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# Skin Factor Effect in Horizontal Wells

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## Abstract

*Whenever we have putted in function one well, we have met the Skin effect factor, witch has helped us, or contrary make difficult our task to design a production or an injectivity process. We have not to ignore the existence of this factor for any well from production or injectivity from starting till last flow rate.*

**Key words:** skin effect, pressure drops, drains.

## Introduction

In case of production wells, as well as in water injection processes, drains are drilled to achieve either higher oil or gas production or a more efficient washing at high injection flow rates and low injection pressure. Taking into account the rocks which form the reservoir are neither homogeneous nor isotropic, a drain, no matter of its length, opens a reservoir section (L) characterized by variations of porosity (Φ) and permeability (k) (see fig. 1), so the fluid flow from layer to well and the other way round as well in not a uniform flow in case of injected water, and non-uniformities of channeling front result in cases of injection drains.

Many pressure drops can occur in a horizontal well [1]. There is a pressure drop between the two ends of drain, and it is known that the pressure at drain inlet is higher than the one at drain shoe. Pressure drops can occur alongside drain due to physical properties of layers crossed by drain.

The injection flow rate will be lower in an area with decreased porosity and impermeability, so pressure in drain in that area will be considerably higher. For an area with higher porosity and impermeability values, the flow rate of injected water will be higher and the pressure will be lower. The amount of water flow rates injected in an injection drain that corresponds to each area of layer with different physical properties will be equal to the water flow rate injected in drain. There will be a differential pressure alongside the drain. This case is merely theoretic because at every layer crossed by a well appears a Skin factor, so every drain section has a layer well pressure drop which contributes to the total pressure drop between the drain ends.

The ideal case is when the Skin factor is zero, this meaning that the distorted/ modified area in the bore hole proximity gas the same physical properties as undistorted/ unmodified area. In case of injection wells, both straight and horizontal wells, an additional benefit could be a negative Skin factor, meaning the physical properties of the container rock located in the bore hole proximity should be higher than physical properties of container rock located in undistorted area, in order to achieve a good receptivity; if the Skin factor is positive, water will be injected at high pressures and low flow rates

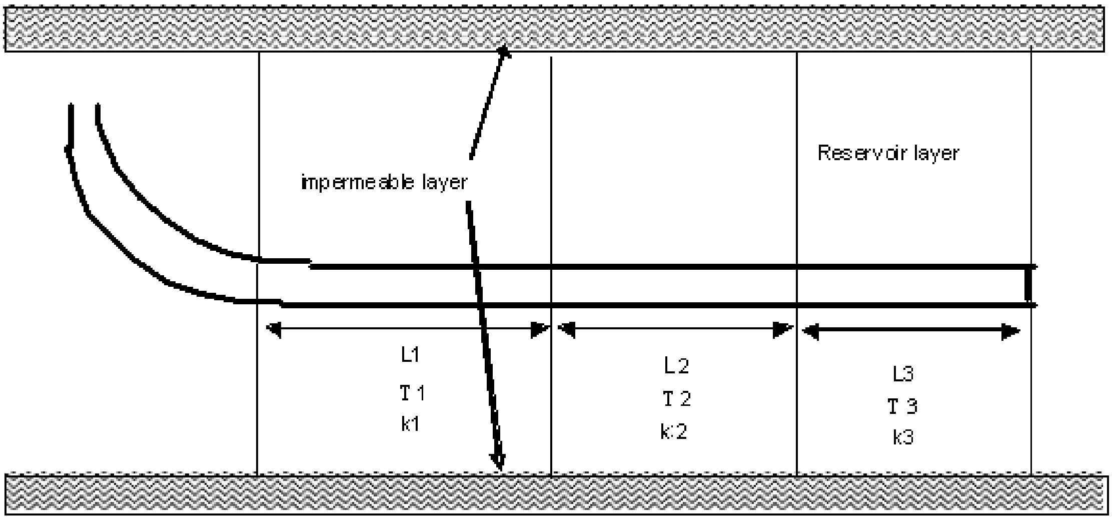


**Fig. 1.** The design of a drain in reservoir layer with different characteristics [3]

## Skin Factor Showing

The decreasing of physical properties of a container rock in proximity of the bore hole is due to the following conditions [2]:

- Penetration of related layers during drilling;
- Way and degree of opening for related layers;
- Injection of channeling agents;
- Oil producing conditions.

