FORMATION DAMAGE DURING DRILLING AND COMPLETION PRACTICES - A REVIEW

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Abstract

A review of formation damage during drilling indicates that the mechanism of fluid filtration occur in 3 stages i.e. invasion by spurt loss; initial external and internal bridging and filter cake build up. The constituent of the filter cake build up. The constituent of the filter cake and its deposition mechanism crucially controls the extend of formation damage, but during drilling process continues erosion of the surface of the cake occur resulting in dynamic filtration.

Fluid filtration onto the formation will causes particle plugging, clay swelling, scale deposition, water blocking, oil wetting or emulsion blocking.

A formation damage research programme is drawnup to elucidate borehole filtration and the subsequent damage to the formation.

Introduction

The development of a well which allows fluids to be removed from or injected into a hydrocarbon reservoir involves

(a) the drilling of the wellbore and usually the concurrent installation of protective steel casing strings

(b) the mechanical completion of the well to provide a safe and controllable flow string

(c) the initiation of production

At each of these stages a fluid is displaced into the borehole. The fluids used at the various stages of the drilling and completion procedure can be different depending upon the proposed fluid function and the properties required. For example, during the development of any one well, a different fluid may be required for the drilling fluid, the completion fluid and the perforating fluid, etc.

The selection of fluids for these functions is dependent upon a large number of variables. And this paper will elucidated the mechanism of fluid invasion, borehole filtration and future research programme in formation damage.

Mechanism of Fluid Filtration in the Formation

When the porous medium is instantaneously exposed to the wellbore fluid with the pressure differential to generate filtration, the initial filtration rates will be very high since they are dependent primarily upon the resistance to flow offered by the porous media i.e. a function of the formation permeability. However, as filtration proceeds, particles which are unable to enter the formation are deposited on the borehole wall as a filter cake. The size of particles which are unable to enter the formation initially, is normally dependent upon the formation pore sizes.

Once this has occurred the pore throats of the bridge then act as the controlling ofifice for the subsequent filtration and migration of particles. Thus smaller particles migrating with the filtrate will enter the filter cake bridging at pore throats and thus decreasing the effective pore throats diameter available for further migration. Therefore the permeability of the particle bridge will continue to be reduced.

In this way, a filter cake is deposited which is comprised of a series of particles of varying sizes, which are in many cases orders of magnitude smaller than the particulate constituents of the formation. The permeability of these filter cakes is therefore usually several orders of magniture lower than the formation permeability. Initially during the filtration process, the rate of filtration will be control by the resistance offered by the formation. However in the majority of cases it will very rapidly decline as a filter cake of low permeability is generated.

Since drilling fluids are composed of a variety of chemicals of various sizes and shapes in a base fluid of oil, water or an emulsion of both, a cake will ultimately be generated which eliminates most if not all particle migration into the formation provided the cake is stable and remains in position. Particle migration into the formation is therefore at its greatest during the period before the early deposition of particles is established on the bore hole wall, i.e. during the spurt loss period when filter cake deposition is initiated. These stages are shown schematically in Fig. 1. The constituents of the filter cake and hence of a mud and the manner in which the cake is deposited thus crucially controls the volume and constituents of the fluid which invades the formation in the near borehole region.

Borehole Fluid Filtration[1]

The complexities of filtration is a real borehole can be elucidated by considering the chronological sequence of events and the associated filtration in the drilling of the formation. Before the bit actually penetrates the formation, the formation beneath the bit is subjected to mud jetted onto it through the nozzles in the bit. Under the hydraulic impact created by these jets, the mud filters through the formation providing the initial invasion of the formation. This "beneath the bit" filtration can lead to substantial invasion of the formation, however the permanent effects of this invasion are limited in most cases since the formation will subsequently be drilled out, Fig. 2. Once the formation has been drilled, mud will continue to flow down the drill string and up to annular space between the borehole and the drill string.

Since an over balance of pressure the mud column and the formation will still exist, there is still a driving force for filtration. In this case a filter cake will continue to be deposited but since the mud flow is parallel to the deposited cake surface, the surface of the cake will be continuously eroded because of the hydraulic shear force of the mud. In this dynamic situation, two opossing mechanisms control the cake thickness, and hence resistance to filtration, i.e. deposition by filtration, and erosion because of the mudflow. This phase of the fluid loss is defined as "dynamic filtration"[2,3] and is depicted in Fig. 2.

