (oil swelling and water swelling packers). While swelling, mechanical properties degrade. Sealing capability largely depends on the wellbore diameter, packer diameter, wellbore temperature/pressure conditions, water salinity and elastomeric composition. The major benefit from expandable sand screens is a large inflow area once expanded.

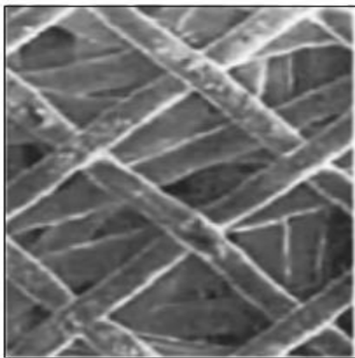
4. Screen Design and Selection:

Screen section length depends on perforated interval length and it should extend 1.5–2.0 m above and below perforations. Screen type selection depends on the operator practice and downhole conditions. If the gravel pack operation is to be done in HP/HT (high pressure – high temperature) environment with (H_2S) occurrence, premium or special design screens are used. Mainly, they are made of high grade alloys and chrome resistant to corrosion. But, if downhole conditions are not aggressive, cheaper versions like wire wrapped screens are installed instead.

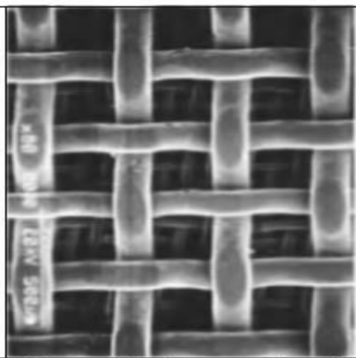
4.1. Sand Retention Tests:

The selection of standalone screens is basically done by the use of sand-retention tests. Two tests have been used in industry: (1) pre-pack (sand-pack) and (2) slurry test. With the pre-pack test, flow of high concentrated suspension of formation sand in a viscous fluid is used to form a sand-pack on the screen. When such sand-pack is formed, clean carrier fluid is pressurized through the sand-pack and screen at a given differential pressure. The solids that pass through such screen/deposit layer are gathered, injected fluid volume and pressure drop measured and recorded. Total amount of produced solids is measured and solids retention performance of the screen evaluated.

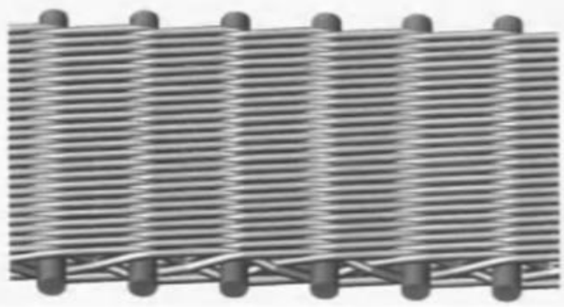
Two possibilities of screen positioning are possible. The first is down position, when sand-pack is forming on top of screen. The second is screen up position and the sand-pack is lifted toward the screen. This up-flow test is more challenging for the screens, with greater chance to be plugged, especially of premium mesh-type screens.



Layered laminate with non-uniform pore(Ott 2008)



Sintered laminate with uniform pore (Ott 2008)



Dutch weave laminate (Ballard and Beare 2003)

Metal mesh screen (Underdown and Sanclemente 2002)

Figure III.21: Display of different premium screen weaving

4.2.Screen or Slotted Liners Erosion:

The main wearing problem with installed screens and slotted liners is the erosion. The main cause of erosion failure is the production rate accompanied with the amount and hardness of the carrying particles. So the erosion is the function of sand carrying capacity of the fluid that is flowing through the screen or slotted liner. To evaluate the risk of the erosion, so called "C – factor" is used [57]. It was basically intended for use when selecting erosional velocity flow lines, production manifolds and lines transporting gas and liquid. The loss of wall thickness or basic material is determined to be due the process of erosion combined with corrosion. Loss of material is accelerated by the fluid velocity, presence of hard particles (sand) and contamination with aggressive gasses. Without other information of fluid properties, the velocity of the fluid flow above which the erosion may occur is determined using the following equation:

$$C = v_p . \rho_m^{0.5} \qquad \textbf{(III.2)}$$

The data correspond to the "$\boldsymbol{C}$ – factor" (empirical constant) obtained when the slurry or fluid velocity $\boldsymbol{V_p}$ is defined in (ft/s) and mixture density $\boldsymbol{\rho_m}$ in (lbs/ft^3).

5. Gravel Packs:

Gravel packing is the most widely used method of controlling sand production today. The best effect of the method is realized in initial completions [58].It can be performed as Openhole and under-reamed completion or in casedhole completion treatment (Figure III.22).

Also the old wells that produce sand can be good candidates for such treatment. In such systems a pressure pack of graded sand can be placed out beyond the casing with the effect of re-stress and stabilize the formation.

Moreover, gravel Packs can be used in the following wells [59]:

- Producer, Injector, Deviation & Size.
- Off-shore, On-shore, sub-sea.