Fines, small-size particles can block the layer permeability in different ways [2]:

- mineral particles detached from the rock walls; we can mention here fine shaly particles which suffer the swelling phenomenon, these particles get loose from the walls of porous spaces where they were set down due to their sensitivity against the drilling fluid nature that invade the porous space in that area, resulting in the pore blocking.
- solid particles inserted in well operating fluids; we can mention here the intervention fluids or transport fluids used at major overhaul (workover) operations, which are originated from the reservoir water collected from wells located on the same reservoir. The fine, small-sized particles inserted into the layer at the same time with transport fluids come from both mineral particles run out together with reservoir water and settling down products existing in reservoir water.
- way and degree of opening of permeable porous layers, we can mention here that the majority of layers are closed by lining and cementing and then opened depending on production interests. However those layers are well lined and however high the cementing quality is (to avoid the fluid circulation behind the casing), layers closed by lining and cementing can be opened only by perforating operation, but their perforation, no matter of chosen method for perforating, will not provide a degree of opening similar to layers produced by free hole, and the oil recovery can bring some difficulties by increasing water cut and solid contaminant percentage (solid particles run in into the well or in its vicinity mainly by a great pressure drop in the well layer).

Horizontal, injection wells and production wells as well are more exposed to the formation of a positive Skin factor.

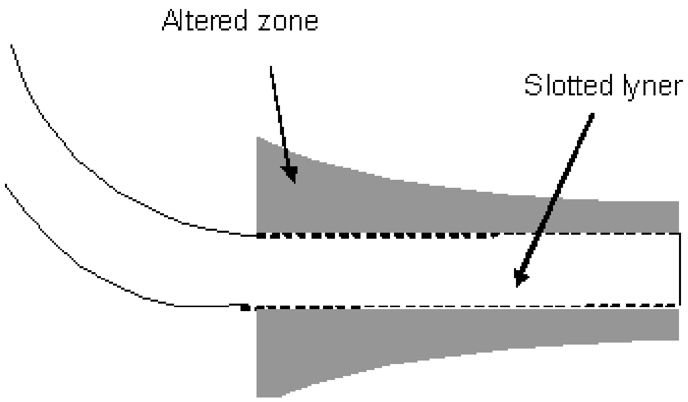


**Fig. 2** The variation on the thickness of the altered zone along a drain

The permeability of affected area should be lower than one of a unaffected area because horizontal wells have in general a simple construction, either unlined or lined with slotted liners and without packers which can separate the related layers. So, it can be considered as unlined layers because the fluid circulation behind liners is not restrained by any technical barrier. Depending on the number of operations executed in well, and just before putting the well in operation, the distorted area for a horizontal well will be larger than a distorted area for a straight well, knowing that the majority of straight wells are lined, cemented and then perforated, so the fluid losses in layer will be considerably lower even at high pressure drops in well layer. In these situations there can occur major difficulties regarding the permeability decrease. In a drain, either an injection or production one, there is a pressure drop between drain curvature and shoe, and the volume of injected water or operating fluid which affects area in the close vicinity, is higher at drain inlet than at its shoe, the thickness of distorted area varies alongside the drain (see fig. 2). This phenomenon can occur even during drilling because the drilling time for a drain is longer than drilling time for a straight well, so the volume to be filtered, which will wash the invasion area, will be higher in the vicinity of curvature then in the vicinity of shoe.

Taking into account that layers crossed by drains are neither homogenous nor isotropic, there will appear sections within the distorted area where the drilling filtered fluid or water originated from operations executed in drains can have thicker invasion areas even to the drain shoes. In case of injection drains, the appearance of a positive Skin factor in conformity with the above figure, can lead to the shortening of the injection process as long as the drain is not used on its entire length.

