Con-slot® Formation Link ®
Wire Wrapped Screens without Base-Pipe
For vertical, deviated and horizontal Oil and Gas Wells.

Introduction

A key factor affecting the profitability of oil and gas production from unconsolidated sand reservoirs is the ability to achieve effective sand control completion in production (and injection) wells.
Effective sand control reduces liner failure, simplifies individual well operating problems and protects expensive pumping equipment, not to speak of the greater efficiency of the well thus reaching the 'break-even-point' at an earlier stage.
A survey of professional literature and current completion practices indicate a gravel pack completion (separately packed or pre-packed) as the only method currently available for sand control in unconsolidated reservoir formations.
At the same time one can hear of more and more performance failures of such completions without any prejudice against the cause of these failures.

In order to achieve effective sand control it is of no advantage to cover the well periphery with flow restrictions like:

- Cemented casing and perforating
- Fracking jobs
- Gravel packing the annulus between casing and screen
- Base pipe screens or
- Protected base pipe screens
- Or the combination of the above

This can lead to:

- Flow restriction
- Increase in fluid velocities
- Decrease of fluid handling
- Creating uncontrollable turbulence
- Selective sand production
- Plugging
- Erosion
- Scaling
- Corrosion
- Early coning in and OWC

Background

- Deep-sea well completion costs are very high.
- High permeable formations / reservoirs require sand control initially to retard water break through to the latest possible stage, but still allow proper exploitation.
- Initial cost of a gravel pack from a Semi-Sub is approx. US$ 3.000.000 per well. If a gravel pack is required after a water break through the cost is approx. US$ 10.000.000 per well.
- The success of gravel pack in high permeable high producing reservoirs is poor and the experienced lifetime of a gravel pack is less than 4 years.
- Replacement cost of a gravel pack is estimated at approx. US$ 11.500.00 per well.
- Reduction of CAPEX and OPEX cost are essential to make a well field profitable.
- Optimisation of uninterrupted production and avoidance of Semi-Sub intervention was highlighted as a significant cost factor.
- The background for this investigation and development was the uprising exploitation of the North Sea Well Fields.
- The open hole installation was prioritised.

Investigations

Testing of Formation Link ® Screens:

- Strength based upon environmental and physical completion requirements.
- Quality requirements based upon SQUAIR specs.
- Installation, flow and sand control behaviour with different formation sands.

Results

- Starting in 1993, investigation into alternative sand control systems and to develop the Formation Link ® Screens without Base-Pipe design.
- Set out basic design parameter for the Formation Link ® Screens.
- Open hole completion with natural gravel pack development is a practicable and recommended installation and completion method.

Benefits

- Significant reduction of drilling cost and Rig Time.
- Reduction of over all completion cost.
- Production can start earlier than planed with conventional completion methods.
- Increase of productivity of a well.

History

The history of these conservative 'sand retention' media's has not evolved, here are two reasons why:

- The industry has failed to provide a reliable wire wrapped screen.
- As far as definition of capacity combined with strength is concerned, the development of the 'sand retention' media offered to the resources industry has always been a 'curing' of the disease, never a progressive 'prophylaxis'!

One has to look at effective sand control from multiple points of view:

- Grain distribution of the reservoir and its permeability,
- Viscosity of the oil/gas to be produced.
- Temperature of the reservoir.
- Reservoir pressure for a self-producer or a pumped well.
- Type of pump.
- Open hole or inside casing completion.
- Accurate slot design of the sand controlling Formation Link ® Screens.
- Permeability of the Formation Link ® Screens in relation to the permeability of the reservoir.

Many times it has been proven, and it is common engineering knowledge that:

> The simplest solution is the best ! <

Instead of looking for that, the resourcing industry had to adapt step after step against hydraulic laws : the pre-bond gravel pack screen was born and not enough with that, a double pre-bond gravel pack screen was born and in order to protect this delicate construction, a protective perforated pipe has been slipped over the outside, thus contributing besides the base pipe once more to flow restrictions !
Of course it was necessary to handle this 'delicate system' very careful on site.

