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Prediction of sand production in gas and gas condensate wells

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Sand production is a major concern during petroleum exploitation from unconsolidated sandstone reservoirs. For efficient management, sanding predictive tools are necessary. While several models have been developed for sanding in oil reservoirs, gas and gas condensate reservoirs have received little attention because of the widespread belief that such reservoirs are not prone to sanding. This study utilized erosional failure mechanism concept to formulate a model for predicting the volume of sand produced from gas and gas condensate reservoirs. The model showed that sanding in weakly consolidated gas reservoirs is influenced by flow rate, fluid density and viscosity, density of sand, particle size and borehole radius.

Key words: Sand production, mathematical model, gas well, gas-condensate wells, cavity arch radius

INTRODUCTION

Sand production and its impact on well productivity have been mostly associated with heavy oil reservoirs (Geilikman et al., 1994). However, increasing aggressive gas production from conventional reservoirs has led to sand production from gas reservoirs (Weingarten and Perkins, 1992). A necessary condition for sand production is breakdown or disaggregation of rock into pieces small enough to readily pass through perforations or screen openings (Papamichos and Malmanger, 1999). In many cases, breakdown of rock occurs gradually; a process referred to as strength degradation. Following the onset of strength degradation in the field, the reservoir rock needs to undergo further degradation before it breaks down into producible aggregates in response to production conditions (Ghalambor et al., 1989; Salama, 1998). Therefore, for predicting and managing sand production over the life of well, it is important to recognize and quantify the field-scale rock strength degradation and have it implemented into a suitable sand production quantification model (Vaziri et al., 2002). Sand production is also a natural consequence of fluid flow into a wellbore from the reservoir (Penberthy and Shaughnessy, 1992). The process may be divided into the following stages, the loss of mechanical integrity of the rocks surrounding an open hole or perforation (failure), separation of solid particles from the rocks due to hydrodynamic force (post-failure) and transportation of the particles to the surface by reservoir fluids (transport). An essential condition for sand production in weakly consolidated formations is therefore the failure of the rock surrounding the cavity (Tronvoll and Fjaer, 1994; Tronvoll and Halleck, 1994).

There is a large number of sand production prediction

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models used in the industry (Morita et al., 1987a, 1989; Veeken et al., 1991). They range from cut-off criteria based on depth or geophysical parameters (Lantz and Ali, 1991), closed form analytical solutions of either stresses or plastic zone surrounding a borehole or perforation tunnel based on elastic and plasticity (Risnes et al., 1982), to numerical models (Morita et al., 1987b). Between these two extremes, the popular industry approach is the application of closed-form solutions to an open hole or perforation, combining the advantages of the two extreme approaches. Modeling of sand production from gas wells have received little attention, hence this study was derived to develop a geomechanical model for sand production when producing from gas and gas condensate reservoirs.

THEORETICAL FRAMEWORK

Considering a loosely consolidated reservoir, sand production can be easily induced by erosion failure around the near wellbore region. A model can be developed by considering erosion failure mechanism as the primary mechanism causing sand production under some simplifying assumptions:

(1) Darcy's law validly describes the fluid flow.
(2) Cavity is cylindrical and sand production will cause it to grow until equilibrium is attained.
(3) Sand particles are spherical and uniform.
(4) Particles are uniformly submerged in the moving fluid
(5) Fluid is Newtonian
(6) Particles produced from the formation settle down to the bottom.

Using the approach by Isehunwa and Olanrewaju (2010) for vertical oil wells and resolving the forces on a sand particle, we have:

$$R_a = \frac{Q_{gc}\mu_{gc}}{g\pi H\left[\rho_s - \left(x\rho_o + (1+x)\rho_g\right)\right]\frac{4}{9}R_s^2} \quad (1)$$

or

$$V_{sp} = \pi\left(\left(\frac{Q_{gc}^2\mu_{gc}^2}{\left[R_s^4\right]\left[\rho_s - \left(x\rho_o + (1+x)\rho_g\right)\right]^2 \frac{16}{81} g^2\pi^2H^2}\right) - R_w^2\right)H \quad (2)$$

or in general,

$$V_{sp} = k\left(\left(\frac{Q_{gc}^2\mu_{gc}^2}{\left[\rho_s - \left(x\rho_o + (1+x)\rho_g\right)\right]^2 \frac{16}{81} R_s^4 g^2\pi^2H^2}\right) - R_w^2\right)\pi H \quad (3)$$

where

$$x = 1 - \frac{gas\ produced}{gas\ produced + gas\ equivalence\ of\ condensate\ produced} \quad (4)$$

Wet gas density can be expressed as:

$$\rho_c = x\rho_o + (1-x)\rho_g \quad (5)$$

The gas equivalence of condensate produced can be obtained as:

$$\text{Gas equivalence} = \frac{133000}{M_o}\ \text{scf/stb} \quad (6)$$

Molecular weight of oil, M_o was obtained from Isehunwa and Falade (2007):

$$M_o = 92601(API)^{-1.2894} \quad (7)$$

The empirical constant *k* was determined using data from each well.

