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Development of an Oil Well Casing Program for Optimal Production

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Abstract

This paper deals with the development of a casing program on a well called A4-1 (for confidentiality reasons) for safe and cost-effective production. The data used are geological data and information on different depths. To achieve the paper's objective, first, the different casing installation depths are determined using Excel software, and the mud program required for drilling, as well as the different casing diameters, are found through analysis of the tool selection diagram. After calculating the various pressures and loads, the drilling handbook is used to select the different grades for each casing. The results show that, at a depth of 6480 feet, the surface casing has a diameter of 11"3/4, weight of 65 ppf, and grade K55. At a depth of 9,200 ft, an 8"5/8 diameter casing is used, with a weight of 44 ppf, and a grade C90. At depths of 10333.6 ft, the production casing is 6"5/8 in diameter, weighs 32 ppf, and is grade C90. The investment for the casing is profitable for a casing installation time of one month.

Keywords: Casing program; Mud program; Surface casing; Well drilling; Production casing; Economic evaluation.

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1- Introduction

Today, oil is still the world's most widely used energy source [1-3]. Oil is the basis of our consumer society, present in every moment of our daily lives [4-6]. To satisfy this permanent need for oil, oil exploration must be carried out (Nguyen, 1991). The purpose of oil exploration is to discover new oil deposits [7-9]. Drilling refers to all operations involved in drilling wells, usually vertical [10]. It refers to all the work involved in drilling and constructing a well to determine and confirm whether potential deposits really do contain oil. To exploit the oil deposits scattered around the world, it is necessary to drill wells [11-13]. The casing is an essential step in the installation of an oil well, an operation performed on a section of a well while drilling [14]. It is intended to consolidate the walls of a drilled section so that work on the next section can proceed under optimum conditions since the earth's subsoil is rife with various problems encountered during drilling operations [15-17]. These problems can be eliminated, others contained or controlled, and one of the important designs in the process is therefore steel tubing or casing [18-20]. The various casings of a well must be well established and safe, from the point of view of the mechanical and chemical stresses that can be generated by geological and operating conditions. It is therefore necessary to design a casing program that is more favorable to the well. That said, an underdeveloped casing program can make it impossible to reach the target, i.e. the reservoir, resulting in a complete failure of the work, and an overly heavy program can unjustifiably increase the cost price and reduce the number of wells that can be drilled within a given budget [21-23]. The environment in which the oil well is to be drilled is a real challenge, given the numerous constraints to be faced and the multitude of variables to be taken into account if the targeted objectives are to be achieved safely and cost-effectively. An absence of planning or a lack of planning would be a handicap for the operations and could lead to the insecurity of the personnel present on the site, a delay in completion, and abnormally high costs. Well A4-1 is located in the X field of the Y basin, so called for reasons of confidentiality. This paper asks what is the best casing design for a well, in order to produce hydrocarbons at the lowest possible cost. In other words, what is the best solution for achieving the objectives of complete safety, while at the same time minimizing the cost of the operation.

The aim of this paper is therefore to propose a detailed casing program for a directional well, enabling the target to be reached safely and economically. In order to achieve

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this main objective, specific objectives have been set: to determine casing shoe depths; to design a suitable mud program; to determine the various casing diameters and grades; to present the well profile, and to make an economic evaluation. This paper demonstrates that the application of computational determination techniques, Neals Adams diagram analysis, and the Drilling handbook applied to geological data, geophysical data, and economic data through eRedBook and Excel software appear to be effective in achieving these objectives. The paper is divided into three sections. The first section presents the introduction. The second section presents the data, the methods used, and the results obtained. The third section gives the conclusion.

2- Data, Methods, and Results

The well A4-1 data consists of well trajectory and profile data, field geological data, and depth information as shown in Table 1 to Table 3. The geological data in Table 1 are used to determine the various casing shoes.

