SAND CONTROL AND MANAGEMENT - DEVELOPMENT OF A
SAND CONTROL STRATEGY

by
Navjeet S Benipal, B.Tech.

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Approved by
Supervising Committee:


Dedication

To my parents, their lives and accomplishments continue to be an inspiration.
Preface

Most of the hydrocarbon production in the present world comes from formations with the potential to produce sand during well life. In the United States, sand producing formations occur commonly in the Gulf of Mexico, California and Texas. Around the world, sand production is common in West Africa, Canada, China, Venezuela, Trinidad, Cameroon, Azerbaijan, Malaysia, Indonesia and parts of the North Sea and Nile Delta.

Sand production is on the rise as the existing fields are maturing (depletion and water production); new fields are of poorer quality, high rate and high ultimate wells, and sub-sea wells. The drilling of high rate and high ultimate wells and poor quality of the reservoirs have put so much stress on the formation sand that the majority of wells require either downhole sand control or management of the produced sand at the surface based on the severity of the problem. In addition, a large number of developments involve sub-sea wells where the consequences associated with unmanaged sand production are even more severe.

Another reason for the management of the sand is more stringent environment and safety regulation, which require the operators to minimize risks arising from sand production by better control and disposal of the sand produced during operations.

This report “Sand Control and Management – Development of a Sand Control Strategy” presents current industry practices for sand control, production problems related to sand influx and existing sand prediction techniques with the objective of documenting the best technology for existing sand control methods. The findings would help the engineers and field supervisors to select, design, and apply the best sand control techniques for a particular situation.

Chapters 1, 2, 3 and 4 give a detailed description of what is involved in sand control and management. These chapters focus on fundamentals of sand production, accurately predicting the reservoir potential for sand production, reducing sand production to avoid damaged assets and decreased production rates, assessing the ability of currently available sand control technologies to counter sand production and combine
sand control and sand management to effectively supervise sand production and sand damage.

Chapter 5 presents the design of a sand control strategy. The chapter is intended to help engineers identify, understand and implement sand control or management strategy that will work best.

This report is intended for the use of completion, petroleum and drilling engineers involved with well design and implementation, reservoir and surveillance engineers putting together reservoir or well management and depletion plans, and facilities engineers looking to design and manage surface and sub-sea production facilities in sand-prone environments.

The scope of the report is very wide. However, special emphasis is put on detailed presentation of the sand production concepts for deeper understanding.
Acknowledgements

Every project has a long list of contributors. I am privileged to have my name on the cover of this report that is the product of many great minds that shaped my thoughts over the time at The University of Texas at Austin. To all those who have given me their time and trust, I offer my thanks and these acknowledgements.

Ken Gray, who conceived this project and contributed his hard-won expertise in the field of drilling and completion engineering, I thank you for teaching me the basics of drilling and completions. His continuous help and supervision during the work are the most important factors in the completion of this report. I would like to thank Jon Holder for reading the report and providing suggestions for improvement.

Also I am fortunate to have many friends who have provided insights, encouragement and importantly criticism. Not least, perhaps, I should thank my wife, for her patience and forbearance whilst I have spent hundreds of hours working on it.

They all have shaped some aspect of my personality and so this report. Thank you all.

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Abstract

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Navjeet S Benipal, M.S.E

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Supervisor: Ken Gray

Sand production is one of the major challenges faced by the petroleum industry moving into the next century. The history of sand production dates back to the 1900’s with the completion of water wells with sand control installations. A lot of work has been done from that time to control and manage sand production. Several sand prediction models have been developed to predict the onset of sand and the amount and rate of sand production. More efficient and advanced sand control installations have been put into wells to stop sand from moving into the wellbore. A deeper understanding of the failure mechanisms (reservoir and rock parameters) governing the physical process of sand production is achieved and applied towards the development of new technologies for sand control. The production facilities are better designed using erosion resistant materials. All these technical developments and the related work have been recorded in the literature in form of research papers, professional journals and field experiences. This report is a review of the efforts made by the industry to control sand production and thereby help field engineers utilize the knowledge and experiences from global best practices. Finally, a methodology is presented to develop a sand control strategy for sand prone reservoirs.
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Chapter 1: Sand Control

1.1 INTRODUCTION

Oil and gas are produced in many areas of the world from unconsolidated or poorly consolidated weak formations vulnerable to sand production. Sand may be produced with the fluids either in surges or gradually over longer periods of time. The production of sand is a result of the drag force created along the path of fluid flow. Depending upon the degree of natural intergranular cementation, compaction, intergranular friction and cohesion of formation particles, sand may be drawn into the wellbore as the drag force exceeds these restraining forces. In general, high flow rates result in larger quantities of sand production. Sand produced has no economic value. On the contrary, sand production causes reduced productivity, loss of reserves and added cost in combating equipment damage and sand accumulation problems. Every year industry spends millions of dollars in combating sand related problems. Thus there’s a tremendous incentive to study and develop optimal sand control and management methods to increase profits.

There are some general rules of thumb, which have been used in identifying excessive sand producers. For oil wells the limit is set between 5-10 lb sand/1000 bbl or 0.001-0.002 percent; for gas wells it is 1 lb/MMSCF. In higher GOR oil wells (> 10,000 SCF/bbl), the limit is sometimes as low as 5-lb/1000 bbl due to high wellhead velocities achieved. In the past, industry has recommended that sand control methods be used where sand production exceeds these levels. However, the limits vary with field conditions. It is up to the engineers to decide the amount of sand production, which can be tolerated in their respective fields, depending upon wellbore design and surface equipment.

1.2 DEFINING SAND PRODUCTION

It is important to identify and differentiate the various terms relating to sand production before delving into the mechanics of sand production. This will help define and assess the type of sand production and the possible ramifications.
All wells produce some clean-up sand, near-wellbore fines, drilling mud, and particles from the formation or crushed zone of the perforation tunnels during initial production. However, this is usually a temporary phenomenon and is characterized by spikes of sand production after each major rate change during the first few hours or days of production or later when plugged perforations break open. The amount of sand produced rapidly decreases as the well cleans up and the formation stabilizes. Once this has occurred, changes in production conditions cause little additional sand influx. Therefore, temporary sand production should be expected in all new completions or new perforations and is not necessarily an indicator that sand control will be required. Conversely, many wells may either completely sand-up or produce sand continually or semi-continuously beyond the first few days of initial production. This is a good indication that some method of sand control may be required. It has been shown that continuous sand production is a function of production conditions and can be controlled, even in many unconsolidated sands, by natural arching through regulation of production rates or bottomhole pressure drawdown. Once initial formation failure has occurred sand production may rapidly decrease as natural arching limits the growth of the cavity [37]. Failure of the cavity will occur and sand production will resume if sand-free production rates are exceeded or if other destabilizing actions occur (e.g., onset of water production). In friable sands, drawdown tests have shown that considerable increases in rate and drawdown may be possible after initial failure is reached. However, some unconsolidated sands, called running sand or quicksand, will not arch and tend to run into the wellbore uncontrollably.

A well can also produce fines resulting from natural fines migration, stimulation treatments, or sand production. "Fines" are interstitial materials, generally smaller than 90 percent of the formation particles whereas the “sand” is the load-bearing particles making up the formation. By this definition fines include particles in the silt range (< 62.5 microns) and smaller. Erosion tests have shown that particles in this size range are unlikely to create a downhole erosion problem [3, 4]. Production of fines from some turbiditic formations has been reported to be severe, so as to fill the wellbore. Fines production frequently is blamed for productivity losses; however, this has not been
substantiated. However, fines production contributes to the compaction-induced mechanical well damage as fines production from the near-wellbore area temporarily increases near-wellbore porosity and thereby worsens compaction strains when load-bearing grains compact. Also, the removal of the fines allows load-bearing grains to slip past one another and reorient more easily. Fines production may be reduced by proper completion fluid selection, stimulation design, pumping procedures, well unloading/flow initiation procedures, completion drawdown, and flow rates. There are no proven remedies for stopping fines production, and attempted remedies may worsen the situation.

Not all wells that continually produce sand are sand production problems. Obviously, some wells must employ sand control methods to be produced. However, low levels of sand production may be tolerable in many situations. Sand production becomes intolerable whenever costs (i.e., from erosion damage and failures) and risks (i.e., economic exposure and safety and environmental risks) become unacceptable.

1.3 CAUSES OF SAND PRODUCTION

Sand production occurs when a destabilizing action exceeds or removes the forces, which hold sand grains together. These forces are the cementing materials which bonds grain together, friction between grains coupled with compressive stresses which result in the formation of naturally stable arches, and the cohesion or capillary forces due to a common fluid phase wetting the grains.

The drag force from produced or injected fluids can shear the intergranular cement bonds and destroy the natural arches of unconsolidated sands, which then leads to sand production. There are other destabilizing actions, which can exceed or remove the holding forces and lead to sand production. Cementing material can be dissolved or eroded by produced fluids, stimulation fluids (e.g., acid treatments) and injectants (e.g., steam). The cementing bonds can be broken by changes in the principal stresses caused by initial drilling and cementing operations, compaction due to pressure depletion, excessive pressure drawdown during production, pressure surges due to facility upsets, large choke changes, stimulation procedures, and sudden starts of artificial lift.
Figure 1.1 Sand production during a rate test.

There are other factors which affect the strength of these forces, such as the degree of compaction, which is generally proportional to the overburden loading (or depth) and inversely proportional to the reservoir pressure, porosity and permeability of the formation.

The magnitude of this drag force is dependent upon the fluid flow rate. Figure 1.1 illustrates sand production during an increasing flowrate test. The test record indicates that a new sand production peak occurs after each increase in oil rate. The peak is followed by a decline to a minimum level, which is essentially sand free production. At the highest oil rate, sand production continues indefinitely. This oil rate at which the sand production becomes uncontrollable is called the critical sand free oil rate. It is recommended that every operator establish this critical sand free oil rate for each field.

Other factors that play a role in the influx of sand are geology, natural consolidation, time dependence (depletion and maturing of fields), multiphase flow and thermal effects.
Sand production is a regular phenomenon in unconsolidated, shallow and geologically young formations. These low strength (< 100 psi compressive strength) formations produce sand from the first day of production or after the first shut-down.

Natural consolidation of the formation by means of intergranular bonds, intergranular friction, gravity forces and capillary forces restrains sand particles from being drawn into the wellbore by the drag force created due to fluid flow. The intergranular force is best estimated by the compressive strength of the formation. It is believed that the formations with a compressive strength greater than 1000 psi generally remain sand-free.

In some cases, sand production starts after the well has produced for a considerable period of time. It is because the reservoir pressure decreases with time and thus the sand grains experience more overburden stress. Natural arches in unconsolidated sands can also be destroyed by grain slippage resulting from pressure depletion, changes in the principal stresses, excessive pressure drawdowns and pressure surges.

Multiphase flow (water or gas breakthrough) increases the probability of sand production. The water dissolves the cementing materials and weakens the intergranular bonds or reduces capillary pressure. In some wells, connate water provides intergranular cohesion as oil and gas are produced. However, sand production begins at the onset of water production due to connate water becoming mobile.

High temperature in the steam injection wells has initiated sand production when there was no sand production before. This phenomenon has not been very well understood but has been experienced in the field. For example, in high viscosity crude, it is believed that the viscous crude provides formation stability. Sand production begins as the oil decreases in viscosity and becomes more mobile due to steam injection. Also, the injection of miscible fluids (e.g., as in a miscible CO2 flood) can lower the cohesive forces by affecting the surface tension of wetting fluids. It is apparent from this discussion that most sand problems will occur with young, poorly cemented rocks, especially at shallow depths; in heavy, viscous oil wells; in highly overpressured and geopressedurized zones as compaction begins to take place; in certain high rate producers; and in reservoirs which are rapidly depleted. It should also be apparent that sand
production will often be rate-sensitive, since this determines the drawdown, drag forces, and, in some cases, the water saturation. A maximum sand-free rate can often be established by very slowly increasing the production rate until a trace of sand production is noticed. Immediately reducing the production rate below this point should restore sand-free production. However, this will change with the production conditions and with reservoir depletion.

1.4 Problems caused by Sand Production

The production of sand in oil and gas reservoirs causes the petroleum industry millions of dollars every year in operational expenses. The produced sand causes damage to production facilities (equipment), instigates casing collapse, and most importantly productivity losses. The severity of these problems varies depending upon the amount of sand produced and numerous other factors. Damage to the equipment involves plugging, sticking, filling and erosion as shown in Figure 1.2. Plugging, sticking and filling of the wellbore or the surface equipment can be repaired by cleaning the well or the equipment. It is erosion, which is detrimental for the well as it creates holes in tubing, sticks wireline tools, sticks and erodes downhole pumps, cut chokes and surface lines. These problems can, in a worst-case scenario, lead to a blowout, fire, loss of life, loss of assets, and pollution. Casing collapse is due to the formation of a cavity behind the casing wall. As the sand is produced it forms a cavity behind the casing and these cavities increase in size as larger amount of sand is produced. This generally does not appear until later in the life of the well. The removal of transverse support leads to buckling of the casing and then collapse due to compaction-induced loading (Figure 1.2 b). Equipment related problems leads to the temporary production shut-off for cleaning and removing the sand but casing collapse requires abandonment of the well and thus loss of productivity.

1.5 Erosion

Erosion is an important form of equipment failure caused by sand production. It is a complex phenomenon and is affected by numerous factors and small or subtle changes in operational conditions can significantly affect the damage it causes. Detection of
Figure 1.2 (a) Wire-wrapped screen damage caused by sand production (Penberthy and Shaughnessy). (b) Casing buckling caused by sand production is evidenced in this example from a South Pass area well offshore Louisiana. The 7-inch casing was deflected 8 inches within a vertical distance of 5-10 feet (Suman, 1974). (c) Erosion of a wellbore due to sand production. (d) Accumulation of sand in a wellbore. (e) Collapsed formation into a wellbore. (f) Fracture of the wellbore due to excessive pressure inside the wellbore.
erosion as it progresses is also difficult and plant operators rarely have a good measure of the internal condition of the pipe. Erosion has been long recognized as a potential source of problems in oil and gas production systems. The inherently variable nature of the erosion process makes it very difficult to develop definitive best practice recommendations that will apply to all equipment in hydrocarbon production systems.

Attempts have been made to correlate particle velocity or sand concentration in the well to equipment damage caused by it. Figure 1.3 shows the superficial velocity limits for liquids and gas in the petroleum system beyond which the erosion of the equipment takes place, as recommended by American Petroleum Institute (API). These are the maximum allowable velocities at which the well can produce without causing erosion. The magnitude of erosion is controlled by the concentration of sand in the system. The line moves further to the left depending upon the amount of sand production. The graph shows how the conditions become severe at high sand concentrations. This correlation is by no means true for all fields, as erosion by sand impingement is a complex phenomenon dependent on numerous variables such as particle properties of size, density, shape, hardness, concentration; material properties of hardness, strength, composition; fluid properties of viscosity and density; and other factors such as angle of impingement, flow velocity, flow regime, etc. Erosive wear is believed to be strongly proportional to the kinetic energy of the impinging particles (some studies suggest erosion is proportional to velocity cubed). Particle impact velocity can vary substantially with flow velocity, especially in liquid flow streams where the impact velocity tends to be much lower. Changes in gas flow are less likely to affect the inertia of sand particles immediately prior to impact. Smaller particles have lower inertia and thus exhibit lower collision efficiency. The velocity of smaller particles is more easily affected by the sudden changes that occur as the flow stream is diverted through turns and elbows.

1.5.1 Erosion Mechanisms

The erosion mechanisms can be classified into particulate erosion, liquid droplet erosion, erosion-corrosion and cavitation. However, the petroleum industry is mainly concerned with the particulate erosion (sand and proppant), which is responsible for the
majority of damage done to hydrocarbon systems. The degree of erosion is different in parts of the production system depending upon the design of the equipment, material properties, and operational conditions. The most affected components are upstream of the fluid separators, as they carry multiphase mixtures of gas, liquid and particulates.