If dynamic filtration were allowed to continue, an equilibrium cake thickness would be achieved which would be determined by the balance between the erosive and deposition forces. However, other mechanical factors may influence the creation of an equilibrium cake thickness. Mechanical attrition of the cake is most likely to occur in a conventional drilling system because of one or more of the following mechanisms:-

(1) rotation of the drill string in a borehole, with even a slight degree of deviation, could lead to intermittent or cyclical contact between the filter cake/borehole wall and the string components e.g. stabilisers, drill collars, etc.

(2) the regular retraction of the drilling bit from the base of the borehole, to allow the addition of a single and therefore an increase in the length of drill string, could result in the removal of previously deposited filter cake. This mechanism could also occur at each round trip.

When the mud circulation is stopped, to allow the addition of a drill pipe 'single' or a round trip, the erosion of the cake is discontinued but filtration will continue to occur by the "static" filtration mechanism because of the pressure differential. Therefore in the drilling process the filtration is a sequence of alternating dynamic and static filtration phases.

Borehole filtration, in the drilling process, will normally result in invasion due to all 3 of the above mechanisms. However, it has been shown that of the total filtrate invasion that takes place during the drilling process, about 80% is due to the dynamic filtration mechanism. In the case of completion or perforating fluids, beneath the bit filtration will not normally occur and in addition the invasion due to dynamic filtration will be minimal.

Table 1 shows the range of variables influencing fluid invasion into the formation.[4]

Effect of Fluid Filtration onto the Formation

Contact with a foreign fluid is the basic cause of formation damage and most of the oilfield fluids used contain 2 phases i.e. liquid and solids. Either phases can cause formation damage through one of solids. Either phases can cause formation damage through one of several possible mechanisms. The mechanisms that result in formation damage may be classified according to the way in which productivity decrease:

a) Reduction of absolute permeability[5,6,7] This is caused by plugging of pore channels by induced or inherent particles. Large particles cause formation damage by plating out on the surface of the formation but very small particles may be carried for some distance into the formation to create serious plugging. Liquid filtrate entering the formation can cause clay swelling or dispersion of clays or dissolution of cementing materials allowing fines migration within formation or scale precipitation due to mixing of incompatible waters resulting in formation damage. Asphaltene of paraffin may also be precipitated within the formation due to changing equilibrium conditions.

b) Reduced relative permeability to oil[8] This is caused by incrrease in water saturation or oil wetting of the rock. The increase water saturation near the borehole is from filtrate invasion is termed as 'water blocking' which reduced oil productivity. The reduction of oil productivity depend on the degree of water saturation and the radius of the affected area.

Oil wetting can result from surface-active materials in oil-field fluids. Surfactants change silicate rock surface to become oil-wet hence reducing permeability to oil flow. The effect of oil wetting on well productivity depend on the radius of the affected area and the reduction in permeability to oil.

c) Increased fluid viscosity. This is caused from emulsions or high viscosity treating fluids. Emulsions plugged the pores of formation and the extent of productivity reduction depends on the viscosity of the emulsion and the radius of the affected area.

Fig. 3 shows the major formation damage mechanisms associated with the fluid invasion due to borehole filtration.

Formation damage research programme[9]

Extensive investigations have been undertaken to understand fluid filtration into the formation but the complexity of borehole filtration and the range of variables which potentially could effect fluid loss in a borehole have left many questions unanswered. And with extremely high cost of developing offshore oilfield, a more exact understanding of the variables influencing borehole filtration is necessary in order to employ thecorrect fluid characteristics to minimize fluid invasion into the formation and its related problem.

So an extensive program to investigate formation damage potentially associated with drilling fluids is initiated in 1980.

1) Drilling mud characterization

2) Construct an experimental rig to study wellbore damage due to drilling fluids

   a) Water based muds
   b) Oil based muds
   c) Others

3) Modified experimental rig to study well cleaning techniques

   a) Backflushing
   b) Backsurging
   c) Acid washing

4) Make a mathematical model to predict formation damage due to drilling mud and subsequent cleaning operations.