Table 1. Geological Data

Depth in ft	Types of formation
0-196.8	Quaternary sandy-clay
196.8-393.6	Sandy
393.6-656	Clayey to sandy-clayey
656-2296	Sandstone
2296-4920	Cretaceous marly
4920-13120	Cretaceous sandstone
13120	Base

Table 2. Geological Sampling Program

Top of formation		MD in m	Top of formation (TVD) in m	Formation pressure in psi
Cretaceous system	Kome Fm	1095	1095	1 320.0
	Doba	2198.82	2196.06	4067.0
	Kedeni Fm	2504.32	2470.92	4504.0
	Mangara Fm	2860.28	2754.6	5984.0
	Mangara 2	3071.81	2918.9	6810.0
	Mangara 3	3259.52	3064.7	7000
Total Depth (TD)		3370	3150.49	8500

Well trajectory and profile data are presented in Table 3. The data in Table 1 and Table 2 are used to design and determine the casing shoes, the mud program, and the optimum casing program, as well as to carry out simulations involving calculations concerning the design of the well A4-1 casings. They are also a great help for the economic evaluation.

2.1. Methods

The methods used in this paper consist in calculating the different pressure gradients to determine the casing shoe and determining the density of the mud to find the right type of mud, then calculating by analyzing all possible cases to find the forces applied to the casing all this using eRedBooK and Excel software's.

2.1.1. Determining casing shoes and mud types

During drilling operations, the fixed depth is mainly determined by the following factors: mud weight and fracture gradient. The equivalent mud weight is the pressure divided by the actual vertical depth. The required hydrostatic mud pressure is taken to be equal to the formation pressure (p_f) + 200 psi, where 200 psi is the magnitude of the imbalance.

$$Mud\ pressure = p_f + 200 \tag{1}$$

Formation pressure and mud pressure gradients are calculated by dividing formation pressure and mud pressure by depth to obtain the gradient in psi/ft. The fracture gradient is calculated using the following equation:

$$FG = \left(\frac{v}{1-v}\right)\left(\frac{\sigma_v - p_f}{D}\right) + \frac{p_f}{D} \tag{2}$$

Where v=0,43 and 0,35 depending on the types of formation, $\frac{p_f}{D}$ is the formation pressure gradient and $\frac{\sigma_v}{D} =$ 1 psi/ft. The mud weight is obtained from the equation:

$$P = \rho.g.h \tag{3}$$

Where P is the hydrostatic pressure (psi), ρ the fluid density, g the acceleration due to gravity, and h the mud height. When the pore fluid is normally pressurized, the pore pressure (P_g) is assimilated to the hydrostatic pressure and is obtained by:

$$P_g = 0.052 \times MW.TD. \tag{4}$$

Where TD is the total depth. Hence, the mud weight (MW) is:

$$MW = \frac{P}{0{,}052 \times TD} \tag{5}$$

The pressure gradient of the pore is $P_g = 0{,}465$ psi/ft and the mud weight becomes:

$$MW = \frac{G}{0.052} \tag{6}$$

Where G is the gradient.

2.1.2. Determination of collapse pressure, burst pressure and axial stress/load

The initial step in casing design is to determine the design load, which will affect the calculation of burst, collapse and tension loads. After this, the internal and external pressures at each burst and collapse are calculated for each section. The worst-case scenario of loss of circulation when drilling mud enters the formation was taken into account to calculate the collapse pressure (C) through equation:

$$C = pression\ external\ pressure - internal\ pressure \tag{7}$$

Where for each result the value is multiplied by the safety factor. The safety factor is the value that allows a safety margin to be set for casings and in the case of collapse pressures its value is 1.1. Like the collapse pressure, the burst pressure (B) was found by considering the worst case which is the kick when the mud pressure is not sufficient to prevent fluids such as methane from entering the hole and it is obtained through the equation:

$$B = internal\ pressure - external\ pressure \tag{8}$$

In this case, the safety factor is 1.25. Axial tension or load is obtained using Eq. 9, which takes into account the maximum weight of each type of casing and the corresponding depth.

$$W = g.\rho.L \tag{9}$$

Where L is the depth of the casing.

2.2. Results

The depth of the well in this field is 10333.6 feet, taking into account only the true vertical depth (TVD). Calculations are made using EXCEL software and the results are presented in Table 3.