Figure 1.3 API recommended superficial velocity limits for erosion.

1.5.1.1 Particulate Erosion

Particulate erosion in equipment is mainly because of sand particles and proppant present in the flowstream. The important factors controlling particle erosion are the flowrate of sand and the way it is produced and transported; the velocity, viscosity and density of the fluid; and the size shape and hardness of the sand particles.

The flowrate of the sand and the manner in which it is transported accounts for the rate of erosion within a production system. Gas wells tend to erode faster as they have
high fluid velocities as compared to oil wells (This should not be confused with the wells producing more sand due to water breakthrough. Water breakthrough tends to increase the amount of sand production but not the fluid velocity and erosion increase with increased sand production). Slugging in particular can generate periodically high velocities that may significantly enhance erosion rate.

The particle erosion rate is highly dependent on particle impact velocity which will be close to the fluid velocity. It is generally accepted that the erosion rate is proportional to the particle impact velocity raised to a power, n (typically n ranges between 2 and 3 for steels).

Particle size is important as it determines the path of the particle inside the flow system. Large particles tend to move slowly and settle out of the fluids whereas the smaller particles hit the surface of the pipe and lead to erosion. The hardness and shape of the particles are other important factors, as the harder and sharp particles tend to cause more damage than lighter and spherical particles.

1.5.1.2 Erosion-Corrosion

Erosion-corrosion is the combined effect of particulate erosion and corrosion. Depending upon which of these processes is predominant in the system, results will vary.

In a purely corrosive flow, without particulates in it, new pipework components typically corrode very rapidly until a brittle scale develops on the surfaces exposed to the fluid. After this scale has developed, it forms a barrier between the metal and the fluid that substantially reduces penetration rate. This is also the case when very low-level erosion is also taking place simultaneously with corrosion.

In highly erosive flows, in which corrosion is also occurring, the erosion process predominates and scale is scoured from exposed surfaces before it can influence the penetration rate. Corrosion therefore contributes little to material penetration. At intermediate conditions, erosion and corrosion mechanisms can interact. In this case scale can form and then be periodically removed by the erosive particles.

Erosion-corrosion mechanisms are potentially very complex. This makes prediction of erosion-corrosion penetration rates for a particular field situation very
difficult. Erosion-corrosion can be avoided by ensuring that operating conditions do not allow either erosion or corrosion. Figure 1.4 (a) shows damage dome to a pipe due to erosion-corrosion.

Figure 1.4 (a) Erosion-Corrosion damage to a pipe. (b) Severe pitting due to cavitation (Venkatesh, 1986)

1.5.1.3 Droplet Erosion

Droplet erosion is related to the wet gas or multiphase flows in which droplets are formed. The erosion rate depends on a number of factors including droplet size, impact velocity, impact frequency, and liquid and gas density and viscosity. As many of these values are unknown for field situations, it is very difficult to predict the rate of droplet erosion. This type of erosion is hardly encountered in hydrocarbon production systems. For further investigation, the readers are advised to read Salama & Venkatesh [3].

1.5.1.4 Cavitation

When liquid passes through restrictions low pressure areas can be generated, for example downstream of a sudden step. If the pressure is reduced below the vapor pressure of the liquid, bubbles are formed. These bubbles then collapse generating shock waves. These shock waves can be of sufficient amplitude to damage pipework. Cavitation is a very rare phenomenon in oil and gas production systems as the pressure never goes
below the vapor pressure of the liquid. Evidence for cavitation is sometimes found in chokes, control valves and pump impellers, but is unlikely to occur in other components. Figure 1.4 (b) is an example of cavitation.

1.5.2 Erosion Management

Erosion in production systems can be controlled largely by employing methods of sand control. The production rates can be reduced before a permanent solution is obtained for sand control. Reducing production rate reduces both the sand production rate and the flow velocity through the pipework. Design of the production system should be done keeping in mind the erosion problem. Pipework should be designed to minimize flow velocities and avoid sudden changes in flow direction (e.g. at elbows, constrictions and valves). The use of full bore valves and blind tees in place of elbows can also reduce erosion problems. Slugging flows can be particularly damaging, therefore, the inclusion of slug catchers and drains may be appropriate for certain installations. Thick-walled pipes are often used to increase the wear life of pipework. However, care should be taken, when doing this, as increasing wall thickness reduces the pipe bore, elevating flow velocities and increasing the erosion rate, particularly with small bore pipework.

The parts of production system, which experience high degree of erosion, tend to be components in which the flow direction changes suddenly and the high flow velocities occur caused by high volumetric flow rates or flow restrictions. All such system points should be carefully monitored and actions be taken based on the information as the failure of equipment may lead to a dangerous situation.
Chapter 2: Sand Prediction

2.1 INTRODUCTION

Sand prediction model is a means to assess the risk of sand production in the life of a well. Most of this work is essentially done in the initial appraisal stages of a field as to get a better handle on reservoir management strategy, completion design, perforation strategy, planning of the surface facilities, sand monitoring strategy and above all the economics of the project.

Sand production significantly restricts production rates by putting constraints on the reservoir and causes expensive well intervention in terms of costly completion installations to prevent the sand from being carried into the wellbore. In addition, initial downhole sand control is costly and lowers productivity of the well. Thus, sand production prediction has become an integral part of reservoir management, completion design and production optimization. The benefit of accurate sand failure prediction can be tremendous in terms of revenue enhancement (i.e., wells without sand control are more productive) and cost reduction (e.g., elimination of failures, workovers, and unnecessary sand control installations).

Sand failure prediction is applied almost exclusively to reservoirs with friable to consolidated and harder sandstone formations, since sand production is virtually always a problem in unconsolidated to loosely consolidated formations. Sand prediction models indicate the onset of sand production, the amount of sand produced and the rate at which sand is produced. There are a variety of numerical and analytical sanding models available in the literature, varying in complexity and approach towards the problem. A brief description of the models with the different parameters involved and the failure mechanisms leading to sand production are presented in this chapter. In addition, other sand prediction techniques are discussed to cover the whole gamut of prediction methods. This helps engineers look at the sand prediction problem from a wider perspective and give a better understanding of the problem.
2.2 SAND PREDICTION METHODS

The present sand prediction methods are based on field observations and experience of sand production, log analysis, laboratory sand production experiments and theoretical modeling of sand production. However, no single method is capable of predicting sand production on its own. Most of the time, a combination of these techniques is employed to predict sand production in the field.

2.2.1 Sand Prediction based on Field Observations and Log Analysis

Sand prediction techniques based on field observations and experience rely heavily on sand production data obtained in the field. Log data coupled with field data have proved to be very successful in predicting sand production. An attempt is made to correlate well production data or log data to field characteristics and operational parameters. This is the most absolute method of predicting sand, as it represents actual field conditions. A comprehensive list of parameters that may be involved in the prediction is presented in Table 2.1 (Veekan et al [6]). The prediction models are generally based on a small selection (one, two or three) of these parameters due to the practical difficulties of monitoring and recording several years worth of data for all the wells involved in a study.

The simplest sand prediction method uses only one parameter. For example, a cut-off depth criterion for the installation of sand control measures is used in several deltaic environments; sand control is not installed below a certain depth. The critical depth is regionally dependent. Another cut-off criterion frequently applied specifies a compressional sonic wave transit (Δt_c) time below which sand control is not required; the limit is again field or regionally dependent, and may vary from 90-120 µs/ft.

Tixier et al [8] introduced the first log derived model in the form of a mechanical properties log. It establishes a limit value for the sonic and density log derived parameter G/c_b (G is the dynamic shear modulus, c_b the bulk compressibility); no sanding problem is expected when G/c_b exceeds 0.8*10^{12} psi. This limit value has been applied successfully but appears to depend on the regional environment as well. The limitation of such a model is that it only predicts whether sanding will be a problem at the current situation.
<table>
<thead>
<tr>
<th>Parameters</th>
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<tbody>
<tr>
<td><strong>Rock</strong></td>
<td></td>
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<tr>
<td>1. Strength</td>
<td></td>
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<tr>
<td>2. Vertical and horizontal in-situ stresses (change during depletion)</td>
<td></td>
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<tr>
<td>3. Depth (influences strength, stresses and pressure)</td>
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<tr>
<td><strong>Reservoir</strong></td>
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<tr>
<td>1. Far field pore pressure (change during depletion)</td>
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<tr>
<td>2. Permeability</td>
<td></td>
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<tr>
<td>3. Fluid composition (gas, oil, water)</td>
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<tr>
<td>4. Drainage radius</td>
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<td>5. Reservoir thickness</td>
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<td>6. Heterogeneity</td>
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<tr>
<td><strong>Completion</strong></td>
<td></td>
</tr>
<tr>
<td>1. Wellbore orientation, wellbore diameter</td>
<td></td>
</tr>
<tr>
<td>2. Completion type (open-hole, perforated)</td>
<td></td>
</tr>
<tr>
<td>3. perforation policy (height, size, density, phasing, underbalance, overbalance)</td>
<td></td>
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<tr>
<td>4. Sand control (screen, gravel pack, chemical consolidation)</td>
<td></td>
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<tr>
<td>5. Completion fluids, stimulation (acid volume, acid type)</td>
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<tr>
<td>6. Size of tubulars</td>
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<tr>
<td><strong>Production</strong></td>
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<tr>
<td>1. Flow rate</td>
<td></td>
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<td>2. Drawdown pressure</td>
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<td>3. Flow velocity</td>
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<td>4. Damage (skin)</td>
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<td>5. Bean-up, shut-in policy</td>
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<tr>
<td>6. Artificial lift technique</td>
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<td>7. Depletion</td>
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<td>8. Water gas coning</td>
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<tr>
<td>9. Cumulative sand volume</td>
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</tbody>
</table>

Table 2.1 Parameters influencing sand production (Veekan et al [6]).
In addition, the method was not able to estimate maximum sand free rate for a sand producer. The criteria specifying critical depth, $\Delta t_c$ and $G/c_b$ are related. For example, $\Delta t_c$ decreases as depth increases; thus, the $\Delta t_c$ criterion can be translated into a depth criterion and visa versa. Also, $G/c_b = 0.8 \times 10^{12} \text{ psi}$ typically corresponds to $\Delta t_c = 115-120 \ \mu s/\text{ft}$. The one-parameter approach is practical, though conservative, and frequently used due to its ease of use.

The one-parameter models fail to account for the depletion of the reservoir pressure and drawdown pressure. An important two parameter model is described by Stein et al [7]. Stein developed the first significant method to estimate maximum sand free production rate by relating shear strength of the formation to the well’s sand production. The sonic and density logs of the sand producing wells were used to relate them to new wells. The problem of pressure depletion and water production were not addressed.

Veekan et al [6] plotted the total drawdown pressure, $(P_r-P_w)$, versus sonic transit time, $\Delta t_c$, for sand and no-sand producers in the same field. The plot is shown in figure 2.1. A risk region was established in which it is possible to produce sand. Sand free production can be realistically expected to the left of the risk region. The position of the risk zone is field dependent, sand production tests and regular monitoring can be used to determine its position.

Multi-parameter correlations can further improve the resolution between the sand and no-sand producers. Figure 2.2 illustrates the use of the multiple discriminant analysis technique for the data set of Figure 2.1. Sand production is correlated with a wide range of parameters including depth, sonic transit time, production rate, drawdown pressure, productivity index, shaliness and water cut. The sand and no-sand producers are well separated. The parameter influencing sand production pressure most from Figure 2.2 is water cut, sand and no-sand producers are characterized by an average water cut of 19% and 2% respectively. The discriminant function describing the influence of various factors is regionally dependent. In a similar analysis, Ghalambor et al [14] used regression to correlate the critical drawdown pressure observed in water-producing gas wells with seven parameters. The method used field data and existing correlations to
Figure 2.1 Total drawdown versus transit time for intervals with and without sand problems. (Veekan et al [6])

Figure 2.2 Plot showing result of multiple discriminant analysis. (Veekan et al [6]).
extend Mohr’s stress analysis method to include depletion and water production in gas wells. The multi-parameter techniques, however successful, are not commonly used because of extensive data requirements.

Field data correlated with log data has proved to be reasonably accurate in predicting the onset of sand production. The method is field dependent and thus requires data gathering and interpretation efforts in every field.

2.2.2 Laboratory Experiments

Laboratory experiments simulate sand production phenomenon in a controlled environment. The influence of various field parameters on sand production is better understood through laboratory experiments. In addition, theoretical sand prediction models can be validated against laboratory observations before being applied in the field. The idea of experiment modeling is to simplify reality. Specific laboratory experiments have been designed and performed [30, 31, 32, and 33] with the aim of quantifying the effects of various operational parameters on sand production, individuating different physical mechanisms and developing experimental techniques to be used routinely as sand production prediction tools. Several papers cover laboratory experiments performed on drilled or perforated samples under different conditions of geometry, stress state and fluid dynamic state, monitoring behavior of the sample in terms of onset of the sand production, evolution of the process and final collapse of the perforation.

2.2.2.1 State of the Art - Consolidated Formations

Exxon research labs conducted an experiment to relate sand production to pressure drop and flow rate across the formation sand. The equipment shown in Figure 2.3 was used to determine the magnitude of the pressure drops that core samples could withstand before onset of sand production. The test results established that the formation produces sand if the fluid flow stresses exceed the compressive strength of the formation. The general rule of thumb is that fluid flow stresses have to be 1.7 times the compressive strength of the formation, where the compressive strength is in psi. This relationship holds true only for consolidated sediments; no correlation exists for unconsolidated
sediments which are assumed to be producing sand from the very beginning of production.

Figure 2.3 Exxon apparatus for drawdown-to-failure tests.

2.2.2.2 Sanding Index

Chow et al [19] presented a method based on correlations developed from laboratory measurements to assess the risk of sand production in wells. The tests examine the tensile failure of the formation induced by fluid drag forces. The correlations predict a sanding index and a maximum sand free rate (MSFR) using acoustic log data and compressive strength of the formation. The results of the correlations were field tested on 21 different wells in different locations. All the wells produced sand free at target production rates.

Core (sandstone) samples of different compressive strength (1000 psi or lower) were artificially manufactured using Portland cement and silicone resin as the
consolidating agents. The uniaxial compressive strength of all the samples is measured on a load frame.

Transducers were used to transmit and receive both compressional and shear acoustic waves through the samples. The wave velocities and the sample length is calculated and correlations were developed to relate the compressive strengths, $C_s$, to the shear wave velocity, $V_s$, and the compressional wave velocity, $V_p$. 

(a)

(b)
Figure 2.4 (a) S-wave predicted and measures Rock Strengths of Cement Sand Cores. (b) P-wave Predicted and measured Rock Strengths of Cement Sand Cores (Chow, 1994). (c) S-wave predicted and measures Rock Strengths of Silicone Resin Sand Cores. (d) P-wave Predicted and measured Rock Strengths of Silicone Resin Sand Cores (Chow, 1994).
The effect of overburden or confining pressure on static mechanical and acoustical properties of unconsolidated and weakly consolidated sand samples was examined in a high pressure cell. The results from these experiments were combined with the Cs-Vs and Cs-Vp correlations to give equations which used log data to predict the stability of the formation rock, represented by an empirical sanding index (Sc), to failure induced by fluid drag.

To establish a correlation between tensile failure and fluid drag, fluid flow experiments were conducted by setting up a high pressure flow cell to simulate production into a perforated cased wellbore. The experiments showed different modes of sand production at different rates. The amount of sand produced increased with increasing flow rate. A correlation was developed to relate the sanding index with fluid drag force at failure.

2.2.3 Theoretical Modeling

Theoretical sand prediction models are based on modeling of the wellbore, perforation and production cavity stability. These models require mathematical formulation of the failure mechanism. In either case, the sand is assumed to be produced due to rock mechanical failure of the load bearing sand grain matrix. The accuracy of the prediction depends closely on how the rock constitutive behavior is modeled, what failure criterion is chosen, and whether the materials and other parameters affecting the rock failure are precisely determined.