Flow characteristics of Formation Link ® Screens

Testing a Formation Link ® Screen structure at the Hydraulic Lab of the TU of Munich, FRG, and at RF Rogaland Research, Stavanger, Norway, one was able to determine the requirements for excellent flow parameters and performance of a Formation Link ® Screen.

The most important design parameters include:

- A sharp cornered shape slot was contributing to the bridging effect of grain sizes across the slot opening thus keeping the slot open and preventing blinding. The flow pattern is excellent. There is always a surplus of permeability and inflow capacity, than inflow restriction.
- Development of a natural gravel pack from the formation sands creates a link to the formation near screen inflow region.
- The physical screen dimension in relation to the flow capacity can be designed to the application requirements.

Development of these procedures and formulas allows us to determine:

- The slot size, based on careful coring and sieve analysis.
- The permeability of the screen.
- The screen capacity.
- The pressure losses (skin effect)

Physical strength of a Formation Link ® Screen

The next demand was to design the screen structure physically strong enough that it could be handled similar to other completion equipment: casing and tubing.

- Development of a welding process that allows a full fusion-weld between the structural members of the wire wrapped screen on rod base structure and to obtain nearly pipe rigidity to make a standard WWS become a Formation Link ® Screen.
- Providing a shoulder tight threading and coupling, power tight make up of the completion string.
- Proven by several installations and tests :
  Formation Link ® Screens can be handled similar to a pipe, without any specific precautions or running procedures !
- A Formation Link ® Screen can be pushed into the boreholes without any exterior protection.
- A Formation Link ® Screen can be rotated, pulled and pushed !
- A Formation Link ® Screen is inside and outside flush.
  Also at the threaded connections.
  Therefore it is an excellent combination tool for MONOBORE completion.

Structural properties of a Formation Link ® Screen

One can provide pipe based screens and pre-packed screens, to comply with the requirements of the customers. But based on experience and research the Formation Link ® Screen is the only solution according to the actual state of research !

Many different types of screens have all been developed for the same purpose,

'Sand retention' in unconsolidated reservoirs, holding ALL the sand back with the above mentioned disadvantages :

- Wire Wrapped Screen with Pipe Base.
- Wire Wrapped Screen combined with Pipe Base and with Pre-bond Gravel Pack.
- Multi Layer Mesh Screen on Pipe Base.
- Multi Layer Mesh combined with Porous Sinter Screen on Pipe Base.

The Formation Link ® Screen has been developed for one purpose:

'Sand control' in high permeable formations!

- Controlled production of fines.
- Development of Natural Gravel Pack.
- Increased permeability of the formation.
- To provide a link to the formation throughout the lifetime of the well.

A Formation Link ® Screen consists of a V-shaped profile wire wrapped around a number of longitudinal support rods and simultaneously welded to the rods at each crossing point.
The slot left between the wrapping is continuous.

The slot size is designed in order to develop a natural gravel pack from the formation material.

The performance of the screen depends entirely on the slot design such as:

- Corner radii.
- Relief angle.
- Slot width.
- Relation of slot width to width of the wire.

The Formation Link ® Screen is an ideal combination of high efficiency due to its large permeability combined with its structural strength.

Material selection of a Formation Link ® Screen

Careful selection of the material is paramount, whether high alloys are needed for strong corrosive environments, or standard alloys are sufficient. However, not only the base material is of importance, as well careful craftsmanship and handling according to the state of technology.
Welding should be gas-shielded.
Full fusion weld at each crossing is mandatory not only to guarantee the strength required but also to avoid crack corrosion.
Relevant hardness and the selection of correct base material and filler material for all welds are the best warrants against stress corrosion.
Hardness requirements according to relevant standards shall be considered.
After weld treatment is mandatory to assure high corrosion resistance of a surface-stressed material.

