Assessment of S–Profile for Multilateral Directional Well-Using Well Data

Yuri Ryagin[1], M. Arulmozhi[2,*], C. Christina Angelin[3], C. Satheesh[4]

[1]Department of Low Temperature Physics and Nanoscale Systems, Ural Federal University (UrFU), Yekaterinburg, Russia.
[2,3]Department of Mathematics, Dhaanish Ahmed College of Engineering, Chennai, Tamil Nadu, India.
[4]Department of Robotics and Automation, Dhaanish Ahmed College of Engineering, Chennai, Tamil Nadu, India.
yuri.ryagin@urfu.ru[1], arulmozhi.m@dhaanishcollege.in[2], christeenaangelin@gmail.com[3], satheesh@dhaanishcollege.in[4]

*Corresponding author

Abstract: A confidential service provider supplies geological data to design an S-profile in directional drilling. This data helps design the geometry of the S-profile and classify it into types of directional wells. It includes the bottom hole assembly and instruments for directional surveying, such as Thermo shields or battery packs. All this is connected with the correct application of calculation methods, along with the use of the following tools: multi-shot, single-shot, deflecting tools; high-torque, bent subs, whipstocks, jet bits, downhole motors, and turbine motors. These include vertical, horizontal, and transitional sections. Other points can also be observed inside the well, which are similarly important, such as the kickoff point, build section, tangent section, true vertical depth, measured depth, and start and drop sections. The components of the HDD, the bottom hole assembly, and the end points together specify the total depth of a well. The procedure will take into account the geometry of the directional well, ensuring accuracy in achieving the target depth of 2,262 meters. It is an all-around approach to the S-profile for developing directional drilling, improving its efficiency, accuracy, and applicability to various geological variations.

1. Introduction

The actual evaluation of S-Profile designs for multilateral directional wells is a critical aspect of modern drilling practice, particularly for complex geological formations that contain reservoirs [5]. Directional drilling has been a revolution for the oil and gas industry, as it enables the ability to reach certain reservoirs that could not be easily accessed by conventional vertical wells alone [12]. Advanced drilling practices provide for much more operational flexibility and resource optimisation, but also pose peculiar challenges. In many ways, it is a multiplanar version that combines vertical, buildup, tangent, and the optional drop to navigate through widely varying geological layers and hit your target zones more or less precisely, as described in Barreto and Schiozer [7]. This study evaluates the S-Profile's performance in conjunction with design considerations, using actual field well data to address key challenges, along with best operational practices [4]. The data presented here indicate that the reservoir exists within a geologically complex structure that requires a specific S-Profile type well design [9].

The measured total depth of the well was 2262 meters. However, initially, it had been drilled vertically to the measured depth of 258 m [1]. From this take-off point, the trajectory was gradually transformed into the buildup section, which resulted in a maximum angle of inclination of 40.23° at a depth of penetration of 708.12 m [3]. The buildup section aligns the trajectory with the target zone of the reservoir, which is one of the reasons that enhances resource recovery, as observed in other studies [10]. During this process, the angle of the tangent section was maintained to ensure maximum lateral drilling contacts with the reservoir [13]. The S-profile well is very instrumental and ideal for deeper laterally aligned reservoirs, compared to other boreholes created and left in operation [7].

The geometrical configuration begins with an initial vertical section, followed by a buildup section that redirects the trajectory to an angle of inclination, and then the tangent section, in which it continues at the same angle. There may be an optional drop section, where it will either return the well to a vertical position or continue at the current angle, depending on the reservoir geometry and production requirements [11]. This adaptability enables S-Profile wells to respond to changes in geology without significant inefficiency during operation, as demonstrated earlier by Zhang et al. [6]. Drilling an S-profile requires advanced equipment and technology for maintaining precision along the trajectory. The Measurement While Drilling tools play a significant role as they provide information regarding the wellbore trajectory during actual drilling. Using such real-time information, the operator can adjust and steer back onto the correct trajectory [1]. The buildup and tangent sections of the wellbore are steered using deflection tools such as jet bits, bent subs, and whipstocks [15]. In combination with advanced surveying instruments, these tools ensure that the well trajectory follows the planned S-Profile, thereby reducing the risk of complications related to deviation [8].

One of the important factors in this research was the critical parameters for the S-Profile well, which included the kickoff point, the buildup rate, the true vertical depth (TVD), measured depth (MD), and the drop rate, if any [4]. All these values were acquired with great care, ensuring the wellbore was stable and the stress related to the drill string was minimized [2]. Based on geological information and the limits of well operations, the inclination angle selected was 40.23°, balancing the requirement to access the reservoir efficiently against the risks of overshoot resulting in excessive deviation [14]. The operational challenges described for S-Profile wells are inherent to the complexity introduced by the directional drilling process. Constant monitoring of pre-wellbore stability and buildup, as well as tangent sections, is ensured through the maintenance of parameters involved in drilling, which include WOB, rotary speed, and mud characteristics [11]. This is associated with preventing the problems of wellbore collapse and equipment breakdown during the transition from vertical to inclined drilling, as in Botechia and Schiozer [10]. Without such analyses, it is clear that contingency planning and real-time decision-making are crucial in related research [13].

The other most critical component in this study is to integrate geological, seismic, and lithological data for optimising well design. For example, these datasets were analyzed, and various hazards were recognized and adjusted through modification of the well's trajectory [7]. Such a multidisciplinary approach necessitates the integration of efforts among geologists, drilling engineers, and specialists in the reservoir to ensure that the well design does not deviate from the objectives and goals of the study [6]. This, together with advanced techniques in geological modeling, further improved the accuracy of the well trajectory, a testament to the integration of information from different disciplines [14]. One of the distinctive features of S-Profile wells is that they return to a vertical or remain at an angle after the tangent section.

The choice would depend on the reservoir's geometry and the production plan [3]. Returning to the vertical simplifies production operations and enhances the integrity of a well; however, if it remains at an inclined angle, it increases contact with the reservoir and eventually leads to higher recoveries [9]. These demands therefore necessitate a well-constructed system, specifically, depending on the requirements of the reservoir, coupled with the recovery objectives [5]. This S-Profile well was executed very well and thus proved to be a viable approach to reaching challenging reservoirs [12]. It has been planned and executed according to the best industrial practices, which ensure operational efficiency with the least risk involved in the operation [15].