Moore et al [5] presents an extensive list of parameters to be considered in the complete design of a sand prediction model (Table 2.1). Currently, no method of sand prediction will pass the test of considering all the parameters from Table 2.1. The primary reason is the whole process would be very extensive and there is no way all that data or information can be obtained in a commercial development.

Sand production process starts with the failure of the reservoir rock in the vicinity of the wellbore. The sand grains become loose enough from the rock matrix due to the shear dilation of the rock that they become available for the fluids to carry them into the wellbore. The process is mainly governed by the strength of the rock and the
Data Considered in a Complete Evaluation for Predicting Sand Production Potential.

1. Field Data
2. Cyclic Loading
3. Directional in-situ stresses
4. Quality of cementation
5. Perforation and geometry and spacing
6. Cavity evolution effect of varying perforation geometry
7. Well pressure
8. Flow rate (fluid forces)
9. Perforation cavities geometry and shot density
10. Permeability, viscosity and relative permeability for two and three phase flow.
11. Rock deformation characteristics
12. Rock strength characteristics
13. Flow through porous media where non-Darcy flow is included
14. Log derived rock mechanical properties
15. Laboratory tri-axial measurements of core samples
16. Regional tectonic forces

| Table 2.1 Data considered in a complete evaluation for predicting sand production potential (Moore, W. R). |
effective in-situ stresses at that depth in the formation. Once the sand grains are loose, the rate and amount of erosion of the matrix depends on factors such as the production rate, the fluid velocity and the fluid viscosity. Sand failure mechanisms can be subdivided into three types:

1. Compressive or Shear failure
2. Tensile failure as a result of drawdown (fluid drag) alone, and
3. Cohesive Failure or erosion failure as a result of the degeneration of cementation.
4. Chemical Effect induced Failure

2.2.3.1 Compressive or shear failure

Compressive failure refers to an excessive, near cavity wall, tangential stress which causes shear failure of the formation rock. Shear failure occurs as a result of far-field stresses (depletion) and drawdown. Shear strength consists of two components; the physical bonds between adjoining grains or cohesion and friction. Shear failure may cause reduction in hole size due to plastic failure near the perforation tunnel. Around any perforation tunnel there is a stress concentration field established. The rock will either respond elastically (strong formation) or yield (weak formation), in which case a plastic zone is developed around a perforation tunnel. Once shear failure occurs, large and small size solids are generated and the formation starts deteriorating at the failure plane. This shear failure can be predicted by the Mohr-Coulomb failure criterion. This criterion postulates that the failure occurs when the shear stress on a given plane within the rock reaches a critical value given by:

$$\tau = c + \sigma_n \tan \Phi$$

where, \(\tau\) is the shear strength, psi
\(\sigma_n\) is the stress normal to the failure plane, psi
\(c\) is the cohesive strength, psi
\(\Phi\) is the internal friction angle, degrees

The equation has two components; cohesion (\(c\)) and friction (\(\sigma_n \tan \Phi\)). Shear failure breaks the rock along shear planes; however, cohesive failure will produce sand particles.
2.2.3.2 Tensile Failure

Tensile failure refers to a tensile radial stress exceeding the tensile failure envelope and is triggered exclusively by drawdown pressure. Tensile failure mechanism occurs around a perforation tunnel where the radial stress is controlled by the wellbore pressure and reservoir pressure. The abrupt change in pressure can exceed the tensile strength of formation, therefore causing sand production and perforation-tunnel enlargement. Tensile failure may occur at the perforation tip or the perforation wall which is usually penetrating within the plastic zone. Tensile failure predominates in consolidated sandstone.

2.2.3.3 Cohesive or Erosion Failure

This mechanism is especially important for the case of poorly consolidated sand. Cohesive strength is the controlling factor of erosion, which occurs at any free surface within the formation, which includes; perforation tunnel, wellbore surface for open-hole completion, hydraulic fracture surface or surface of induced shear planes, and other boundary surfaces. Shear strength of a formation consists of two components:

1. Contact forces and friction between the grains.
2. Physical bonds between adjoining grains or cohesion.

Cohesion is due to two factors; (1) cementing material and (2) capillary forces. Sand production may also occur when the drag force due to fluid velocity exceeds the cohesive strength of formation.

2.2.3.4 Chemical Induced Failure

Rock strength is derived from two components; the contact forces between the grains (friction), and the physical bond adjoining grains (cohesion). Depending on the cementation materials, chemical interaction may cause weakening effect due to deterioration of the cementation materials. It is important to observe the following when studying any formation for sanding tendency:

1. If clay particles are part of the cementation material, a given formation should be treated as potentially water sensitive.
2. Hydrochloric acid (HCl) used in completion fluids may adversely affect the strength of the formation. If the cementation material is carbonate and formation is exposed to acid, the rock structure will collapse causing sand production.

Compressive and tensile failures are analyzed by continuum modeling (i.e., the granular structure and grain-to-grain interactions of the sandstone are disregarded). Erosion failure considers the dislodging of individual grains and thus accounts for individual grain-to-grain interactions. Erosion failure is still under investigation and has not been included explicitly in the models used so far.

Several models have been developed based on these failure mechanisms. Some of the published work is listed. Morita et al [10] developed the numerical model to quantify perforation cavity stability and thereby predict sand production. The model presented a safe operating envelope defining the shear failure and tensile failure of the formation around the perforation. This was the first model to handle both shear and tensile failure taking into account fluid forces, boundary loads and residual stresses. Dimensional analysis [11, 12] was performed to identify the variables critical to perforation cavity stability. An engineering system to predict sand production was also presented integrating rock mechanics, geology characterization, logging and reservoir management information [13].

Ghalambor et al [14] provided an analytical method for predicting sand production in gas wells making water.

Willson et al [17] developed an analytical model to predict the rate of continuous (steady-state) sand production. The model uses non-dimensionalized concepts of loading factor (near-wellbore formation stress normalized by strength) and Reynolds number (a function of permeability, viscosity, density and flow viscosity). The model uses laboratory sand production experiments to derive an empirical relationship between loading factor, Reynolds number and the rate of sand production.

Yi and Valko [16] developed an analytical sanding onset prediction model based on the theory of poroelastoplasticity, assuming shear failure or tensile stress induced sanding. The model is simple as compared to existing analytical models, as it only
requires the following rock mechanics parameters: Biot’s Constant, Poisson’s Ratio, Uniaxial Compressive Strength (UCS), and in-situ stresses.

Chin et al [38] presented a numerical model that couples rock deformation and fluid flow in weak reservoirs.

2.2.4 Computer Programs

Sophisticated proprietary computer programs to predict sand failure are also available in the industry. Shell’s Fully Integrated Sand Prediction Tool (FIST), Schlumberger’s IMPACT, and Conoco’s 3-D Finite Element models are some of the significant ones. Awal [39] developed a user friendly computer program “SandPro” to identify potential sanding locations. The model is recommended for production engineers to make preliminary calculations for the critical flow rate for a well.
Chapter 3: Sand Control Methods

3.1 Introduction

There are numerous sand control methods available in the industry. No one practice, however, can control sand effectively under all circumstances. Based on successful field experience, advantages and limitations, operators usually develop a particular preference for a specific method. The different sand control methods used are:

1. Rate Control
2. Non-impairing Completion Techniques
3. Selective Perforating
4. Screens (without gravel packing)
   a. Slotted Liner
   b. Wire-wrapped Screens
   c. Prepacked Screens
   d. Premium Screens
   e. Expandable Screens
5. Gravel Packs
6. Frac Packs
7. Chemical Consolidation
   i. In Situ Formation Consolidation
   ii. Consolidated Gravel

These methods are further classified into two groups: mechanical exclusion methods and arch stabilization methods. Arch stabilization methods can be further divided into natural arches and reinforced arches. Table 3.1 sums up proposed classification of the above sand control methods.

Mechanical exclusion methods prevent sand production by either bridging type retention or filter type retention. In bridging type retention, a certain amount of sand production is tolerated until a bridge is formed against a filtration medium such as a screen or sized gravel or combination, as in a gravel pack. Sudden production rate changes easily disturb these bridges, resulting in additional sand production until new
bridges form. Additionally, a certain amount of plugging is more likely to occur, since the filter medium is sized to allow smaller particles to flow through.

Sand Control Method Classification

Mechanical Exclusion (listed in order of increasing effectiveness and reliability)
- Consolidated Gravel (Filling Perfs Only)
- Screens Alone
- Consolidated Gravel (Filling Perfs & Wellbore)
- Prepacked Screen
- Expandable Screen
- Gravel Packing
- Frac Packing

Arch Stabilization
- Natural Arches
  - Non-impairing Completion Techniques
  - Selective Perforating
  - Rate Control
- Reinforced Arches
  - In Situ Chemical Formation Consolidation

Table 3.1 Sand Control Method Classification

Filter type retention methods are designed to exclude all sand production. These do not rely on bridging, and therefore are more stable. Filter type sand control is attained simply by further reducing slot size of the screen and size of gravel, below that required for bridging type retention. In theory and in practice, all of the mechanical exclusion methods can provide bridging type retention. In practice, only prepacked screens alone
(without gravel packing) and gravel packing are used to provide filter type retention. Mechanical methods listed in Table 3.1 are in order of increasing effectiveness and reliability in providing filter type sand control.

Arch stabilization depends completely on formation of stable arches near the wellbore to restrain sand production. Natural arch stabilization occurs by avoiding the creation of destabilizing actions, which will cause sand production. Reinforced arches utilize a chemical bonding agent, such as plastic resin or other material, to strengthen existing bonding between touching particles and to create new bonds. Of the natural arch methods, the effectiveness of rate control is the most easily observed. It is more difficult to ascertain the sand control effectiveness of the other two; however, there is little doubt that these can have a substantial impact on sand production potential. Sand control methods are sometimes combined when the reliability of a single method is in question and added assurance is desired. This can occur when well parameters exceed the design applicability of a specific sand control method.

Sand detection techniques at surface are also successfully employed by operators to know the onset of sand production. The prospects of successfully stopping sand production and maximizing well productivity are enhanced when sand production is detected early and is held to a minimum prior to application of sand control methods. A brief discussion of the sand detection methods is presented before the actual sand control methods.

3.2 SAND DETECTION TECHNIQUES

A good sand detection program is vital in areas where economic exposure, safety risks, and environmental risks are high. Such is the case in offshore locations. Regular inspections for the presence of produced sand or the erosional effects resulting from sand production should be standard operating procedure in any field where there is a potential threat of sand production and where sand control methods are utilized. The frequency and stringency of the detection methods should be geared to the well type and to the potential risks resulting from equipment related and formation related problems. For example, shakeout tests combined with visual inspections for sand fill and erosion have had good
results in oil fields. However, sand production rates are more difficult to determine in gas wells and high gas liquid ratio (GLR) oil wells. Acoustic or erosional monitoring devices [49] may be necessary where early warning for an increase in sand production is required. High-pressure critical gas wells which produce sand may be more likely to develop leaks quickly due to high erosional energy with little time to detect and react. Likewise, high pressure, high rate oil wells could also fail quickly. Conversely, a low amount of sand production in some low rate wells may be tolerable.

Generally, visual inspection techniques prevail as the detection methods for monitoring wells for sand production. These include wellhead shakeouts, inspecting choke internals for erosion, and inspecting sand traps and surface facilities for sand fill. These methods are simple and add minimally to operational burden since they are accomplished while performing other routine tasks. Other detection methods include batch monitoring, erosional sand probes, acoustic sand detectors, and X-ray and ultrasonic inspection of surface equipment. Erosional sand probes are used commonly in gas wells (with and without sand control), especially in high pressure/high rate completions. Probes are typically installed on each well in the flowline a short distance from the last choke on the Christmas tree and are typically designed to shut in the well when the probe erodes through. The remaining detection methods are used infrequently, probably due to the apparent adequacy of the above methods and the various drawbacks including high installation cost, added operational burden, varying reliability, and lack of visual confirmation. Several papers [45, 46, 47, 48 and 49] have been written discussing the methods and devices to detect sand in the flowlines. A brief discussion on each of these methods follows.

3.2.1 Choke Inspection

Inspection of choke internals for erosion and presence of sand is the most reliable means to confirm a sand production problem. Produced sand tends to accumulate inside choke bodies. Also, erosion of the choke bean and body is easy to recognize.
3.2.2 Fluid Sampling

Fluid sampling can be the most precise means of determining sand production rates, although some brands of acoustic and erosional sand probes boast a similar accuracy. Fluid sampling is applied only to oil wells or high liquid to gas ratio (LGR) gas wells. Sampling methods include wellhead shakeout, batch sampling, and continuous sampling. In all of these, a specified volume of produced fluid is collected. Then an analytical procedure is utilized to determine sand content. Concentration is usually expressed in pounds of sand per thousand barrels of produced fluid (or grams per cubic meter).

3.2.2.1 Wellhead Shakeout

A wellhead shakeout (also called a grindout or a centrifuge) is fast and easy to obtain but may not have the accuracy necessary to detect a sand production problem. A sample of produced fluid obtained at the wellhead is placed in a 10 ml graduated cylinder and then centrifuged. The sand and other particulate material settle to the bottom of the cylinder and can be read as a volumetric percentage of the produced fluid. The lower limit for measuring sand in a shakeout test is for most tests only 0.1 percent of the liquid or about 560 lb/1000 bbl. Considering that sand producers are commonly described in the literature as any well making 5-10 lb/1000 bbl or more, the shakeout test is incapable of measuring this range of sand producer. Since shakeout cylinder volumes are small (only 10 ml), it is fairly easy for a moderate sand producer to go unnoticed. Therefore, other methods, such as visual inspection of surface equipment, should also be used. Shakeouts should be taken frequently with several tests before a choke size change and following, but after the well has produced bottoms up. Samples should be obtained as close to the wellhead as possible to be representative. It may be difficult to get reliable information from slugging wells, since the sand production rate can vary with fluid production rate.

Another reason a shakeout may not provide an accurate sand measurement is because the sampling outlet and procedure are not designed to provide a scientifically accurate or representative sample. The sampling time period is usually very brief (i.e., less than a minute). Since a shakeout is obtained by opening a needle valve located off the wellhead wing to atmospheric pressure, it is common to throttle the valve tightly in
order to do this safely. Produced sand sometimes bridges inside the needle valve. Thus, a severe sand production problem could go undetected by shakeout tests. Shakeouts are sometimes difficult to evaluate because of paraffins, which settle in the bottom of the centrifuge. Sometimes salt or scale crystals may be mistaken for sand.

### 3.2.2.2 Batch Sampling

Batch sampling may be used to overcome problems associated with the shakeout test. It involves obtaining a much larger sample than obtained from shakeout tests. The length of the collection time and volume of fluid collected are dependent on the desired measurement accuracy and the production characteristics of the well. It is used in place of the shakeout test when fluid production is low and/or when there is a need to detect low sand production rates more accurately. Production is temporarily diverted to a collection container until an adequately larger volume of sample is obtained. The collection container may consist of a large bucket or a pressure vessel. A pressure vessel is preferred since needle valve throttling and associated sand bridging problems can be eliminated. This is accomplished by fully opening the sample needle valve on the flow line. A secondary needle valve located on the pressure vessel can be used to bleed off gas to allow more liquid to enter, the pressure vessel. Obviously, the location of the needle valve on the flow line and the flow velocity are important factors in obtaining scientifically representative samples. As with shakeout tests, results from slugging wells may not be representative. The sample is filtered to collect all produced solids. The solids are cleaned of hydrocarbons and weighed to determine the sand production rate.

### 3.2.2.3 Continuous Sampling

Continuous sampling offers the most accurate and representative means to measure sand production. This is well-established technology, designed to ensure that scientifically accurate and representative samples are obtained. Therefore, application of this technology to monitor sand production should yield very good results.