It is known that a horizontal well is drilled in an area with high permeability on vertical direction, otherwise the flowing of fluids inside the layer and the well itself could not achieve economic flow rates [4]. High permeability values on vertical directions facilitate the distortion, weathering of rock in the vicinity of bore hole by the fact the distorted, weathered area of container rock will spread on sections of high thickness. In actual fact, on sites, the higher value of permeability on vertical direction and the higher value of well layer pressure drop, the higher is the thickness of distorted, weathered area. One should take into account these values while designing horizontal wells, stimulation processes and other intervention works to these wells.

In conformity with [4], the Skin factor can be calculated using the formula:

$$S = \frac{kh\Delta p_{skin}}{141.2q\mu_o B_o} \qquad (1)$$

where $K$ is the permeability, $H$ – layer actual thickness, $\Delta p_{skin}$ – pressure drop in Skin area (distorted, weathered area), $\mu_o$ – oil viscosity, $B_o$ – oil volume factor, $q$ – flow rate of recovered fluid.

Taking into account that the Skin factor can be established by pressure measurements, the pressure drop in distorted, weathered area can be calculated.

It is possible to cross the related layers at equilibrium during drilling, and this fact will create a distorted, weathered area with low thicknesses, and it can result a decrease of difficulties when the well is put in production or when the well is changed into a water injector.

The models of fluid flow through a horizontal well are different and depend on the drain position. In a reservoir, it can be talked about [3]:

- Semi-radial flow, which is achieved when the drain is located close by a vertical limit of reservoir such as: sealed faults, marling limits, related layer balking, etc. The semi-radial flow does not exist around the bore hole, but only on directions in which the reservoir limits are not close to drain. In this situation, even if the Skin factor is zero (ideal case), it can be considered that there is an imperfection of well – layer flow because the fluid gain would be small on a direction close to the reservoir vertical limit, and the flow would be turbulent on this direction. The semi-radial flow will go on as long as lines of flow on the directions of vertical limits meet these vertical barriers, and the draining area shape will be semi-ellipsoidal.
- Radial flow, which is achieved when the drain is situated at long distances far from the reservoir vertical limits. Considering the Skin factor is constant alongside the drain (meaning the penetration speed of drilling bit would be high at the drain entrance and would decrease to the final depth in order to achieve a constant loss of filtered fluid on the entire length of drain, and the drilling fluid density and reservoir rock physical properties would be constant), the gain of well layer fluid could have equal values around the well. The radial flow will be kept as long as the lines of flow meet the reservoir vertical limits, and the draining area shape will be ellipsoidal.
- Linear flow, which is achieved after the lines of flow have met the reservoir vertical lines on both sides of drain. Taking into account that in a drain, no matter if it si used for production or injection, the affected area will have higher thicknesses close to curvature and smaller ones in vicinity of shoe, and it comes out that also the Skin factor will have higher positive values close to curvature. The draining area will spread itself from o vertical limit of reservoir to the other one, will have the width of drain, actually the lines of flow will be orthogonal on drain.
- Pseudo-radial flow, which is achieved when the lines of flow enter into the well from all directions, inclusively from the drain curvature and shoe. To have this flow, the Skin factor must be zero or negative so that the well layer flow close to the well cannot be affected by additional hydraulic resistances.

All these models can be achieved on the condition that the horizontal well flow rate is constant.

Taking into account that the thickness of distorted, weathered area is not constant in case of horizontal wells (as shown above), the Skin factor needs to be established on sections, portions of length depending on the thickness of distorted, weathered area alongside the drain. But the drain stimulation is very difficult, many times impossible to make on sections depending on the thickness of distorted, weathered area. In case of drains completed with slotted liners on their entire length (many times without packers which can separate the related layers, so they can be considered as unlined layers because the fluid circulation behind liners is not obstructed by any technical barrier).

Whatever drilling fluid is used and well completion, there will be a Skin factor, so there will be a distorted, weathered area close to the bore hole which generates a certain well layer pressure drop. Irrespective of kind of well, straight or horizontal, the reducing of Skin factor can be achieved by stimulation after opening related layers in case these are lined and cemented, or by stimulation before putting the well in production if layers are lined by slotted liners. In case of horizontal wells, the works requested to stimulate related layers are more expensive and difficult to execute because of high inclination of bore holes. Stimulation can be also requested in case of reputing wells in production after major overhaul (work over) operations.