To install a combination of 'black/white' material induces electrolytic corrosion.
The most negative side effect of electrolytic corrosion is a depositing of the corroded carbon steel material in the slots of the screen.
This depositing phenomenon develops increasingly with higher and turbulent inflow velocity.
Consequently a decrease in production is a question of time.
Expensive work over can be avoided if the installation material selected properly!

Therefore each screen member should be of the same material.

Hydraulic properties Formation Link ® Screen

The transmissibility of a reservoir indicates the possible yield from the reservoir to the well.

We are able to determined the transmissibility of the screen structure as well as the capacity of a Formation Link ® Screen by means of a flow calculation, based on the results of earlier research.

This enables con-slot SCREENS International to design a Formation Link ® Screen in view of:

- Optimising the slot size.
- Optimum diameter of completion.
- Required length of completion.
- Staggered or Non-Staggered completion.
- Expected productivity.
  Expected flow conditions and pressure loss

The questionnaire (ENCLOSURE Q) can be used to maintain detailed information and to enable a proposal.

An optimal designed slot opening will allow the 'bridging' or 'key stone' effect of the formation material across the slot, allowing free flow into the screen.
Simultaneously the 'bridging' is the basis for developing the 'Natural Gravel Pack', which will retain finer formation material and allow sand free production through all lifetime of the well.

Slot selection criteria for Formation Link ® Screen

The conscientious selection of the slot size is the most important capital for a successful completion using a Formation Link ® Screen, subsequently enabling the combination of high productivity with a low-pressure loss and sand free production. Many different approaches to slot design can be found in the relevant international literature, but all have one thing in common:
They all differentiate between slot design for uniform and for non-uniform unconsolidated formations.

A Formation Link ® Screen retains the same formation material like a gravel pack, yet having more permeability, with a slot designed for the 'bridging effect' to the formation.
This qualification is of major importance for well completions, where gravel packs are still difficult and expensive to install.

Con-slot SCREENS International is using different criteria for setting the above mentioned parameters, and is furthermore considering the Uniformity Coefficient 'C' of the reservoir.

Con-slot SCREENS International criteria has been confirmed by practical application.

- Con-slot is using 80% retained grain size of the sieve analysis for uniform formation –
- (C < 2.50).
- Con-slot is using 30% retained grain size of the sieve analysis for non uniform formation –
- (C > 3.00)

However, there are applications where a gravel pack is required, such as:

- Inside-casing completion where a Formation Link ® Screen has to be protected against the 'sandblasting' effect through the casing perforations.
- Under reamed open boreholes where the periphery is too far away and the formation needs support for stabilization.

A gravel pack, whether packed separately or pre-bonded to the screen, is an artificial tool preventing direct link between the main 'sand control' element, the Formation Link ® Screen, and the formation.

Therefore it should only be considered as a last resort.

Con-slot SCREENS International differentiates between:

- Gravel pack completion.
  - artificially poured.
  - pre bonded.
  - under reamed open hole.
- Open hole completion.
- Inside Casing completion.

Gravel pack completion of a Formation Link ® Screen

The function of a gravel pack is to prevent the formation from entering the pack, yet being permeable enough to allow the fines of the formation to pass through and enter the screen and to allow flow from the formation into the screen. Bridging of the formation against the gravel pack is the key of sand control.

Table 1 to 2 shows these parameters set forth by SCHWARTZ and by Jürgens Consulting.

Experience has proven that Schwartz' parameters are very conservative, leading to fines to immigrate into the gravel pack. Reduced permeability, reduction of productivity, higher skin effect and coning-in are the results.

(1) Critical Formation Grain Size :

- SCHWARTZ is using 10% retained grain size of the sieve analysis for uniform formation –
- (C < 2.5).
- SCHWARTZ is using 40% retained grain size of the sieve analysis for uniform formation –
- (C > 3.0).