Table 3. Pressure

TVD (ft)	Pore pressure in psi	Mud Pressure in psi	Mud pressure gradient in psi/ft	Pore pressure gradient in psi/ft	Fracture gradient in psi/ft
3591.6	1 320.0	1520.0	0.42	0.37	0.84
6445.2	2 000.0	2200.0	0.34	0.31	0.68
7203.1	4 067.0	4267.0	0.59	0.56	0.80
8104.6	4 504.0	4704.0	0.58	0.56	0.79
9035.1	5 984.0	6184.0	0.68	0.66	0.84
9574.0	6 810.0	7010.0	0.73	0.71	0.87
10052.2	7 000.0	7200.0	0.72	0.70	0.86
10333.6	8 500.0	8700.0	0.84	0.82	0.92

The various results presented in Table 3 are obtained following the application of Eqs. 1 and 2. It shows the different mud and formation pressure gradients, and the fracture gradient obtained using Eq. 2. It can be seen that as formation pressure increases, so does the mud gradient. The first column and the fourth, fifth, and sixth columns yielded the pressure gradient versus depth curves shown in Fig. 1.

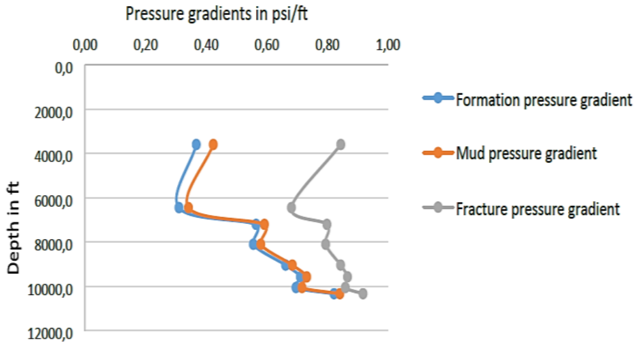


Fig. 1. Curve Showing Pressure Gradients as a Function of Depth

Fig. 1 shows that the fracture gradient is greater than the mud gradient, which is greater than the formation pressure gradient. This result is acceptable in the sense that if the fracture gradient is lower than the mud gradient, the well will fracture. Similarly, if the mud gradient is lower than the formation pressure, an underbalance will occur, causing the well to collapse. Fig. 1 is used to highlight the different casing shoes and the corresponding mud gradient shown in Fig. 2.

The results in Fig. 2 demonstrate the selection of different casing shoes. Fig. 2 shows the formation, mud, and fracture pressure gradients as a function of depth. We started with the highest mud weight; the highest mud weight is used at TD. From the TD hole (10336.25 ft), a vertical line (line 1) was drawn through the mud gradient until it crossed the fracture gradient line. In this paper, the mud gradient at TD is 0.84 psi/ft, and a vertical line through it (line 1 in Fig. 2) intersects the fracture gradient line at 9200 ft (point A in Fig. 2). Above 9200 ft, the mud gradient, 0.84 psi/ft, will exceed the fracture gradient until a certain depth between 2000-4000 ft where the mud gradient will touch the fracture gradient. This means that if it intends to drill with this density to the surface, the opening section of the hole will fracture, and this section must therefore be cased before bringing up the mud weight to 0.94 psi/ft to drill the lower section. Between 9200 ft and 10336.25 ft, the open hole must be cased with either a production casing or a production liner. Above 9200 ft the hole must be drilled with a mud weight of less than 0.94 psi/ft. The new mud gradient is obtained by drawing a horizontal line from point A to the mud gradient line. Point B in Fig. 2 gives the new sludge gradient at 0.685 psi/ft. It moves vertically from point B (line 2) until the fracture gradient line is intercepted at 6480 ft at point C. Point C establishes the maximum depth that can be drilled before transitioning to the new mud gradient of 0.685 psi/ft. Thus, between points B and C, an intermediate casing can be set at point B. From point C, move horizontally along the mud gradient line to point D, where the mud gradient is 0.37 psi/ft. A vertical line from point D (line 3) shows that a hole can be drilled with a mud gradient of 0.68 psi/ft at the surface without fracturing the formation, but there is a risk of Under balance as the vertical line from point D touches the formation pressure gradient, so the hole must be drilled with a value slightly greater than 0.37, but this value must not be too large either at the risk of fracturing. However, with a mud gradient of 0.40 psi/ft, a hole can be drilled down to the surface. So, a surface casing can be set at point D.