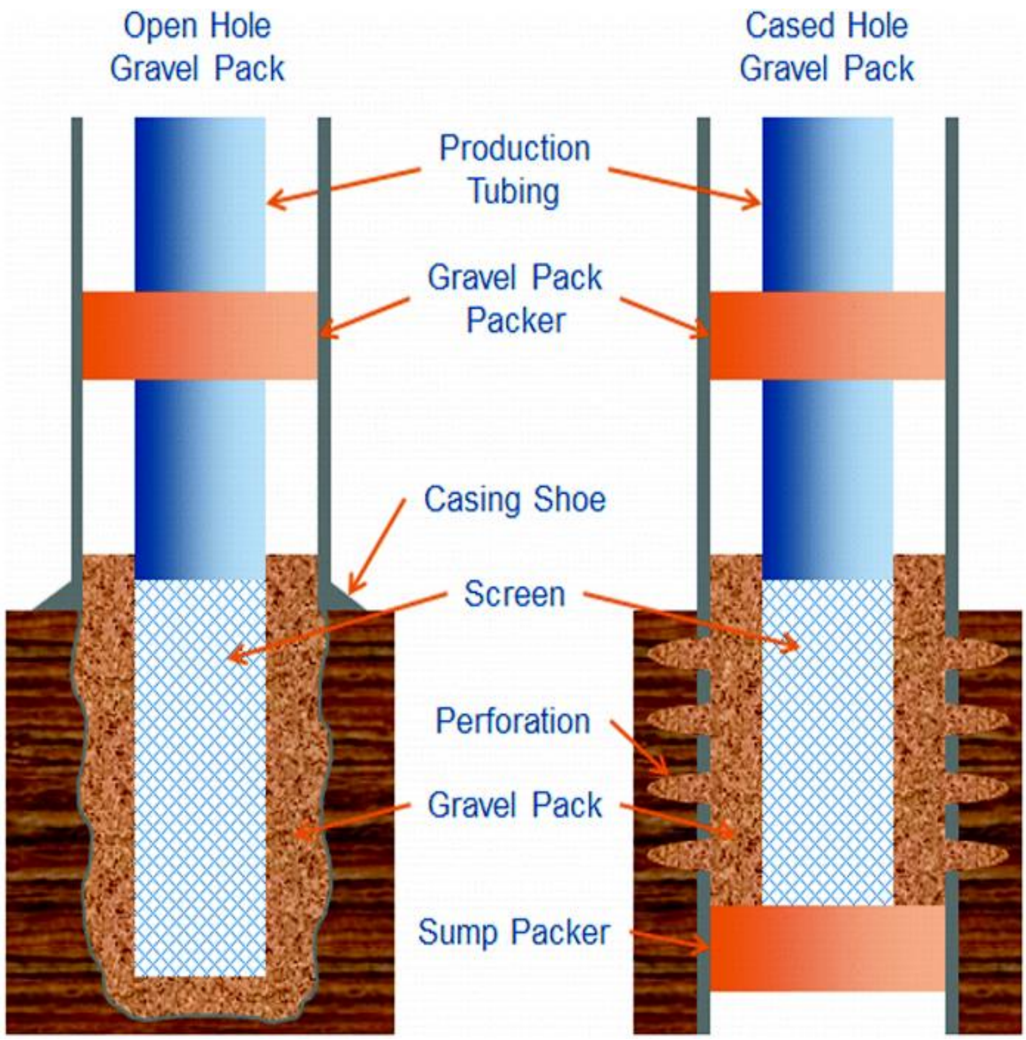


Figure III.22: Gravel pack in Openhole and cased hole completion.

6. Maintenance and work over:

Maintenance and work over is a passive approach to sand control. This method basically involves tolerating the sand production and dealing with its effects, if and when necessary. Such an approach requires bailing, washing, and cleaning of surface facilities routinely to maintain well productivity. It can be successful in specific formations and operating environments. This type remains undesirable Due to the high cost of well operations **[**60].

7. Conclusions:

Mechanical methods of through- tubing sand control involve the use of gravel pack screens design to be deployed through tubing, then set inside tubing, casing, or even another larger gravel- pack screen. In addition to the use of screens, a sand medium is often used to help keep the formation sand in place. The method is employed mostly for the following reasons [61]:

- Cost efficiency- the operation does not require a work over rig since the screen assembly can be deployed with standard coiled tubing equipment or wireline and the well returned to production faster.
- Effectiveness- sand production is controlled allowing production to match previous rate or better.
- Quick intervention- operation could be accomplished quickly without impacting existing well completion jewelry or deferred production in dual completion.
- Maintenance costs- maintenance costs associated with surface and downhole equipment due to sand production are now eliminated.

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CHAPTER IV:

SAND PRODUCTION PREDICTION

1. Introduction:

Given the importance of forecasting sand production in the oil industry, great efforts have been made in developing robust numerical methods for predicting sand production. Sand prediction models provide a better assessment of sanding capabilities and a realistic knowledge of the production behavior of a problem Sand.

A number of methods have been developed to predict or aid in understanding the problem of sand production. The many published techniques for predicting sanding initiation can be classified into four basic approaches: experimental methods using field observations and well data, laboratory simulations, numerical methods and analytical methods [63].Often two or more methods are used together for prediction.

Most of the models developed are based on a discrete component model or the continuity hypothesis. Some models only have the ability to evaluate conditions that cause sanding, while others have the ability to make volumetric predictions. Some developed models use analytical formulas, especially those used to determine the start of sanding, but other models apply numerical models, especially in obtaining the sanding rate. Although major improvements have been made earlier, the sander still cannot predict the sanding rate and mass of all field problems in a reliable procedure.

Usually, it is not necessary to forecast sand production on a per-well basis because wells in the same reservoir tend to behave similarly. The forecast required is on a tank by tank basis. The importance of controlling sand in production tanks was highlighted in order to reduce the risks that may result from its production.

So from an economic point of view, the overall effect of implementing sand control method (s) during well completion must be analyzed [64].

2. Sand Production Effects:

The impacts of sand production are often detrimental to well productivity in the long term. Downhole equipment may be blocked or damaged and / or surface facilities disrupted.

2.1. Erosion of downhole and surface equipment:

Sand production from formation sand at high speed can corrode surface and downhole equipment resulting in frequent maintenance to replace this equipment. Blast joints or opposite holes for tubes, screens, or cleft bushings that are not packed in the installation of gravel packs are potential sites of downhole erosion.

Figure IV.23: Surface choke failure due to erosion by formation sand [65].

If corrosion is severe or occurs over a sufficient period of time, complete failure of the surface and / or downhole equipment may occur, resulting in critical environmental and safety problems as well as production delays.

FigureIV.24: eroded screen[66]

The high-pressure gas containing sand particles that expand through the throttle surface is the most dangerous condition. For some equipment failures, auxiliary platform maintenance may be required to repair damage.

2.2. Formation subsidence:

The cumulative effect of formation sand production is the collapse of the formation. Over time, a large amount of sand will be produced on the surface creating a void behind the casing. This void expands as more sand is produced. Sand or shale may collapse over the void due to a lack of support materials. Sand grains are rearranged to create a lower permeability than it was originally especially in formations with higher clay content or a wide range of grain sizes. The complete loss of productivity is likely in situations where the upper shale collapses. Formation breakdown is particularly important if the formation material fills or partially fills the perforation tunnels. Even a small amount of formation material filling the perforating tunnels will cause a marked increase in the pressure drop across the formation near the wellbore for a given flow rate [67].

2.3. Sand accumulation in surface equipment:

In cases where the reservoir fluid production velocity is sufficient to transport sand through the tube to the surface. Sand particles often settle in surface installations such as separators, heaters, pumps, and condensers. With the accumulation increasing to a tangible size in these facilities; Equipment cleaning becomes inevitable. This causes production to be postponed (the well is closed) and an additional cost is queried as a result of the cleaning activity. The production capacity of the separator is reduced if it is partially filled with sand. This is a result of its low ability to handle gas, oil and water.

2.4. Subsurface accumulation:

When the production flow velocity is insufficient to transport sand particles to the surface. Sand accumulates in the casing or bridges in the tube, over time the production interval may be filled with sand. This reduces the production rate of these wells which may eventually stop because the accumulation of sand makes it impossible for production to continue. Work on activities is often required in such cases until the well resumes production. If sand production is continuous, regular good cleaning operations may be required. This increases maintenance cost and lost production, which in turn reduces well returns.

