Designing Multiple Alpha Waves Open Hole Gravel Pack Operations

João Vicente Magalhães
Petrobrás, Cidade Universitária, Q.7, Ilha do Fundão, prédio 20,sala 1019 – Rio de Janeiro, RJ , Brazil,
jvmm.PUC@petrobras.com.br

Agostinho Calderon
Petrobrás, Cidade Universitária, Q 7, Ilha do Fundão, prédio 20, sala 10017 – Rio de Janeiro, RJ, Brazil,
agoscal@petrobras.com.br

Thiago Judson Lima de Oliveira
Petrobrás, Cidade Universitária, Q.7, Ilha do Fundão, prédio 20, sala 1019 – Rio de Janeiro, RJ, Brazil,
judson.FUNPLF@petrobras.com.br

André Leibsohn Martins
Petrobrás, Cidade Universitária, Q.7, Ilha do Fundão, prédio 20,sala 1017 – Rio de Janeiro, RJ , Brazil,
aleibsohn@petrobras.com.br

Abstract. *Multiple alpha wave placement is an effective strategy to minimize operational time and risk in open hole gravel pack operations. This article deals with the adaptation of a mechanistic model, originally developed for OHGP placement, to account for flow rate variation throughout the operation. The final goal is to provide charts of flow rates versus time for a constant downhole fracture pressure. Based on these charts, a feasible pumping schedule can be proposed for each specific operation aiming time reduction and operational safety. Finally, a case study of the multiple alpha wave design is presented and its advantages highlighted.*

Keywords: *Sand Control, gravel pack, horizontal wells.*

1. Introduction

Offshore scenarios often include ultra deepwaters and heavy oil reservoirs. Many of these reservoirs are composed by non-consolidated sandstones, where sand control techniques are required. Sand production results in several subsurface and surface problems, such as: facilities erosion and sedimentation inside the oil/gas/water separator.

There are many techniques for sand control available in petroleum industry. Economic development of deepwater projects requires that a minimum number of wells be drilled and nevertheless getting effective reservoir drainage to maintain a high productivity index of the wells.

An important option for accomplishing this task is to drill long horizontal wells. Openhole gravel-packing of horizontal wells in unconsolidated formations is a very effective way to achieve all of these goals.

The gravel packing technique consists in filling out the annular space between screen and formation with sand, ceramic or other solid particle with selected grain diameter based on different criteria, such as the one proposed by Saucier[1]. The idea is to create a second porous medium with a pore throat diameter smaller than the formation grain diameter and, in this case, during production, the oil would easily flow through the gravel pack settled while formation particles would not. More details about gravel pack technique can be found in de Magalhães *et. al.*[2].

Due to the critical conditions, gravel pack placement is a risky job. Usually in ultra deepwaters, the overburden stresses are considerably low, normally resulting in a low formation fracture resistance. Besides, to pump gravel in long horizontal section wells generates large dynamic pressures in the openhole. These aspects were the main motivators for a software development, which calculates accurately the pressures drop during gravel pack placement and optimizes operational pump rate.

In order to achieve a successful gravel packing operation, different hydraulic limits should be respected. Dynamic pressures during the operation should be maintained between a window limited by the pore pressure and the fracture pressure. If the wellbore pressure, at any time, is lower than the pore pressure, there will be influx of formation fluid to the well. On the other hand, if the wellbore pressure is greater than the formation fracture pressure, there will be uncontrolled influx of completion fluid to the formation, generating damage, generalized fluid loss and premature gravel packing screen-out (Magalhães *et al.*[2]).

Another important issue is to guarantee that the operation will be run at a minimum flow rate which avoids premature screen out of the rat-hole. Since a larger diameter openhole section is exposed (rat-hole), if the flow rate is too low, alpha waves formed may be high enough to block sand passage to the openhole, generating immediately a beta wave in the rat hole. The consequence is that the pressure at the last casing shoe will immediately increase and the operation will have to be aborted without packing the openhole (Marques *et al.*[3]).