(2) Gravel-to-Sand Ratio 'G-S' :
The G-S is the multiplier of the Critical Formation Grain Size to find the Critical Gravel Grain Size through which the grain distribution of the gravel pack has to be designed by trial and error. It is recommended to use the more common standard gravel packs available on the market (see TABLE 7)

- SCHWARTZ is using a G-S of 6 for both uniform and non-uniform formation.
- Jürgens Consulting is using a G-S of 8 for uniform and 10 for non-uniform formation.

(3) Uniformity Coefficient C :
The Uniformity Coefficient is $C= D_{40}/D_{90}$ is received by dividing 40 % retained grain size of the formation by 90 % retained :
UNIFORM formation with C <= 2.50.
NON-UNIFORM formation with C => 3.00

One can detect the uniformity of a grain analysis by the steepness of the curve, the steeper a grain analysis curve, the more uniform the formation material!

Once the gravel pack has been established through the critical grain size, the slot size for the screen is determined as follows:
for sharp cornered profiles = D_{90}
for round cornered profiles = D_{50}

A profile with a large corner radius is to be considered round cornered. A bridging effect across the slot to avoid blinding can only be achieved by reducing the slot size to D_{50} of the gravel pack.

Such reduced slot size will allow accumulation of fines in the gravel pack at the screen 'SKIN' thus reducing the permeability and productivity and increasing the skin effect !

Inside Casing completion of a Formation Link ® Screen

The screen-liner must be installed with a gravel pack protection opposite to the perforations. Otherwise fine sand produced from the formation through the perforated holes would damage very quickly the Formation Link ® Screen due to a sandblasting effect.

There are many alternatives that have been tested to control the fine sand flow from the formation behind the tubing/casing, like fracing and squeezing the gravel into the void area behind the tubing/casing. However, all these procedures have shown little success in comparison to the cost involved.

To design a gravel pack to retain 100 % of the formation material has always shown an increasing skin effect within the time of production - a clear indication of fines concentrating from the formation at the outer periphery of the gravel pack. Reduced productivity and early coning-in of water/gas is a consequence.

Considering costly work-over, this solution is always a cure and not a prophylaxis.

The gravel pack should be designed to allow 10-15 % of the fines to pass through and to enter the screen being then produced to the surface.

By producing the fines from the formation its permeability will be increased, gravity flow will be reduced, and the possibility that the flow of fines will cease after a certain period of production is ascertained.

The G-S-Ratio for such a gravel pack should not be less than 8 and increased to 10 depending on the uniformity of the reservoir formation.

Open Hole completion of a Formation Link ® Screen

It is easily demonstrated in theory and in practice to the OIL/GAS industry that non-gravel, open hole completion has more than just technical advantages, there are also economical advantages!

The following explanations are concentrated on non-gravel installations, we promote this technique with priority.

Slim borehole drilling and development of drilling fluids allow installation of a Formation Link ® Screen with a diameter very close to the diameter of the borehole.

- The formation can collapse and surround directly to the screen surface, close contact to the formation is the result.
- Preventing cross-flow of different zones due to the collapsing with production start-up.
- Developing the screen surrounding formation by choking.
- The slot design, depending to the formation allows the production of fines.
- Natural gravel pack, sand free production with reduced skin effect and higher productivity.
- No base pipe and pre-pack is restricting the direct link to the formation and to the periphery of the borehole.
- High return of permeability by easier controllable clean out of the drilling fluids and mud cake.
- Uniform performance throughout the lifetime of the well resulting in minimum work-over costs.

