Chapter 2
Formation Sampling and Sand Analysis

Contents

Abstract The starting point for any kind of sand control with respect to geomechanical approach is proper sampling and sand screen analysis. Use of bailed or produced sand samples leads to mistakes and problems and is the poorest kind of data that can be used in designing sand control. The representative samples are obtained by coring the whole length of the interval with adequate coring equipment. Particle size distribution is then determined through sieve and laser particle size (LPS) analysis.

LPS is used to determine the amount of fine particles that exist due the swelling and migration of bonding clays, or due the crushing during production.

Such analysis is the basis for proper design of liner openings, screens or gravel pack sizing.

When analyzing gravel-pack effectiveness it can be stated that most of such completions are only partially effective. One of the factors that mostly contribute is the use of improper gravel size. The analysis should be done on the representative samples from the reservoir. Due the changes in porosity and permeability (heterogeneity) of the formation it is possible that core samples will vary a lot within the interval. The best samples of formation rocks are obtained by continuous coring with adequate equipment and proper control according to core measuring and spacing.

Because of an expense that is not likely in all situations, so only the interesting parts of the reservoir would be cored continuously. The work that has showed the best the problem of representative formation sampling (Maly and Krueger 1971) states that there is no simple, clear answer to the best sampling procedure. It will depend upon possible level of investment, quality of core recovery, desired well production, quality of available screen or gravel etc. Because of formation horizontal and vertical heterogeneity it is not enough to provide random coring in

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non-uniform sands. In such situations even coring of closely spaced intervals does not give good enough information. It is strongly recommended to core the entire interval and analyze samples from regular distances (0.3048 m). Whenever that is not possible high quality gravel of very small size (0.297 mm i.e. 60 mesh) is recommended, but also clean fluids and well designed screens should be used to. When formations are proved to be uniform it is possible to use wider spaced samples (1.5, 3.0 or 6.0 m). Formation sands can be: quick sands (that means completely unconsolidated sands), partially or weakly consolidated sands (with some cementing materials present) and friable sands (with good cement bonding but with potential to be produced). Depending on mentioned consolidation the use of double-tube core barrels or those with rubber sleeve is strongly recommended. Using such equipment will enable to get full volume of formation cored. Such coring equipment is shown in Fig. 2.1.

When such samples are not sufficient or have not been obtained it is possible to use side coring equipment. They are less expensive and can be used even in workover operations. The main disadvantage is in the sample dimensions because they are small. Sometimes several side core samples are combined but that can also mislead and give wrong data for further analysis. Combined samples can be used only to confirm that a sand production exists.

Screen analysis of bailed or produced materials is the poorest kind of data to be used in designing sand control. That is because bailed or produced material will not contain all size ranges of formation material. Due to flow velocity and the carrying capacity of produced fluid, different particle sizes should be separated and settled in the well or somewhere else in the production or separation system. The difference in obtained samples is visible when the so called “log probability” plot is drawn. The benefit of the method is that sampling and testing errors can be detected on the plot because the anomalies are easily visible, as shown in Fig. 2.2.

The representative formation samples are plot as the straight line. Those points that deviate from the straight line could indicate a mistake in sampling, sieve analysis or in data recording. In fact produced samples will have a large amount of fine particles, because the coarser material will remain in the rathole, and the plot will have a rise on the right side and the flatter slope. As the opposite, bailed samples will have coarse particles; the plot will tend to the left side, with a stepper slope.

2.1 Sieve Analysis

Routinely performed core analysis that are done in laboratories, are given in *API Recommended Practices 58* (API 1995). Their results are used to help design the best sand control method. Because the clays and silts are also in many cases combined with sands there is a need for spectrographic analysis to determine the amount and the type of clays or silts within the formation. That is especially important when selecting the servicing or carrying fluid and additives included