Many times there is no feasible operational window for gravel pack placement. In these situations, placing OHGP with a multiple alpha wave approach presents several advantages, such as:

- minimizing operational time, since the operation may start at high flow rates;
- postponing the risk of premature screen out in the rat hole or at eventual enlarged sections at the open hole;
- enabling a safe large alpha wave design for situations where the beta wave can not be fully placed due to fracture pressure restrictions. In these cases, alpha waves would be designed to fully cover the screens before beta wave propagation starts and within fracture pressure limit.

The central goal of this article is to establish a methodology for multiples alpha waves design, based on an adaptation of a mechanistic model for gravel pack placement, accounting for flow rate variation throughout the operation.

2. Variable Flow Rate Calculations

The main tool for the proposed calculations is a mechanistic model proposed by Martins *et al.*[4]. The model allows the calculation, for a given flow rate, of pressure propagation during the following operational steps: string injection, alpha wave and beta wave placement. In order to predict alpha wave deposition heights, a two layer model is considered. The present model is an extension, for horizontal gravel packing applications, of the model proposed by Martins[5] for drilled cuttings transport analysis.

The proposed modeling was implemented in a computer code for use in projects and during the gravel packing operations. This code was written in PASCAL language using DELPHI™ 7.0 environment. More software details are explained in Martins *et al.*[6]

The methodology developed for the analysis proposed in this article consists on the calculation of the operational window where flow rates vary with time in a way that a constant downhole pressure is maintained. The implementation methodology is as follows:

- First, flow rate values are arbitrated.
- The dynamic pressures, as function of flow rate, are calculated for each arbitrated value and compared with the fracture formation limit pressure.
- The dynamic pressure which does not overcome fracture formation limit pressure is selected for a given time step.
- After that, the dynamic pressures at the casing shoe are ploted for the several time steps which characterize the operation.

This methodology enables the construction of an operational window plot, where the upper limted designs flow rates as near as possible to the fracture pressure. The implementation of the methodology shows the operator, for each time step, the operational limits composed by the minimum flow rate which avoids premature screen-out of the rat-hole (red line) and the maximum flow rate which does not induce formation fracture (blue line). Figure 1 shows a graph composed by the operational window software output. The optimal gravel packing flow rate should be settled between these limits.

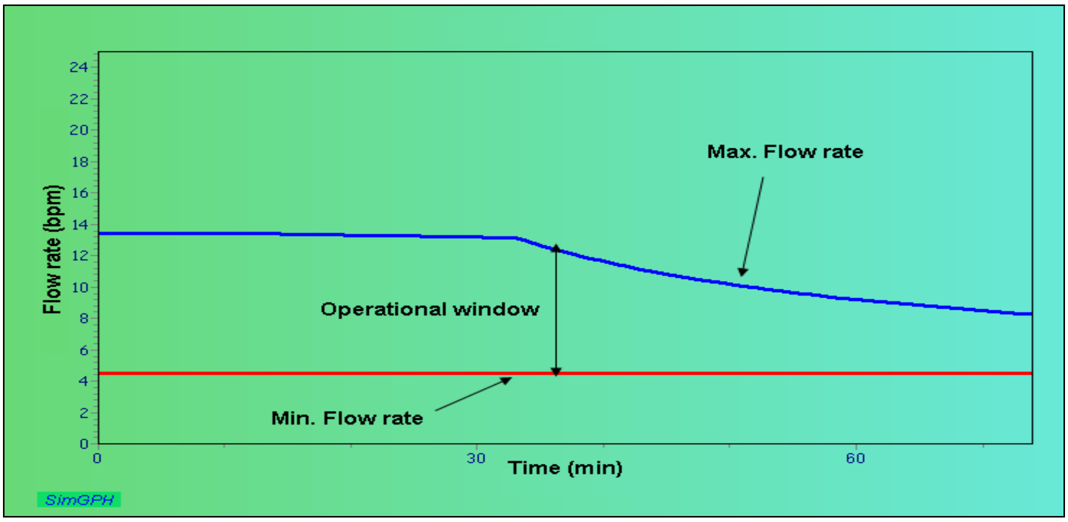

Figure 1. Gravel packing operational window.