Figure IV.25: blockages of flow lines.

2.5. Sand disposal:

This poses a problem in formations that produce sand especially in areas where there are severe environmental restrictions. Offshore treatment systems that do not meet pollution control regulations, separated sand must be transported to the shore for disposal, which constitutes an additional production cost.

3. Sand prediction types:

3.1. Empirical Methods Using Field Observations and Well Data:

This technique uses the correlation between sand production well data and field operational parameters in forecasting. Usually one or a combination of parameters is used to assess the sanding potential and establish a standard for sanding or non-sanding. This is due to practical difficulties in monitoring and recording multi-year data for all wells participating in the study [68]. Parameters such as porosity, retraction or flow, compressive slowdown etc. are often used. The field data-based sand prediction tool uses only one parameter, examples include avoiding pores of more than 30%, using the cut depth criterion for fitting sand control measures in many delta environments.

3.1.1. Experiment :

Abbas, Ahmed K.et all have done study about this kind of type with well in the Zubair reservoir (Basra, Iraq) to make an exprimental prediction for more than 350 wells in the field. This study, sanding prediction analyses were conducted using a technique that combines easily measurable lab data, log data, and analytical calculations with empirical methods that are supported by the results from previously run rigorous and advanced numerical code.

- ***Experiment methodology :***

INPUT DATA :

The main input data to the analyses include a mechanical earth model (MEM) and sand grain size. Ata minimum, a MEM typically comprises in-situ stress magnitude, in-situ stress direction, pore pressure, and rock mechanical properties. A more detailed discussion on the sand grain size test and generating the MEM are provided in the following section.

The grain size analysis was carried out on selected samples from Zubair sandstone formation in order to identify potential sandy interval [69]. Grain size analysis included the determination of the grain size distribution by sieving. The sieves, up to five screens and a pan, were used to identify their characteristic grain size distribution. The selected samples for the analysis were thoroughly cleaned from the pore-filling hydrocarbons and salt by using a Soxhlet as a cleaning solvent. Then, the cleaned samples were allowed to dry at a low temperature (about 35–40 C°). The samples were soaked in distilled water for about 24 hours. The period of soaking allowed each particle to be surrounded by a film of water or the pores of the rock to be filled by water, what loosened the grains and soaided their dispersion. After prolonged soaking, samples were allowed to dry in room temperature. Partially indurate daggregates, unsuitable for direct analysis, were disaggregated by using a mechanical disaggregation. A suitable amount of sample material was then weighted and separated by the use of standard metal sieves with mesh-widths of 1.25 mm, 0.50 mm, 0.25 mm, 0.125 mm, 0.0625 mm and pan. The weight and weight percentages of the sample are listed in (Tables IV.3) and illustrated in (Figure IV.26) The obtained results are shown that the average grain size was 0.0625–0.125 mm with weight percentage of more than 85% of total investigated samples.

Table IV.3 : Weight and weight percentages

Grain size (mm)	Weight (g)	Cumulative (g)	Weight percentage (%)
1.25	0.00	0.00	0.00
0.5	0.74	0.74	1.58
0.25	5.29	6.03	11.29
0.125	26.98	33.01	57.58
0.625	13.08	46.09	27.81
<0.625	0.77	46.86	1.64

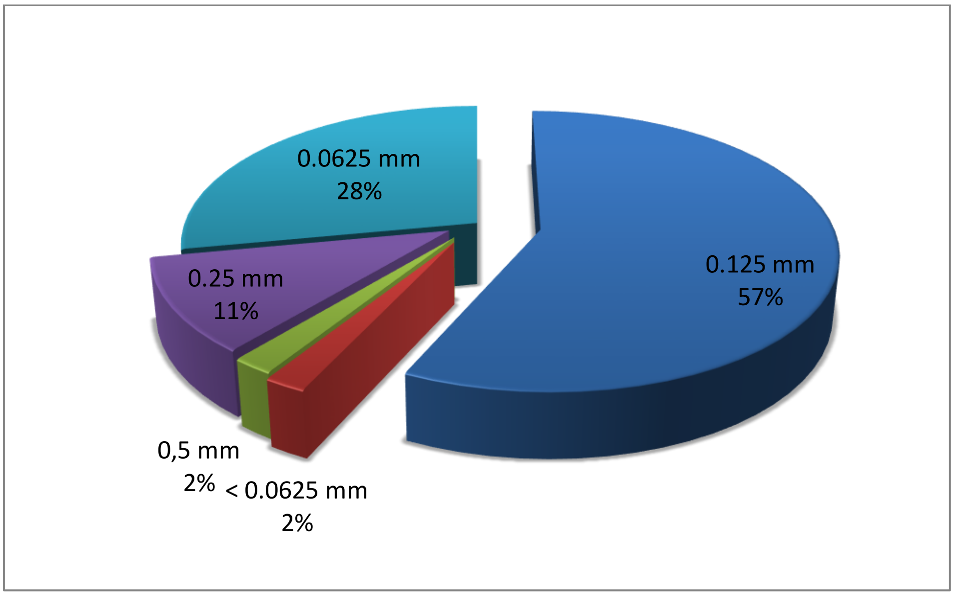

Figure IV.26 : Grain size distribution of investigated Zubair sandstone samples (total sample weight 46.84 g).

- ***Results :***

MEM technology was able to assess that completed wells and durations were subject to sanding. Besides, the use of sanding analyzes and sanding prediction technique can help determine the year of sanding initiation in specific wells while describing the reservoir pressure . He can also predict correctly [70].

3.2. Laboratory Simulation:

This approach is also widely used to establish an association between sanding hazards and measurable parameters such as stress, flow rate, and rock strength and to provide insights into the sanding mechanism in the formation in question. Laboratory experiments involve the use of available primary reservoir samples or protruding rock samples (with similar mechanical properties). There are two common types of laboratory sand production: laboratory sand production experiments and hollow drum breakdown tests [71].Laboratory experiments usually model the phenomenon of sand production in a controlled environment. The laboratory sand production test involves using cores to produce a small simulation of flow through holes or cylindrical cavities located within a compact cylindrical core sample. This technique provides investigation of factors such as slope, stress boundary conditions, flow rates, water interruptions, and rock properties. The conditions expected during the useful life of the well can be chosen as test parameters. This method is widely used to calibrate and validate predictions from analytical and numerical models. However, a large number of well-equipped cores and utilities are required for testing.

3.2.1. Experiment :

PERERA M.S.A et al. to obtain a comprehensive understanding on sand production prediction, an experiment laboratory simulation was done by them to calculte the quantify of sand production during oil recovery from unconsolidated quicksand formations [72].