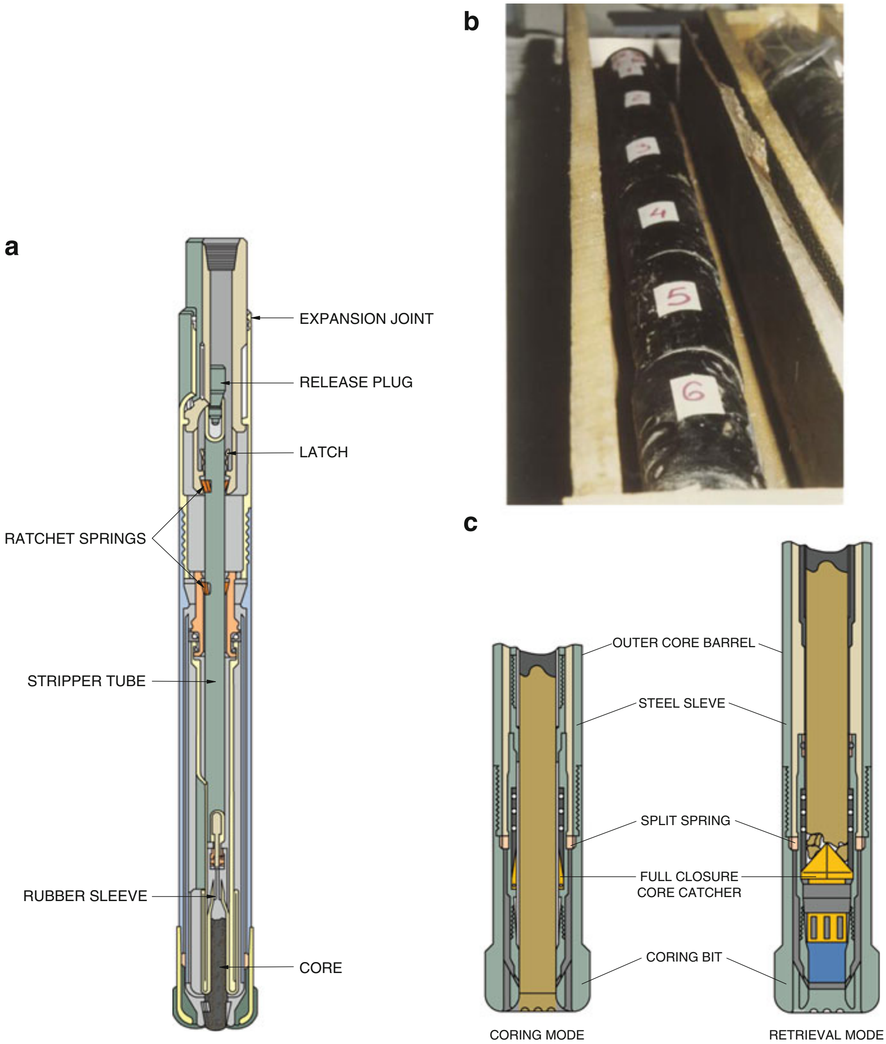

Fig. 2.1 Rubber sleeve core barrel (**a**), rubber or plastic sleeve core sample (**b**), full close core barrel (**c**) (Baker Hughes Inteq 1999)

with the treatment. The main postulate is to remain core intact during storage, transportation and testing. Also the permeability studies are recommended to determine the rock sensitivity to water encroachment (formation or fresh injected water). But the most important part is the determination of the size of particles, because they have to be contained with applied treatment method.

Being the most common cementing (binding) material in young deltaic formations clays and silts have considerable role in the efficiency of selected sand control method. With more than 15% clay or silt content, there are always problems in sand

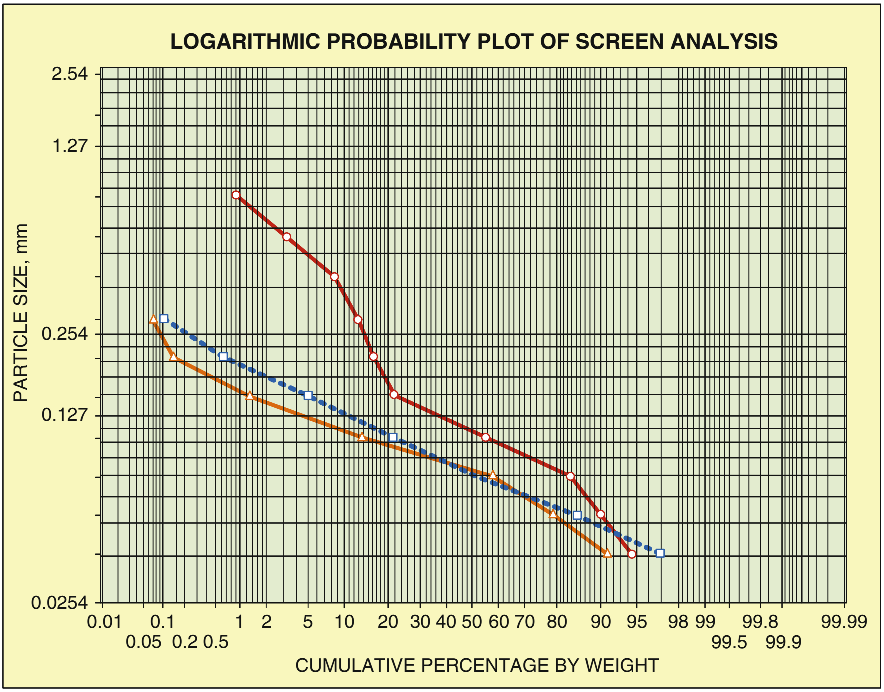

Fig. 2.2 Logarithmic probability plot of screen analysis (Dowel-Schlumberger 1979)