Application

Equation 4 was applied to 3 gas condensate wells in Field X in the Niger Delta and one gas well from Sawan Field, Pakistan. Production from Field X started in 1957 and peaked at 11MSTB/d in March 1974. The cumulative production as at 1.1995 was 52 MMstb oil, 308 Tscf gas (168 MMMscf non associated gas) and 20 MMbbl water. Table 1 shows the input parameters used.

The Sawan Field on the other hand is located in the Thar Desert Southeast of Pakistan. The sand is about 70 m thick and classed as sublith-arenites to lithic arenites, with a high content of partially altered basic volcanic fragments and pore-lining of pore filling iron chlorite cement. The reservoir sands are overlain by transgressive, siderite cemented, shaly silt to very fined grained chamosite sandstones. Initial reservoir pressure was 5389 psi, while temperature is 352°F. Gas gravity is estimated as 0.642 and water density at 56.44 lb/ft^3. Sawan-3 was drilled between May and November, 2001 (McPhee and Enzendorfer, 2004).

RESULTS AND DISCUSSION

Equation 1 is a simple analytical model which can be combined with Equations 2 and 3 to predict sand production is gas or gas condensate wells. It is similar to the model developed for sanding in oil wells by Isehunwa and Olanrewaju (2010) and it shows the effect of flow rate, gas viscosity, grain size, grain density and cavity height on sand production.

To obtain the radius of cavity and volume of sand produced, it is necessary to calculate the molecular weight of the condensate and estimate the gas equivalence of the condensate using Equations 6 and 7. The magnitude of sanding and volume should normally be an issue of concern. It is obvious from the results obtained that the flow rate has a large effect on the volume of sand produced when there is an erosion sand mechanism. This is due to the fact that high flow rate increases the velocity which in turn increases the volume of sand produced.

Figures 1, 2 and 3 show sand production with calibration, for each well, respectively, plotted with the actual sand produced (field data). The result of the model prediction for Field X with calibration, not only quantitatively agreed with the trend observed in the real field, but also reasonably matched with the actual field sand produced (in terms of amount and quantity of sand produced cumulatively). Like reported by Isehunwa and Olanrewaju (2010), it was observed that each well

Table 1. Input parameters for field X.

Input parameter	Condensate wells	Gas well
Reservoir pressure, psi	3362	5386
Temperature, ˚F	190	352
Condensate specific gravity	0.751	-
Condensate API	56.92	-
Gas molecular weight, g/mol	19.99	-
Gas specific gravity	0.69	0.642
Condensate gas ratio, stb/MMscf	108	-
Gas expansion factor, scf/cf	217	1344
Sand particle radius, microns	200	250
Fluid viscosity, cp	0.4	0.00486
Arch cavity, ft	10-60	10-30
Sand density, lb/cuft	165.434	165.434

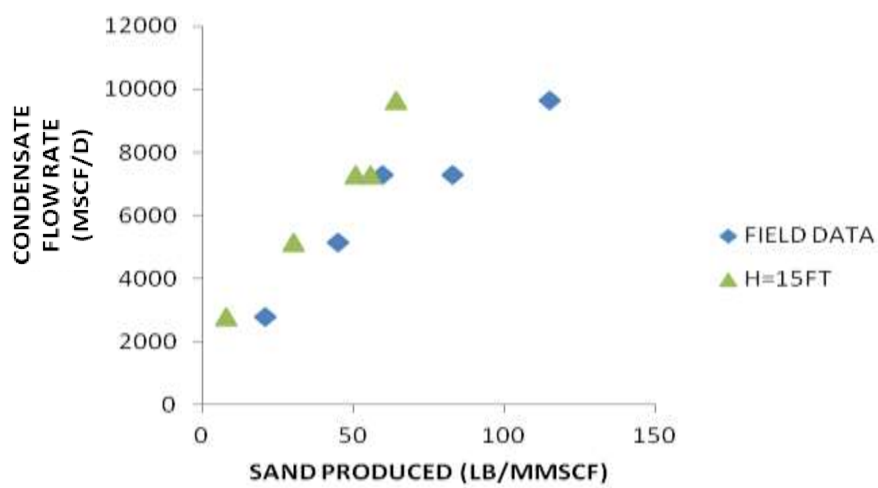

Figure 1. Sand production for gas condensate well 1 at K= 4.1825 × 10^{-5}.