5) Upgrade experimental rig for precision measurement of variables affecting fluid invasion to be tested in the mathematical model.

Concluding Remarks

Eventhough numerous works have been going on but the complexity of borehole filtration and subsequent damage to the formation has perhaps raised more questions if we tried to extra polate previous laboratory findings to actual field operations.

So this ambitions programme of researchwould elucidated the constituent particles of drilling mud that cause the severity of damage, the bridging mechanism that control the amount of particles invasions and the procedure of cleaning up of impairment due to the invasion of fluid/particles prior to bridging so that we could understand the mechanism of formation damage and find methods to avoid or minimise them to enhance our oil recovery.

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ROCK PROPERTIES	WELLBORE FLUID PROPERTIES	WELLBORE HYDRAULIC CONDITIONS	PHYSICAL ENVIRONMENT OF WELLBORE
(a) tortuosity	(a) type of fluid	(a) the annular velocity of mud flow	(a) temperature of fluid in the borehole
(b) relative permeability to both in-situ and invading fluids	(b) base fluid properties (filtrate) particularly viscosity	(b) the duration and sequence of the various methods of filtration in the borehole	(b) absolute pressure within the borehole
(c) mean pore size	(c) chemical activity of constituents, e.g. surface activity	(c) the shear stress/shear rate on the filter cake surface	(c) differential pressure between borehole and formation
(d) porosity	(d) concentration of constituent particles	(d) the mud circulation rate and nozzle discharge velocity	(d) inclination angle of the wellbore
	(e) shape and size distribution of constituent particles		(e) frequency and severity of physical contact between the drill string and the filter cake on the borehole wall
	(f) rheological properties of fluid		(f) drilling rate
			(g) Rotary speed and type of bit