control application. The main problem is in selection of compatible completion and treatment fluid. Also due the small particle sizes, the controlling element (screen or liner slots, gravel size or high-resin-content plastics) impairs in decrease of permeability what leads to decrease in production. The problem with clays can be due the swelling or migration. Montmorillonite can swell six to ten times its original volume when in contact with fresh water (or the completion fluid with a considerably lower salinity of the fluid in formation). Because of that the use of brines is recommended to stabilize clays. Also oil-based servicing fluids can be used because in water-wet formation they will not cause clay migration. Kaolinite and ilite will disperse and fill or bridge the pore throat. This mechanical instability is present when wetting phase is mobile and its velocity exceeds the critical velocity that will cause particle movement. Dispersion test is simple method for determination of type and amount of clays and silts in sample. The sample is mixed with water and dispersant, and than left to stand for 1 h. The sand and silt particles will settle and the clay particles will be suspended in water. The clay content is than determined by comparing dispersion clarity with known standards. Other possible methods are: the hydrometer analysis method, solubility determination, spectrographic examination and use of scanning electron microscope (SEM) as well.

Reliable method to separate clays and silts from sand grains is the wet analysis. Through the procedure, a sample of known weight is mixed with water containing dispersant. Using the rubber pestle the sample is disintegrated without crushing the sand grains. All material is than washed through a 44 μm sieve where the silt and clay particles are separated. The dispersion is then dehydrated, weighted and recorded showing the silt and clay content. The rest of material is sieved using conventional sieving method, sieve cuts weighed and plotted. The dispersed silt and clay dried and sieved too. The sieve analysis is done according the data obtained by sieving through the different amount of screens depending on the commercial testing laboratory. It can vary from 15 to 25 different sieve openings. Measures that can or are usually used in screen analysis are shown in Fig. 2.3. Sand, silt and clay size ranges are shown and related to the Tyler standard series and Phi scale.

The *Phi* scale is calculated from the equation:

$$Phi = -\log_2 d \tag{2.1}$$

Where d is the grain diameter in millimeters.

Tyler and U.S. Standard screen numbers and corresponding sieve openings are listed in Table 2.1.

The disaggregated and dry sample is weighted and passed through a series of sieves mounted one over another. Usually with maximal diameter on the top and with minimum diameter of 44 or 38 μm on the bottom are used. The material on each sieve is weighed. To determine certain point on the cumulative grain size the percentage retained on the individual screens, starting with that with the larger openings are added together until the total equals determined percentage

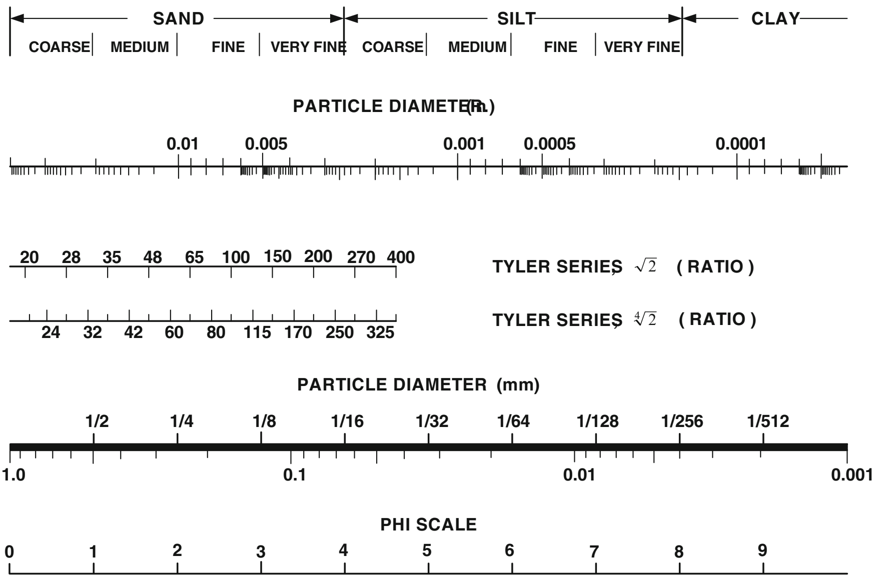

Fig. 2.3 Relation of particle size in millimeters, inches, Phi scale and Tyler standard screen series (Buzarde LE Jr et al. 1982)