- ***Experiment methodology :***

Experiment equipment :

The newly developed sand production cell was modified (max. 300 kPa static pressure) (Figure IV.27). The cell has three internal pressure transducers at the top, middle and bottom and thus can be used to determine pressure changes within the cell with sand production [73]. The pressure measurements obtained from the transducers are recorded in a computer using an advanced data acquisition system.

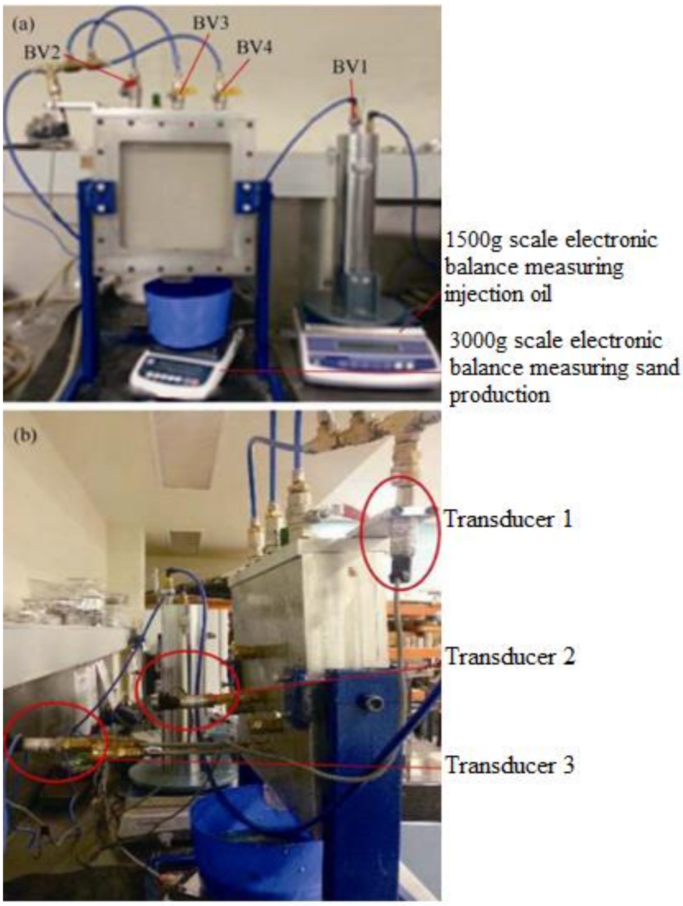

Figure IV.27 : Sand production cell [74].

Two balances with scales of 3000 g and 1500 g were used to measuresand production rate from the reservoir and the rate of oil injection into the reservoir formation.

The weighing data obtained from the scale was transferred to a computer using Datacom (DC) 500 software to provide a weighing time series. The pressure of the injected oil was adjusted using a pressure regulator to obtain different tractive force conditions. A high-resolution digital camera was also used to record the sand production process in each test.

Sand used for experiments :

The sand used was from the washed white sand group and the particle size distribution curveis shown in (Figure IV.28). The uniformity coefficient of the sand is 1.67. According to the standard [75], the sand has a uniform particle size distribution.

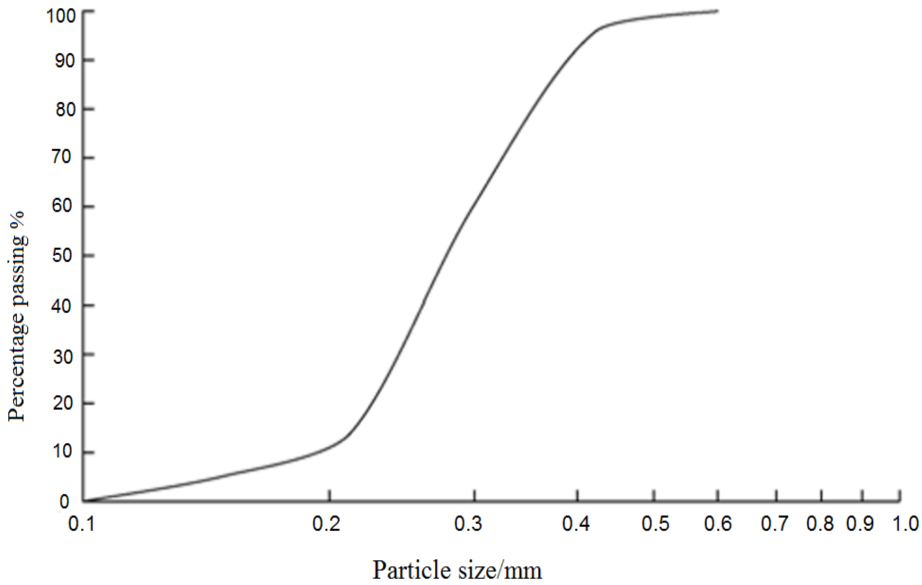

Figure IV.28 : Particle size distribution of the sand used.

Experiment conditions :

The experiment conditions are listed in (Table IV.4). Based on the sand production data from the preliminary experiments, a 5 mm outlet was chosen, as the duration for sand production is too long for a smaller outlet size. All pressures in the experiments are gauge pressures.

Table IV.4 : Experiment conditions.

SN	Injection fluid	Clay(%)	Injection pressure/KPa
1		5	50
2	Oil	5	100
3		5	150
4		5	200
5		10	100
6		15	100
7	Gas	5	100
8		5	150
9		5	200

Experiment procedure :

In order to form the oil tank, 4 kg of sand (mixed with required clay content and 5% distilled water) was placed in the cell to achieve the same uniform bulk density for each test. Each sample was compressed in three layers, each layer was pressed with 25 strokes with a tamping of 2.7 kg from a height of 300 mm.After making the first layer of soil, disturb the uppers oil surface to it and then pour the second layer over it and repeat the same procedure for compaction. Then the third layer was poured and pressed similarly. After all the soil was poured and compacted into the cell, the top cover of the cell was in place and the screws were fully tightened to prevent any oil leakage during the test. When the sand formation is ready and it is necessary to create a pull force for sand production to occur. The required pulling force was created by increasing the pore pressure in the formation by injecting the oil at a predetermined pressure. The oil was injected with a pressurized oil tank that was placed on a 1.5 kg scale, then the first BV1 valve opened to inject the oil from the tank. The pressure can be adjusted to the desired value using a pressure regulator. Once the required pressure was adjusted using the regulator, the BV2, BV3 and BV4 valves were opened (to ensure even pressure distribution) simultaneously to inject the oil at the required pressure into the tank to obtain the required pore pressure condition in the configuration to create the pulling force. Before opening BV2, BV3, BV4, pressure recording program and electronics cale registrations were started simultaneously to ensure time scales were synchronized. Weights of the injected oil and the resulting oil sand were recorded using electronic scales. Injection pressures were recorded at the top, middle and bottom of the cell using a high-resolution data acquisition system. In addition to primary data recordings, a digital camera wasplaced in front of the transparent cell to capture a video of the entire sand production process. When the sand is saturated with oil, the gradual formation of the sand cavity can be seen, and the sand production process started sometime after the sand cavity formed (Figure IV.29). When the cavity was filled with oil, BV1, BV2, BV3, and BV4 were closed to stop the experiment. The weigh trecorded at this point is the final cumulative sand production. The injection pressure was then released by setting the pressure regulator to zero and all data recordings were terminated.