These results have been made possible by advanced tools and real-time data analysis, demonstrating that technological innovation has become very significant in modern drilling operations [2]. This study merits the findings based on the knowledge gained in the widening of S-Profile well reservoir applications and their various uses in multi-lateral directional drilling. Since deviated wells present technical challenges, valuable practical knowledge from design to actual well construction is essential for advancing new concepts in production, as seen in future papers on similar geology [4]. Notably, the depth of 2262 meters and the maximum angle of inclination of 40.23°, as obtained in the work as mentioned above, clearly present possible perspectives for optimising resource extraction from wells of such designs in complex reservoirs [13]. An assessment of design concepts for multilateral directional wells in terms of S-Profiles also illustrates the difficulty of managing complexity without new technologies and detailed planning, as well as the benefits of multidisciplinary integration [11]. This also testifies to the innovative approaches and technical expertise that have been employed so far in dealing with the complexities presented by the oil and gas industry, particularly in the successful design and execution of the well trajectory [7]. It confirms the effectiveness of S-Profile wells, providing a benchmark for optimizing design and execution in future papers [8]. It is the

strength of real-time data and advanced tools, along with a multidisciplinary approach, that makes S-Profile wells remain relevant over time for efficient and reliable resource extraction under challenging geological conditions [1].

2. Literature Review

Recovery of hydrocarbons from conventional reservoirs is depleting, and there has been an urgent need for innovative and economical solutions to extract oil from mature, marginal, and unconventional reservoirs [5]. Multilateral well technology promises to meet this challenge, and it is one of the tools to propel the oil and gas industry into the future [12]. This technology involves the extraction of resources with increased contact areas by using more branches or laterals of the main wellbore, and optimizing drainage area performance. This research utilizes architecture to examine how design parameters, such as branch density and lateral penetration level, influence the performance of homogeneous reservoirs [3]. Performance concerning anisotropic reservoirs is a key aspect of this paper, as issues related to changes in permeability and pressure gradients pose a significant challenge [8].

The results show that multilateral well technology can significantly enhance recovery rates and, therefore, is an economical technique for overcoming declining yields in conventional reservoirs [13]. One of the most important technologies applied in deep formations to search for and extract oil and gas is directional drilling [9]. Besides energy, directional drilling is now also applied to geothermal energy and the exploitation of geo-resources, in addition to international continental scientific drilling programs [14]. Indeed, from the 1890s, technology in drilling had taken tremendous leaps, advancing from simple vertical drilling to highly advanced directionally drilled horizontal drilling methods [7]. This overview provides an in-depth examination of the historical development and classification of drilling technologies, encompassing a comprehensive review of vertical, directional, and horizontal drilling technologies and their applications [4].

The application of the directional drilling technique offers an additional possibility for further improving the control of the wellbore trajectory, providing access to deeper and more complex reservoirs, particularly in the presence of deep and complex geological formations [10]. Such critical breakthroughs are witnessed in the design of tools for deflection, down-hole motors, rotary steerable drilling systems, and vertical drilling systems, which, together, enable a level of extremely high precision to be achieved while optimizing the directional drilling process [2]. Further development of exploration technologies revealed measurement and transmission technologies, which enhanced the observation of trajectories and increased the accuracy of observations [15]. Drilling bits can be classified into three categories, namely roller cone bits, fixed cutter bits, and hybrid bits, which accelerate the rate of formation drilling with high intensity [6].

Fluids used in drilling can be gas-based, water-based, or oil-based, and have played a critical role in maintaining wellbore stability, cooling the drill bit, and enhancing cuttings removal [11]. This summary highlights advancements in depth drilling and length, utilizing the top 15+ deepest holes in the world and the top 20+ longest holes in the world, with consideration given to technological competence and achievements as per [13]. Time, quality, and safety requirements can no longer be met solely in a construction budget. Now, it has become an emerging requirement for stakeholders, authorities, and the broader public to design a safer, more livable world for the remainder of the world [9]. Among the numerous trenchless utility methods that have gained popularity over time, one method inherently supports sustainability goals [5]. Advantages of HDD include reduced interference with traffic, businesses, and neighbourhoods; lower restoration costs; minimal dust generation; reduced noise; and lower import and export costs for construction materials [12].

This method is particularly useful in densely congested cities, where conventional methods are inapplicable due to the existing utilities [1]. HDD boasts several advantages, with minimal surface disruption being a key one. This results in reduced cutting time, making the technique a strong fit for paper with low cutting times. Regarding sustainability, HDD supports the principles of reduction, reuse, and recycling, as these practices minimise waste from material consumption, thereby mitigating adverse environmental impacts [11]. As is the case with every methodology, HDD also comes with its disadvantages that hinder its use. For example, factors such as very high upfront costs, the need for an operator with the necessary experience, and the likelihood of technical challenges when drilling into hard or erratic subsurface conditions should be balanced against [6]. This paper reviews the merits and demerits of HDD in the construction industry, with major emphasis on how it can accomplish local authority expectations as well as popular public aspirations towards sustainable development [13].

The S-profile is a drilling technique that utilises vertical, buildup, tangent, and drop sections to create an intricate curve path, thereby accessing difficult reservoirs with adequate penetration [8]. It is particularly suitable for papers involving complex geological formations and stringent operational constraints in directional drilling [10]. The technique also maximises contact with the reservoirs while keeping surface interference at a minimum; it is thus ideal for urban or environmentally sensitive areas [3]. On the other hand, complex tools and great control are required to implement its strategy effectively and at a low cost [7]. The latest multilateral well designs, directional drilling technologies, and S-profile techniques appear to be the most promising direction for addressing challenges in resource recovery from mature, marginal, and unconventional reservoirs [15].

These technologies offer innovative solutions in enhancing hydrocarbon recovery rates, adapting drilling activities to sustainability, and aligning with sustainable development principles [2]. This has placed the industry in a strategic position, enabling it to effectively meet the demands of modern energy and construction sectors seeking to harness the benefits of drilling tools, survey techniques, and fluid technologies [14]. This research examines how interdisciplinary cooperation, innovative design, and technological advancements can address the challenges hindering the development of sustainable and efficient reservoirs for the oil and gas industries and the construction sector [9].