3. Multiple Alpha Wave Design

The methodology described in the previous item allows gravel pack design with variable flow rate for different objectives. The focus in this article is the design of multiple alpha wave operations, which started to become popular due to the advantages previously discussed. This technique consists in to pump a gravel package under a flow rate schedule, which will be change along the operation. This schedule must keep downhole pressures always between the operational window limits.

In the beginning of placement, during the injection step, the mixture should be pumped at high flow rates in order to prevent sand sedimentation in the drill string. Alpha wave placement should start at high flow rates generating low bed heights, until fracture pressure (or a maximum safety pressure) is reached. As soon as the beta wave begins to be formed, a hard decrease in the flow rate that does not overcome fracture pressure upper limit can be noted (blue line in Figure 1). This is a result of the flow path deviation to the restricted annular space formed between screens and wash pipes. Starting from this point, a flow rate schedule to guarantee formation integrity is arranged by downward stairs. The flow rate would be then decreased and, consequently a new and higher alpha wave starts to form. This process would be repeated several times within a feasible flow rate range until the annulus is fully packed.

This strategy guarantees total screen coverage. If, for any well trajectory tortuosity or wash-out problem, it was not possible to displace the beta wave until total annular packing, the screens would be already protected by the multiple alpha waves placed. This is an interesting technique which allows gravel packing in narrow operational windows scenarios. In the next item we will show a critical scenario case study.

4. Case Study

In order to support a case study, a typical ultra-deepwater well design was simulated. Critical conditions were considered, such as: 2000 m water depth, 1500 m horizontal openhole length and low frac gradient. The input data for simulation follows and Fig. 2 shows the well path:

- Open hole diameter: 8 ½ in
- Rat hole diameter: 12 ¼ in
- Water depth: 2000 m
- Last casing shoe: 3175 m (MD); OD = 9 ⅝ in; weight = 47 lb/ft
- Open hole length: 1500 m
- Reservoir TVD: 2929.72 m or 9611.9 ft
- Screen: OD = 6.13 in; ID = 4.89 in
- Screen position: centralized
- Column: OD = 5 in; weigth = 19.5 lb/ft
- Wash pipe: OD = 4 in; ID = 3.48 in
- Kick off point: 2500 m
- Build up rate: 4º/100 ft
- Open hole inclination: 90º
- Fluid density: 9.1 ppg
- Gravel concentration: 1 lb/gal
- Gravel type: sand 20/40
- Fracture gradient: 0.58 psi/ft
- Pore pressure ECD: 8.60 ppg
- Fracture pressure ECD: 10.77 ppg
- Open BOP configuration

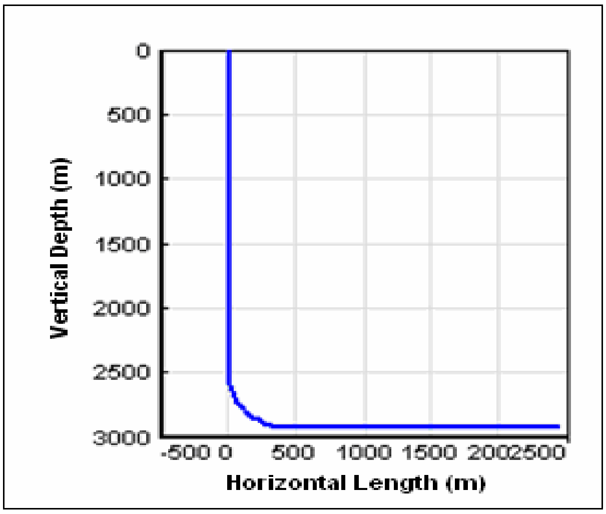

Figure 2. Simulated well path.