(a)Partially saturated sand (b)Sand cavity formation (c) Oil-cavity cavity

Figure IV.29 : Test steps.

- ***Results :***

The experimental results showed that the production rates of sand and oil increased with the increase of the drag force affecting the formation and its decrease with the increase of the cement content, and the rate of sand production was close to zero in the high cement content. The high pressure tank is more likely to produce sand during development due to the high pulling force, and the effective formation stress and drag force together affect the oil production. Therefore, the sandyield rate can be estimated according to the clay content and with it appropriate sanding prevention measures can be taken in return.

3.3. Analytical methods:

This method has gained more popularity in the petroleum industry due to its computational simplicity, easily executable calculations, and ease of running multiple perceptions to compare many different scenarios. Sand prediction analytical models are based on hole modeling and production bore stability. This tool requires mathematical formulation of sand failure mechanism [76].

3.3.1. Experiment :

Ibrahim Ayuba, et al in group work had gatten an analytic expriment of free gas wells with PROSPER program help to make a prediction about the influence of free gas on sand production in Nigerian petroleum field [77].

- ***Experiment methodology :***

After providing the PROSPER program with well parameters (Table IV.5), under the influence of sand production (roughness of pipes, free gas, skin, liquid rate, oil rate),

Table IV.5 : Well Parameters under the effect of Sand Production.

Years	Tubing Roughness	Free gas (MMsct/day)	Skin	Liquid rate (STB/day)	Oil rate (STB/day)
2016	0.0005	1.5	2	6368.9	4776.4
2017	0.0008	2.78	4	6127.3	4595.5
2018	0.001	4.023	6	5847.2	4385.4
2019	0.005	6.14	8	4956.6	3717.5
2020	0.01	8.55	10	4190.7	3143.0

With same parameters but without the influence of sand production (initial Condition) (Table IV.6). within a certain period of time (2016-2020) (as in the studied case), the program analyzes these parameters according to the experimental limits in cluded then provide us an analytical diagrams .

Table IV.6 : Initial Condition of well without Sand

Years	Free gas (MMscf/day)	Liquid (STB/day)	Oil (STB/day)
2016	1.5	6160.8	4580.1
2017	2.78	6222.0	4666.5
2018	4.023	6299.0	4671.7
2019	6.14	6115.9	4586.9
2020	8.55	5894.8	4421.1

with a comparison between the two cases (Figure IV.29) and (Figure IV.30).

- The first cas is diagram present oil production rate without sand (Figure IV.30).

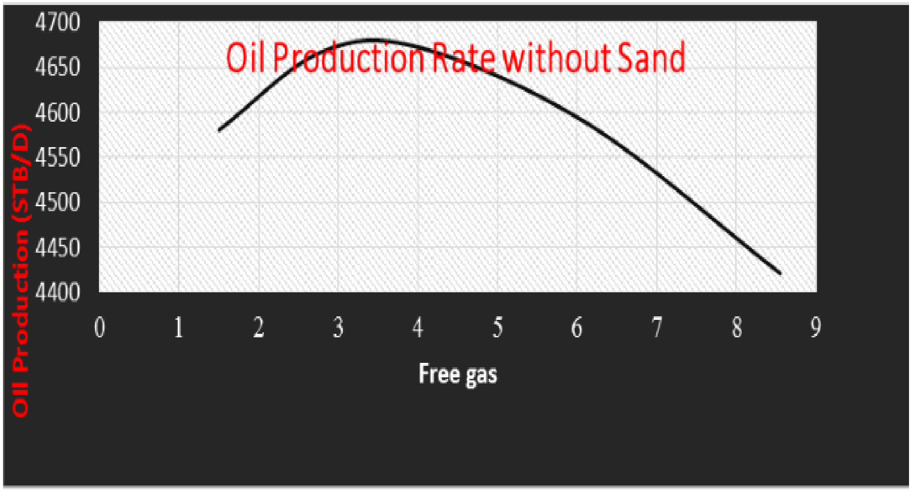

Figure IV.30 : Oil production under effect of free gas.

- The second is the diagram has given by PROSPER program (Figure IV.31).

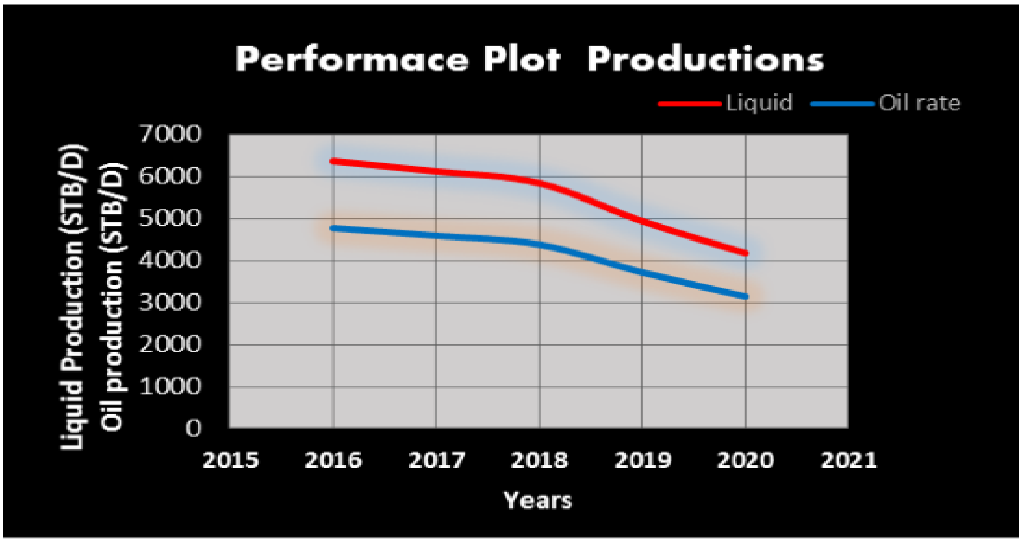

Figure IV.31 : Performance Plot across the Years.