3. Methodology S-Profile in Directional Drilling

Advanced drilling techniques for testing S-Profile in multilateral directional wells involve methodologies that combine innovative practices to pass through complex geological formations effectively and precisely. For diameters of 6 inches and above, long-radius methods were used in the initial phases of drilling with conventional tubulars. Gradual curvatures were between 2 and 5 degrees per hundred feet for a turning radius of 300 to 1,000 feet. That brought gentle curvatures, through which full drilling and completion equipment could access the bottom of such a well, allowing casing along its entire length for structural integrity and operational stability. Assemblies that could provide turn rates of 5 to 30 degrees per hundred feet were used in the intermediate-radius drilling. For such assemblies, curvatures tightened up to a minimum radius of 287 feet. However, the tighter the curves, the more trouble they caused with normal casing operations, and very frequently open-hole completions or special casing techniques were required. For moderately complex reservoirs, these methods were well within the approximate optimum balance between precision and efficiency.

For steeper and steeper angles, the borehole was to be curved a minimum of 30 to 40 feet for 4.5-inch bits, or as much as 50 to 60 feet for 6.25-inch bits. A drill string with whipstocks and the directional drilling assembly was drilled forward until inclination had been achieved to the required depth. Thus, in straight drilling assemblies, averages could range as low as 200 feet and as high as 900 feet in terms of lateral extensions. Short radius methods were perfectly suited to the type of well, particularly in unconventional reservoirs where horizontal drilling was required. High-radius, ultra-short radius methods enabled drain holes to be directly provided by the vertical well. This could be achieved with high-pressure nozzles equipped with flexible tubing that form high-pressure water horizontal extensions of relatively small diameters under high pressure, often hundreds of feet from a vertical wellbore. These became ideal for tight formations as well as some other unconventional reservoirs.

The steps as mentioned above were being supported by directional drilling. The technique aimed to overcome challenges such as water entry, field economics, and navigating difficult terrains, including rivers, cities, and mountains. The trajectory was controlled precisely with azimuth and deviation angles, with the proper underground survey acting as the guide. This was achieved using the sidetracking technique, which involves passing over or around any problem, such as a stuck drill string or, in some instances, more broadly referred to as a "fish," with the intention of drilling from just above the location of the problem to continue operations. Fault drilling techniques were utilised to eliminate casing shear by slipping along fault planes. The strategies sometimes avoided structural instability by designing wells drilled parallel to or across fault planes. Like salt domes, salt dome drilling was strategic and avoided problem zones, such as those that might cause washouts, lost circulation, and corrosion.

Wells were drilled around or below the salt domes to reach the production formations safely and efficiently. Relief wells were directionally drilled into the blowing well, and heavy mud was pumped down the well to stabilise and kill it. Thus, if there is an uncontrollable blowout, the operation becomes safe. There was also wildcatting or exploratory drilling, which was another integral part of the process. This involved drilling deviated wells from existing vertical wells to explore possible reservoirs at a lower cost. Since there was no requirement for a new surface and intermediate casing, wildcatting also saved costs while allowing for a full reservoir appraisal. Throughout the appraisal process of challenging well paths, advanced downhole motors, bent subs, rotary steerable systems, and jet nozzles were utilized. Information regarding real-time data from underground surveys ensured that accurate vertical and horizontal deviations could be maintained, allowing for the recovery of optimum resources. The integration of all the techniques used in S-Profile evaluation provided a strong foundation for overcoming the geological challenges in multilateral directional drilling operations to increase reservoir contact.

Figure 1 presents the workflow process for assessing and implementing an S-profile in multilateral directional drilling, including methods, techniques, tools, and optimisation. Four clusters are interlinked in groups, namely drilling methods, key techniques, advanced tools, and survey and optimisation. The Drilling Methods group can be further divided into three Turning Radius groups: Long-Radius (300-1000 ft), Medium-Radius (approximately 287 ft), and Short-Radius (30-40 ft), giving the impression that the radius of curvature continuously decreases as drilling complexity increases. Key Techniques fall under Directional Drilling, as it provides azimuthal and deviation controls. Sidetracking is used to bypass obstacles, such as stuck drill strings, and fault drilling is used to bypass fault planes.
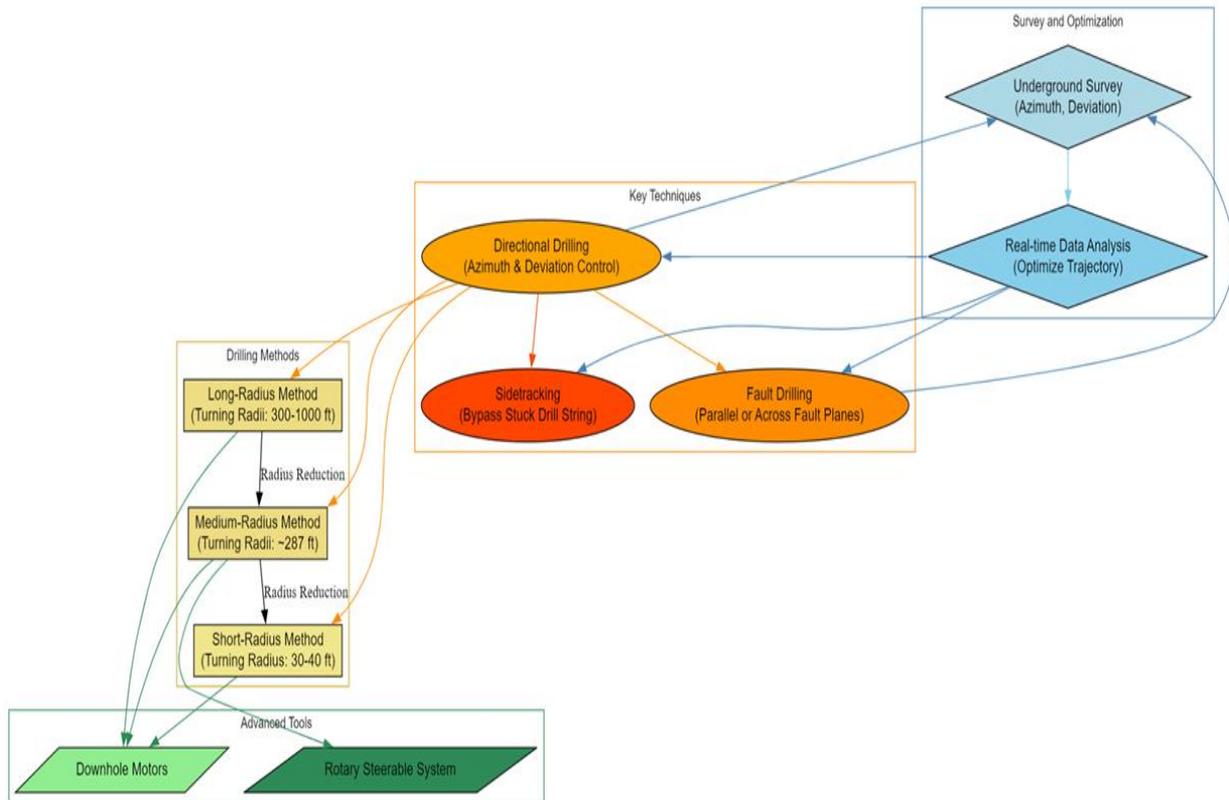
Figure 1: Workflow of S-Profile assessment and multilateral directional drilling techniques