The installation for sand monitoring consists of a static mixer. (i.e., a series of baffles inside of the flow line) followed by a continuous, automated fluid sampling device. The sampler is located on the flow line upstream of the test separator. Each well
is sampled when it is placed on test. The fluid sampler can be programmed to retrieve a small volume of fluid over a specified time increment (e.g., 1.5 cm$^3$ every 10 seconds) until a sufficient fluid volume is obtained. After the sample is obtained, it is shipped to shore for filtering, weighing and analysis. Alternatively, this analysis could be performed in the field. As expected, the results to date show very good repeatability even for sand production rates below the low rate of 5 lb/1000 bbl. Obviously, the delay between sampling and analysis is a drawback. However, the accuracy and ease of operation make this an attractive consideration.

3.2.3 Sand Traps

Any point downstream of a producing wellhead where there is a sudden increase in cross-sectional flow area may be considered a sand trap. Sudden reduction in fluid velocity may be sufficient for settling to occur. Separators and other surface facilities are typical sand traps. Obtaining a sand production rate may not be feasible unless flow through the trap can be limited to one well, and before and after inspections of the trap can be made during a specified test period. Also, if substantial deposition fills the trap, fewer particles may be deposited due to the increasing velocity, which occurs, as the flow area is further reduced. If the critical depositional velocity is again exceeded before the test is completed, sand production rates may be underestimated.

3.2.4 Erosional Detection

Erosional detection of sand production may be accomplished in several ways, including visual inspection of choke and valve internals, which is most common in the industry. Other methods include X-ray and ultrasonic inspection and the use of sand probes and plugs. These methods give only a qualitative measurement of sand production; determination of real sand production rates is not possible. Additionally, not all erosion is caused by sand production. High flow velocities, where corrosive fluids and high GOR (gas oil ratio) occur, may also cause erosion.

Ultrasonic and X-ray inspections are indirect methods of monitoring sand production. Periodically, the flow line thickness is measured ultrasonically where erosion is expected to be greatest (e.g., elbows, tees). Small, hand held ultrasonic devices are
fairly inexpensive and easy to use but are only good for point inspections. If pitting is suspected, the more expensive X-ray method can be used to obtain a two-dimensional picture of a whole section of flow line. There are a variety of different "sacrificial" erosional devices available, and some can be equipped with alarms to signal that a certain amount of erosion has occurred. These devices are intended to be placed within the flow line where greater erosion will be more likely to occur on the device than on the line or other components. Two devices used are sand probes and safety plugs. Sand probes are hollow tubes which when penetrated by erosion, transfer flow line pressure to a pilot valve which may sound an alarm and/or shut the well in. Safety plugs are similar devices, which indicate failure of the thin-walled plug by a show of flow line pressure on an external gauge. Both devices are widely available and have been used extensively in the past when sand control methods were less reliable.

3.2.5 Electronic Sand Detectors

Electronic sand detectors provide real-time (continuous and instantaneous) sand production measurement capabilities and are mounted in or on flow lines. Three types available include intrusive erosional probes, intrusive acoustic (also called "sonic") probes, and non-intrusive acoustic sand detectors. Intrusive probes are placed inside of the flow line downstream of the wellhead. One or more probes bisect the ID of the flow line to ensure that suspended particles will collide with the probe. Erosional probes utilize the electrical resistance principle to monitor material loss resulting from sand erosion. The material loss signal can be processed and correlated to a sand production rate. Acoustic probes utilize the Piezo-electric effect to detect the noise created by impinging particles on the probe. The noise generates a voltage signal which can be refined and correlated to a sand production rate. Non-intrusive acoustic sand detectors also utilize the Piezo-electric effect. These devices are clamped to the OD of the flow line near an elbow to detect particles impinging on the wall of the flow line. Non-intrusive probes are particularly attractive to subsea developments since they offer the possibility of ROV (remotely operated vehicle) intervention to allow servicing.
3.3 SAND CONTROL METHODS

3.3.1 Rate Control

It has been demonstrated in both the laboratory and the field that reducing production rates and bottomhole pressure drawdown will reduce sand influx. Usually a rate/drawdown threshold can be identified above which sand production is caused. A slight reduction in choke bean size stops the sand. In time, as the reservoir conditions change (e.g., pressures, fluid ratios), excessive sand production may occur again, and then production rates must be further curtailed. Rate control facilitates the formation of stable arches at the wellbore, thereby stopping sand production. Generally, rate control is more effective when little sand has already been produced.

Rate control is used as both a temporary and a permanent method of sand control. It is used temporarily, pending installation of a more effective sand control method, when the value of continually deferring production greatly exceeds the cost of installing an effective sand control method. In the case of high-pressure gas wells, rate control may be utilized temporarily until reservoir pressure has declined to the point where the well control risks which will be incurred during sand control installation are acceptable. Permanent use of rate control as a sand control method usually results when the cost of a more effective sand control method cannot be justified or is not operationally feasible. Rate control may be suitable in situations where production rates must be limited anyway to control water influx or gas coning. A common use of rate control occurs in deep gas wells producing from consolidated sandstones. Rate control is initiated later in the productive life of the well when sand production begins due to reservoir compaction and water production. A gravel pack installation in these wells is often not justified, because the initiation of sand production occurs near the end of the productive life of the well.

3.3.2 Non-impairing Completion Techniques

Indirectly, the use of non-impairing completion techniques may be considered a form of sand control, especially in marginal sanding situations. An impaired formation requires a higher-pressure drawdown to produce the same fluid rates as an unimpaired well. Consequently, the higher-pressure drawdown may lead to a premature formation
failure in a marginal sand producer. It is fairly common to notice sand failures which resulted from excessive drawdowns being attributed to an impaired formation. However, the converse (i.e., knowing which wells would have produced sand if not for the use of non-impairing completion techniques) is generally unknown, and therefore, the value of this sand control method is likely underestimated. Wells which have produced sand during drill stem tests and which were later completed have been known to produce sand-free when formation impairment was removed using appropriate completion techniques. The important completion considerations include the use of clean, filtered, nondamaging completion fluids along with proper stimulation design and treatment. Acid jobs, which are necessary to remove impairment prior to initiating production, can cause problems if improperly designed. Similarly, a stimulation job can do more harm than good, especially in acid-sensitive formations where a high percentage of the formation is acid soluble. Excessive fines generation may create more damage than was initially present. While after-stimulation sand influxes should be only temporary, the volumes involved can be quite sufficient to cause a sand-up or a buildup of fill over the perforations.

Good techniques should be part of any completion. When passive sand control methods, such as rate control, are the only methods to be used, an unimpaired completion becomes even more essential in minimizing sand production.

3.3.3 Perforating

In cased-hole completions, well productivity is most heavily dependent on perforation design. Perforating factors affecting well productivity include perforation dimensions (diameter and penetration), shot density, and phasing. Generally, larger, deeper perforations, higher shot density, and uniform phasing yield the highest productivity. Actual perforation dimensions are determined by perforating gun/charge design and quality, the position of the gun/charges in the wellbore when they are fired, and well conditions such as temperature, pressure, well fluids, casing size and metallurgy, and cement and formation properties.

Perforation damage impairs productivity. Damage is caused in a number of ways. The act of perforating tends to crush and compact the formation surrounding each
perforation tunnel, thereby restricting inflow. Debris such as spent perforating charge and
gun debris as well as dirty completion fluid can also impair perforations. Perforation
cavities which subsequently collapse (most typical in unconsolidated formations) also
will be impaired if not properly cleaned. Perforation cleaning methods are used to remove
these types of impairment.

In completions where sand control may be required, it is important that
perforation impairment be minimized so that the productive stresses which tend to cause
sand production are minimized. In gravel packing, the objective is to have large diameter
perforations which have been thoroughly cleaned, leaving an open cavity where gravel
can be placed. The gravel, in many cases, is an order of magnitude more permeable than
the formation sand. Therefore, placement of highly permeable gravel out into the
perforation cavities serves to increase the effective wellbore radius, potentially increasing
productivity to that of an open-hole completion.

Perforation cleaning is necessary to remove perforation damage caused by
formation crushing and compaction, drilling mud, cement, dirty completion fluids
(resulting from dirty equipment, rust, pipe dope, etc., in addition to the other
contaminants listed) and perforating gun debris. Cleaning is accomplished in any of three
basic ways including: (1) surging or backflowing, (2) perforation washing, and (3)
treating. Surging or backflowing is the most commonly used method of cleaning the
perforations. This can be accomplished in any of a number of ways including
underbalanced perforating, conventional backsurging, and flowing the well (prior to
installing sand control).

Perforation washing involves pumping through each perforation with sufficient
pressure and rate to establish return flow communication with other perforations and flow
communication with the formation. The fluid used may be completion fluid or a solvent
(e.g., acid). In soft rock completions, once communication is established between two or
more perforations, debris is removed from the perforations by washing out a void behind
casing. In gravel packed completion, this void is subsequently packed with highly
permeable gravel. In hard rock completions, the objective is to establish communication
with the formation rather than with other perforations. Perforation washing is better
suited than surging or flowing methods for long intervals. Although surging and flowing techniques have been used by other companies in conjunction with perforation washing in gravel packed completions, this is likely unnecessary since both methods when used alone give good results when properly performed.

Treating may involve the use of solvents to dissolve perforation damage and in hard rock formations, may involve fracturing through the damage into the formation with solvents or other fluids. It is common practice in completions to acidize the perforations after other perforation cleaning techniques have been used (typically conventional backsurging or underbalanced perforating), immediately prior to gravel packing. Experience has shown that this is necessary to remove damage which is not removed by the other cleaning processes.

### 3.3.3.1 Selective Perforating

If adequate petrophysical and reservoir information is available, selective perforating may be used in some formations as a passive method of sand control. Avoiding completion near water contacts and thereby minimizing water influx will greatly minimize sand production potential. Another practice is to avoid perforation of poorly cemented, low permeability stringers, especially when these intervals are not expected to contain unique reserves which cannot be drained from cleaner, more stable sections. The problem is that these weak streaks are often the main productive zone. The critical issue then becomes whether avoiding potentially troublesome streaks will impact recovery or limit production rates. The key to the application of the selective perforation technique is identifying the potential sand-producing zones from core examination and log measurements.

### 3.3.3.2 Overbalanced Perforating

A new method of extreme overbalanced perforating or surging with resin has been successfully used by Oryx Energy in both their onshore and offshore wells [53]. This extremely overbalanced perforating and stimulation method could cause the industry to reconsider how to perforate wells for sand control. Not only does this method provide a means to sand control but also combining perforating with sand control as a single
operation reduces the completion fluid volume requirements and the average time to complete the well. The overbalanced perforating resin method is used in a wellbore suspected of producing sand in its life and the overbalanced surge resin method is used when the casing has existing perforations in a wellbore suspected of producing sand. The resin solution is made up of Furfuryl alcohol resin, solvent, a coupling agent and a wetting agent. The resin catalyzes with an acid to form a furan plastic and consolidates the formation.

3.3.3.3 Oriented Perforations

Orienting perforations in direction of maximum horizontal stress in a vertical well, increase the probability of more stable perforation tunnels for a perforated only completion. Thus, eliminating the need for conventional sand control. This type of technology can be successfully applied in marginal fields with economic constraints. Oriented perforations with 180 degree phasing have resulted in almost no sand production in weak reservoirs [41]. The use of 180 degree phasing is believed to reduce the risk of sand production due to a reduced probability of hitting the most unfavorable perforation direction. In case of horizontal completions, the dominant stress field will be vertical or overburden. Therefore, in horizontal completions, the perforations are directed to the top and bottom of wellbore to the maximum stress field.

The greatest challenge is to determine maximum horizontal stress direction in a field. There is always a factor of uncertainty in stress orientation and magnitude as determined in field. Even if the initial stress field is close to hydrostatic, the change in reservoir pressure with production leads to change in relative stress magnitude, inducing stress anisotropy.

3.3.4 Screens

The simplest and oldest sand control method employs only a screen to restrain sand production. A screen is run into the open hole or into a cased hole after perforating. This concept involves using a slot width sized to provide bridging type retention rather than filter type retention. The desire is that sand bridges will form before excessive sand production, screen plugging, or erosion occurs as shown in Figure 3.1 (a).
Figure 3.1 (a) Bridging of sand control screen opening with well-sorted sand grains. (b) Plugging of sand control screen opening with poorly sorted sand grains.
Coberly [40] presented a sizing criterion which states that the slot opening should be smaller than the d10 of the formation (i.e. 10% of the sand particles are larger than the slot size. The 10\textsuperscript{th} percentile or d10 designation is equivalent to a sieve mesh which would retain 10 weight percent of the formation sand and allow the remaining 90 percent to pass through.

Filter theory and field experience have shown that particles with a median diameter as low as one-third of the opening size will effectively form bridges due to grain interference (Abrams [35], Coberly [40]).

The finer sands and silts will initially pass through the screen, but as a bridge develops, they will be trapped by a combination of filtration and bridging on the pore throats of the coarse material. Of course, bridges tend to be easily upset by sudden production fluctuations which are common occurrences (e.g., due to pump-off controllers or bringing a well on too hard or too quickly, etc.). Each time a bridge is upset, some sand production will occur until the bridge is re-established. Slow, gradual increases in production rates have been shown to give the best productivity and minimize the risks of screen cutout, especially in formations that produce fines. Screen-alone applications generally should be limited to the producers that meet the Coberly’s criterion and open-hole completions, particularly horizontal wells or wells with extremely long completion intervals. The two concerns in screen-alone applications are erosion failure and well impairment due to the plugging of the screen as shown in Figure 3.1 (b). Screen alone generally is not recommended for cased completions.

Screen alone is a relatively low installation cost sand control method and may be reasonably successful in proper applications. The real cost, however, of using screen alone must take into account other costs besides installation such as increased workovers to clean out the well and remove bad screens, deterioration of downhole equipment, pumps, and surface equipment due to sand erosion, sand removal and disposal costs, and longer term problems such as inter-zonal communication problems and casing damage.
### 3.3.4.1 Slotted Liner

A slotted liner is a pipe with slots in it as shown in Figure 3.2, hung off from the previous casing, in an open-hole section. It is slotted with a precision saw or mill. Normally cut longitudinally (i.e. along the length of the liner). The smallest cut is equal to 0.012 inches or 300 microns, which is much larger than most sand sizes. The advantage of a slotted liner is that it is cheap. The biggest drawback of a slotted liner is its susceptibility to plugging by filter cake.

![Figure 3.2 Shape and geometry of different types of slots in a slotted liner.](image)

Non-Staggered Slotted  Staggered Slotted  Gang Slotted Staggered  Horizontal Slotted

### 3.3.4.2 Wire-wrapped Screen

A simple wire-wrapped screen consists of an inner base pipe with holes in its sides and specially shaped wire wrapped around the outside as shown in Figure 3.3. It comes in a variety of configurations, depending upon the manufacturer. The properties and design of a wire-wrapped screen is very much the same as of a slotted liner. Smallest
slot size in use is 0.002 inches or 50 microns with 50 – 70 mesh gravel. Like the slotted liners, it is widely used for horizontal wells but is more likely to plug than a slotted liner.

Figure 3.3 Multi-layer wire-wrapped screen [51].

3.3.4.3 Prepacked Screen

Where sand exclusion capability exceeding that of slotted liner or wire-wrapped screen is required, prepacked screens are used. The different types of prepacked screens are shown in Figure 3.4. Prepacked screens usually consist of an inner and an outer screen with the annulus between them being filled with a filter media, usually gravel pack sand. This sand is frequently consolidated with plastic resin; however, the resin deteriorates when exposed to typical completion and stimulation fluids and thus presents a potential impairment problem. Prepacked screens are expensive and may be more
costly than gravel packing (using regular screens) in longer intervals. Due to their mechanical design, prepacked screens tend to impose the greatest ID restriction of all sand control methods. This may be extremely important when ID limitations preclude the capability to conduct routine through-tubing workover operations.

The consolidated sand or other media acts as a downhole filter. Since the pore throats will be only about 15-25 percent of the sand grain size, it is possible to retain much finer sand than can be retained with a slotted liner alone or a wire-wrapped screen alone. Moreover, the consolidated sand provides a depth filter which is much less susceptible to erosional failure. The larger flow area helps to increase erosional resistance and to minimize the effects of plugging. The small pores, however, can be easily plugged during handling and running procedures, and special precautions should be taken to minimize this.