Well completion cost comparison
Conventional vs Formation Link ® Screen with natural gravel pack

Equipment and Performances	Conventional	Formation Link®	Difference
Tools	$ 100.000,00	$ 100.000,00	./.
Pipes	$ 100.000,00	$ 50.000,00	$ 50.000,00
Logging	$ 80.000,00	$ 60.000,00	$ 20.000,00
Cementing	$ 50.000,00	./.	$ 50.000,00
Perforating	$ 250.000,00	./.	$ 250.000,00
Fluids	$ 400.000,00	$ 150.000,00	$ 250.000,00
Manpower	$ 80.000,00	$ 40.000,00	$ 40.000,00
Pumping	$ 500.000,00	./.	$ 500.000,00
Rig Time 18 days	$ 1.800.000,00	./.	$ 1.800.000,00
Lost Production 18 days	$ 3.600.000,00	./.	$ 3.600.000,00
		Total savings	$ 6.560.000,00

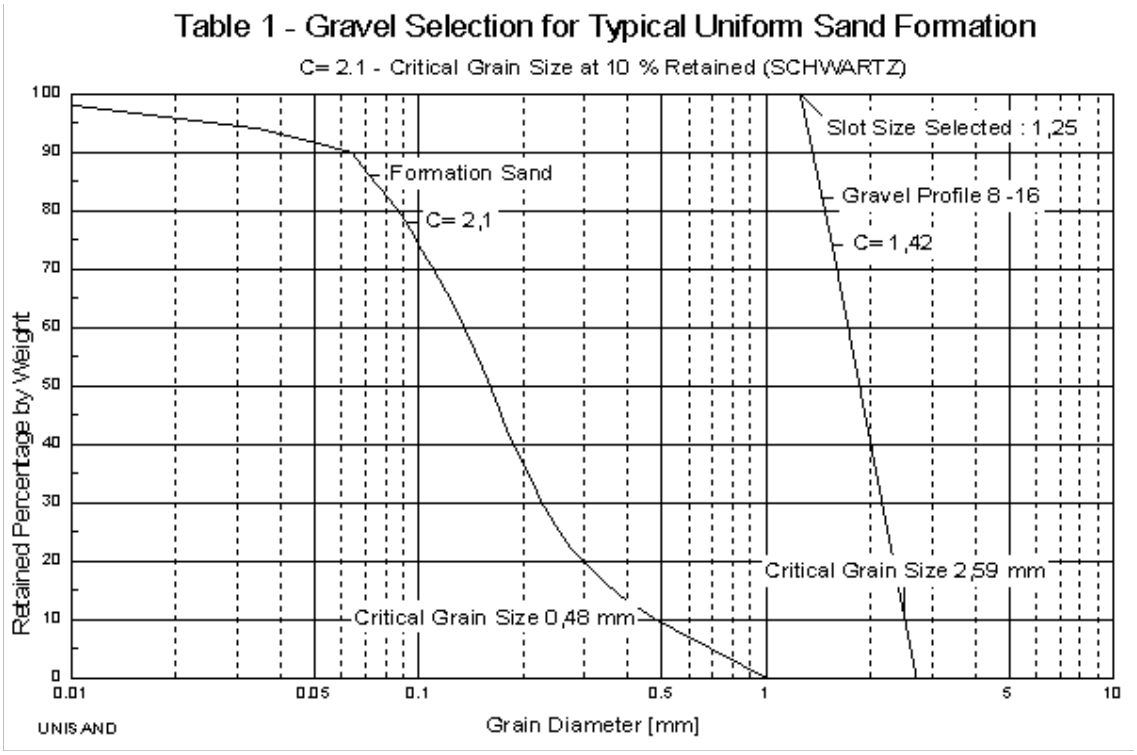


Table 2 - Gravel Selection for Typical Nonuniform Sand Formation

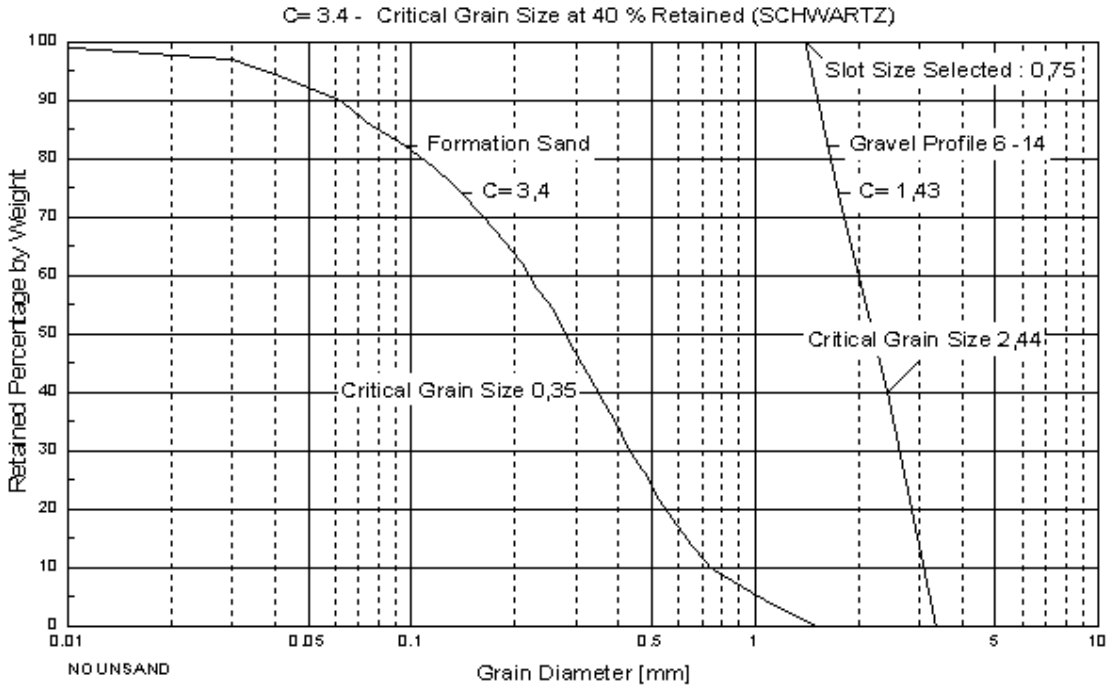


Table 3 - Slot size determination for NATURAL Gravel Pack

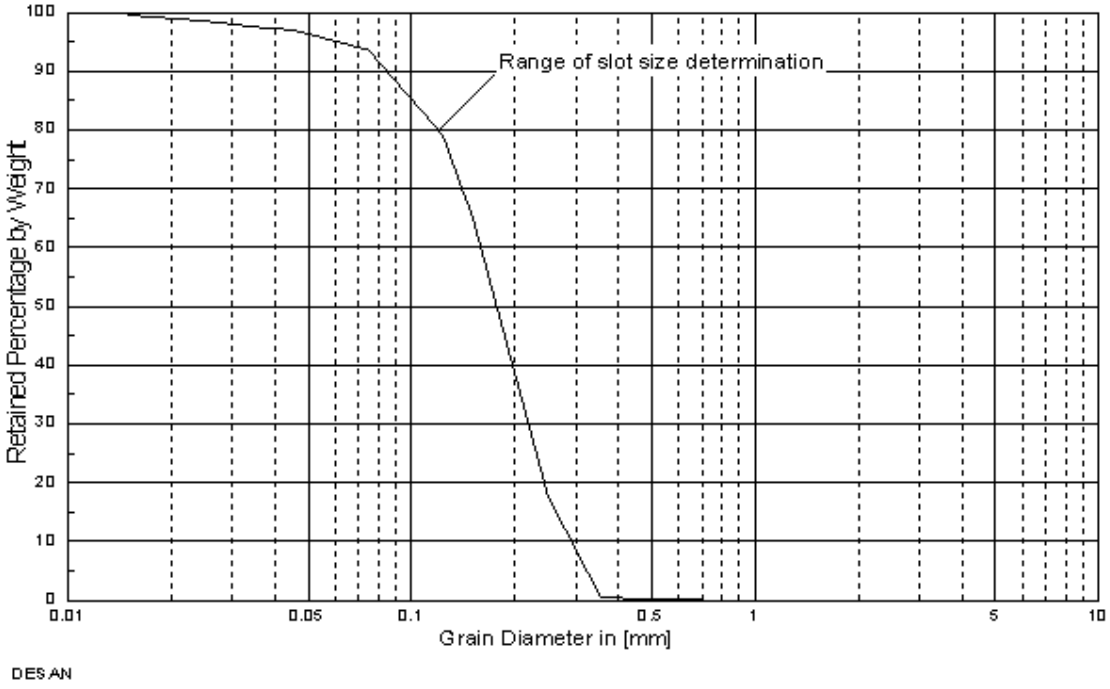
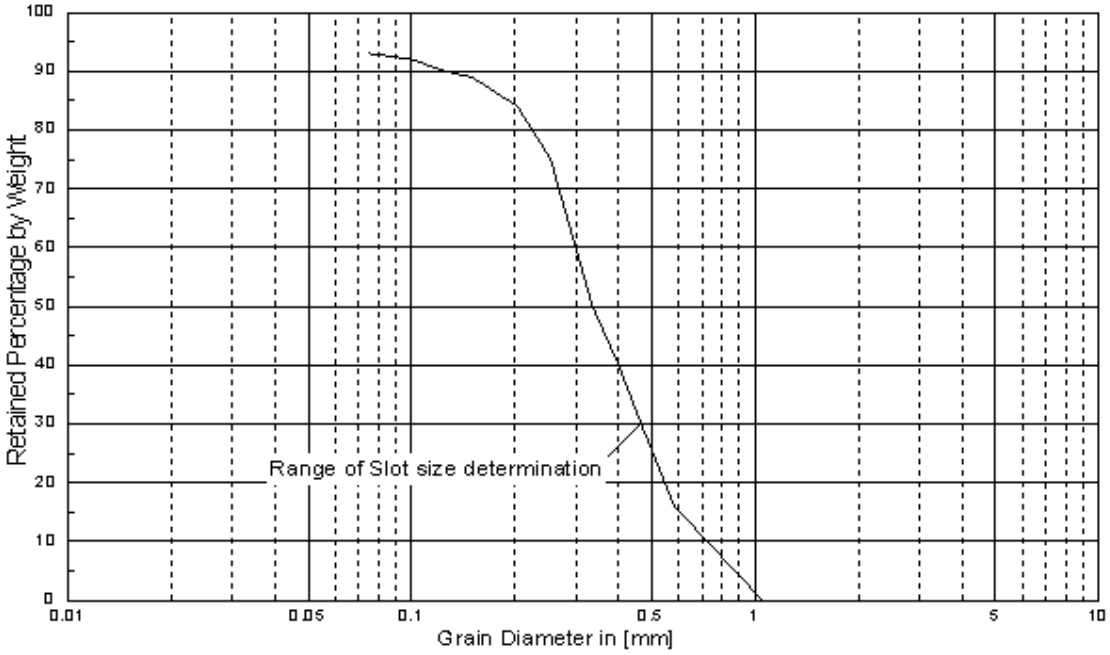
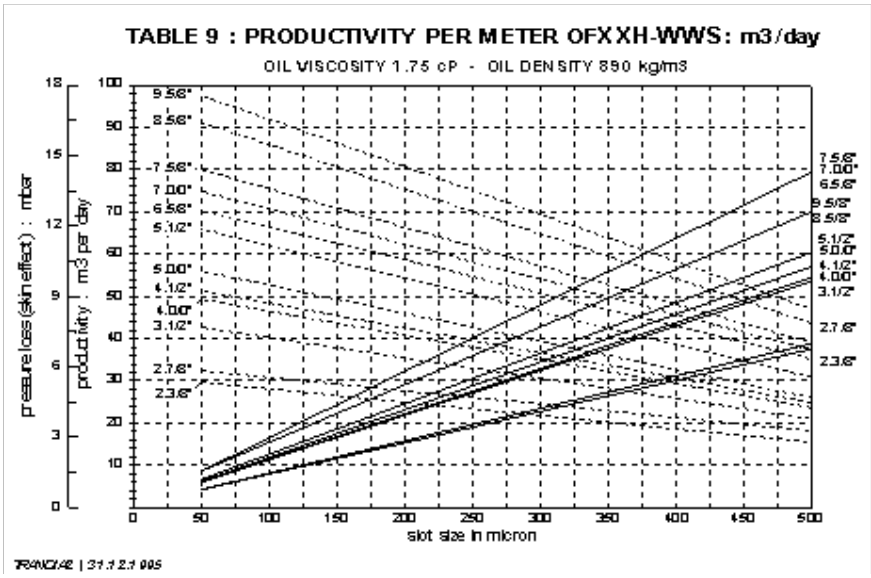