These technologies ensure the maintenance of the wellbore's trajectory and stability. It comprises Downhole Motors, along with Rotary Steerable Systems, as a highly necessary apparatus to monitor with much better control and productivity regarding precision at trajectories in the Advanced Tools cluster. Approach Survey and Optimisation involve Underground Surveys for measurements on azimuth and deviation, as well as real-time data analysis of adjustments made concerning optimum utilisation of the extracted resources. Connections between clusters reflect the flow of information, as well as methods, tools, and techniques, into one another. For example, Directional Drilling impacts all radius-based techniques and is hence supported by tools like Downhole Motors. Information from surveys and real-time feeds informs the optimisation of techniques, ensuring key methods are effectively coordinated in drilling operations. This workflow illustrates an overall systematic process for the effective execution of S-Profile in geologically challenging environments.

4. Results

This therefore provides a comprehensive explanation of the types, applications, and critical parameters necessary for effective drilling operations, offering a thorough evaluation of the S-profile for drilling multilateral directional wells based on well data. There are three types of directional drilling: L, S, and J-profile, which provide solutions for reaching difficult spots in reservoirs under challenging geological and operational conditions. Among these, it is best suited for multi-zone production, relief wells, and other operations requiring a moderate or gentle change, where slight changes in inclination can be tolerated. The S-Profile deviates at a shallow depth and then approaches the maximum required inclination as closely as possible. That angle may be constant or gradually reduced towards vertical, depending on the aims of the operation. It requires robust monitoring and trajectory control for wellbore follow-up of the desired target.

The directionality of the wells is planned based on a correct foundation for a successful operation. Some of the most critical considerations include defining the surface and target coordinates, determining the size and shape of the targets, meeting inclination requirements, and addressing potential difficulties such as geological limitations or casing program limitations. Offset well data and historical bit and bottom hole assembly (BHA) performance guide planning. Three-dimensional visualisation of the well path is required to represent the geometry of S-Profile directional wells, including vertical and horizontal planes. Inclination, measured depth (MD), true vertical depth (TVD), and azimuth are the critical parameters for the trajectory planning and execution. Measured Depth (MD) calculation is given as:

$$MD = \int_0^T \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2}\, d \qquad (1)$$

Inclination Angle (θ) computation is:

$$\theta = \arccos\left(\frac{\Delta z}{\sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}}\right) \qquad (2)$$

Table 1: Measured depth parameters across S-profile zones

Zone's	Measured 1	Measured 2	Measured 3	Measured 4	Measured 5	Measured 6	Measured 7
Zone 1	245	829	124	959	467	265	106
Zone 2	214	253	907	603	243	917	722
Zone 3	533	977	427	365	551	155	992
Zone 4	528	239	117	163	266	351	956
Zone 5	957	503	146	193	486	894	869
Zone 6	261	938	185	634	500	837	343
Zone 7	616	377	279	624	894	938	213

Table 1 presents a tabulation of measured depth (MD) parameters for seven zones, labeled Zone 1 to Zone 7. The columns headed "Measured 1" to "Measured 7" depict a series of measurements taken as calculated at every step of the S-profile track. All the cells will be numeric, representing crossings with a measured depth segment of a zone; the value given is in uniform units. That is to say, it's either feet or meters. So, for example, Zone 1 in Measured 1 means the MD of the first stage of the initial zone. Generally, Table 1 is of considerable importance since it provides a broad view of vertical and horizontal displacement in the S-profile well, with some indications concerning geometric planning in general. For a driller, the values given in Table 1 provide a broad representation of the varying measured depths due to the difference between zones, and thus, in any case, either left-right or top-bottom. This enables accurate planning and trajectory adjustments, as well as the identification of patterns within the data. This may help identify areas that require intervention or adjustments in drilling to align with the target.
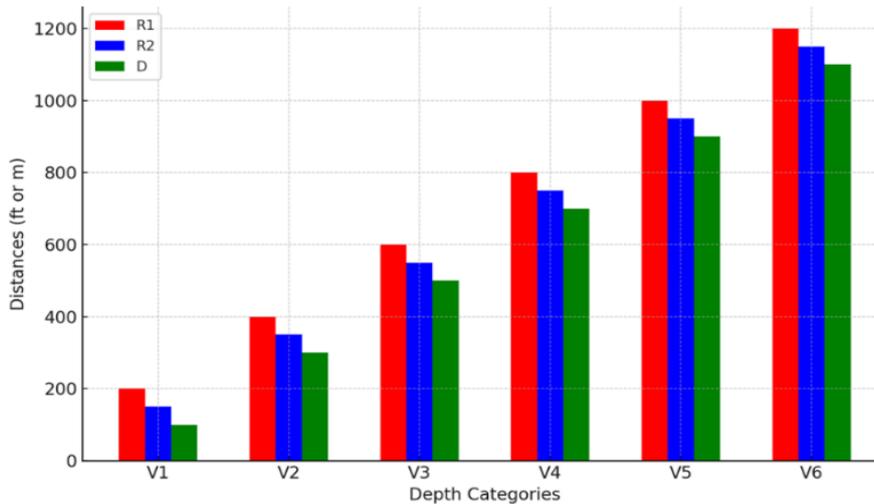