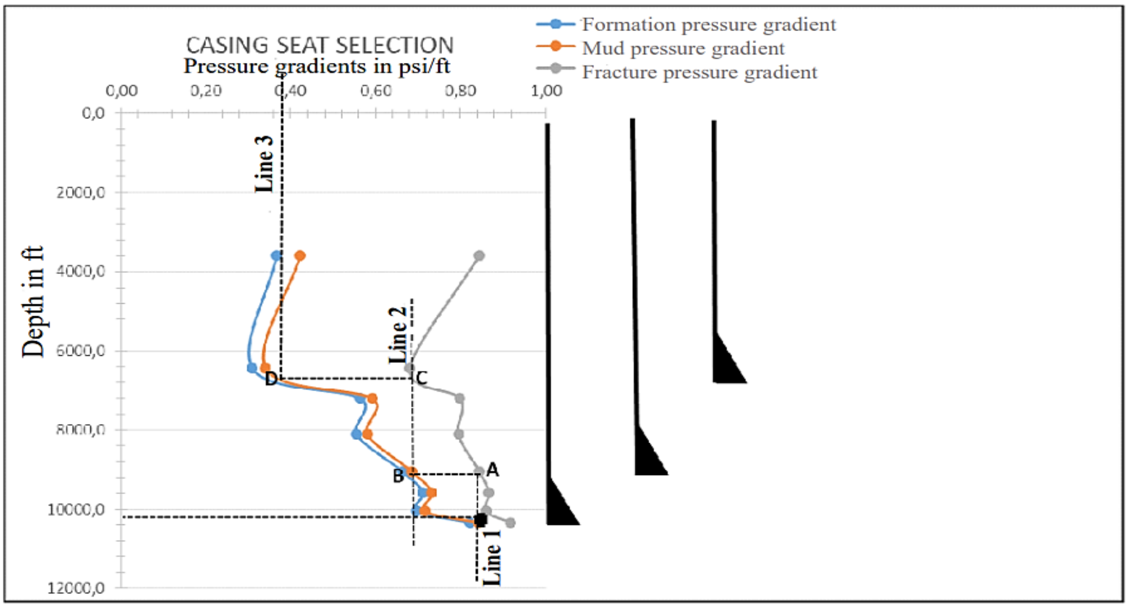


Fig. 2. Casing Shoe Selection

2.2.1. Well configuration

For safe and successful drilling, fluid pressure should always be higher than pore pressure, under both static and dynamic conditions. However, it should not exceed the fracture gradient. Using the equations presented in subsection 2.1, the mud parameters obtained are presented in Table 4.

Table 4. Mud Parameters

TVD	PP (ppg)	FP (ppg)	MW (ppg)	Df (sg)
3591.6	7.07	16.24	8.14	0.98
6445.2	5.97	13.11	6.56	0.79
7203.1	10.86	15.37	11.39	1.37
8104.6	10.69	15.29	11.16	1.34
9035.1	12.74	16.23	13.16	1.58
9 574.0	13.68	16.67	14.08	1.69
10052.2	13.39	16.54	13.77	1.65
10333.6	15.82	17.66	16.19	1.94

For each drilling phase, the different mud properties are:

- For the 11"3/4 surface column phase: At depth 6480 ft, pore pressure is 6.15 ppg, fracture pressure 13.08 ppg. The drilling mud used will be water-based (WBM) with a pressure of 6.65 ppg. The permissible mud density is 0.79 sg.
- For the 8"5/8 intermediate column phase: At a depth of 9200 ft, pore pressure is 12.88 ppg, fracture pressure 16.35 ppg. The drilling mud used will be water-based (WBM) with a pressure of 13.16 ppg. The permitted mud density is 1.58 sg.
- For the 6"5/8 production column phase: At depth 10333.6 ft, pore pressure is 15.82 ppg, fracture pressure 17.16 ppg. WBM is characterized by a pressure of 6.65 ppg. The permissible mud density is 1.94 sg.

Table 5 summarizes the results obtained.

Table 5. Summary Table

Type of casing	Depth	Mud density	Mud type
Surface casing	3591,6-6480	7.69	WBM
Intermediate casing	6480-9200	13.17	WBM
Production casing	9200-10333.6	16.15	WBM

Worst-case collapse and burst are shown in Table 6.