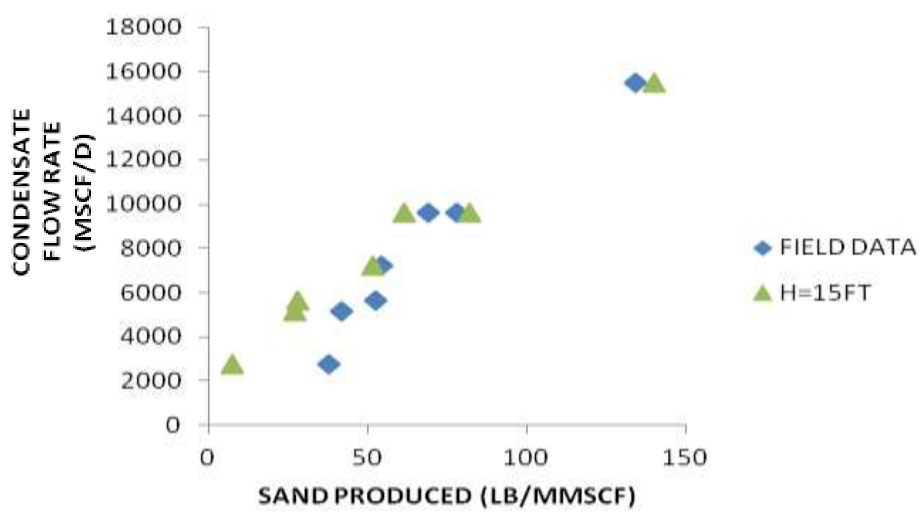

Figure 2. Sand production for Gas Condensate Well 2 at K = 4.3601 × 10^{-5}.

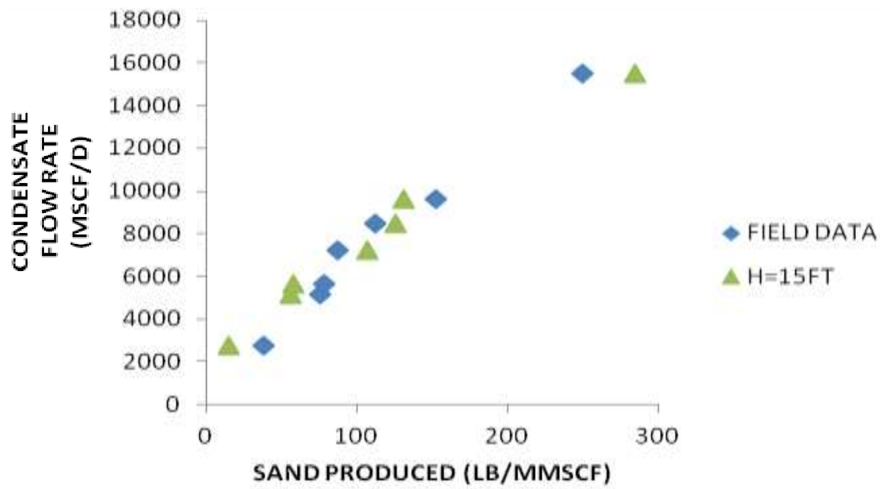

Figure 3. Sand production for condensate well 3 at K = 1.7114×10^{-4}.

Table 2. Field derived empirical constant.

Well	Type	Empirical constant
1	Gas condensate	4.1825×10^{-5}
2	Gas condensate	4.3601×10^{-5}
3	Gas condensate	1.7114×10^{-4}
4 (Sawan – 3)	Gas	8.3400×10^{-3}

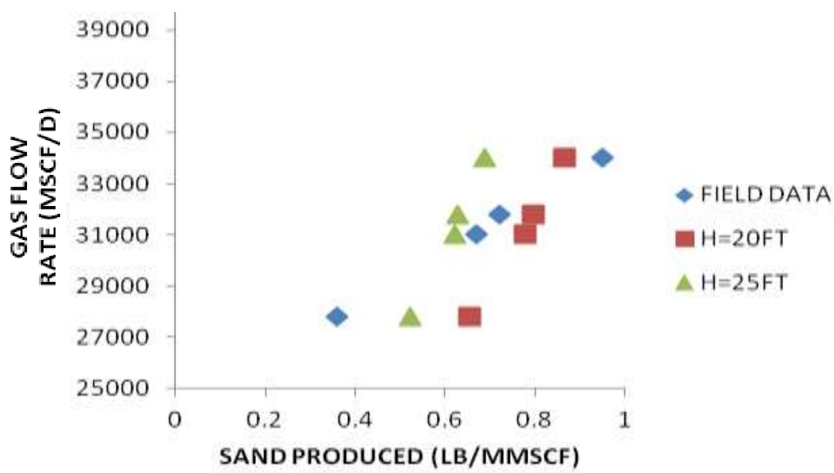

Figure 4. Sand production for Sawan-3 Gas well at K = 8.340×10^{-3}.

required a calibration factor (*k*) in order to obtain good match between field trends and the pure geomechanical model. The calibration factors have been accounted for in Equation 3 and the values shown in Table 2 for the four wells considered. Figures 1, 2 and 3 also show that sand is produced at flow rates as low as 2500MMSCF/D. This indicates that the reservoirs are low-strength, poorly cemented and unconsolidated. Similarly for the Sawan-3 well, Figure 4 shows sand production with calibration, plotted with the actual sand produced (field data). The calibration factor has been shown in Table 2. Figure 4 shows that sand is produced at flow rates as high as 27000MSCF/D. This indicates that the reservoir is weak but consolidated.