Figure 2: Depth and displacement representation for S-profile

Figure 2 presents the relation of depth categories (V1 to V6) and related displacements in three parameters: R1 (red), R2 (blue), and D (green). The grouped bar chart clearly illustrates the development of each parameter across all zones of depth, facilitating a discussion of the planning and performance of an S-profile directional well. R1, red is the greatest value in practically all the groups of depth measurements. It therefore primarily represents the measured depth or displacement obtained in the S-profile design. R2, blue will be of the second class in size, and it symbolises other kinds of measurements or deviations obtained during the same zone. And D, green shall represent another category of displacement or depth adjustment as usually required to obtain the proper target position in the trajectory of a well. Hence this diagram current implies step up with all variables: from V1 to V6 therefore this means in-depth displacement analysis this is, step by step process; consequently, in step by this model it states its ability of delivering S-profile during geometric transfer where there has an increment on it about the building-up and tangents

dropping and following to which comes trajectory align considering target geologico-physicial domains. In a grouped visualisation, comparisons can be easily made between R1, R2, and D at every depth category, and anomalies or deviations that may warrant corrective action can be identified. Generally, a graph is one of the primary tools in the analysis and optimization of depths and displacements involved in S-profile directional wells, which can benefit from improved decision-making during both the design and execution phases. Azimuth Angle (φ) determination is:

$$\varphi = \arctan\left(\frac{\Delta y}{\Delta x}\right) \tag{3}$$

Tortuosity Index (T) evaluation can be done as:

$$T = \frac{MD - TVD}{TVD} \times 100 \tag{4}$$

Where TVD is the True Vertical Depth.

The kickoff point, KOP, is the most important S-Profile milestone. This is an important point defining the deviation of the wellbore from the vertical track. This will depend on geological considerations and proximity to other wells that have already been drilled, as well as the intended geometry of the well. The buildup section of the kickoff process gradually increases the angle of inclination to the intended value. From here on, this section will control torque, drag, and all other mechanical limits. Critical accumulation rates are between 1.5 and 30 degrees per 100 feet; thus, the transition from the vertical to the tangent section is smooth and gentle. Then, in the tangent section, an angle is maintained over some length; hence, the shaft can now be extended into the desired zone with precision. This is just as important because it determines how the angle should be dropped to the wells, either coming back vertically or being driven at a certain bottom-hole angle. The mechanical capabilities of the drill string, the casing, and logging tools do influence these drop-off rates. In S-Profile wells, this computation is capable of controlling these drop-off rates without risking danger and ensuring a smooth pass-through throughout the entire wellbore.

Table 2: Geological reservoir properties by wells

	Reservoir A	Reservoir B	Reservoir C	Reservoir D	Reservoir E	Reservoir F	Reservoir G
Well A	439	326	755	1331	1364	1326	42
Well B	962	266	989	856	395	1286	1019
Well C	1066	664	898	478	1266	553	625
Well D	1105	1135	786	745	764	229	704
Well E	367	1011	398	1316	1435	235	1477
Well F	525	431	1065	209	515	1144	1418
Well G	739	722	694	1291	1419	470	401

Table 2 illustrates geological reservoir properties. The rows are Wells A through Wells G. The columns are Reservoir A through Reservoir G. Numerical values in cells track specific reservoir properties, such as pressure, porosity, or thickness, at the intersection of each well with each reservoir. For example, the value in the Well A and Reservoir A cell measures a reservoir characteristic unique to Well A. Table 2 is then applied to compute the variance in geological properties across several wells and different zones of reservoirs. Optimal placement strategies and optimization of well drainage strategies are computed through comparisons between values from wells and reservoirs. Of course, patterns in the data will also reveal geologic heterogeneity and help inform decisions for completion designs and more aggressive recovery methods. Results indicate that advanced tools and technologies are the critical enablers to achieving the planned trajectory.

4.1. Measurement While Drilling

The MWD tool can obtain real-time measurements of inclination and azimuth, allowing for on-the-fly adjustments. Magnetic survey tools, such as single-shot and multi-shot devices, can accurately measure wellbore direction and inclination, pointing towards the planned trajectory. Bent subs, whipstocks, and jet bits are deflection tools. All these tools enable the borehole to steer very accurately, especially in tight formations or less accessible environments. The research demonstrates that downhole motors can be effective for directional drilling purposes. Surface rotation is circumvented by providing direct rotation of the bit, thereby improving control over the well trajectory. Among the two major downhole types, the turbine and positive displacement are found. These are selected according to the needs of the operation. Turbine motors operate on multi-stage blade assemblies, providing rotation and positive displacement. They function based on the high-pressure flow of mud, which generates rotational force. Both have beneficial applications in drilling smooth, curved holes with less dogleg severity, as well as in maintaining the stability of the wellbore. *S*-Profile Curvature (*C*) analysis is:

$$C = \frac{1}{R} = \frac{|\Delta\varphi|}{\Delta L} \qquad\qquad (5)$$

Where R is the radius of curvature, $\Delta\varphi$ is the change in azimuth angle, and ΔL is the_C^r.
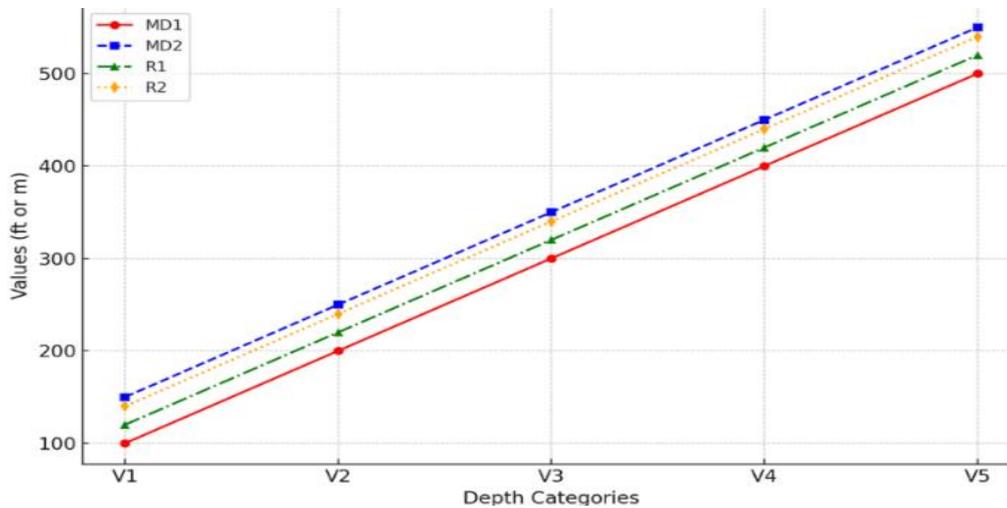