The case study software output is show in Fig. 3. The critical case was simulated and results indicate a narrow operational window at the end of beta wave placement. In this case, it is impossible to guarantee the total annular packing. After that, an alpha wave height search as function of flow rate was performed, as highlighted in Fig. 4. With these two simulations on hand, it was possible to set up an operational flow rate schedule, as show on Tab. 1. Figure 4 details the alpha waves generated by the proposed flow rate profile. For the present geometry, 72% of well diameter alpha wave height would be enough to promote total screen coverage. Pumping schedule started at 13.0 bpm and was reduced in steps every time the upper limit of the operational window was reached. Figure 4 indicates that, at the last flow rate step, a dune height of 76% was reached, guaranteeing total screen coverage even if the beta wave would not be concluded.

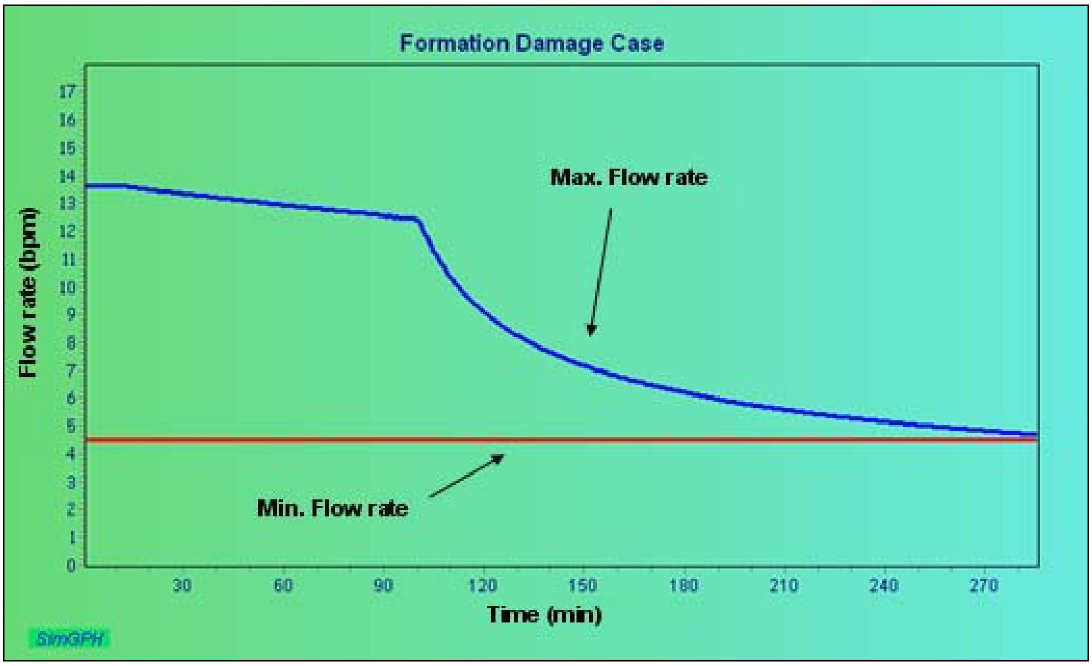

Figure 3. Operational window software’s output.