TABLE 1. Parameters influencing borehole filtration

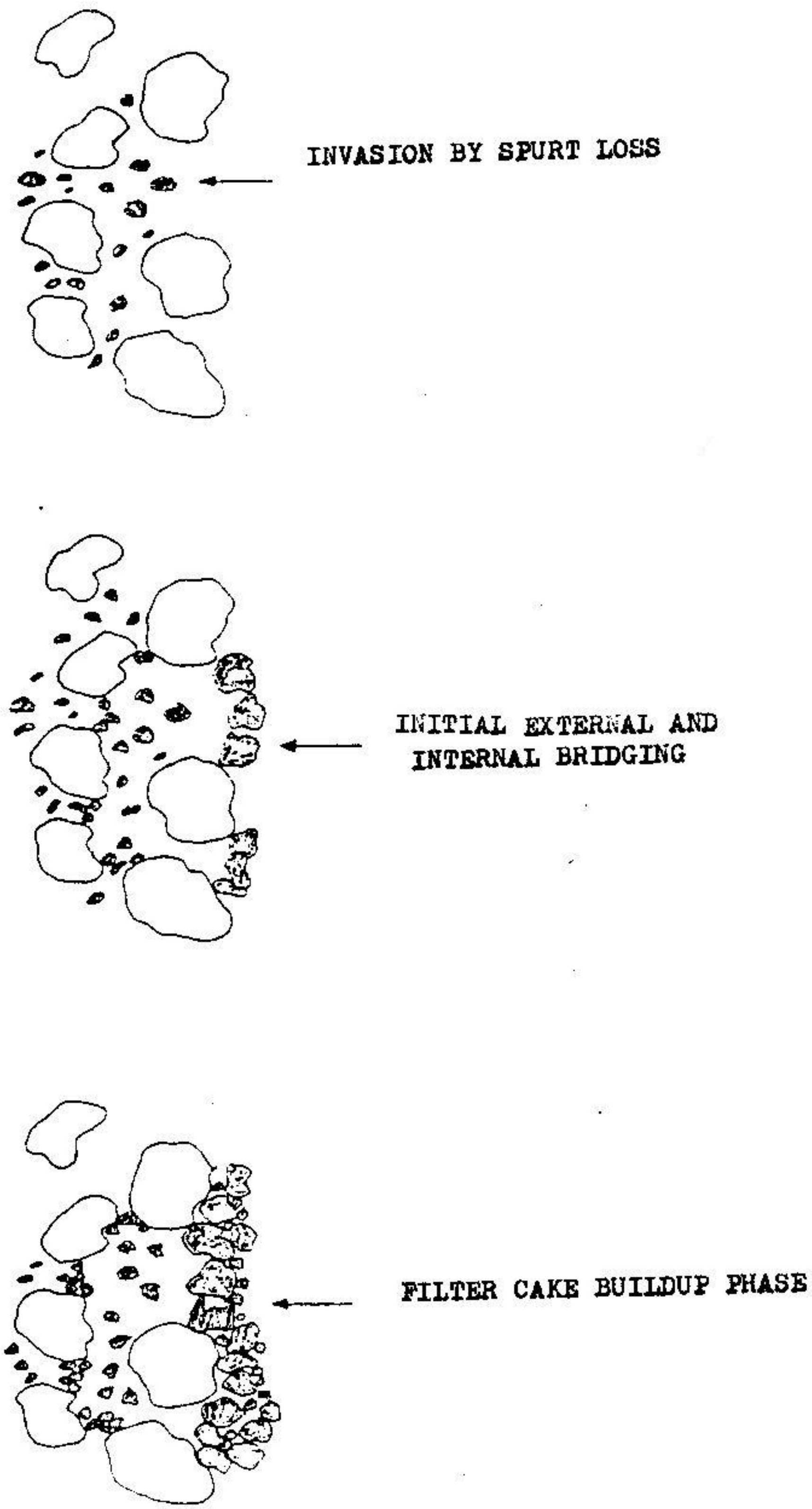

Fig. 1 The sequential bridging of mud upon the borehole wall and the associated invasion of the formation.