Table 2.1 Sand sieve sizes (Buzarde LE Jr et al. 1982)

Mesh		Sieve opening		Mesh		Sieve opening	
U.S. series	Tyler series	(in.)	(mm)	U.S. series	Tyler series	(in.)	(mm)
2 1/2		0.315	8.00		20	0.0328	0.833
	2 1/2	0.312	7.925	25		0.0280	0.71
3		0.265	6.73		24	0.0276	0.701
	3	0.263	6.68	30	28	0.0232	0.589
3 1/2		0.223	5.66	35		0.0197	0.50
	3 1/2	0.221	5.613		32	0.0195	0.495
4		0.187	4.76	40		0.0165	0.42
	4	0.185	4.699		35	0.0164	0.417
5		0.157	4.00	45	42	0.0138	0.351
	5	0.156	3.962	50		0.0117	0.297
6		0.132	3.36		48	0.0116	0.295
	6	0.131	3.327	60		0.0098	0.250
7		0.111	2.83		60	0.0097	0.246
	7	0.110	2.794	70		0.0083	0.210
8		0.0937	2.38		65	0.0082	0.208
	8	0.093	2.362	80		0.0070	0.177
10		0.0787	2.00		80	0.0069	0.175
	9	0.078	1.981	100		0.0059	0.149
12		0.0661	1.68		100	0.0058	0.147
	10	0.065	1.651	120	115	0.0049	0.124
14		0.0555	1.41	140	150	0.0041	0.104
	12	0.055	1.397	170	170	0.0035	0.088
16		0.0469	1.19	200	200	0.0029	0.074
	14	0.046	1.168	230	250	0.0024	0.062
18		0.0394	1.00	270	270	0.0021	0.053
	16	0.0390	0.991	325	325	0.0017	0.044
20		0.0331	0.84	400	400	0.0015	0.037

(10%, 50%, 90%, etc.). The size of the screen opening which would have retained the largest part of the percentage is considered to be that percentage grain size. In practice some kind of interpolation is necessary.

Because fine particles are not defined through sieve analysis, the laser particle size (LPS) analysis (Underdown et al. 1986) is used in combination. LPS analysis is more representative of the fine particles (down to 0.1 μm), requires smaller sample (1 g), it is cheaper and quicker. The method is based on the theory which relates the intensity of light scattered by colloidal particles. By assumptions regarding the adsorption and refractive index of the particles, the particle volume passing the detector is calculated and converted to the diameter through assumption that the particle is a sphere. The problem with fines was long time solved by allowing them to pass the sand control system used. Those are in fact those parts of the rock which can move inside and between pore spaces of the rock. Practically those are all particles smaller than 44 μm. The fact is that that number results from the diameter of the finest screen in practical use. Much more the Ottawa sand (quartz, roundness, sphericity) is the most common gravel in use with grain sizes between 0.838 and 0.432 mm (20/40 mesh), and if loose packing or even tight packing is achieved it is