Finally, the comparison gives an idea about the possibility of the well producing sand or not (articl).

- ***Reults :***

Future performance indicates that sand control treatment should be deployed to maintain and revive the well for optimum flow potential. Free gas effect analysis was used to determine the highest value of free gas under reservoir conditions to produce the optimum well. (3.5 - 4.023) MMscf/day gave the optimum flow potential of the well. This analysis shows the amount and condition of free gas in the well prior to the effect of sand production.

❖ PROSPER: is a key component of the Integrated Production Model (IPM) as defined by the petroleum experts, linking it to GAP, the Production Network Improvement Program for System Modeling and MBAL, and the reservoir engineering and modeling tool, to create a fully integrated holistic system modeling and production pridection [78].

3.4. Numerical methods:

These are models for finite element analysis that incorporate the full range of formation behavior during plastic, flexible, and time-dependent deformation. Numerical models provide a detailed description of a stress state and can be accurate. Compared to other prediction methods, the numerical method is superior because it represents more factors affecting rock collapse and sand production. However, the main disadvantage of this method is its complexity and time consumption. The time, resources and data needed for the method may not be available. When the properties required in numerical modeling are assumed or approximated due to the lack or deficiency of real data, the results from complex modeling are not necessarily more accurate or reliable than those resulting from other methods that use simpler, more accessible data.

4. Effective methodology for sand prediction:

A study of formation sands forecasts should answer the question, will the formation produce sand, the rate or volume of sand production and the likely production time of sand. If not, at least every two questions must be answered. The integration of different sand forecasting techniques results in an efficient prediction. Therefore, to effectively predict sand production, the following methodologies are presented [79]:

4.1. Mechanism causing sand production:

It is crucial to know the mechanisms involved in sand production, especially as one can be more dominant in the formation. These will aid in the prediction approach. Factors are categorized into three sectors of formation, completion, and production. These include: reservoir depth, permeability, rock strength, flow rate, and pressure drop to name a few. However, it is impossible to include all of these in the forecasting method due to the data not being available at the time of field development.

4.2. Formation classification:

Understanding what type of formation is in the reservoir should be the first step to predicting sand formation. These help either to classify the reservoir as either standardized or non-standardized [80]. In their work presented typical sand production configurations. The information they provided helps in understanding the behavior of different formation in terms of sand production and can be used in classifying formation for prediction purposes. It is known that sand production is specific to unconsolidated reservoirs and therefore first-hand information is obtained that the formation is likely to produce sand.

4.3. Porosity:

The porosity prediction property can be used. Formations with porosity between 30-34% are mostly incoherent with a high probability of sand production, and the porosity can be determined from cores and well stems. If the porosity is lower then sand control is not necessary in such formations.

4.4. Analogy method and/or field history:

The green field uses the measurement method, while a new well to be drilled in an existing field can use information from the field measurement and history. This is because the field has wells already in place; Experience from these wells is transferred to the new well, and this method provides first-hand information that gives insight into what to expect from the reservoir. Well stopped data from other wells in the same area, field, or sedimentation environment are used to predict the potential for sanding in the tank. Deductions especially from production data and the type of completion used in such environments are useful.

4.5. Drill Stem Test (DST):

This includes testing of individual wells through DST. The tank flushes after conventional completion to determine its sanding potential. The well flows when the progressive flow is increased through the throttle until sand is produced or the maximum acceptable rate at which the reservoir can be produced is derived, and accordingly a sand free production rate can be determined and the achievement decision can be made with regard to sand control.

4.6. Comparison of drawdown to compressive strength:

The strength of the formation rock gives a measure of the cohesion (hardness) of the formation. The tank pressure drop can be related to the tank pressure strength. Sand production occurs when the retraction is 1.7 times the compressive force.

4.7. Well logs:

They provide a continuous profile of configuration data as they are made on site. Acoustic, density and neutron logarithms act as an indication of the porosity and strength of rocks which is important in prediction. Then these properties are used to derive properties of elastic rocks such as Poisson's ratio, Young's modulus, volume modulus and shear modulus which are used later in the prediction [81].

4.8. Laboratory technique:

The laboratory test technique of sand prediction is extensive and time consuming. It provides the best rock mechanics parameters used in prediction because of its reliability. They are used to calibrate the log-derived strength models.

4.9. Supplementary testing:

These are the techniques and tests performed on the core samples that complement the rock strength data because sandstone can consist of many types of minerals and rocks of single strength which can be calculated through supplementary tests. Principal methodologies for these techniques include the Special core Analysis Laboratory (SCAL) and rock analyzes. These must be incorporated for use in the laboratory rock strength testing program. These tests are:

- Scanning Electron Microscopy (SEM)
- X-Ray Diffraction (XRD)
- Cathode-Luminescence Microscopy(CL)
- Particle (or grain) Size Distribution (PSD) analyses
- Thin Section (TS) analysis/ point counting (petrographic microscope)

4.10. Model Selection:

The theoretical / analytical sand forecasting tools are based on theoretical hole modeling and bore stability. The simple Mohr-Coulomb that assumes that rocks behave flexibly under pressure is often used in industry. The choice of the type of model to be used in forecasting (estimating the amount of risk of sand production) should be based on the best fit for purpose with acceptable accuracy taking into account the limitations of data unavailability.

This is why finite element techniques are not used often because the requirements of time, money, and data do not justify their complexity. Prediction sand and production models often relate to safe / critical regression rates, flow rates, volume, and time. The forecast model should answer the question of if and by how much. The model is then calibrated with available field data / dates from the balanced well to remove the reservation.

4.11. Identifying uncertainties:

This involves the quantification of the uncertainty of the deterministic outcome from the prediction model. As mentioned before, uncertainty is inherent in the data entered into the model. "Monte Carlo using risk" can be used to perform these simulations of periods of interest. The correct probability distribution functions (PDF) must be modeled for the model input parameters in the simulation. Measuring uncertainties gives a certain level of confidence in risk.

4.12. Sensitivity analysis:

This is to determine to what extent the model results are sensitive to each input parameter. This will govern the accuracy of obtaining these parameter(s).