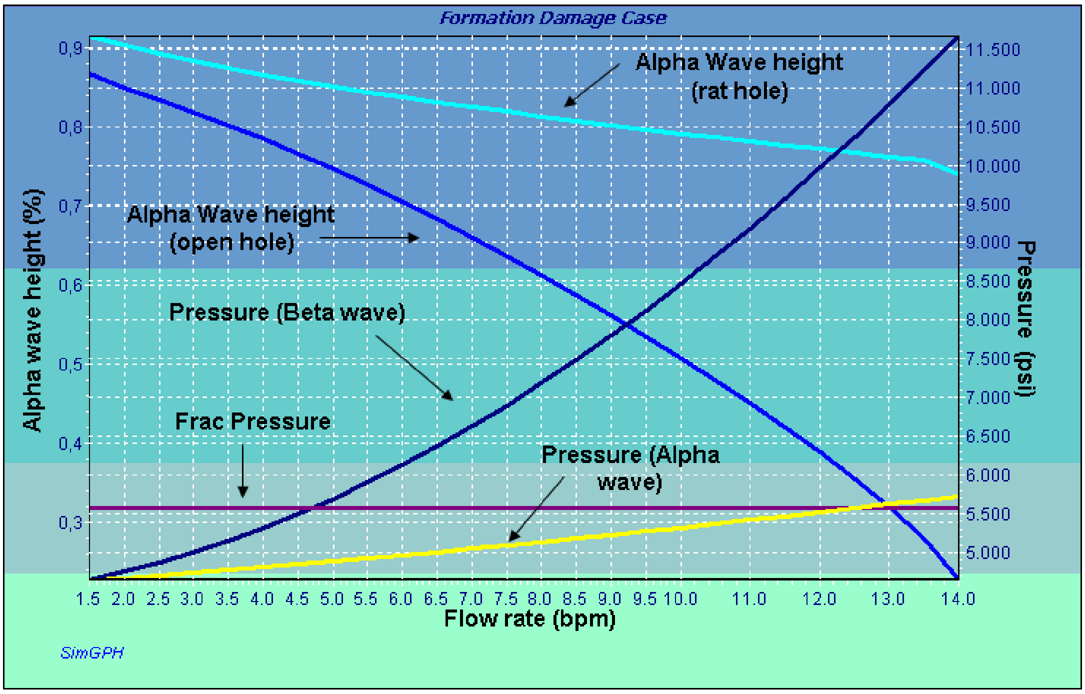

Figure 4. Simulated alpha wave height search.

Table 1. Flow rate program.

Range of Time	Flow Rate (bpm)	Alpha Wave Heights at Openhole (%)	Alpha Wave Heights at Rat-hole (%)
0 - 50 min.	13,0	0,32	0,76
50 - 100 min.	12,0	0,39	0,77
100 - 130 min.	8,0	0,61	0,81
130 - 180 min.	6,0	0,70	0,84
180 - 250 min.	5,0	0,75	0,85
250 - screen out	4,6	0,76	0,86
minimum height to cover the screen at openhole = 0.72%			

Figure 5 shows plots of the pumping schedule and associated alpha wave heights as function of the elapsed time. Is important to highlight, as previously mentioned, that for each new flow rate practiced on the beta wave stage a new alpha wave height is established on the top of the previous alpha wave placed. This will occur for the whole open well where the beta wave has not been placed yet. Figure 6 illustrates the beta wave propagation front as a function of the elapsed time. After 200 minutes of operation, 60% of the well will be packed and the alpha wave height for the flow rate of 5.0 bpm (Fig. 5) is high enough to cover the screens (Tab. 1).