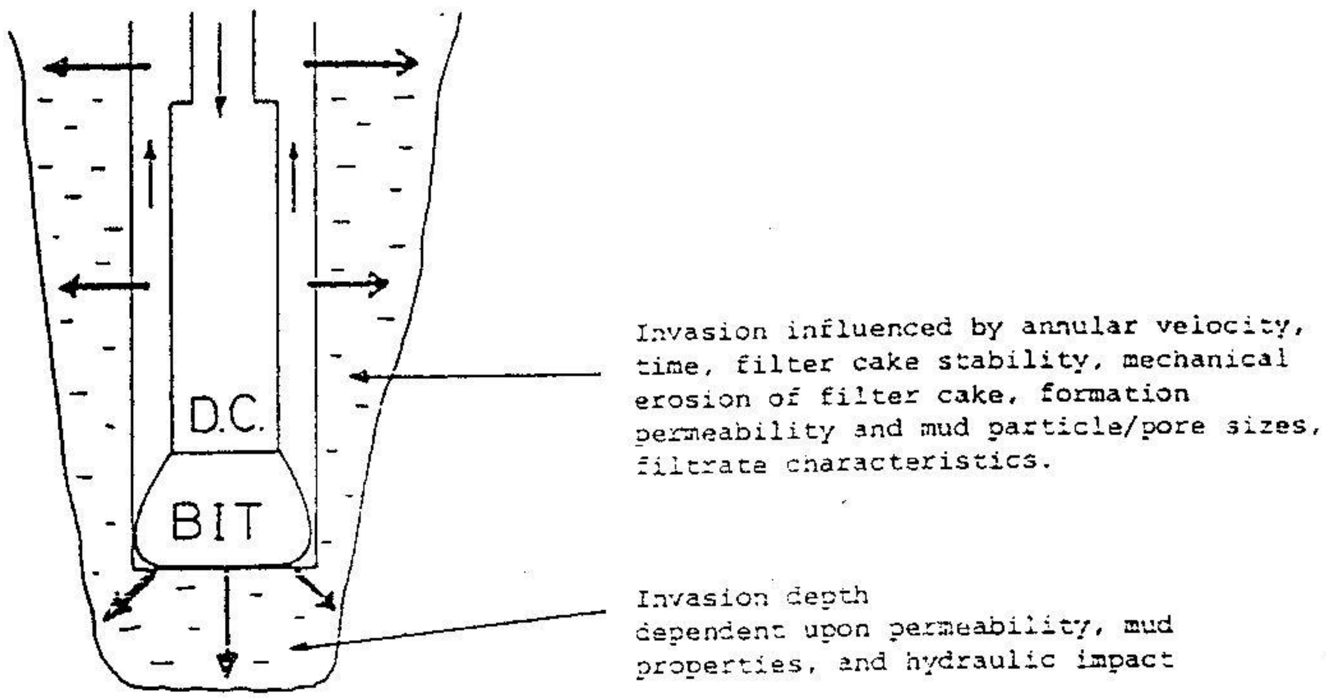

Fig. 2. The occurrence of the three types of borehole filtration mechanism: (1) beneath the bit, (2) dynamic and (3) static filtration.

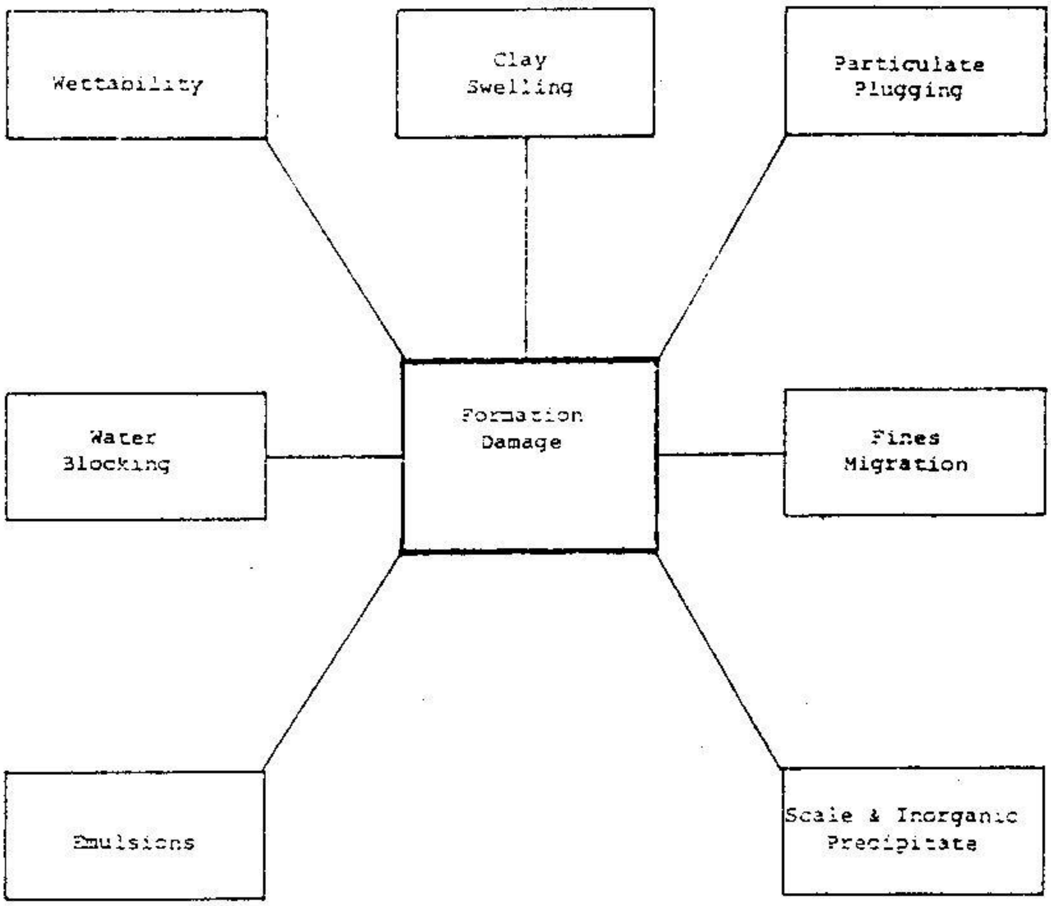

Fig. 3 Major formation damage mechanisms associated with the fluid invasion due to borehole filtration.