Table 4 - Slot size determination for NATURAL Gravel Pack

Typ. Northsea Formation, C > 3 - Critical Grain Size at 30 % Retained



DESAN1



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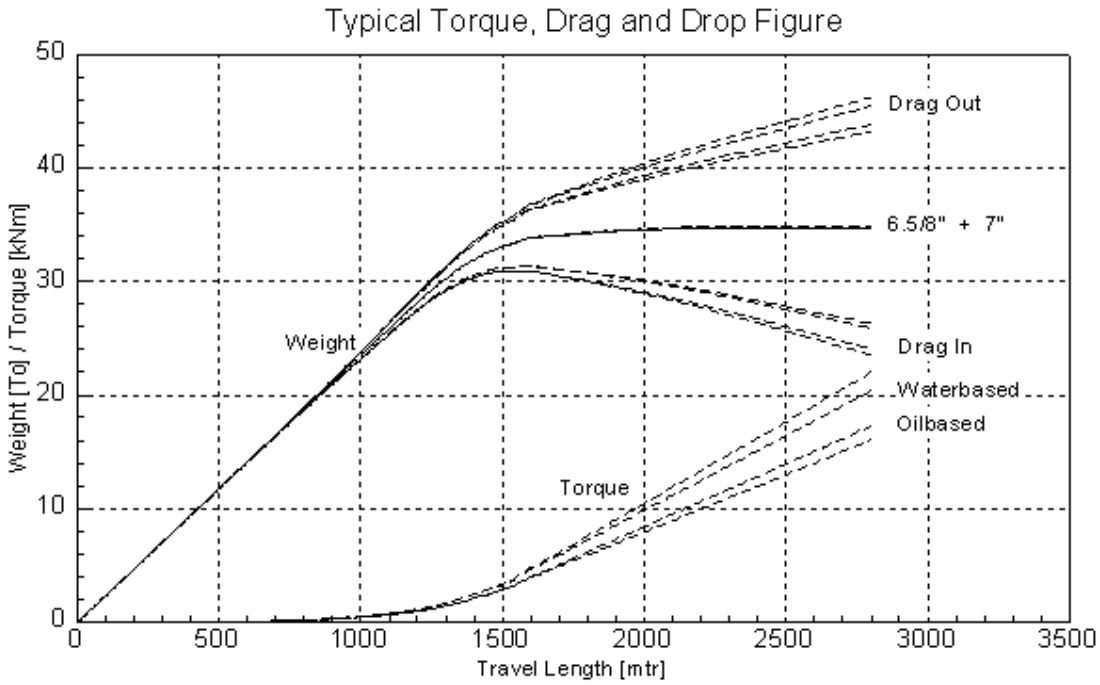
Typical Torque, Drag and Drop Figure
Weight [To] / Torque [kNm]
Travel Length [mtr]
0
10
20
30
40
50
0
500
1000
1500
2000
2500
3000
3500
Drag Out
6.5/8" + 7"
Drag In
Waterbased
Oilbased
Weight
Torque