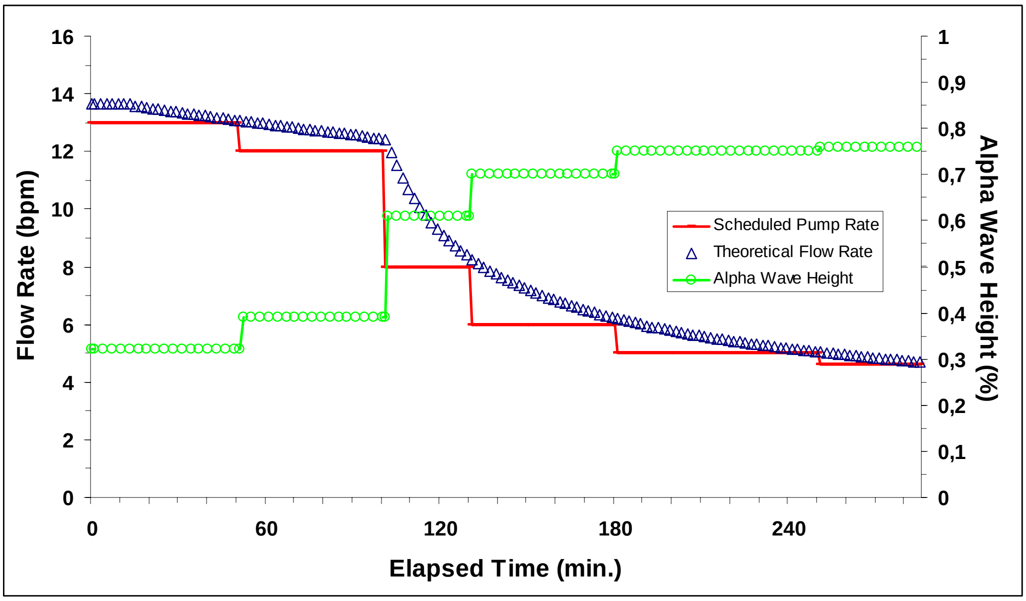

Figure 5. Multiple alpha wave operation.

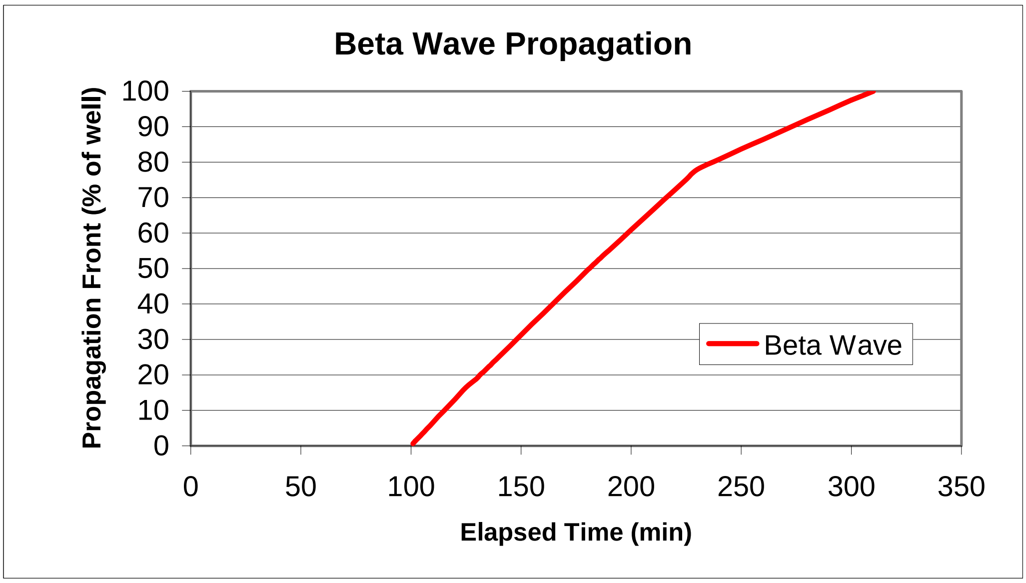

Figure 6. Beta wave propagation front as function of elapsed time.

5. Final Remarks

The presented methodology represents a link between gravel pack design and operational procedure. Defining pumping schedules which guarantee constant downhole pressures slightly below formation fracture is the major goal. Multiple alpha waves are an effective design and operational tool to achieve maximum packed area in critical operational conditions.

Multiple alpha wave design can be combined with other strategies to allow the extension of OHGP hydraulic limits, such as: reducing fluid density, zero rat hole configuration, light weight proppants, etc (Magalhaes *et al.*[2]).

6. Acknowledgments

The authors would like to thank Petrobras S.A. for the permission to publish this paper.

7. Nomenclature

ID = Inside diameter, in
OD = Outside diameter, in

8. References

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