Table 6. Worst-case Collapse and Burst

	Collapse pressure				**Burst pressure**	
	Short run		Long run		_	
	Surface	Depth	Surface	Depth	Surface	Depth
Guiding casing (30 ft)	—	—	0	11.02	—	—
Surface casing (6480 ft)	0	2591.22	0	2010,80	3346.69	1983.89
Intermediate casing (9200 ft)	0	6300.53	0	6093.2	5852.60	679.38
Production casing (10333.6 ft)	0	8678.16	0	8500	7466.64	2300.62

Collapse and burst pressures at the guide columns are negligible, as the pressure at the top is not too great. This is a worst-case scenario for the shaft. As far as collapse pressures are concerned, the short-term at depth is more important than the long-term at depth. It is their value that is considered for each casing by multiplying by the safety factor and also for burst pressures it is found that the greatest values are at the surface, which is why each surface value is multiplied by the safety factor shown in Table 7.

Table 7. Collapse and Final Burst and Tension

	Collapse pressure	Burst pressure	Tension
Guiding casing	—	—	—
Surface casing	2720.78	3932.36	49846.15
Intermediate casing	6615.55	6876.81	121192.31
Production casing	9112.07	8773.30	166927.38

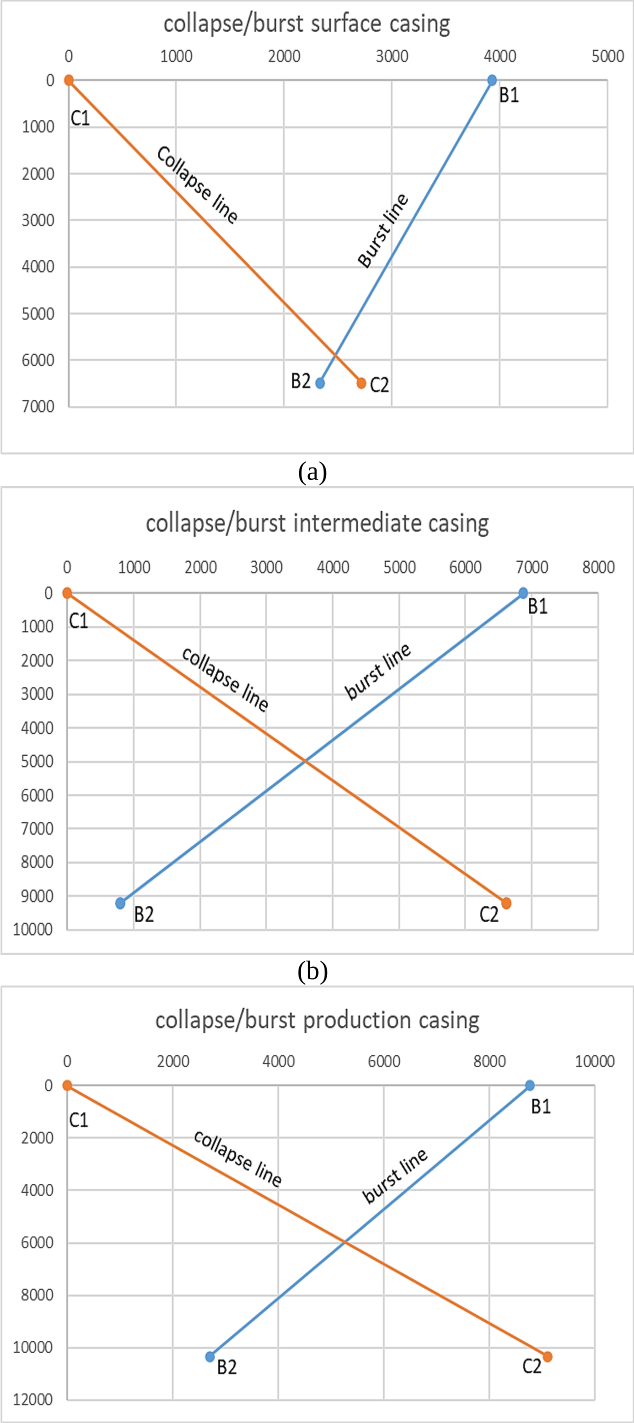
In order to optimize casings for the well A4-1, casing grades must first be selected on the basis of burst and collapse pressures. To do this, a graph of pressure versus depth is plotted for each casing type, as shown in Fig. 3, starting with depth and pressure scales at zero.