![Prepacked Screens](a) (b) (c)

Figure 3.4 Prepacked Screens. (a) Dual-Screen Prepack (b) Single-Screen Prepack (c) Slim-Pak (Source Baker Oil Tools)

Since plugging can be a problem, it is obviously essential that very clean completion fluid and production casing be achieved before running the screen. Similarly,
careful handling and running operations are required, especially when passing obstructions (BOPs, wellheads, liner tops, etc.).

3.3.4.4 Premium Screens

There are several premium screens including, (1) Sintered Metal Screens, (2) Stratapack Screens, and (3) Excluder Screens. All these premium screens are shown in Figure 3.5.

The sintered metal screen consists of a sintered stainless steel gravel pack, made up of an outer sleeve welded onto a perforated base pipe. This screen is more flexible than a wire-wrapped screen, so less prone to damage. However, it is prone to plugging.

The Stratapack screen design consists of a 3-4 layers of porous metal membrane between a drilled prebase and perforated outer shroud. This screen is an excellent sand filter and very damage tolerant, but also very susceptible to plugging.

The Excluder screen has a base wrap, covered with stainless steel wire-wrapped support and drainage layer for the overlaying Vector Weave filtration medium. A Vector Shroud covers this. This screen is more tolerant of plugging with fine particles than the other screens above.

Figure 3.5 Premium screens. (a) Sintered Metal Screen (b) Stratapack Screen (c) Excluder Screen (Source Baker Oil Tools).

The Stratapack screen design consists of a 3-4 layers of porous metal membrane between a drilled prebase and perforated outer shroud. This screen is an excellent sand filter and very damage tolerant, but also very susceptible to plugging.

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3.3.4.5 *Expandable Screens*

An expandable sand screen is made up of a slotted tubular base pipe, covered with a wire weave, which is protected with an outer shroud. A diagram of expandable screen and its design is presented in Figure 3.6. It is expanded by pushing a cone through the screen. It easily opens up forming a tight fit on the casing or hole. This is a big advantage as compared with normal screens, because expandable screen holds the formation in place, which stops the formation from collapsing and so minimizes sand grains coming loose, which could plug the screen. The expandable is widely used in horizontal open hole completions. The biggest drawback is that it is susceptible to collapse in squeezing formations. It is also quite expensive.
Figure 3.6 (a) Expandable Screen [50]. (b) Expandable Sand Screen Design (Source World Oil [44]).

3.3.5 Gravel Packing

Gravel packing is by far the most reliable and effective sand control method known. A gravel pack is a downhole filter which utilizes sized gravel as the primary filtration medium placed between the formation and a wire-wrapped screen, slotted liner, or prepacked screen. Sizing of the gravel and screen slot width is critical in restraining sand production. In the majority of installations, the gravel is sized to provide filter rather than bridging type retention, with the intent that no formation particles are produced. Gravel pack completions generally provide substantially higher productivity than consolidation sand control methods. While the initial installation cost of gravel packing may be more expensive than that of most of the simpler sand control methods (screen alone, prepacked screen alone in shorter intervals, rate control, consolidated gravel, etc.), the difference is usually more than recouped by higher production rates, fewer operational problems, and lower operating costs. The major drawbacks of gravel packed
completion are the increased complexity of completion operations and the obstruction of the wellbore, which complicates subsequent downhole operations and decreases operational flexibility.

There are two basic types of gravel pack: (1) the external gravel pack or open-hole gravel pack (OHGP), and (2) the inside gravel pack or cased-hole gravel pack (CHGP). Figure 3.7 shows an open-hole gravel pack and a cased-hole gravel pack.

![Gravel Pack Diagram](image)

Figure 3.7 Gravel Pack (a) Cased-hole Gravel Pack (b) Open-hole Gravel Pack.

In both types, the gravel pack screen and blank liner are suspended from a packer set in the casing, or the screen and liner weight may be supported from the bottom of the well or a gravel pack base. In the OHGP, the casing is set above the top of the pay zone, and the completion interval is then underreamed with a nondamaging fluid to remove drilling damage and to enlarge the inflow area. Cased intervals can be completed with an open-hole gravel pack by removing the casing from the completion interval with a mill and then underreaming the completion zone. This type of open-hole completion is called a milled casing underreamed gravel pack (MCUGP).
External gravel packs can result in higher productivity than internal gravel packs due to their larger effective wellbore radius and pure radial flow (compared to convergent and linear flow through perforations). In practice, they are often more difficult to install effectively, particularly in thinly interbedded sand and shale sequences. Moreover, improved techniques and perforation cleanout methods have greatly improved the success of internal gravel packs since the early 1970s. Cased-hole or inside gravel packs now prevail as an accepted industry practice since they offer flexibility, selectivity, and effective zonal isolation and are usually easier to install. The elimination of perforating and cost savings in casing and cementing make open-hole gravel packs less expensive than inside gravel packs in shallow, vertical wells. External gravel packs are used predominantly in viscous crude producers, water source wells, and disposal wells where enhanced productivity is essential and economic production rates cannot be otherwise achieved.

3.3.6 Frac Pack

Frac pack is like an internal gravel pack but the pumping is done above the fracture pressure of the formation. This splits the rock open and a fracture is generated, which bypass the near wellbore damage which is present in the case of a gravel pack. It also helps to contact a much larger surface area with the reservoir, thereby, increasing productivity and minimizing impairment. The fracture is filled with proppant.

3.3.7 Chemical Consolidation

There are numerous chemical consolidation methods which have been developed by industry. However, because of their relatively high failure rate and low level of use, these methods are not often used. Suman et al [1] made an extensive review of these processes. All chemical consolidation methods involve a process whereby cementation between sand grains is created and/or strengthened beyond its natural state. The objectives are to increase sand grain cementation with the least amount of permeability reduction and thereby allow the completion interval to be produced sand-free as a natural completion with no sand control equipment obstructing the completion interval. In some
cases, however, mechanical sand control methods have been used in combination with chemical consolidation methods.

Chemical consolidation methods include two groups: in situ formation consolidation and consolidated gravel.

3.3.7.1 In Situ Formation Consolidation

Generally, in situ formation consolidation techniques result in less damage to the formation than that introduced by gravel packing. However, due to the difficulty in achieving effective placement, their use remains limited. Additionally, there are also chemical compatibility and contamination problems. Resin consolidation is the predominant in situ formation consolidation system being used today.

This technique involves cementing formation grains together with plastic resin. Phenolic, furan and epoxy resins are commonly used. Epoxy resins are generally preferable due to their greater durability, ease of storage, and ability to cure without forming a water by-product such as with phenolic and furan resins.

3.3.7.2 Consolidated Gravel

Consolidated gravel (also called resin-coated gravel) is gravel pack sand or other material which is coated with plastic resin and then placed in the wellbore. The resin coating may be either a wet system or a dry thermosetting system (also called precoated gravel). In the wet system, slurry consisting of unreacted plastic resin, gravel, and a viscous water-based or oil-based carrier fluid is pumped into the well. In the dry system, the gravel is precoated with a uniform coating of partially cured thermosetting resin. The precoated gravel remains dry at ambient temperature conditions, eliminates handling of resins at the well site, and can be placed in the well with any of a variety of carrier fluids. Once the gravel is placed, the higher wellbore temperature softens the resin, bonding touching particles together. After the resin is activated, it eventually cures, solidifying the bonds. Precoated gravel has essentially the same applications as a wet system; however; since there is no excess resin, gravel and formation impairment potentials are greatly reduced. Precoated gravels can be handled and pumped in much the same way as regular gravel; however, they must be stored in a dry place at temperatures well below the
activation temperature. The various precoated gravels available may have fluid compatibility factors which must be observed. More widely known precoated gravel was developed by Exxon and is commercially available from Baker Sand Control as Baker Bond. Similar products are available from other vendors.

Consolidated gravel has a small, but fairly well defined, niche of applications. Consolidated gravel is frequently used in place of regular gravel in gravel packed completions to minimize gravel or formation movement.

Remedial sand control installations in wells, which have cavities from sand production, are also candidates for consolidated gravel. The excess resin of wet systems is believed to aid in stabilizing further movement of formation materials which are suspected of decreasing productivity in remedial sand control installations. Similarly, fines production problems may be better controlled by consolidated gravel. Other uses are in two-stage gravel packs where the perforations are packed separately prior to running the screen and blank liner. This may be a consideration in high-angle completions where there is a higher probability that voids will be present in the gravel pack. Resin-coated gravel has been used as a last resort in wells where economics will not justify installation of a gravel pack or replacement of a failed pack or where mechanical restrictions prevent the use of any sand control equipment. As with in situ formation consolidation treatments, successful screen less applications generally include thin (< 10 feet), low rate, clean sands with little to no water production. Outside of sand control applications, consolidated gravel has been used as a tail end in hydraulic fracturing to eliminate proppant flow back problems.
Chapter 4: Gravel Pack – The Conventional Sand Control Method

4.1 INTRODUCTION
Gravel pack is the most efficient and trusted method of sand control. This chapter discusses the different aspects of gravel pack technology such as gravel pack design, gravel pack placement, gravel pack evaluation, gravel pack repair and gravel pack failure mechanisms.

4.2 GRAVEL PACK DESIGN
Gravel pack design constitutes the selection of gravel size and slot width, completions design, gravel pack base, and screen design. The gravel size and the slot width are primarily based on formation particle sizes, so that the formation sand is effectively restrained.

4.2.1 Gravel Sand Size
Saucier et al [34] describes a series of core flow experiments to determine the optimum gravel pack sand size for gravel packing.

\[ D_{50} = (5~6) \times d_{50} \]

where,

- \( D_{50} \) is the median gravel diameter, and
- \( d_{50} \) is the median formation sand diameter.

A plot of the ratio of final/initial permeability for a range of gravel pack sand (\( D_{50} \)) to formation sand (\( d_{50} \)) ratios is presented in figure 4.1. From the graph, Saucier inferred the following:

1. For a \( D_{50}/d_{50} \leq 6 \), good sand control, no formation sand invasion of gravel pack sand.
2. \( 6 < D_{50}/d_{50} < 13 \), good sand control but restricted flow due to formation sand invasion of gravel pack sand.
3. For $D_{50}/d_{50} > 13$, no sand control as the formation sand passes through the gravel pack sand.

Thus for optimum sand control, which maximizes productivity, Saucier recommended that the gravel pack sand to formation sand ratio should be a factor of 6.

Figure 4.1 Saucier’s optimum gravel sand size.

Gravel pack permeability is a function of the gravel pack sand diameter ($D_{50}$) which itself is a function of the formation sand diameter ($d_{50}$). Thus it is important that the formation grain size distribution is determined before the formation is being gravel packed. In poorly sorted formations, some of the particles will pass all the way through the gravel pack and other particles may get plugged in the gravel pack sand.

The first step in determining the formation sand size is to perform a sieve analysis on qualified samples of formation material. Grain size is usually plotted as cumulative weight percent of retained material on a linear vertical scale versus grain diameter on a logarithmic horizontal scale as shown in Figure 4.2. The classification of sand according to its size is given in the Table 4.1.
Past criteria consisted of sizing gravel to induce arching or bridging of the formation sand against the outer surface of the gravel. While this allowed some sand production and maximized initial permeability of the pack, the result was reduced pack permeability due to penetration of the pack by formation sand. It has now been believed that mixing sand and gravel rapidly reduces the pack permeability. Therefore, the trend over the years has been to decrease the size ratio of the gravel pack sand to the formation sand. Since Stokes’ law indicates that particle-settling rates are directly proportional to the square of the particle diameter, it might be concluded that a smaller gravel size could provide certain transport and placement advantages over larger gravel sizes in high angle wells. This aspect, however, has not been explored due in part to the minimum slot size limitations of screens and to gravel pack permeability considerations in using too small a gravel size.

![Figure 4.2 Sieve analyses for poorly sorted and well sorted sand.](image)

Oftentimes, the gravel size and slot width for a specific formation are well established from numerous completions within the zone. In this case, unless evidence (e.g., variations in log responses) suggests the formation rock properties differ from those
<table>
<thead>
<tr>
<th>Wentworth Designation</th>
<th>Size, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gravel</strong></td>
<td></td>
</tr>
<tr>
<td>Boulder</td>
<td>&gt; 256</td>
</tr>
<tr>
<td>Cobble</td>
<td>256 – 64</td>
</tr>
<tr>
<td>Pebble</td>
<td>64 – 4</td>
</tr>
<tr>
<td>Granule</td>
<td>4 – 2</td>
</tr>
<tr>
<td><strong>Sand</strong></td>
<td></td>
</tr>
<tr>
<td>Very Coarse Sand</td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>2 – 1.414</td>
</tr>
<tr>
<td>Lower</td>
<td>1.414 – 1.000</td>
</tr>
<tr>
<td>Coarse Sand</td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>1.000 – 0.707</td>
</tr>
<tr>
<td>Lower</td>
<td>0.707 – 0.500</td>
</tr>
<tr>
<td>Medium Sand</td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>0.500 – 0.354</td>
</tr>
<tr>
<td>Lower</td>
<td>0.354 – 0.250</td>
</tr>
<tr>
<td>Fine Sand</td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>0.250 – 0.177</td>
</tr>
<tr>
<td>Lower</td>
<td>0.177 – 0.125</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Upper</td>
<td>0.125 – 0.088</td>
</tr>
<tr>
<td>Lower</td>
<td>0.088 – 0.062</td>
</tr>
<tr>
<td><strong>Silt</strong></td>
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</tr>
<tr>
<td>Coarse Silt</td>
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</tr>
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</tr>
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<td>Fine Silt</td>
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</tr>
<tr>
<td>Very Fine Silt</td>
<td>0.008 – 0.004</td>
</tr>
<tr>
<td>Clay</td>
<td>&lt; 0.004</td>
</tr>
</tbody>
</table>

Table 4.1 Udden-Wentworth Scale (Source Schlumberger website).
of the rest of the field, these values can probably be used reliably. Verification by sample analysis, however, is always recommended, especially when size requirements are uncertain.

4.2.2 Gravel Selection

Gravel selection involves specifying the appropriate material for use as the filter medium between the screen and the formation. In nearly all cases, sand will be used. However, for special applications, bauxite, wet resin-coated gravel, precoated gravel, low density (also called neutrally buoyant) gravel, or other variations may be used. Anytime a material other than plain uncoated sand is used, the material should be tested for compatibility with stimulation fluids, viscosity breakers, and other completion fluids. Hydrofluoric acid is known to weaken ceramic materials such as bauxite. Acid or persulfate viscosity breakers are incompatible with some resin coatings. In certain conditions, it may be appropriate to examine the gravel properties which affect gravel placement, longevity, and productivity.

4.2.3 Gravel Density

The emphasis in gravel sizing is to size the gravel properly to prevent sand production. However, in special circumstances such as extremely high angle wells, another concern could involve selecting gravel with parameters which will ensure the best pack placement. For example, Stokes’ law shows that single particle settling rates are directly proportional to the difference between the densities of the particle and the fluid and to the square of the particle diameter. From this, it appears that gravel placement can be impacted by varying either the size or the density of the material used for gravel.

4.2.4 API Recommended Practice

API Recommended Practice 58 (RP 58), Recommended Practices for Testing Sand Used in Gravel Packing Operations (1st Edition March 1986), is the standard which all gravel pack sand should meet.
4.2.5 Slot Sizing

Proper slot sizing is critical to the effectiveness of sand control. Slots that are too large will leak sand, eventually resulting in the well sanding up or an erosion failure of the screen or surface equipment. Slots that are too small may become severely plugged during installation or subsequently during production.

4.3 COMPLETION DESIGN FOR A GRAVEL PACK

The different types of gravel packed completions are open-hole, cased-hole, single, dual, selective, and multizone commingled completions.