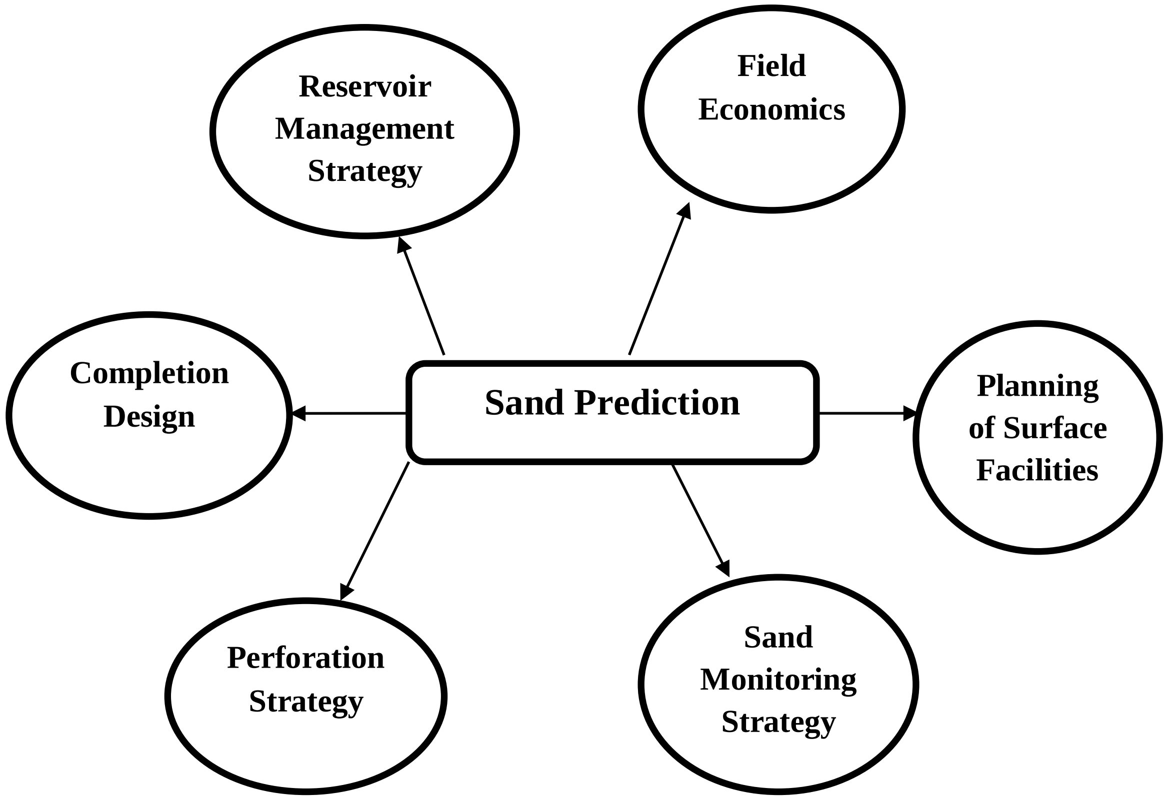

Figure IV.32 : Sand Prediction Applications.

5. Conclusion :

Based on the theoretical studies included and practical notes (field) in the chapter about some petroleum fields around the world, it was determined that the more the methodology used in the prediction process of sand production is sound, the more expectations reflect a correct idea about the sanding problem, through a good evaluation of the state of the formation of the reservoir and determining how To deal with it in order to build good communication between the well and the reservoir, including improving the well production mechanism and avoiding negative influences that would prejudice the general economy. However, research remains on going to improve prediction mechanisms and develop them as much as possible

Field experience plays an important role in identifying uncertainties and enhancing the level of confidence while dealing with the results drawn from the experiences and in developing the level of oil and gas production in the future.

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CONCLUSION

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RECOMMENDATIONS

Conclusion:

Sand production is a complex phenomenon and needs to be customized based on the type of reservoirs.

After the literary study mentioned in the first three chapters, the parameters of the problem of producing oil wells for sand and the extent of their impact on the petroleum industry in general became clear, which prompted us to highlight the effective prevention measures necessary to reduce its risks by displaying the mechanisms produced, whether we choose production chemical or mechanical sand control.

Based on field experiences and experimental work, sand prediction technology provided us with a broad and broader under standing of the phenomenon, which allowed us to embody modeling techniques and mechanisms that would help in controlling and managing the sand.

By following a well-thought out forecasting methodology, we can reduce the incidence of problems or reduce the severity of the problem.

The mechanisms used, whether in controlling, managing and predicting the problem of sand production, remain dependent on the general conditions of the case being treated.

Even in light of the many efforts made by many researchers and practitioners related to this problem, there are still some large gaps in knowledge that must be filled in order to develop proper models for it.

Recommendations:

Based on this study, we propose the following recommendations:

1- Since formation strength is an important factor in sand prediction, methods that can measure this parameter must be developed on site to aid in accuracy.

2- Taking into account the issue of monitoring sand production, as it is an important and new issue for our oil fields.

3- Good knowledge of all exclusive developments in the petroleum industry, including technologies, structures, processes and plans.

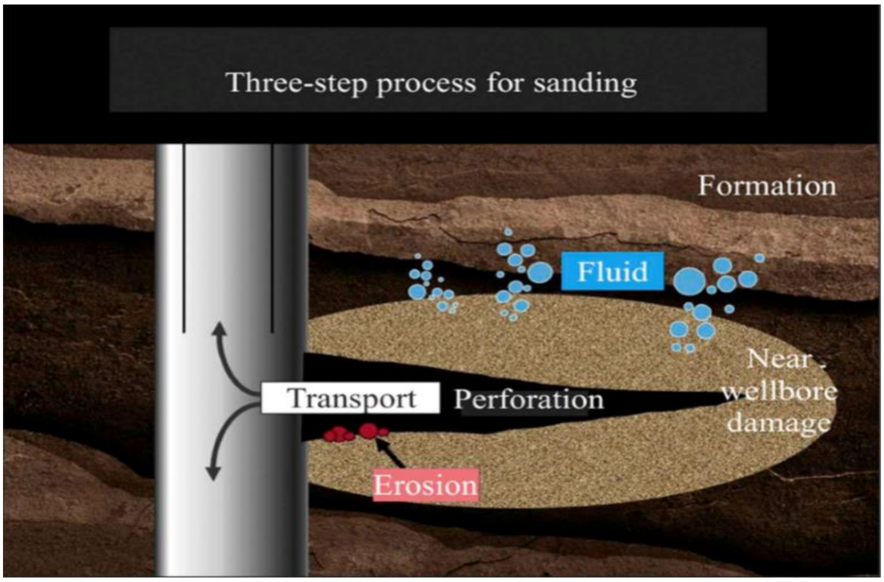
4- Providing laboratory facilities and practical devices to embody experiences that speak in the field.

5- Concluding partner ship and cooperation agreements with companies researching in this field, with the aim of better communication and gaining sufficient experience.