Collapse Line is the straight line passing through point C1 at zero depth and point C2 at the CSD Burst Line: plot point B1 at zero depth and point B2 at the CSD (see Fig. 3 a). The collapse Line is the straight line passing through point C1 at zero depth and point C2 at the CSD Burst Line: plot point B1 at zero depth and point B2 at the CSD (see Fig. 3 b). Having obtained these different curves illustrating collapse and bursting pressures, other curves of collapse pressure and bursting strength of the available casing taking into account the safety factor were drawn as shown in Fig. 3 for the different grades. Casing strings satisfying both collapse pressure and burst pressure were selected. Fig. 4 shows the variation in internal and external pressure in the surface column and two grades of the same diameter:

- The gray and black lines represent the grade of a K55 casing with a weight of 65 lb/ft;
- The yellow and green lines represent the grade of a L80 casing with a weight of 60 lb/ft.

For collapses below 6000 ft, grade K55 presents no problem, but beyond this value, the casing will not withstand collapse pressure, as shown in Fig. 4. L80, on the other hand, will withstand collapse perfectly, but at burst level, this will be problematic. For good productivity and optimum good life, the choice remains with K55 grade surface casing with a capacity of 65 lb/ft, which has a pressure of 3291.5 psi for collapse and 4379 psi for burst, which is higher than the collapse and burst pressures at the surface column level. Fig. 5 shows the selection based on internal and external pressures for the intermediate casing. The external pressures of the intermediate casing range from 0 to 6615.5 psi, and the internal pressure from 0 to 6876.8 psi. Sizing resulted in three casing grades.

- L80 and N80 grade casing with the same 44 lb/ft capacities and the same constant internal and external pressures of 6945.5 psi for external pressures and 8120 psi for internal pressures.
- A C90 grade casing, also with a 44 lb/ft capacity, with an internal pressure of 9135 psi and an external pressure of 7496.5 psi. This brings us to the latter choice.



(a)

(b)

(c)

Fig. 3. Collapse/Burst of: (a) Surface, (b) Intermediate, and (c) Production Casings

It can be seen from Fig. 5 that, for good productivity and optimum well life, the choice remains with a C90 grade surface casing of 44 lb/ft capacity, which has an internal and external pressure higher than the collapse and burst pressures at the intermediate column. The production string grade chosen is C90, which has a collapse pressure of 11324.5 psi and a burst pressure of 11295.5 psi, well above the collapse and burst pressures of the production casing shown in Fig. 6.