4.3.1 Open-Hole vs. Cased-Hole Completions

Open-hole completions are used where enhanced productivity is essential. This is typical where reservoirs produce heavy, viscous oil (e.g., onshore California; Cameroon, Africa) and in high rate water source wells. Desirable features for an open-hole completion include; low to near vertical well deviation, good hole stability, low clay content and few shale streaks, moderate to low pressure, minimizing well control problems, reasonable isolation from fluid contacts. In most open-hole gravel packs, casing is run and cemented above the interval. The drilling mud is then displaced from the well with a non-damaging viscous fluid (or fluid with dissolvable solids), and the open-hole section is drilled and then underreamed several additional inches using a hole opener or underreaming tool. Open-hole gravel packs can be affected in cased intervals by milling out casing and then underreaming the open-hole section by several inches. These completions, known as milled casing underreamed gravel packs (MCUGP), provide the benefits of greater productivity along with cased-hole benefits of isolation above and below the interval. Where open-hole gravel packs are not required, completions are usually cased to provide the benefits of hole stability, greater well utility, and zonal isolation.

4.3.2 Single vs. Dual Completions

The majority of gravel packed wells are completed as single-zone producers. Dual-zone producers are generally limited to wells, which do not require sand control.
Studies have indicated that dually produced completions are less profitable in offshore operations due to increased mechanical complexity and an associated high failure rate.

4.3.3 Selective Completions

4.3.3.1 Mechanically Isolated Selective Completions
Mechanically isolated selective completions are frequently used for the purpose of selectively producing and selectively isolating completion intervals. From a design standpoint, these completions are mechanically very similar to dual completions but with only one production string.

4.3.3.2 Packerless Selective Completions
Packerless selective completions are a less expensive attempt to selectively produce or selectively isolate two or more zones or sections of the same completion interval. The mechanical design is essentially that of a single-zone gravel pack completion. In this completion design, all of the zones are perforated at once and one gravel pack is placed, using two or more sections of screen each separated by a length of blank liner. Usually the lower screen section is a selective screen. There is no annular isolation between the sections other than the settled gravel column. This design relies solely on the permeability of the gravel column to restrain flow between the sections until the selective is utilized. Packerless selectives do not provide total isolation and, therefore, their use should take this aspect fully into consideration.

4.3.3.3 Multizone Completions
Multizone completions involve several zones to be gravel packed in one trip. Production from all of the zones is commingled into one production string. Hydraulic packers set inside production casing separate each zone, allowing each to be separately gravel packed. Generally, completion designs of this mechanical complexity are shunned.

4.3.3.4 Through-Tubing Completions
Through-tubing gravel packed completions are becoming an increasingly important method of remedial sand control and as a repair alternative to failed gravel
packs. Workover costs can be dramatically reduced, since the equipment can be run with a small work string or coiled tubing for short intervals by wireline. Figure 4.3 shows a through tubing gravel pack completion. This is called vent screen method [54, 55]. Through-tubing completions are especially desirable for low rate wells or where remaining reserves are low.

![Figure 4.3 Through Tubing Gravel pack – Vent Screen Method [54]](image-url)
4.4 Gravel Pack Base

The gravel pack must have a stable base which will support the gravel column and form an adequate seal between the screen and any rathole to prevent gravel from falling below the completion zone. The gravel pack base also provides the reference depth from which the remaining gravel pack design is determined. The gravel pack base should be no more than about 5 ft and preferably only about 2 to 3 feet below the bottom of the completion zone (a lowest perforation).

4.5 Screen Design

Screen refers to a mechanical device used to restrain the production of gravel and formation sand. Therefore, screen design deals with the selection of the type of restraint device as well as the physical specifications of the device. For convenience of discussion, screens are categorized here into regular applications and special applications. Regular applications represent the vast majority of screen designs which are used. Of these, slotted liners and wire-wrapped screens are the two screen types available. Special applications represent less common designs which have been used for particular purposes such as selective completions or wells which are difficult to gravel pack, requiring extra assurance to prevent sand production. The special application screen designs include selective screen, prepacked screen, protected screen, multiply wrapped screen, steel wool, and combination screen. An overview of the available screen designs and their variations is provided in Table 4.2.

4.5.1 Regular Application Screens

Slotted liners and wire-wrapped screens account for the majority of the screen designs used in oil field completions. If all of the following criteria are satisfied, then one of these regular application choices may be sufficient and a special application design may not be needed:

a. The ability to place gravel effectively within a gravel pack completion is considered good.

b. The ability to control sand production with a wire-wrapped screen or slotted liner either with or without gravel packing is considered good.
c. The subject zone is not intended to be selectively utilized (produced, injected, or shut off).

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Table 4.2 Various screen types.

**4.5.1.1 Slotted Liners**

The simplest and cheapest of screens is the slotted liner. The slotted liner is nothing more than a production tubing or casing having a number of parallel slots. The slots are cut from the outside using rotary saw blades to yield the desired slot width. A variety of slot patterns is available (Figure 3.2), depending upon the desired flow area and percent of retained original pipe strength. Vertical slots with staggered rows are most common, being stronger in tension and less prone to shape distortion caused by linear buckling. However, horizontal slots may provide some advantages in fishing operations since the joints are likely to pull part more easily.
With present technology, slots smaller than about 0.012 to 0.016 inch (depending on pipe thickness) wide are not practical due to high saw blade breakage costs. In some cases, slots are undercut (also called keystone cut or half keystone cut) so that the faces of the slot sides are not parallel but form a “T”. This design has the narrowest width of the slot at the outside of the pipe and widens towards the inside. Undercut slots are intended to be self-cleaning and minimize slot plugging. However, field experience suggests that undercut slots plug just as easily as the straight-cut slots, and since they are more expensive, undercut slots are not frequently used. Undercut slots are also more susceptible to erosion and corrosion attack. Slot widths vary in availability ranging from 0.012-0.500 inch for straight cut and 0.020-0.500 inch for undercut. The smallest available slot widths may be too large for many formations, necessitating the use of wire-wrapped screens.

Slotted liners are used primarily in shallow onshore wells and low cost operations where minimizing cost requires some compromise in quality. They are also used in cases where damage to wire-wrapped screens (either on surface due to handling or downhole due to well damage) is likely. Slotted liners are often used in steam flood completions because they are easier to clean after installing than pipe-based wire-wrapped screens. The slots are accessible to hydraulic and mechanical tools which can be used for cleaning. Also, placement of solvents directly on plugged slots is unobstructed as compared to wire-wrapped screens. Steam flood completions have a tendency to plug due to the precipitation of soluble formation materials and due to the precipitation of heavy crude ends in the screen slots. Of course, the smaller flow area of the slots in slotted liners, as compared to wire-wrapped screens, may worsen the plugging problem due to a somewhat greater pressure drop during production.

A disadvantage in using slotted pipe is the smaller effective slot inlet area as compared to an equivalent size all-welded wire-wrapped screen. Slots tend to plug easily with gravel during gravel packing and with formation fines, corrosion products, and precipitates during production, further reducing the inlet area. The pressure drop across a plugged liner can become quite significant and continually worsen as plugging increases. Conversely, wire-wrapped screens have 10 to 30 times the open area of slotted liners and,
therefore, are capable of tolerating substantially greater plugging with minimal impact on inflow performance.

4.5.1.2 All Welded Wire-Wrapped Screens

Wire-wrapped screens, more often just called screens, have replaced the cheaper slotted liners in all offshore completions and in many onshore completions. Of the two design groups, only all-welded screens are recommended for oil field use. Wire-wrapped screens provide a much larger flow area than equally sized slotted liners.

All-welded screens as shown in Figure 4.4 are probably the most expensive screens but are the strongest and provide the highest flow area and best slot width control. Wire-wrapped screens have 10 to 30 times the open area of slotted liners. The wire is wrapped spirally around longitudinal wire ribs and induction welded at each wire intersection, which gives the screen its strength.

Figure 4.4 Cutaway view of an all-welded wire-wrapped screen (Source Variperm Canada Limited).

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4.5.2 Special Application Screens

Special applications include all designs other than the slotted liner or wire-wrapped screen designs previously discussed. In this area, there has been a continuous development of new types of screens for a variety of purposes and offering varying benefits. Generally speaking, screen suppliers can design and build screens to any needs.

4.5.2.1 Prepacked Screen

A prepacked screen is a screen design incorporating an internal filtration medium. There are numerous ways to design a prepacked screen. The most common of these are dual-screen prepacks and single-screen prepacks, shown in Figure 3.4. Gravel pack sand is always used as the prepack material. Full-size screen prepacks utilize an inner and outer wire-wrapped screen jacket. The gravel prepack may be plastically consolidated or unconsolidated. The various prepacked screen designs are [52]:

1. Pipe-Based Screen (Inner) by Screen Jacket (Outer)
2. Pipe-Based Screen (Inner) by Perforated Pipe (Outer)
3. Wire Mesh-Covered Pipe (Inner) by Screen Jacket (Outer)
4. Pipe-Based Screen (Inner) by Pipe-Based Screen (Outer)
5. Pipe-Based Screen (Inner) by Consolidated Gravel Cylinder

The most recent development in dual-screen prepacks is the low-clearance designs. These designs incorporate a microscreen as the inner jacket and a regular-sized screen jacket as the outer jacket. Radial clearance between the two screens is minimal, generally around 0.25 inch or less.

The primary problems with prepacks are plugging due to dirty completion fluids and damage while running. For this reason, it is preferable to avoid bull plugging the bottom of the screen when using a prepack. The bullplug causes brine to flow through the prepack in order to fill the screen and work string as it is run into the hole, thus increasing the potential for impairment. If a prepacked screen is not gravel packed, then as with other screens, formation sand is allowed to move, mixing with clays and shales, filling the wellbore annulus and perforations in cased wells. These all cause productivity losses;
however, the losses may not be quite as severe as compared to a plain screen-alone completion. If the prepack remains unplugged, the high permeability prepack will lessen the problem.

4.5.2.2 Protected Screen

Protected screen can be used whenever all-welded screen is required and there is a reasonable chance that the screen will be damaged while running it into the well. Corroded and damaged casing may allow passage of a tubular, but burrs could snag and damage a wire-wrapped screen. Protected screen has an all-welded screen jacket centralized inside a perforated outer tubular.

4.5.2.3 Multiply Wrapped Screen

Multiply wrapped screen consists of three wire-wrapped screens concentrically layered with each succeeding inner layer of screen having a smaller slot size. These screens were used in an attempt to control sand production without gravel packing. As with any screen installed without gravel packing, erosion by sand production quickly leads to a failure. Due to the number of erosional failures and high cost, these screens are no longer used

4.5.2.3 Steel Wool

Texaco developed a patented prepacked filter utilizing compressed stainless steel wool sandwiched between coarse (0.0125 inch gap) steel cloth (i.e., steel wool cloth or SWC) for use in vertical and horizontal thermal tar completions which produce sand, steam, hot water, and high viscosity bitumen (with solid hydrocarbons) at high rates.

4.5.2.4 Combination Screen

Combination screen includes all the permutations of combinations of all the different screen types mentioned. One practical example is a selective prepack screen. The selective prepacked screen utilizes a large conventional prepack design (outer pipe-based screen by inner pipe-based screen) but with a third concentric blank tubular inside. These screens are very stiff and should be used with caution if there is even slight casing damage. Their ability to bend through tight spots is minimal.
4.5.3 Screen Size and Clearance

It is important to remember that the screen type selected strongly affects sizing and clearance considerations. For example, the actual outer diameter (OD) of wire-wrapped screen is considerably larger than the nominal diameter of the pipe base by which its size is designated and is often larger than the pipe connection. Conversely, in a slotted liner, the connection OD is always the largest OD. Prepacked screens will have the largest OD and thereby further restrict alternative inner diameter (ID) choices. Screen ID usually should be less than or equal to the blank liner ID which should be less than or equal to the production tubing ID to facilitate wireline and concentric workover operations (except when large OD artificial lift equipment or other equipment is to be run and/or set inside of the screen). Minimum allowable radial clearance for screen and screen connection is 0.5 inch for cased zones, and a minimum of 2 inches is suggested for open-hole zones.

4.6 Gravel Slurry Design

Slurry design involves selecting the proper carrier fluid and any additives, including the appropriate gravel concentration to ensure effective placement of the gravel pack. A gravel packing fluid must; (1) have adequate gravel suspension to provide a uniform slurry throughout mixing, pumping, and transport downhole, (2) have sufficient leak-off to provide gravel compaction in perforation cavities (for cased hole) and screen annulus, and (3) be non-damaging to formation permeability. Other desirable characteristics of all gravel packing fluids include their being easy to mix in the field, low cost, readily available, not toxic, environmentally safe, and compatible with completion and stimulation fluids.

4.7 Gravel Pack Placement

Gravel placement involves transporting the gravel from the surface to the completion interval to install a downhole filter. There are numerous possible combinations of equipment, pumping schemes, procedures, and miscellaneous accessories to affect the various types of gravel pack placement techniques [1, 2, 56, 57, 58, 59, 60]. Some of these techniques include:
1. Top-Down Circulating Pack
2. Top-Down Circulating-Squeeze Pack
3. Top-Down Squeeze Pack
4. Bottom-Up Circulating Pack
5. Bidirectional Pack
6. Washdown Pack
7. Gravitate Pack

Circulating packs are considered to be the most capable of providing the highest packing efficiencies under most conditions. Squeeze packs are often used in short zones and vertical wells where placement problems are not expected. A bottom-up circulating pack or a bidirectional pack may be better suited than a top-down circulating pack in some instances, although these techniques have not been fully evaluated. Washdown packs and gravitate packs should generally be avoided where possible because of their greater likelihood of resulting in an impaired completion and/or ineffective sand control.

4.7.1 Top-Down Circulating Pack

A top-down circulating pack as shown in Figure 4.5, or more commonly a circulating pack, is the recommended placement technique for practically all situations. However, in order to affect a circulating pack, there must be adequate bottomhole pressure to support pack placement pressures, allowing fluid returns to be circulated to surface. If this is not feasible, then the placement technique becomes essentially a squeeze technique.

A top-down circulating pack involves circulating slurry down the top of the gravel pack annulus and taking fluid returns at the bottom through the wash pipe. Once the fluid enters the gravel pack annulus, possible fluid flow paths include (1) into the formation, (2) down the liner and screen/casing annulus (or screen/formation annulus in open-hole completions) entering the screen near the bottom to return up the washpipe, or (3) down the screen/washpipe annulus to enter the bottom of the washpipe. The division of flow among these three paths has a major impact on placement efficiency.
Figure 4.5 Top-down circulating gravel pack (Source Baker Oil Tools).
Since a circulation path is established over the zone, circulating packs offer potentially improved annular packing efficiency over squeeze packs. In theory, a circulating pack should provide enough return circulation to provide adequate gravel transport down the annulus and provide adequate leak-off to pack perforations. Perforation packing efficiency of a circulating pack is potentially less than that of a squeeze pack since less leak-off occurs. An adequate leak-off rate into the formation must occur for the perforations to be well packed with gravel. In practice, leak-off rates are not usually measured (from return rates), tend to vary substantially depending on numerous factors, and are probably high enough to provide reasonable perforation packing efficiencies (based on good well productivities achieved).

4.7.2 Top-Down Circulating-Squeeze Pack

A top-down circulating-squeeze pack, or more commonly a circulating-squeeze pack, is a variation of a top-down circulating pack in which fluid returns are stopped during slurry placement and remaining fluids are squeezed into the formation. A circulating-squeeze pack requires the same equipment as a circulating pack design and incorporates both circulating and squeeze placement techniques into the gravel placement plan. This placement technique can be performed in any of a number of ways and often occurs unintentionally when flow resistance up the washpipe results in nearly all remaining fluids being squeezed away.

4.7.3 Top-Down Squeeze Pack

A top-down squeeze pack as shown in Figure 4.6, or more commonly a squeeze pack, involves circulating slurry down the top of the gravel pack annulus and squeezing all fluids into the formation as the gravel is being placed. Possible flow paths are identical to that of a circulating pack, except no fluid returns occur. Placement is strongly influenced by the leak-off rates of individual perforations. Since all fluids are squeezed away, squeeze packs offer a potentially higher perforation packing efficiency than circulating packs. This placement technique, however, is more likely to result in poor annular packing efficiency since gravel placement adjacent to tight perforations will be
inhibited. Therefore, squeeze packs are generally recommended only for short zones with low deviation and only in longer zones that are nearly vertical wells.