Figure 3: Representation of depth and displacement relationships

Figure 3 is the plot of measured depths MD1 and MD2, and radii R1 and R2 in five depth categories, V1 to V5, against depth. In Figure 3, the parameters are represented by four lines: red for MD1, blue for MD2, green for R1, and orange for R2. Each depth category represents a particular depth in the vertical direction; hence, their study provides a comparative analysis of these parameters in the S-profile well trajectory. MD1 and MD2 measured depths indicate an increasing trend by depth classes. The measured depth MD2 represents a second correction that is always greater than MD1; therefore, this accounts for the alignment of trajectories during measurements. Similarly, R1 and R2 represent radii that show the positive trend holds good for the curvature change of the S-profile.

Their values are on the higher side for R2, indicating better adjustments towards a softer trajectory at the deeper points. The same graph illustrates the dependency between depth measurements and how the design works in the radius for planning and designing an S-profile well. Consistent spacing and an upward trend for all parameters have indicated efficient geometric planning and the execution of a well trajectory. This multi-line representation provides an easy way to compare parameters, allowing engineers to identify areas of dispute or potential optimisations. In this regard, Figure 3 provides an overall overview of depth-displacement relationships; thus, it is vital for understanding and refining the design of the well and the drilling process itself.

The three principles of directional drilling techniques include pendulum, fulcrum, and the packed-hole stabilisation used in S-Profile well design. Thus, the Pendulum principle depresses the angle through gravity when deflecting the wellbore back into a vertical condition. The fulcrum principle raises the angle through a near-bit stabiliser acting like a fulcrum. Packed-hole stabilisation implies that more than one full-gauge stabiliser is used, and this provides an angle and direction stability in the tangent section of the wellbore. Such practices can be flexible and establish a necessary adjustment trajectory with reduced risk and increased efficiency. Applications of S-profiles and multilateral directional wells are numerous and demonstrate their effectiveness in overcoming most operational problems posed. For example, sidetracking is utilised to bypass "fish" or stuck drill strings while maintaining the intended well path without interruption. Drilling through faults and salt domes is performed in a manner that allows for safe drilling past problematic geology. Structural risks such as casing shear are thus eliminated. The last significant application of directional drilling involves the use of heavy mud to kill by blowing relief wells across to these areas. This application is critical to highly mitigative techniques, such as mitigating risks associated with blowouts and operational risks.

The horizontal and multilateral drilling technique significantly expands the capabilities of directional drilling. These are multilateral wells, wherein two or more branches protrude from a single wellbore, thereby increasing exposure of the reservoirs and enhancing recovery rates. This type of well has been especially useful in placing more efficiently into high-permeability zones and minimizing water and gas coning, as well as accelerating production from thin reservoirs. Horizontal wells have cumulative production nearly six times that of conventional wells, and therefore, have provided the background for establishing

multilateral technology. Multilateral well data from the study support the following: cost-effective operation of the multilateral system; operational performance better than conventional for open-hole wells; and optimised reservoir drainage efficiency.

Horizontal directional drilling is now the fastest-growing segment in directional drilling, entering most infrastructure projects. HDD is one of the forms of trenchless technology used for pipe, conduit, and cable installations, causing minimal disturbance to the surface. The processes involved include site investigation and design, pilot hole drilling, hole enlargement, and pullback. HDD advantages include reducing completion time, minimizing environmental impact, and enhancing wellbore stability. However, it requires specialized equipment and highly skilled operators, making it expensive but rewarding for complex paper. The results also indicate the importance of surveying tools for monitoring the progress and accuracy of directional wells. Surveys are performed to verify that the intended trajectory is followed, to prevent collisions with other wells, and to determine the bottom-hole location. Data from sources such as inclination-only devices, magnetic single-shot and multi-shot tools, and advanced MWD systems provides valuable data for decision-making.

This data also enables operators to calculate dogleg severity, optimise trajectories, and address deviations in real-time. This gives S-Profile wells distinct designs in geometry, with aspects that account for maximum efficiency and precision in S-Profile. Parameters of such conclusions in this study depend on the coordinates on the surface and targets, target displacements, angle levels of inclinates, and the azimuth and building up, as well as the rate of fall off. All these aspects can be incorporated within a well's structure, thereby providing an operator with a seamless transition through all sections of the wellbore without leaving parts of the targeted zone untreated, while minimizing operational risks. This appraisal highlights the impact that S-Profile and multi-lateral directional wells will have on the oil and gas industry. In this context, geology and operational problems can be easily addressed through the complete removal of these aspects, leveraging state-of-the-art equipment, technological applications, and planning skills at full reservoir contact, alongside the effective utilization of production efficiency. The proper knowledge of designing and executing a good S-Profile enables its application in further building directional drilling, with potential applications in resource extraction, sustainable use, and reduced operational costs.

5. Discussions

Graphical presentation of the data, tables, and figures from the S-profile directional wells results facilitates the review. However, based on key parameters, displacement-depth relations, geological constraints, and drilling plans, it ensures proper design and practice of the well. Table 1: Important parameters of S-profile design: Kickoff depth, Buildup rate, Drop-off rate, Total horizontal displacement. The following values illustrate how these calculations must be refined to achieve accurate geometric planning in directional wells. For example, the depth of kickoff is that critical point wherein the trajectory is no longer perpendicular, and the buildup and drop-off rates are the smooth markers of transitions in the trajectory through different geological structures. This information, therefore, underscores the critical necessity for proper planning and tight, real-time monitoring to ensure the accomplishment of the requisite objectives for the reservoir alongside the successful realization of the entire drilling operation. Table 2 elaborates on the geological reservoir properties, including possible variations in parameters such as pressure and porosity, as well as risks, such as mud loss. The interplay between the reservoir and the trajectory for optimisation presents challenges, including water intrusion into casing instability or the avoidance of issues in a salt dome, which could significantly contribute to these areas.