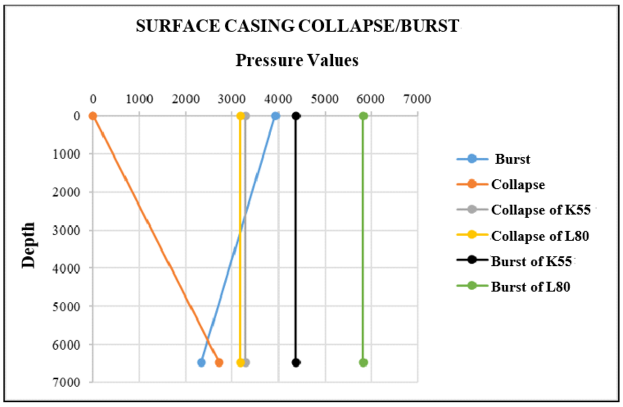


Fig. 4. Selection based on the Collapse and Burst of the Surface Casing

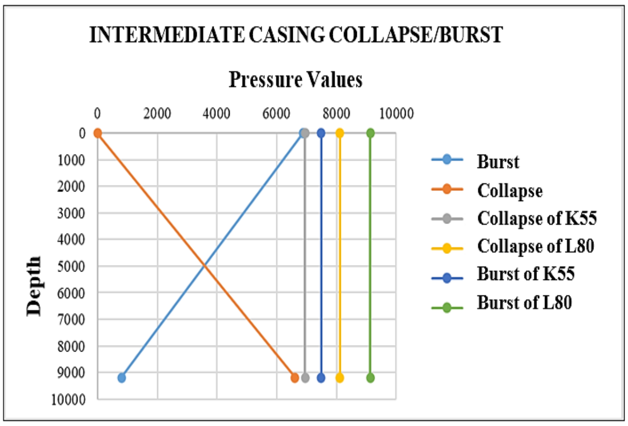


Fig. 5. Selection based on the Collapse/Burst of the Intermediate Casing

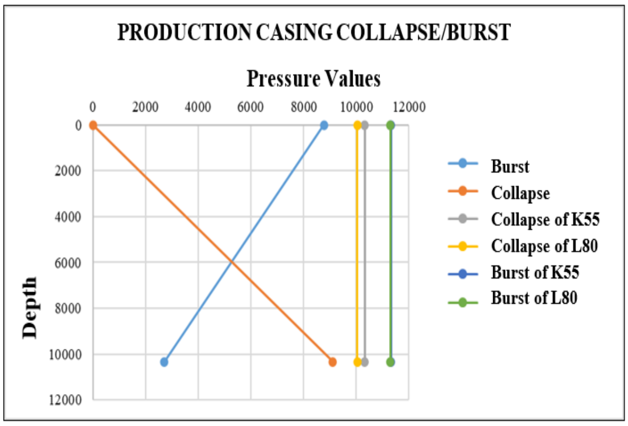


Fig. 6. Selection based on the Collapse/Burst of the Production Casing

Analysis of the various curves shown in Fig. 4 to Fig. 6 is produced in Table 8, which clearly presents the casing specifications obtained using different calculation methods. Table 8 shows the different grades, internal and external diameters, and pressures.

Table 8. Casing Specifications

Casing OD (inch)	**11''3/4**	**8''5/8**	**6''5/8**
Depth (ft)	6480	9200	10333.6
Type of connection	BTC	BTC	BTC
Weight (lb/ft)	65	44	32
ID (inch)	10.682	7.625	5.675
Grade	K55	C90	C90
Burst load (psi)	3944	99193	12745.5
Collapse load (psi)	2566.5	6960	9106

With the various results obtained, a design of the well profile is obtained through the eRedBook software presented in Fig. 7.

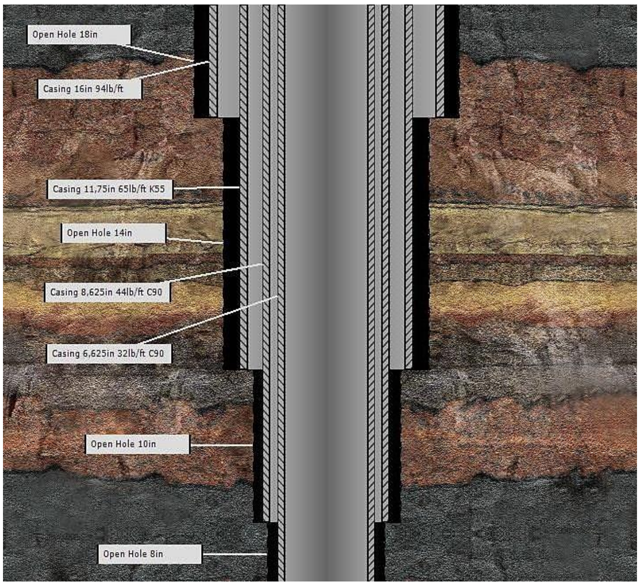


Fig. 7. Representative Scheme of the Profile of Well A4-1

2.2.2. Economic evaluation

An economic evaluation is carried out to determine whether the project is economically viable. The nominal weights in lb/ft and the total weight of the different casing grades and their lengths are presented in Table 9.

Table 9 shows the weights in tones and prices of the various casings. Table 10 shows a comparison of when the well is dead and when it is producing.

Table 10 shows the production rate per month, the price per barrel of oil, and the total cost of casing. The production limit is 1000 STB/d, so to obtain the total expenditure shown in Table 11, all the total prices for the different grades are added up.

