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Attenuation of pump pressure in long wellbores (v02)

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ABSTRACT

Drilling of long oil wells introduces the challenge of long delay time before the pump pressure has been built up to its expected level. After pump-start in long wells the generated hydraulic friction pressure requires a transient period of several minutes, due to pressure wave attenuation, before the steady state level is reached. The true pressure along long wellbores after changing the flow rate will be unknown, since the pressure normally is recorded only at the surface. Changes in pump pressure will take place not only during pump-start, but in other operations like pressure testing, managed pressure drilling, etc. Transient pressure behavior in the field was therefore investigated. For theoretical modeling we applied the water hammer theory. Theoretically estimated transient time was compared with observed transient periods in long wellbores. Model results fitted well with observations, thus emphasizing the long transient time period.

1. Introduction

To drill oil wells longer than 4 km is becoming more common now a days. Long wells are being drilled from offshore platforms to reach the outskirts of a geological basin. A problem related to long wells is the long pressure transient periods, i.e. the time needed to reach steady state pressure after a change in flow rate has taken place. The pressure is transient both spatially and in time. During the transient time period the true wellbore pressure is therefore more or less unknown along the well, since it is normally measured only at the surface. The field approach to meet this problem has been to wait until steady state has been reached before resuming the ongoing drilling operation.

Attenuated pump pressure has so far not been an important problem in drilling operations. In relatively short wellbores (<4000 mMD), the delay period is negligible (seconds), and therefore not a practical problem. In longer wells (>4000 mMD) the accumulative delay time may become substantial (minutes). Each change in the mud pump flow rate represents a transient situation. Frictional pressure increases when the flow rate is increased, is a direct response to the downstream friction pressure. The information of the downstream pressure increase must be transmitted back to the discharge pump.

Reported studies on pressure transients related to the length of the pipe in the petroleum industry were scarce. Studies on pressure transient behavior have mostly been related to two areas; to well testing during production and to surveillance of transport of oil and gas in pipelines. The majority of the publications were focusing on gas production.

Surveillance and diagnosis of long pipelines are vital and need an accurate transient model for operations like detection of pipeline leakage, well shut-in and production startup/restart. Ling et al. (2012) and Adeleke et al. (2012) are two representatives of such investigations. They investigated surface pressure response after sudden restriction occurring downstream through 1D partial differential equation based on conservation of mass and momentum. Reported two-phase flow transient period was largely dictated by the gas compressibility, and none of the studies considered the effect of pipe length.

The second group of transient pressure studies was well testing (e.g. Raba and Ertekin, 2012), also called draw-down tests. The reservoir responds with useful transient data. The transient data are compared to type curves to determine the permeability and the extent of artificially induced fractures. Type curves, however, do not contain the transient behavior related to the length of the wellbore, although Rbeawi and Tiab (2011) indicated that the length of the horizontal wells have an effect on the pressure response during pressure drawdown tests, but without quantifying it.

Pierre and Gudmundsson (2011) developed a model for one phase transient oil flow. Their model of transients, based on conservation of mass and momentum, fitted well with observations. This study involved a sudden local flow change in a

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Nomenclature

a	speed of pressure pulse, m/s
a	acceleration, m/s^2
A	cross sectional area, m^2
C	pipe capacitance, g A/a^2, m s^2
c_1	effect of pipe constraint conditions on pulse speed, dimensionless
d, D	diameter, m
e	wall thickness, m
E	Young's modulus of elasticity of material, Pa
f	Fanning friction factor, dimensionless
g	gravitational acceleration, m/s^2
H	pressure head, m
HGL	hydraulic grade line, m
K	bulk modulus of elasticity for the fluid, Pa
K	consistency index in the Power Law model, Pa s^{-n}
L	length, m
n	flow index in the Power Law model, dimensionless
p	pressure, Pa
q	fluid flow rate, m^3/s
R	viscous resistance, dimensionless
SPP	stand pipe pressure, Pa
t	time, s
v	fluid velocity, m/s
v_0	steady state fluid velocity, m/s
V	volume, m^3
x	axial distance, m

Greek

Δ	difference, dimensionless
μ	Poisson's ratio of deformation of material, dimensionless
ρ	mass density, kg/m^3
τ	viscous stress, Pa

Subscrips

A, B	at points A, B
0	steady state condition
1, 2	section numbers
csg	casing
fm	formation
i	inner; section number
liq	liquid
P	predicted
s	solids
tot	total

Metric conversion factors

in	0.0254 m
bar	10^5 Pa

relatively short (2.7 km) pipeline. They pointed out that the material's elastic properties in pipelines, consisting of several concentric layers, were both inaccurately modeled and specified.

Due to the lack of awareness of the transient pressure phenomenon in long wellbores, the influence of wellbore length on pressure transients was therefore investigated by present authors. From several wellbores, a 9.5 in. well section was selected for demonstrating transient behavior. Fig. 1 presents the base–case well and its geometry. Fig. 2 presents a typical example of a transient behavior after turning the pump on. In that well we recorded transient pressure behavior as a function of wellbore length. The observed data are presented in Fig. 3. Only the end part of the transient period is included, the one occurring after the pump rate increase was completed, as indicated by the vertical line on the time scale in Fig. 2. Curve fitting of the data plot in Fig. 3 showed that transient time $t_{transient}$, increased exponentially with wellbore length L (with an associated regression constant $r^2=0.98$)

$$t_{transient}=cL^{1.91} \tag{1}$$

The theoretical approach had already been derived under the heading of water hammer. The solution technique which fitted well for our purposes was derived by Wylie and Streeter (1978). We adopted their solution technique and could apply it more or less directly. We will therefore first present the basic ideas behind the water hammer phenomenon and then the more complex solution technique for viscous fluids; the so-called Characteristic Method.

2. Classical water hammer theory

Transient flow is often used synonymously with water–hammer, although the latter term is customarily restricted to water, as the name suggests. In the present paper we will apply Wylie and Streeter's (1978) model of water hammer on transient pressure signals in oil wells. In oil wells the theory will not be applied for shutting down the flow, which is the common case of water hammer, but rather for increasing the flow. The result of these two opposite actions is similar; a transient pressure is generated. We intend to make the readers aware of the potentially dangerous phenomena and associated problems.

The main assumptions behind the model are summarized here

(1) To accommodate the pressure–wave speed the fluid is assumed isentropic compressible: $\rho=\rho_0+\partial\rho/\partial p|_S\ (p-p_0)$ and sound speed $a=(1/\partial\rho/\partial p|_S)^{0.5}$; (2) The fluid's density is only mildly influenced by pressure. This effect on the mean flow is therefore neglected; (3) The fluid is for other purposes assumed incompressible, and only the wall's elasticity is impacting (dampening) the wave speed; (4) The wave pressure amplitude is dampened by viscous shear (dissipation); (5) The pressure wave is partially reflected at every area change and partly transmitted further downstream, while fully reflected at channel ends. Reflections involve phase shift; (6) The two-phase system is assumed to be a liquid phase with continuous dispersed solids with no complex wave speed effects.

In classical water hammer theory, the dependent variable pressure p is converted to pressure head H, also referred to as piezometric head, the elevation above an arbitrary datum;

$$p=\rho gH \tag{2}$$

All factors involved in the momentum changes in a control volume when closing a valve are summarized in Fig. 4. The figure is modified to fit the case when a pump is turned on and up, rather than abruptly closing a valve. The valve represents hydraulic pipe friction vs. pipe length. While initially running the mud pump at constant rate, it delivers a constant flow velocity of v_0. By increasing the flow rate by the upstream located pump (a positive