Relationship between depth displacement illustrated in figures from figure 2: There, the depths (MD, HD, and radii: R1 and R2), inclusive of the incremental displacement in each case, through all the gauged intervals. This Figure illustrates the competency of S-profile design in ensuring alignment with geological targets along the trajectory. Progress along the categories of depth and displacement values depicts how the planning phases have proved effective in delivering the required geometric transition as planned. Differences in R1-R2, along with horizontal displacement, depict the changes made to improve the trajectory and ensure easy wellbore geometry. These would create room for the buildup, tangent, and drop-off sections of the S-profile - vital access modes to multi-zone reservoirs or other geologic obstacles such as faults and salt domes.

This continues Figure 3 comparisons of measured depths (MD1 and MD2) and radii (R1 and R2) across the different depth categories. D. Hespondingly, interlinks between these variables become critical for ensuring an optimum wellbore trajectory while achieving maximum possible production. Therefore, uptrending trends in the measured depths, as well as the radii, support the adequacy of geometrical planning precision. Minor differences between MD1 and MD2, as well as between R1 and R2, result from minor real-time corrections imposed by geology or other operations. All these changes are based on the principles of directional drilling, which incorporates techniques such as pendulum and fulcrum, where either the angle of the wellbore is kept unchanged or altered throughout the process. Thus, in this visual comparison of these parameters, Figure 3 will demonstrate how online monitoring and decision-making align with intended targets and optimize contacts in the reservoirs.

Together, tables and figures sum up the overall importance of directional well planning in efficient drilling operations. The basics of the S-profile design include KOP, buildup rates, tangent sections, and drop-off rates that will provide a smooth

transition and good alignment with reservoir targets. Advanced instruments, such as magnetic survey tools and MWD systems, are crucial for real-time monitoring of these parameters, allowing operators to implement corrective actions and minimize deviations. The progress of figures 2 and 3 consistently underscores the importance of deflection tools, including bent subs and downhole motors, which guide the wellbore through complex formations while maintaining stability in the trajectory. Table 2: Geological view. This is equally important because it discusses how the reservoir's properties will influence the design and implementation of the well. Heterogeneity of pressure and porosity necessitates tailored mitigation measures to address the risks involved, such as mud loss, casing shear, and water or gas coning. These risks occur significantly enough in multi-lateral wells, which strive for maximum contact of the wellbore with the reservoir via entry zones at multiple points within a single structure. As demonstrated in Figure 3, the trajectory planning aligned with the reservoir's characteristics will enhance production, thereby minimizing environmental and operational risks.

The directional S-profile wells possess immense value in overcoming the complex challenges posed by reservoirs. The measured depth increases in progressive amounts as illustrated in Figure 2. Such measured depths, coupled with the horizontal displacements, ascertain that S-profile designs are efficient for crossing harsh geological settings. The further growth in both R1 and R2 radii suggests curvature should be optimised for smooth transitions between the vertical, tangential, and dead-end corners of a fractal well plan. Such transitions are crucial to wellbore stability and must be maintained as closely as possible to geologic objectives. The results thus suggest that multilateral and horizontal drilling services would be the efficiency generators in production.

Being equipped with various branches from a single wellbore, multilateral wells are effective in increasing reservoir exposure and connecting high-permeability zones. Table 2 knowledge helps to affirm these methods with economic and operational advantages through a better understanding of the properties and implications in the well design of the reservoir. It integrates sophisticated tools, such as MWD systems and magnetic survey instruments, with the principles of geometric planning. The data and graphs in the paper appear to reflect real-time monitoring of issues such as deviations, geological inconsistencies, and equipment limitations. For instance, Figure 3 illustrates trends in how measured depths and radii are frequently adjusted to stabilize the trajectory and optimize production. All of these can be considered part of common practice, serving as a fulcrum or the stabilizing element placed in packed holes, to attain angles within the tangent section of wellbores and sustain them throughout the tangent length.

The results of the study also present lateral balancing, along with measured depth, as it affects S-profile well designs. Figure 2 illustrates the effect of increased categories of displacement on the progressive alignment accuracy related to reservoir targets. This latter aspect is particularly critical in the construction of bypasses, especially in the event of geological obstacles such as salt domes or faults, which require proper planning and execution. Figures 2 and 3 together demonstrate trends that prove the effectiveness of S-profile wells in maximizing the total drainage of the reservoir with improved production efficiency. This discussion, therefore, highlights the synergistic role of precise data integration, advanced tools, and innovative well design techniques in enhancing the efficiency and precision of directional wells, such as S-profile wells. In summary, the article utilises data, tables, and figures to describe geologic and operationally challenging tasks that necessitate accurate trajectory planning, real-time monitoring, and effective solutions. Based on the integration of measured depth calculations, reservoir properties, and trajectory adjustments, the results provided the basis for the S-profile well to overcome geological formation obstacles, maximise reservoir contact, and enhance production efficiency. Based on the information derived from the tables and figures, the complete reference guide should guide future well designs in addressing some of the complex challenges in directional drilling.

6. Conclusion

The challenge of drilling directly underneath a village standing above the reservoir led us to design an S-profile directional well. Since we cannot eradicate the surface constraint mentioned above while trying to retain some form of a vertical well approach, the overall process required highly painstaking directional well planning. The trajectory was developed to ensure the well reaches all sections through the reservoir by giving precise points of alignment on geological targeting. It does not disrupt the surface infrastructure. Less common than the L and J profiles, an S-profile was used. This applies when the feature well has been adequately performed, wherein other profiles do not suffice. This is because the S-profile can pass through complicated geologic formations, thereby optimising production efficiency. With this profile, through its application, the well maximized its potential in producing crude oil compared with other traditional recovery mechanisms. Furthermore, the S-profile's design has a positive aspect in controlling operational and production expenses, as the resource remains undamaged and structurally sound for its eventual usage. This would reduce the maintenance cost and make it an economically feasible option for the petroleum industry. Therefore, it is highly relevant in modern petroleum exploration and production, as it potentially combines the benefits of a high recovery rate with cost-effectiveness. This research has demonstrated that directional drilling can overcome surface and subsurface challenges by adopting innovative approaches, thereby enhancing profitability and operational efficiency.