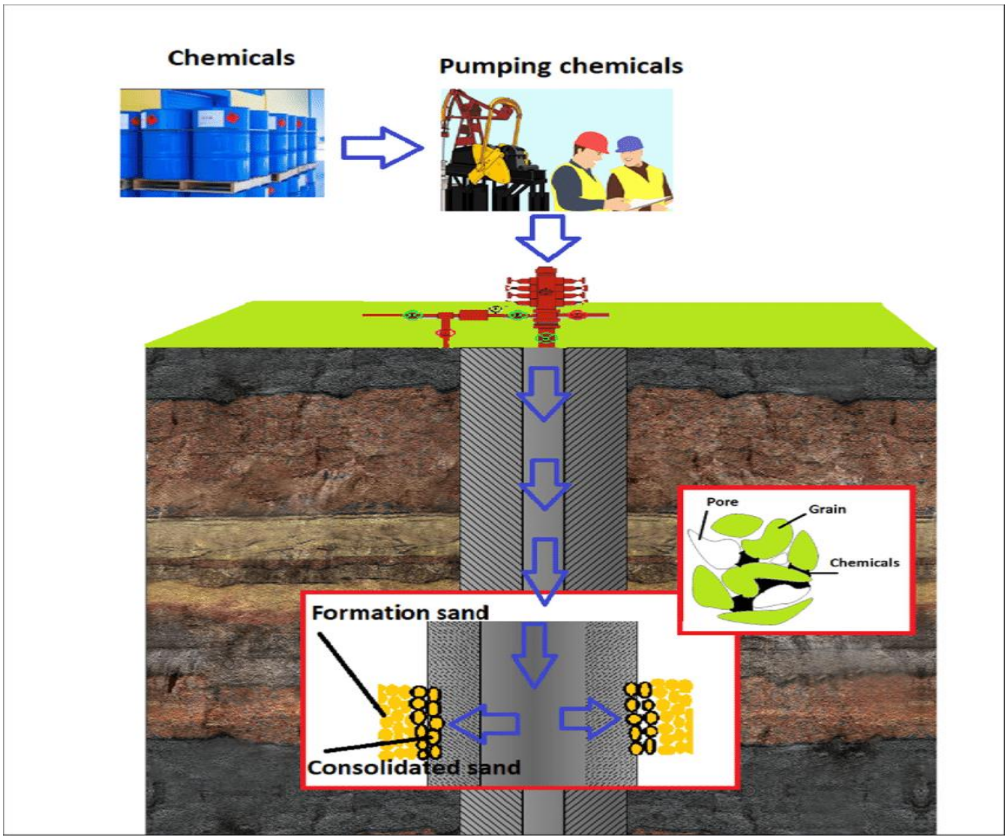
6- Continuous communication with partners working in the hydrocarbon sector and to be aware of all that is new.

7- Intensifying practical scientific outputs for various fields in order to provide information and new ideas used.

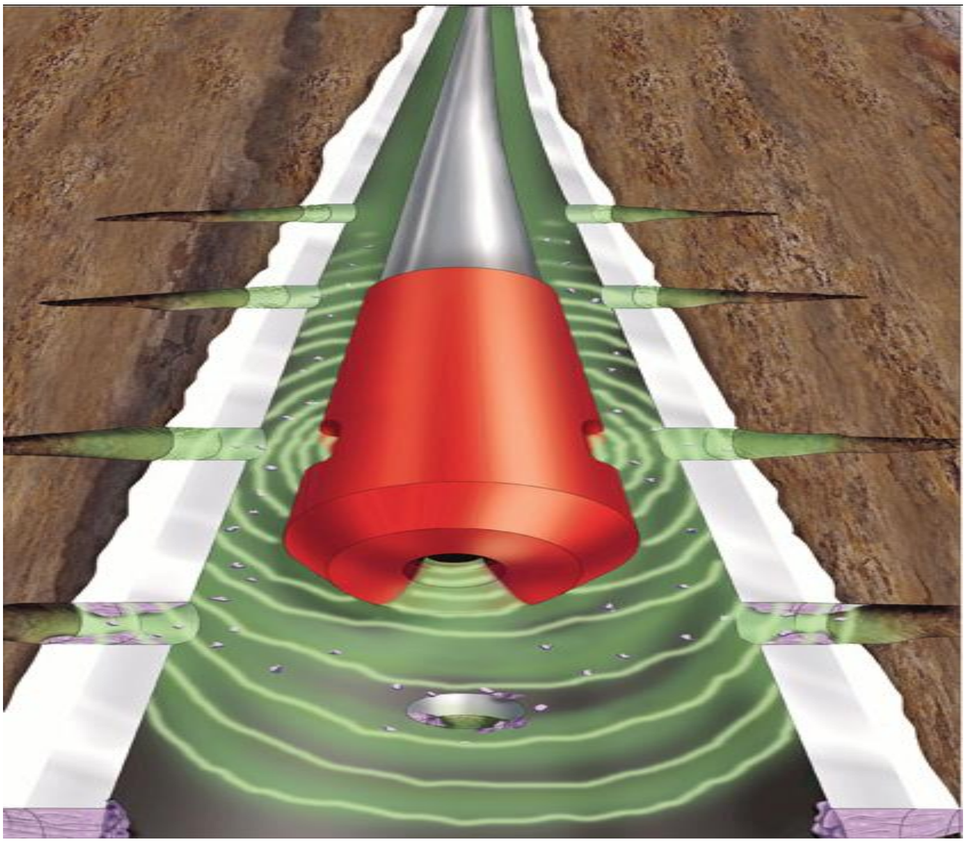
Appendix:



Sanding mechanism



Chemical sand consolidation



Fluidic oscillation technology is recommended for enhancing the placement of resin for formation consolidation. The oscillator generates alternating bursts of fluid to help ach

Various Commercial Consolidation Processes.

Inventor	Year	Base of applied resin	Range of temperatures(F°)	Range of compressive strength(Psi)	Permeability to original (%)
Sain	**1962**	**Phenol–formaldehyde**	**85–200**	**>3000**	**50**
Dees et al.	**1992**	**Epoxy**	**100–220**	**>5000**	**67**
Dees	**1993**	**Epoxy**	**50–250**	**>7000**	**50**
Jennings et al.	**1994**	**Phenol–formaldehyde**	**280**	**>3000**	**70**
Shu	**1994**	**Epoxy**	**175**	**/**	**/**
Todd et al.	**2001**	**Furan**	**40–400**	**>3000**	**90**
Appah	**2003**	**Furan–phenolic**	**/**	**3000**	**/**
Nguyen	**2004**	**Furan**	**80 to>300**	**>3000**	**70**
Nguyen	**2006**	**Furan**	**40 to 400**	**>3000**	**70**
Talaghat et al.	**2009**	**Modified phenol–formaldehyde**		**>3000**	**67–83**
Riyanto et al.	**2016**	**An aqueous based consolidation**	**145**		