In conformity with the equation (1), the Skin factor can be negative when the well layer pressure drop would be negative, that is when the layer pressure is higher than the one at bore hole. To fulfil this condition the related layers should be drilled at sub-equilibrium or works executed at well should be made at sub-equilibrium, fact which would lead to technical complications because the layers would produce during their crossing or work performing.

The Skin factor can be also calculated using formula (2):

$$S = \left( \frac{k}{k_a} - 1 \right) \ln \frac{r_a}{r_s} \tag{2}$$

where: $k_a$ – permeability of distorted, weathered area, $r_a$ – radius of distorted, weathered area, $k$ – permeability of container rock, $r_s$ – well radius.

Using a reservoir data base and knowing the well radius of 0.244475 m, the Skin factor has the following values presented in Table 1 (the permeability values are typical of reservoirs located in calcareous rocks with fractural porosity):

In conformity with equation (2), the Skin factor would have negative values when the permeability of distorted, weathered area has values higher than the undistorted, non-weathered area.  This thing occurred if stimulation works would be executed to well in order to increase the ability to flow.

**Table 1.** Values for relative permeabilities and Skin factor

| k (D) | ka (D) | ra (m) | Skin |
|---|---|---|---|
| 10 | 4 | 0.695 | 1.567 |
| 22 | 6 | 0.752 | 2.996 |
| 28 | 7 | 0.824 | 3.645 |
| 31 | 6 | 0.873 | 5.303 |
| 37 | 9 | 0.957 | 4.246 |
| 42 | 8 | 0.873 | 5.409 |
| 50 | 7 | 0.824 | 7.464 |

## Conclusions

It comes out from the production data that if the pressure difference in distorted, weathered area increases, then the Skin factor will increase. It can also be noticed that the Skin factor value increases directly related to permeability increase.

If a well is going to be drilled at equilibrium, and if the reservoir pressure was equal to the hydrostatic column pressure generated by drilling fluid, there would not exist a pressure difference between layer and well (Skin factor would be zero, and the properties of distorted, weathered area would be the same with the undistorted, non-weathered area properties). This is a theoretical case because there will exist a pressure difference, however small, due to the need of existence of a safe margin. When crossing some productive layers, there will be an uncertainty degree regarding the pressure values of fluids from pores even in case of re-drilling a bore hole because this one must meet the reservoir outside the drain radius of the first bore hole or close wells, that is an area which hasn't been drained. On the other hand, due to the distribution of fluids, there will exist a pressure difference of fluids from pores in a reservoir, which is given by their density variation on vertical, so a variation of pressure while crossing the productive layer on entire thickness of reservoir similar the one given by the fluids settled in reservoir pore rocks is difficult to achieve. At a well layer pressure whatever small, there will exist an invasion area generated by the filtered drilling fluid and by particles that will block rock pores in close vicinity of bore hole. In case of consolidated layers which don't have any gain of solid contaminants or water during exploitation, meaning that is no need to bring up supplies of them, after executing a stimulation the well pressure will decrease under the value of reservoir pressure, and the productive layers will create a fluid afflux in bore hole. The higher this pressure difference, the higher the layer fluid afflux in well, and this thing will lead to a better draining of distorted, weathered area. Therefore there exists the possibility to unblock the distorted, weathered area and to improve its properties up to the values of the undistorted, non-weathered area.

A negative Skin factor is difficult to achieve even in case of unreplenished layers mentioned above, because there is requested an improvement of permeability for productive layers in close vicinity of bore hole. This thing can be achieved by executing some stimulating operations which can improve the layer flowing ability.

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# Efectul factorului Skin în sonde orizontale

## Rezumat

*Ori de câte ori punem în funcție o sondă, întâlnim efectul factorului Skin care ne ajută sau din contră ne face dificilă sarcina de a proiecta un proces de producție sau de injecție. Nu trebui să ignorăm existența factorului Skin pentru orice sondă de producție sau de injecție de apă de la punerea în funcție şi până la ultimul debit.*