Conclusion

A simple analytical model has been developed for predicting sand production in gas and gas condensate wells. The model shows that sand production is affected by flow rate, fluid viscosity, acceleration due to gravity, cavity height, density of sand, particle size, production rate, cavity and borehole radius. The study suggests that high production rates of up to 10000 MSCF/day and above could lead to cavity heights between 30 and 60 ft. High production rates in gas condensate wells lead to increase in cavity arch radius and subsequently sand production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDIX

For a weak reservoir, sand production can be easily induced by erosion failure around the near wellbore region. The premise that the primary mechanism of sand production is caused by erosion failure mechanism is as a result of the drag force exceeding the cohesive strength of the formation material. The effects of wellbore storage, well configuration and completion, interaction of disaggregated solids and flowing fluid, and other complications were neglected.

Using the Geomechanical approach proposed by Vardoulakis (2006) and adapted by Isehunwa and Olanrewaju (2010), we have Buoyancy force given as:

$$F_b = {}^{4\pi}\!/_{3}\, \rho_f g R_s^{\;3} \qquad \text{A1}$$

Gravity force is given as:

$$F_g = {}^{4\pi}\!/_{3}\, \rho_s g R_s^{\;3} \qquad \text{A2}$$

Drag body force becomes:

$$F_{DB} = \frac{(1-\phi)6\pi\mu_f R_s U}{{}^{4}\!/_{3}\pi R_s^{\;3}} = \frac{(1-\phi)\mu_f U}{{}^{2}\!/_{9} R_s^{\;2}} \qquad \text{A3}$$

While the setting body force can be expressed as:

$$F_{SD} = (1-\phi)g\lfloor \rho s - \rho_f \rfloor \qquad \text{A4}$$

The forces on the sand particle were resolved to give:

$$F_d = F_g - F_b \qquad \text{A5}$$

where $F_g - F_b = F_s$

$$F_{DB} = F_{SB} \qquad \text{A6}$$

During wet gas production, we can express the fluid density as:

$$\rho_f = x\rho_o + (1-x)\rho_g \qquad \text{A7}$$

Given that the fluid velocity is:

$$U = \frac{Q_f}{A} \qquad \text{A8}$$

While area of cavity

$$A = 2\pi R_a H \qquad \text{A9}$$

Combining equations A7, A8 and A9 and solving for R_a

$$R_a = \frac{Q_f \mu_f}{2\pi g H\left[\rho_s - \left(x\rho_o + (1-x)\rho_g\right)\right]{}^{2}\!/_{9} R_s^2} \qquad \text{A10}$$

$$V_{sp} = \pi\left(\left(\frac{Q_{gc}^2 \mu_{gc}^2}{\left[R_s^4\right]\left[\rho_s - \left(x\rho_o + (1+x)\rho_g\right)\right]^2 \frac{16}{81} g^2 \pi^2 H^2}\right) - R_w^2\right) H \qquad \text{A11}$$

For practical field applications, we can neglect the well radius and also introduce a calibration factor into equations (A11) to express the volume of sand produced as:

$$V_{sp} = k\left(\left(\frac{Q_{gc}^2 \mu_{gc}^2}{\left[\rho_s - \left(x\rho_o + (1+x)\rho_g\right)\right]^2 \frac{16}{81} R_s^4 g^2 \pi^2 H^2}\right) - R_w^2\right) \pi H \qquad \text{A12}$$

NOMENCLATURE

Ø = Porosity,
Ugc= Gas condensate velocity,
μ_{gc}= Gas condensate viscosity,
ρ_c= Density of condensate,
ρ_s= Density of sand,
ρ_g= Density of gas,
A= Area of cylindrical cavity,
f= Distributed volume force,
F_B= Buoyancy force,
F_D= Total drag force,
F_{d1}= Surface drag force due to shear stress,
F_{d2}= Drag force due to dynamic pressure,
F_{DB}= Drag body force,
F_{SB}= Settling body force,
g= Acceleration due to gravity,
H= Height of cavity,
N= Number of particles,
M_o= Molecular weight of oil,
R_a= Radius of cavity,
S= Sand produced (Mass of sand produced),
V_{SP}= Volume of sand produced,
x= Mole fraction of condensate dropping from gas,
γ_o= Oil specific gravity.