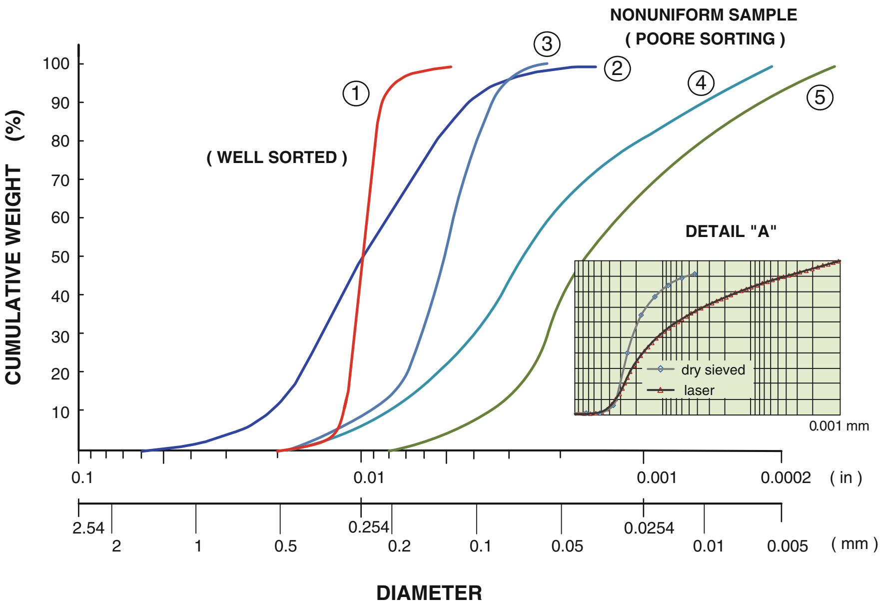

Fig. 2.4 Examples of sieve analysis: (1) uniform sample, (2) non-uniform sample, (3) gas well off-shore; depth 628 m, (4) gas well off-shore; depth 850 m, (5) oil well; depth 875 m, detail “A” difference in curve for dry sieved and laser particle size distribution for the same sample

possible that particles smaller than 38 μm pass the openings between grains, so they can be called mobile fines (Slayter et al. 2008). The problem arising with those mowing fines are: (1) resorting in the annulus and (2) production with potential plugging of the sand control system, plugging of the formation sand pores and erosion of the control system mechanical parts.

Data from the sieve analysis are plotted as the frequency distribution of weight per cent versus size range.

Sand sample (1) in Fig. 2.4 is a uniform well-sorted one with a narrow size range. The other (2) is non-uniform and poorly-sorted sand with a broad size range. Samples (3, 4 and 5) are from oil and gas fields in Croatia as stated in the graph legend.

The difference in the diameter range and curve plot between sieve and LPS analysis for the same sample is shown in detail “A” on the same picture.

The uniformity of the sand can be also determined through representation of weight percent versus particle diameter (Fig. 2.5).

Recently new method of grain size determination was introduced (Chen et al. 2010). The method combines nuclear magnetic resonance (*NMR*) logs and micro-structural rock modeling (*MSRM*). The starting point is again gravel size determination (*GSD*). GSD data is inputted in the MSRM simulation. Additional data needed are than porosity, water saturation and mineralogy information. The result is the relaxation time distribution. Simulation also takes into account different grain

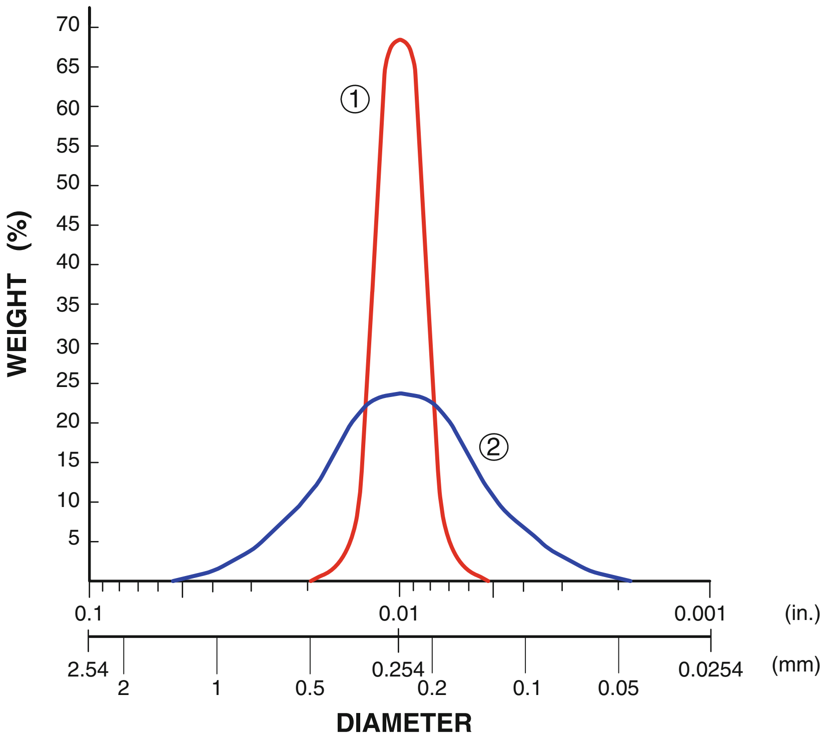

Fig. 2.5 Determination of sand uniformity through representation of weight percent versus particle diameter (1) uniform sample, (2) non-uniform sample (Buzarde LE Jr et al. 1982)

cementations and effect of clays. A surface roughness factor is also defined, because it depends on mineralogy; the amount of quartz, feldspar or clays in the rock. The result is continuous grain size distribution along the well depth realizing the variations of grain size in the formation sands.

Nomenclature

Phi From Eq. 2.1
d Grain diameter, mm

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