Figure 4.6 Top-down squeeze pack without washpipe (Source Baker Oil Tools).
4.7.4 Bottom-Up Circulating Pack

The bottom-up circulating pack or more commonly a bottom-up pack (also called a gravity-assisted gravel pack system), was developed by Completion Services, Inc. as a method to improve gravel placement. In a bottom-up pack, slurry is transported down through the inside of the screen through washpipe, entering the screen/casing annulus at the bottom of the completion zone. Theoretically, after exiting the washpipe through a discharge valve, slurry then travels up to the top of the interval in plug flow. When the slurry reaches the top of the gravel pack annulus, a compacted gravel bank begins forming, growing downward as the slurry dehydrates until it reaches the bottom of the zone.

This design eliminates the need for lengthy blank liner sections above the screen and therefore may be well suited for confined intervals. The bottom-up pack offers improved gravel placement over top-down techniques where there is a high potential of premature gravel bridging occurring at the top of the completion zone. The system appears to be best suited when gravel pack slurry density is higher than that of the displacement fluid. The pack placement efficiency which results when this criterion is not met was not reported and may very well be unfavorable since fluids are more likely to intermix. Obviously, as well deviation approaches horizontal, gravitational effects on the bottom-up pack and top-down pack placement techniques are identical.

Completion Services bottom-up pack design allows the option of both conventional top-down gravel placement and bottom-up placement on the same installation. This is also known as a bidirectional placement. An additional trip and additional equipment are required to perform a bidirectional placement. A bidirectional placement capability has potential application in wells where bridges and voids are more likely to form.

4.7.5 Bidirectional Pack

Another type of bidirectional pack was described and patented by Dickinson [36] and others in 1987. This method involves the drilling of numerous small 1-inch outer diameter boreholes extending radially from a central wellbore. Each radial is bidirectionally gravel packed using some questionable techniques. Because of the hole
size limitation, questionable packing techniques, and questionable reliability, Dickinson’s method is probably not a viable alternative for most applications. The bidirectional capability of Completion Services bottom-up pack, however, appears to be a viable method of implementing a bidirectional placement technique.

4.7.6 Washdown Pack

Washdown packs as shown in Figure 4.7 are now rarely used and are only suited for through-tubing gravel packs or for short intervals in cased- or open-hole completions in shallow operations. The washdown process may result in poorly compacted gravel in the annulus and perforations which may compromise sand control performance.

4.7.7 Gravitate Pack

The use of a gravitate pack is not recommended for oil field operations. Allowing gravitational settling of gravel that has been poured into the annulus results in segregation of particle sizes with larger, heavier particles on bottom and smaller particles and fines on top. Perforations cannot be packed and gravel will not be well packed in the annulus. Due to the size segregation and loose annular packing, this pack may not effectively restrain formation sand and will likely be impaired. As the gravel falls into the annulus, it probably drags with it much of all other suspended solids which add to impairment. A gravitate pack is about the least expensive way to install a gravel pack since no chemicals or pumping services are required. The wellbore must be essentially a straight hole with no mechanical obstructions which might cause the sand to bridge prematurely. Generally, this has been used only in very shallow water wells.

4.7.8 Pumping Considerations

Important aspects of pumping gravel packs include pump rate, pump pressure, defining when sandout occurs, the need for additional batches of slurry, pumping route, and single-stage vs. two-stage gravel packs.

Pump rate affects gravel pack placement efficiency. This effect becomes more important in high angle wells where pack placement problems are more likely to occur.
Generally, higher pump rates yield higher annular packing efficiencies in high angle wells. A higher rate minimizes the chances for the formation of premature bridges.

Figure 4.7 Washdown pack (Penberthy and Slaughnessy)
Generally, there is little concern about exceeding formation fracture pressures when pumping gravel packs. In most formations requiring sand control, formation permeability is sufficiently high and gravel pack fluid volumes are sufficiently low that fracturing is unlikely to occur unless a frac pack is intended.

In all gravel pack placement techniques except the washdown pack and the gravitate pack, pumping continues until sandout occurs. Sandout is defined as the point during placement when pump pressure rapidly increases to sustained level, usually reaching 2000-3000 psi over static surface pressure (which is usually zero). After sandout, pumping is stopped and the pressure bleed-off rate is monitored. The pack is subsequently re-stressed once or twice after the pack has been allowed to settle, to confirm a good sandout. Settling time will vary depending upon the slurry system used. If the bleed-off rate is quick, this is usually an indication that insufficient gravel was pumped. Additional slurry should be pumped until sandout is achieved to pack the zone completely and to provide for adequate reserve gravel.

4.8 POST GRAVEL PACKING OPERATIONS

4.8.1 Initial Well Unloading Procedures

The use of proper well unloading procedures to establish initial production is critical in affecting well productivity. The use of improper procedures may likely severely impair productivity. In unconsolidated sands, it is especially important to unload injected completion fluids and spent stimulation fluids very slowly. For flowing and gas-lifted wells, this means starting out with small choke sizes and low gas lift rates and gradually building up. Pumping wells should be slowly pumped initially, gradually building pump rate. Some trace sand may be noticed in early shakeouts, which is common as the well cleans up. Shakeouts or other sand detection methods which do not show a rapidly decreasing sand production rate may be indicative of a problem. Any sand production should be closely monitored, and well production rate increases should only be made after evidence of effective sand control is demonstrated. Rapid adjustments can tend to cause formation fines movement which can cause impairment. A gradual, stepwise procedure for initiating production establishes stable bridges and keeps the
concentration of moving fine particles low, thereby allowing them to flow completely through the pack and out of the wellbore, rather than lodging within the formation and the gravel pack, causing impairment.

4.8.2 Gravel Pack Evaluation

Many logging tools have potential for investigating the annular space between screen and casing in a gravel pack for the detection of voids that could lead to completion failure. Among these are neutron porosity tools, acoustic velocity tools, density tools, and pulsed neutron decay time tools [13, 14]. Neutron logs are preferred over density logs for gravel pack evaluation (as long as the gravel pack is liquid-filled), because they are less sensitive to variations in the amount of iron in the wellbore.

4.8.3 Gravel Pack Repair

Three types of gravel pack repair problems are addressed in the literature, (a) the in situ cleaning of plugged screen slots, (b) the repair or replacement of screen, and (c) the removal of gravel bridges and voids. Generally, gravel pack repair methods (other than pulling the pack) are a poorly documented subject and, therefore, the risks and successes of the methods are not well defined. Repair attempts, however, may be easily justified in many cases, especially when pulling the screen and repacking runs a high risk of resulting in the same problem (e.g., pulling the gravel pack of a long, high angle interval due to voids found in the pack does not guarantee that the next pack will be void free, unless packing procedures can be substantially improved)

4.9 Gravel Pack Failure Mechanisms

Gravel pack failure usually refers to the inability of the gravel pack to adequately exclude formation sand. Gravel packs having less than 100% completion efficiency are also partially failed to the extent that their productivity does not meet the design intention. There is some connection between impaired gravel packs and sand exclusion failures. However, for the sections that follow, only sand exclusion failures will be discussed.
4.9.1 Failure Mechanisms

There are at least four possible gravel pack failure mechanisms: erosion failure, sand leakage, mechanical failure, and corrosion failure. All but sand leakage pertains to failure of the screen. Sand leakage is a result of a design deficiency. Conceivably, these mechanisms can work alone and together. There are no statistics to determine which of these is more prevalent. However, based on wellbore damage studies, gravel pack modeling, observations of failed screens, and field experience, erosion is suspected as the prevalent mechanism of gravel pack failure. Sand leakage is common to the extent that most gravel packs leak sand at some point. Given that screen slot sizes used generally have been incapable of excluding formation sand, it is probable that a good number of failures resulted from sand leakage. Mechanical failures could become a bigger factor as new fields experience more severe reservoir compaction and associated well damage. Corrosion failure could be important, but where corrosion-resistant screen materials are used, it is considered a less likely failure mechanism. However, in fields where carbon steel slotted liners typically are used, corrosion failure is much more likely. All the failure mechanisms are discussed briefly in the next section.

4.9.1.1 Erosion Failure

Erosion failure occurs after an adequate mass of solid particles has impinged upon the screen with sufficient energy to wear away enough metal to enlarge the screen slots beyond design tolerances or to create new openings such that sand exclusion is no longer possible.

Screens with erosion failures frequently have one to three holes and no other damage. In internal gravel packed completions the location of the holes typically is identical to perforation spacing and is on the high side (in deviated wells) of the well. This can be determined from drag marks that appear on the low side of the screen from washover and fishing operations. In deviated wells, loose gravel pack sand will slump to the low side of the well, potentially exposing the high side of the screen to erosion. Erosion failures are more likely in internal gravel packs rather than external gravel packs, since perforations act to increase local flow velocities and focus erosion on small areas of the screen. Anytime a corrosion failure or a mechanical failure occurs, erosion is likely to
follow if sand is produced. Erosion may destroy evidence of other failure mechanisms. Erosion failure mechanisms require at least three conditions: (1) flow of reservoir fluids into the screen at sufficient velocity to transport sand, (2) a loose area or void in the gravel pack, and (3) loose particles large enough to cause erosion. Once a void or loose pack is formed, erosion may occur by at least two mechanisms: direct impingement and scouring.

In direct impingement erosion, formation particles impact the screen, and most or all particles pass through the screen slots. Those that are restrained may fill the void in the pack before the screen erodes and stop further erosion. If erosion is not stopped, formation sand will continually flow through the screen and the well may sand up at any time. This potential increases as erosion damage progresses. Erosion can progress very rapidly; in some cases gravel pack failures have occurred during the first few hours of initial production. Erosion failure time is directly proportional to the total mass of sand that impinges on the screen.

Scouring erosion occurs when large particles that will not pass through the screen, continually impact the screen due to localized partial fluidization. Partial fluidization of the gravel pack sand or formation sand is initiated in the void or loose area of the gravel pack as fluid flows. It is important to note that a scouring failure can occur before ever producing any significant volume of sand. Particles will eventually pass through after slots are scoured open. At that point gravel pack sand and formation sand will be produced, potentially causing the well to sand up.

4.9.1.2 Sand Leakage Failure

Sand leakage failure occurs when gravel pack sand or formation sand continually leaks through undamaged screen slots. This can occur only when slots are too large. Slots may be too large due to design error, poor manufacturing quality, or by design. The design rules used provide for screen slots to exclude gravel pack sand, not formation sand. If slots are too large, formation sand may pack around the screen and simultaneously leak through. In this case direct impingement erosion or scouring erosion may not occur, and the screen may remain undamaged. However, sand production rates
could be excessive. Periodic bridging may occur, resulting in sporadic sand production. If flow velocities are low, the well may eventually fill up with sand, restricting production as the ID of the lower screen is obstructed. Eventually, as flow is forced through the upper portion of the screen and local velocities increase, erratic pressure fluctuations may occur inside the screen as sand slugs are lifted and fall in an unstable manner. Erosion failure eventually may occur if local flow velocities through the screen and sand leakage rates become too high.

4.9.1.3 Mechanical Failure

Mechanical failure occurs when action other than erosion or corrosion causes screen slots to open beyond design tolerances or a new opening to be created such that sand exclusion is no longer possible. Mechanical failure may occur when the screen is overstressed externally or internally by mechanical, hydraulic, or thermal stresses at any time in the life of the well. This may occur during or as a result of screen handling prior to installation, installation operations, gravel pack pumping operations, reservoir compaction and fault movement.

Mechanical failures probably are more typical of wire-wrapped screens rather than slotted liners. The wire-wrapped jackets attached to the outer diameter of the base pipe are weak compared to the pipe. Slots can be relatively easily distorted by sudden impacts or by more slowly acting bending, crushing, and buckling loads. Severe slot plugging coupled with high drawdowns can collapse weaker screens.

Slotted liner failures are not uncommon. Suman [1] showed photos of severely damaged slotted liners from wells near Long Beach, California. Severe axial loading of the tubulars, caused by reservoir compaction, buckled the liner and created significant slot distortion (i.e., opening substantially beyond tolerances).

4.9.1.4 Corrosion Failure

Corrosion failure occurs when corrosion enlarges screen slots beyond design tolerances or creates a new opening such that total sand exclusion is no longer possible. Screen slots cannot tolerate any corrosion. Very low general corrosion rates of only a few mils per year (e.g., 5 mils/year) may be quite acceptable for most well and facility
components but may cause screens to fail in a few months. Under general corrosion attack, slot openings can easily double in size in less than a year and allow gravel pack and formation sand to flow through. Localized corrosion attack potentially can act much faster. Other types of corrosion such as stress corrosion cracking (due to hydrochloric acid or chlorides in salt water) also can cause quick failures. Screen slots are particularly susceptible since corrosion products, that help slow further corrosion, are likely to be removed (i.e., corrosion erosion) by continuous production or injection operations.

4.9.2 Gravel Pack Failure Prevention Techniques

The sooner that sand production is detected, the sooner action can be taken that may prevent a complete failure or at least avoid a major workover. Once sand production first begins, it is advisable to consider shutting in the well to check for sand fill. Wellhead shakeouts coupled with enhanced sand sampling techniques should be considered, as soon as practical, to accurately determine particle sizes being produced and quantities. Production of larger gravel pack sand (i.e., or any particles larger than the upper design tolerance of the screen slots) is indicative that the screen is damaged and the situation is likely to worsen. Production of only smaller formation sand could be indicative of only a sand leakage problem. If the leakage problem is addressed quickly, it may be possible to stop it before the screen is damaged. Effects of sand production rates versus well flow rates should be noted to determine if the problem could be controlled. Downhole tubular flow velocities needed to lift sand should be compared with actual velocities to ensure that any sand produced is flowing out and not accumulating within the well.

A gravel pack log should be considered to find voids in the pack. If conditions are amenable, it may be possible to compact any voids with wireline tools or coiled tubing before complete failure occurs and a major workover is required. If sand leakage is the only problem (i.e., the screen is not damaged), then elimination of voids and compacting the pack should eliminate sand production. If the screen is damaged, then by determining the exact location of the voids, it may be possible to mechanically isolate the damaged screen and repair the pack with consolidation treatments.
4.9.2.1 Prevent Erosion, Sand Leakage, Mechanical and Corrosion Failures

Achieving a gravel pack that has a tightly packed, void-free annulus and perforation cavities are the most important remedy to prevent erosion, sand leakage, and mechanical gravel pack failures. There are other remedies like best screen selection described by Coberly [34], which can improve upon this and in some cases compensate for failing to accomplish this. However, if good packing is not achieved, chances of failure are substantially increased. The best way to achieve a tightly packed annulus is to use a water pack or comparable low-viscosity slurry coupled with correct mechanical design and slurry placement procedures.

Erosion failures can be minimized by reducing flow velocities entering the screen. If velocities are too low, then sand particles may not be transported and cause erosion damage. Reducing screen inflow velocities by reducing well flow rates is usually undesirable. Preferably, wells should be designed with maximum inflow area to keep velocities low. Inflow area can best be maximized by utilizing long, open-hole completions. The elimination of perforations (by going open-hole) diffuses the flow and drastically lowers flow velocities so that direct impingement erosion is unlikely to occur. Also, flow is no longer focused on small areas of the screen, so that any erosion that did occur would take longer to fail. Adding substantial length to the completion interval is another way to increase area substantially. With long horizontal wells, the best of all worlds is achievable, namely high-rate wells with low screen inflow velocities. Higher completion efficiencies coupled with large diameter, high-density perforating should help reduce erosion failures in cased completions. Low impairment and a large number of large-diameter perforations will minimize perforation flow velocities. However, in practice, internal gravel packs often have low completion efficiencies. The causes for this are currently under study and the conditions under which this remedy can be counted on are not well understood.