6.1. Limitations

In principle, the evaluation of the S-profile for multi-lateral directional wells is informative. However, there are some limitations to it. The main limitation is that the operation strictly depends on very precise geological and reservoir data, which will be less than ideal for trajectory planning and may lead to operational inefficiencies if not precise or even incomplete. S-profile wells are not inexpensive, particularly with high-end drilling tools such as measurement-while-drilling systems and deflection tools. There are cost issues, as well as some association with operating limitations that limit availability on most rigs. Trajectories, by the nature of their creation, have their alignment accuracy compromised, as correcting for deviations may become problematic when such real-time monitoring systems fail. This type also includes other risks, such as wear failure resulting from incidents in complex formations that exhibit high buildup rates or drop off, leading to risky operations and increased operational costs. S-profile profiles are less favourable compared to those in well-designed reservoirs; formations are characterised by extreme depth and anisotropies due to formation effects that assume an extreme form. Another related constraint is environmental concern due to the potential danger to nature, which may lead to possible regulatory issues under existing provisions.

6.2. Future Work

Future innovations in the evaluation and exploitation of S-Profile wells will bring significant improvements in performance efficiency and effectiveness. Maybe artificial intelligence and machine learning algorithms, while evaluating, for instance, in real-time interpretation of data, providing more precise corrections toward the trajectory, predictive maintenance for drilling equipment. Third, developing low-cost but highly robust equipment, such as advanced MWD systems and rotary steerable technologies, will alleviate the challenges of equipment accessibility and durability. The subsurface conditions can be refined through 3D and 4D reservoir modeling, offering a detailed understanding for trajectory planning. Further research into environmentally sustainable drilling practices, which includes waste reduction of fluids and minimum energy consumption, expands the zone of feasibility for S-profile well construction in any area sensitive to its ecological impact. Hybrid profiled S, J-, and L-profiles hybridisation will thus most probably open new access areas, such as complex reservoir exploitation, resources recovered, and reduced costs. These new developments would add to the possibilities of S-profile directional drilling, making this technique even more useful and effective for the petroleum industry.

References

1. E. Eltaher, K. Muradov, D. Davies, and P. Grassick, "Autonomous flow control device modelling and completion optimisation," *J. Pet. Sci. Eng.*, vol. 177, no. 6, pp. 995–1009, 2019.
2. K. Muradov, M. Haghighat Sefat, and M. Moradi Dowlatabad, "Fast optimization of packer locations in wells with flow control completions," *J. Pet. Sci. Eng.*, vol. 205, no. 10, p. 108933, 2021.
3. V. Mathiesen and B. Brough, "Autonomous valve controls excess water, gas production to increase oil recovery," *J. Pet. Technol.*, vol. 72, no. 6, pp. 44–46, 2020.
4. M. Augusto and S. Pinto, "Short-Term and Long-Term Optimizations for Reservoir Management with Intelligent Wells," *in Proc. SPE Latin American and Caribbean Petroleum Engineering Conf*, Quito, Ecuador, 2015.
5. J. Ahdeema, M. Haghighat Sefat, and K. Muradov, "Hybrid framework for enhanced dynamic optimization of intelligent completion design in multilateral wells with multiple types of flow control devices," *Energies*, vol. 16, no. 20, p. 7189, 2023.
6. N. Zhang, H. Li, Y. Liu, J. Shan, Y. Tan, and Y. Li, "A new autonomous inflow control device designed for a loose sand oil reservoir with bottom water," *J. Pet. Sci. Eng.*, vol. 178, no. 7, pp. 344–355, 2019.

7. C. E. A. G. Barreto and D. J. Schiozer, "Optimal placement design of inflow control valve using a dynamic optimization process based on technical and economic indicators," *J. Pet. Sci. Eng.*, vol. 125, no. 1, pp. 117–127, 2015.

8. B. Chen and A. C. Reynolds, "Optimal control of ICV's and well operating conditions for the water-alternating-gas injection process," *J. Pet. Sci. Eng.*, vol. 149, no. 1, pp. 623–640, 2017.

9. N. Shahreyar, B. Butler, and M. Shakeel, "Improved Reservoir Management with Multi-Positioning Interval Control Valves in Multilateral Wells," in *Proc. SPE Middle East Oil and Gas Show and Conf*, Manama, Bahrain, 2023.

10. V. E. Botechia and D. J. Schiozer, "Model-based life cycle control of ICVs in injectors in a benchmark analogous to a pre-salt field," *J. Pet. Sci. Eng.*, vol. 215, no. 8, p. 110707, 2022.

11. M. H. Sefat, K. Muradov, and D. Davies, "Field Management by Proactive Optimisation of Intelligent Wells-A Practical Approach," in *Proc. SPE Middle East Intelligent Energy Conf. and Exhibition*, Manama, Bahrain, 2013.

12. F. A. A. Dilib and M. D. D. Jackson, "Closed-loop feedback control for production optimization of intelligent wells under uncertainty," *SPE Prod. Oper.*, vol. 28, no. 4, pp. 345–357, 2013.

13. E. A. Addiego-Guevara, M. D. Jackson, and M. A. Giddins, "Insurance value of intelligent well technology against reservoir uncertainty," in *Proc. Improved Oil Recovery Symp,* Tulsa, Oklahoma, United States of America, 2008.

14. G. A. Carvajal, N. Saldierna, M. Querales, K. Thornton, and J. Loiza, "Coupling reservoir and well completion simulators for intelligent multi-lateral wells: Part 1," in *EAGE Annual Conference & Exhibition incorporating SPE Europec*, London, United Kingdom, 2013.

15. S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey wolf optimizer," *Advances in Engineering Software*, vol. 69, no. 3, pp. 46–61, 2014.