In one month, the sum earned is $0 when the well is dead and $2790000 when the well is producing. The difference between the expenses incurred is a negative value in the case of the dead well and a positive value in the case of the producing well, as shown in Table 11. For the dead well, there is a negative value and no profit. However, in the case of the producing well, it can be seen that the income is quite substantial. The sum of $448230 spent on a producing well is positive, so the investment in the casing is profitable and contributes positively to the bottom line.

Table 9. Casing Grade Weights and Prices per Ton

Grade	Maximum weight in lb/ft	Length in ft	Total weight in lb	Weight in Ton	Price in $/Ton	Price in $
K55	65	6480	421200	191.05	780	149019
C90	44	9200	404800	183.61	1000	183610
C90	32	10333.6	330675.2	149.99	1000	149990

Table 10. Production Rate per Month and Total Oil Price

	Dead well	Production well
Rate in bbl/month	0	31000
Oil Price in $/barrel	90	90
Total Price in $	448230	448230

Table 11. Revenue of the Project

	Dead well	Production well
Total price in $	448230	448230
Price of oil in $/month	0	2790000
Total price	-448230	2341770

3- Conclusion

At the end of this paper, the aim was to propose a casing program for well A4-1, in order to achieve safe and cost-effective production. To achieve this, we mainly used Excel and eRedBook software and a set of mathematical calculations to find the various parameters. At a depth of 6480 ft, a 14"3/4 tool will be used, an 11"3/4 diameter casing with a weight of 65 ppf, a K55 grade, and drilling fluid with a density of 7.69 sg. At a depth of 9200 ft, a 10"5/8 tool will be used, with 8"5/8 diameter casing weighing 44 ppf, grade C90 and mud density 13.17 ppg. At a depth of 10333.6 ft, a 7"7/8 tool will be used, with a 6" 5/8 diameter casing weighing 32 ppf, grade C90 and a drilling fluid density of 16.15 sg. In order to select a casing quality suitable for this study, the specific requirements of each column were met, taking into account the conditions of well A4-1. In addition, a thorough economic evaluation was carried out to ensure that potential revenues exceeded expenses, taking into account casing costs and oil prices. This study ensures proper design and effective cost management to maximize the profitability and sustainability of well A4-1 casing operations. It was demonstrated that the sum of $448230 spent on a producing well was positive. so the investment in the casing program was profitable and contributed positively to the bottom line.

Data Availability Statement

Data is available in the manuscript.

Conflict of Interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding Declarations

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تطوير برنامج تغليف آبار النفط للإنتاج الأمثل

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الخلاصة

يتناول هذا البحث تطوير برنامج بطانة البئر المسمى A4-1 (لأسباب تتعلق بالسرية) من أجل إنتاج آمن وفعال من حيث التكلفة. البيانات المستخدمة هي بيانات جيولوجية ومعلومات عن أعماق مختلفة. ولتحقيق هدف البحث، يتم أولاً تحديد أعماق تركيب البطانة المختلفة باستخدام برنامج اكسل، ويتم العثور عن طريق البرنامج على الطين المطلوب للحفر، وكذلك أقطار الغلاف المختلفة، من خلال تحليل مخطط اختيار الأداة. بعد حساب الضغوط والأحمال المختلفة، يتم استخدام دليل الحفر لاختيار الدرجات المختلفة لكل غلاف. أظهرت النتائج أنه على عمق ٦٤٨٠ قدم، يبلغ قطر بطانة الانبوب السطحي ١١و ثلاثة ارباع بوصة ووزن ٦٥ باوند / قدم وفئة K55 وعلى عمق ٩٢٠٠ قدم، يتم استخدام بطانة الانبوب بقطر ٨ بوصة وخمسة اثمان مع وزن ٤٤ باوند / قدم، ودرجة C90 وعلى عمق ١٠٣٣٣,٦ قدم، يبلغ قطر بطانة انبوب الإنتاج ٦ وخمسة اثمان بوصة ويزن ٣٢ باوند / قدم وهو من الدرجة C90. يعتبر الاستثمار في الغلاف مربحًا لمدة شهر واحد لتركيب الغلاف.

الكلمات المفتاحية: تصميم البطانة، تصميم سائل الحفر، البطانة السطحية، حفر الآبار، البطانة الانتاجية ، التقييم الاقتصادي.