Mechanical failures are largely preventable by using screens that are both stronger yet can absorb excessive strains in a desirable manner while still effectively excluding sand and maintaining satisfactory production of reservoir fluids.
Corrosion failures are largely preventable by selecting proper metallurgy so that no corrosion occurs. Every effort should be made to maximize gravel pack screen corrosion resistance since, unlike other well equipment; minimal corrosion can lead to failure.

4.9.3 Reservoir Compaction and Fault Movement Induced Gravel Pack Failures

Reservoir compaction occurs more so in less consolidated formations as reservoir pressure declines. The compacting movement of the earth can damage wellbores, causing gravel packs to fail. In many cases, the damage is so severe that the failed gravel packs could not be retrieved, and the intervals had to be abandoned. Compaction failures typically are first recognized when the gravel pack fails and the well sands up. Axial loading (as compared to transverse crushing) causes buckling which presents the most difficulty for completing the workover. Suman [1] reported severe buckling of a slotted liner in a compacting reservoir that caused slots to open beyond tolerance. Good, uniform lateral support around the casing is essential to minimize compaction-induced damage, especially buckling. Failures also are known to occur in wells near or penetrating through faults. As fault movement occurs, casing begins to collapse. Eventually, the wellbore may be sheared in two. There is no remedy to compaction other than pressure maintenance and in most cases it is not possible due to economic constraints.
Chapter 5: Development of a Sand Control Strategy

5.1 INTRODUCTION

Sand production is a major problem in almost all fields that produce from unconsolidated reservoirs. However, there are other phenomena, such as, reservoir pressure depletion, water breakthrough and natural tectonic forces, which are causing considerable amount of sand production from consolidated and friable reservoirs. The difference is that sand production in consolidated and friable reservoirs commence late in the life of the well. Thus, consolidated formations do not need sand control application at the beginning of production as required by unconsolidated formations. The key to selecting a sand control strategy is to fully understand the formation characteristics, causes of sand production, risk involved and safe and optimum sand production limits. The knowledge of formation and cause of sand production particularly helps to predict the onset of sand production, amount of sand production and rate at which the sand will be produced. Above information and the knowledge of sand tolerance limits of production system, completes the list of parameters required to design an optimum sand control strategy for the reservoir.

5.2 SAND CONTROL APPROACHES

There are two basic approaches to sand control, 1) installation of a downhole sand control in case of unmanageable sand production, which will ensure safety of operations but lower the productivity of well, and 2) to accept the tolerable amount of sand production, which will increase the productivity of well but may require a meticulous planning in terms of rate control, reservoir pressure maintenance, equipment monitoring for erosion, wellbore cleaning and surface handling of sand and its disposal.

The first approach is being used by the petroleum industry for decades and is still recommended in sand production from unconsolidated formations. It involves fitting downhole screens in completions, gravel packing or frac packing the well. The second approach, to accept the tolerable amount of sand production is more of a sand management technique than sand control. It has proved very successful in increasing
productivity of wells while maintaining the safety of the operations in some cases and is worth evaluating. A list of sand control methods that would fall under the different approaches is presented in Table 5.1.

<table>
<thead>
<tr>
<th>Classification of sand control methods into sand management techniques and sand exclusion techniques.</th>
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<tbody>
<tr>
<td><strong>Sand Management Methods</strong></td>
</tr>
<tr>
<td>a. Rate Control (maximum sand free rate)</td>
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<tr>
<td>b. Reservoir pressure maintenance (maximum drawdown)</td>
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<tr>
<td>c. Formation Stabilization</td>
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<tr>
<td>d. Selective Perforation/ Oriented Perforation/ Overbalanced perforation.</td>
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<tr>
<td>e. Sand Monitoring</td>
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<tr>
<td>f. Surface handling and removal of sand (Surface Facilities)</td>
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<tr>
<td>g. Sand Disposal</td>
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<tr>
<td>h. Remedial Sand Control</td>
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<tr>
<td>i. Do-nothing Approach</td>
</tr>
<tr>
<td><strong>Sand Exclusion Techniques (Downhole Sand Control)</strong></td>
</tr>
<tr>
<td>a. Gravel Pack</td>
</tr>
<tr>
<td>d. Screen Alone</td>
</tr>
<tr>
<td>e. Frac Pack</td>
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<tr>
<td>d. Water-packs</td>
</tr>
</tbody>
</table>

Table 5.1 Sand Control Methods for Sand Management and Sand Exclusion Techniques.
5.2.1 Sand Exclusion methods

Most of the unconsolidated formations tend to produce sand from the beginning of hydrocarbon production. Sand management techniques may not prove economical in these unconsolidated formations, as it would be hard to manage the amount of sand produced. In addition, remedial installations of conventional sand control would cost a lot more than the initial investment. Thus it is recommended to use sand exclusion methods such as gravel pack, frac ‘n’ pack, screens etc. for these wells as insurance to sand production damage. The selection of a particular method depends upon the merits of the method, wellbore and completion design, reservoir properties and overall economics of the project. The conventional sand control is a complete sand prevention technology. Gravel packs are supposed to be the most reliable means of controlling sand. However, the major disadvantage of using these methods is the lower productivity of well. For details about the sand exclusion methods, refer chapter 3 and 4.

5.2.2 Sand Management

Sand management is the successful co-production of a tolerable amount of formation solids with reservoir fluids. By successful co-production, it is anticipated that the solids do minimum or no physical damage to the well. In addition, the surface facilities and productivity of the well is not impaired much to affect the profitability of well. In recent years, industry’s response to sand production has shifted from downhole sand control to sand management techniques. The number of gravel packs is considerably reduced in the last few years. The reason is believed to be high initial investment and the tendency of the sand exclusion techniques to impair productivity of well. Conversely, sand management optimizes production rates and well productivity such that sand production is managed through monitoring and control of well pressures, fluid flow rates and sand influx. The Canadian Heavy Oil wells remain to-date the most extensive field validation of the reliability and cost effectiveness of sand management.

5.3 Sand Control Strategy

As mentioned in the introduction, sand control strategy depends upon sand prediction philosophy based on formation characteristics and causes of sand production.
The prediction philosophy provides information about onset of sand production, amount of sand production and rate of sand production. The next step is to determine the sand tolerable limits of the hydrocarbon production system, which depends on wellbore design and the design of the production facilities. A risk evaluation of the gathered information at this point gives an insight into the selection of the method of sand control. Some operators would simply base their selection on the field history or prior experience of sand production in the region without using a sand prediction technique. Most of them end up using costly and less productive conventional sand control methods to cover for the risk of slightest doubt of sand production. The operators who invest in initial study of formation and likely cause of sand production would develop field with more prudent approach evaluating both conventional sand control and sand management techniques. Finally, an effective sand control strategy is the one, which sees the well through its production life without major sand production problems and maintaining the best possible productivity.

A methodology is presented to design a simple sand control strategy. The different steps involved in design are as follows:

1. Sand Prediction Philosophy
   a. Formation Characterization (strength and stresses)
   b. Formation Failure Analysis

2. Selection of Sand Control Method
   a. Convention downhole sand control (gravel pack, frac pack, screen etc.)
   b. Sand Management (rate control, pressure maintenance, sand monitoring etc.)

**5.3.1 Sand Prediction Philosophy**

Sand prediction is used to quantify the risk of sand production. Traditionally, sanding models used to derive operating conditions at which sand begins to enter into wellbore. It was perceived that sand production, even in low amounts, is intolerable. However, with the advent of sand management techniques, classical sand prediction
exercise is also broadening. The models are designed to predict the amount of sand production and the rate of sand production along with the onset of sand.

Sand prediction is basically the modeling of formation failure mechanisms based on formation strength and in-situ stress data. The type of formation (consolidated, friable or unconsolidated) governs the failure mechanism. The various prediction models used by industry for sand control are discussed in Chapter 2 of this report.

Sand prediction models, simple or complex, require some kind of formation data. The formation data can be obtained from field measurements (log data, offset field data), laboratory measurements (core samples) and core-log correlations. Formation strength can be obtained from direct core strength measurements and core-log correlations. Core strength measurements involve unconfined compressive strength (UCS) testing and triaxial testing. The three principal stresses, vertical stress, minimum horizontal stress and maximum horizontal stresses also need to be determined. The vertical stress is generally approximated by assuming a gradient of 1 psi/ft. Minimum horizontal stresses are evaluated from mini-frac tests and drilling data. The maximum horizontal stress can be estimated from regional geological studies and field drilling data. Based on gathered data, formation failure analysis is done to model failure mechanism. Formation failure analysis can be comprised of laboratory testing, numerical modeling, field data analysis or a combination. The model results are validated by history matching the model results to the field data.

5.3.2 Selection of a Sand Control Method
The selection of a sand control method is based on results of sand prediction model, field history, wellbore and completion design, reservoir properties, design of surface facilities and economics of the project.

5.3.2.1 Sand Prediction Model
The sand prediction models tell the onset of sand production, amount of sand production and rate of sand production. If the well starts making sand very early in its life, it is recommended to use the downhole sand exclusion techniques. It is not
economical to sustain sand production for that longer period of time through sand management techniques. In addition, amount of sand produced will be enormous and thus difficult to dispose, especially in offshore environments. Conversely, if models predict a moderate amount of sand production and that too in the later life of well, sand management techniques prove to be more economical and successful.

5.3.2.2 Field History

In the absence of prediction models, most important information is obtained from offset wells and nearby field histories. This might not be as effective as a prediction model but can give a lot of insight into formation characteristics and sand production history. If the field has a considerable history of sand production, it is worthwhile to consider using sand control in new wells. Selection of method should be based on degree of sand production. If the sand production is low and can be tolerated by adjusting some operating conditions, sand management techniques should be used. For severe sand production, gravel pack is the best. In addition, the type of formation can lead to the selection of a sand control method.

Morita et al [15] discusses typical sand producing formations. The information presented is an excellent starting point for all sand control strategy development studies.

A major portion of sand production problems are seen in fields that have, (a) unconsolidated formations, (b) high water breakthrough for weak to intermediate strength formations, (c) pressure depletion in consolidated formations, (d) abnormally high lateral tectonic force in young formations, and (e) sudden changes in the flow rate or high flow rate.

Unconsolidated or weak formations are the major source of sand production problems. Sand production is mainly due to shear failure of formation. Unconsolidated formations are the best candidates for sand exclusion treatments, as the sand production starts very early in the life of well or after the first shutdown.

Water breakthrough in an intermediate strength rock, 500-1000 psi unconfined compressive strength, can cause sand production in some fields. The primary cause for
this sand production is the loss in capillary pressure holding sand particles together. To capture this kind of failure, compressive strength tests should be performed at various water saturations. Han et al [27] presented a theoretical model for strength reduction associated with increase in water saturation. Ghalambor et al [14] described methodology to predict sand production in gas wells producing free water. The knowledge of when water breakthrough occurs helps in deciding the methodology to control sand. This type of prediction can only be made by combining reservoir model with a wellbore flow model as described by Augustine et al [28].

Reservoir pressure depletion can lead to sand production in the consolidated formations. However, the sand production rate is very low as compared to unconsolidated formations and normally follows a rapid decline. The cause for sand production is high in-situ effective stress due to depletion as shown in Figure 5.1. However, this late influx of sand leads to a complex situation in terms of applying sand control, as the conventional downhole sand control methods are largely inapplicable due to existing completion types or cost. Remedial sand control installations tend to be more expensive and less productive. Cost effective sand containment methodology in such cases more or less rests on the reservoir management policies or low cost sand control treatments, effective for a shorter duration of production. Reservoir management refers to control of sand production through installation of appropriate sand control in wells where conditions allow, and improving drawdown and depletion control practices. These decisions will be based on an accurate assessment of potential sanding zones and implications of choosing to limit or defer production from these zones, balanced against the need to maintain adequate production and keep production costs down.

High lateral tectonic force in younger formations is a major contributor to sand production problems. Small earth movements induce highly directional in-situ stresses in formation causing borehole breakout, which may result in sand problems if formation has small degree of cementation. Sand production due to sudden changes in flow rate or high flow rate can be minimized or stopped by lowering the flow rate in steps.
5.3.2.3 Wellbore and Completion Design

The casing size, hole deviation and completion types (open-hole, cased-hole, tubingless) can determine the selection of a sand control method. The conventional casing size of 41/2 in. or larger is good for success of sand exclusion methods. Hole deviation as such may cause some problem for sand exclusion methods. Screens used downhole tend to erode more quickly in a deviated hole. In gravel packs, it is difficult to completely fill the spacing between casing and screen with gravel. Open-hole completions provide more productivity but less life of gravel pack as compared to cased-hole completions. Sand management techniques are not much influenced by wellbore and completion design. However, erosion of casing can happen if not designed properly.
5.3.2.4 Reservoir Properties

Sand interval length, sand quality, reservoir temperature and reservoir pressure are some factors that can influence the selection of a sand control method. For larger sand interval lengths, gravel pack is recommended. Sand quality refers to grain size and mineral impurities present in sand. A narrow grain size distribution means a more effective gravel pack. Temperature and pressure does not influence the selection much except in cases of extremely high temperatures and abnormal pressures.

5.3.2.5 Surface Facilities

Factors influencing the selection of a sand control method are the sand monitoring system, resistance to erosion and sand disposal. For sand management techniques, it is extremely important that surface facilities should be designed keeping in mind a tolerable amount of sand production. Material used should be erosion resistant to an extent and sand-monitoring devices should be installed to keep a check on sand production. There should be an environment friendly means of sand disposal. It is easy to dispose the produced sand on onshore facilities. Offshore, it has to be stored on platform and then shipped to land for disposal.

5.3.2.6 Economics

Economic evaluation of a sand control method should be done by considering the initial cost of the method, productivity losses, maintenance costs and remedial costs. The conventional sand control methods have high initial costs and low productivities. However, maintenance and remedial costs are minimum. In case of sand management techniques, initial cost is low and productivity is high. The real threat is maintenance and remedial costs. If the applied sand management technique is unsuccessful, the remedial cost of sand control is very high and can completely jeopardize the profitability of project.
5.3.2.7 Remedial Sand Control

Sand control installations tend to be more successful when installed before significant sand production has occurred. Sand control methods installed within the same wellbore after the well has begun producing sand are considered remedial installations. Remedial gravel pack installations also are known to impair productivity substantially in wells, which have had significant sand production. Post installation production rates are typically much lower. This probably occurs as a result of the injected gravel pack slurry disturbing formation cavities and mixing with formation fines and clays during the placement process.

In wells where sand failure is expected to occur early in the life of the zone, it probably is better to install sand control at initial completion as insurance against these problems, and this is common practice. Conversely, some consolidated formations may be produced indefinitely without sand control. In other cases, sand production problems may not begin until after substantial pressure depletion or after a change in produced fluids such as the start of water production or changes in GOR. In these cases, delaying the installation of sand control until it is needed may be desirable, for several reasons. It may be possible to deplete the well without sand control, making an initial installation a wasted expenditure. If sand failure occurs late in the productive life, restricting production rates may control sand production. Rates will probably be lower anyway due to reservoir pressure depletion. On the other hand, if sand production is brought on by water production or an increasing gas-oil ratio (GOR), production rates may have to be restricted to minimize water influx or gas coning.

5.4 Conclusion

The sand control strategy is unique for every field and is dependent upon numerous factors. However, through complete understanding of the formation by extensive data collection and testing, development of prediction tools, evaluation of risks involved and comparison of different sand control methods, a successful sand control strategy can be designed to control or manage sand production.
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Vita

Navjeet Benipal was born in Chandigarh, India on August 16, 1978, the son of Sohan Singh Benipal and Sukhwinder Kaur Benipal. After completing his work at DAV College, Chandigarh, in 1997, he entered Punjab Technical University in Punjab, India. He received the degree of Bachelor of Technology in chemical engineering from Punjab Technical University in 2001. In January 2002, he entered the Graduate School at The University of Texas at Austin.

Permanent address: 15200 Park Row Apt 623, Houston, Texas 77084.

This report was typed by the author.