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Comparison Study and Statistical Analysis between Rotary Steerable System Performance and Positive Displacement Motor

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***Abstract*-- Deviated wells are very common these days in oilfield due to many reasons like surface obstructions, i.e. mountains or populated areas or down hole reasons i.e. avoiding fractures or hitting many targets.**

To achieve the directional plan and hit the target two major tools may be utilized (mud motor "M.Mot" or rotary steerable system "RSS").

There are many factors can affect the choice of the suitable tool for a certain directional plan like cost, ROP, tortuosity and directional difficulty index (DDI).

Each factor of these has its impact on the efficiency of drilling and borehole integrity as inefficient drilling trough a wasted energy input is reducing ROP and increasing time to drill the section.

In this study we are aiming to evaluate a comparative result of most common directional drilling tools at Qarun Petroleum Company. And discuss the selection of well deviation tool based on four factors that can affect the decision based on actual field data for offset wells and check the impact of each tool on wellbore integrity to present the realistic recommendations for tool selection to improve the performance of directional drilling and as a consequence the wellbore integrity.

***Keywords*— Mud motor, rotary steerable system, rate of penetration, hole tortuosity, directional difficulty index.**

INTROUCTION

A two development wells (4 sections) were drilled utilizing two different directional drilling applications at Qarun fields to enhance oil productivity in that area.

Based on field data of these two wells we are going to study the directional drilling issues.

As we know choosing the best tool for directional drilling is a very important question for drilling engineer.

There are many factors that can affect the choice like having the best ROP to achieve a certain campaign time target, keeping the cost of the well under a certain umbrella, the excess dog leg severity known as tortuosity and as consequence the directional difficulty index.

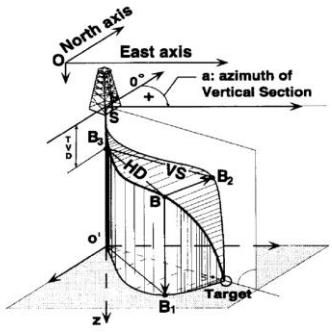

FIG 1. terms used in directional drilling.

The main objective of directional drilling is to avoid surface or down hole problem and hit the target/targets. The two DD tools are very common. steerable M.Mot can help in getting high DLS over a short section and gives higher revolutions for the drilling bit as it has RPG "revolutions per gallon" which can be summed to surface RPM "revolution per minute" for the drill string and as a consequence the total revolutions for the drilling bit will be higher than RSS and this will lead to higher ROP in certain cases specially if we have a long tangent section.

In the other hand, M.Mot needs sliding drilling to achieve the directional plan, the ROP in this sliding interval is lower that rotary sections and in some cases this may lead to differential stuck or high DLS.

In some formations or sometimes in some stringers in the same formation, if it is very soft the DLS would be higher than planned, or if it is very hard, the DLS is lower than planned which makes it very hard to catch the directional plan to hit the target.

In the upcoming field study we have drilled two sections using M.mot, the first section is 8-1/2" BUS " build up section" from vertical to almost =+/- 80 degrees, this sections contains a different lithology containing carbonates and shale which could represent a challenging for directional drilling to catch the directional plan or in worst cases to have a differential or mechanical stuck for the drill string or in ability to run casing or logging or losing down hole tools which are very expensive.

FIG 2:- rotary steerable system

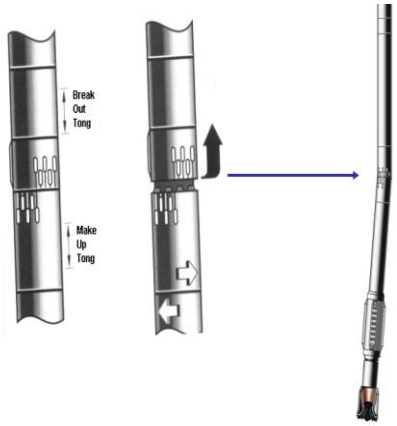

FIG 3: - M.mot with adjustable bent housing

Rotary steerable systems first appeared in the mid-1990s to overcome the problems associated to M.mot.

RSS has as a tool of directional drilling has many benefits compared to M.mot as following.

- Rotate the drill string 100% of the time which decreases the risk of differential stuck.
- Improves weight transfer and ROP.
- Improves hole cleaning by constant agitation of cuttings
- Eliminates slow ROP associated with sliding.
- Allow drilling smoother hole profile.
- Longer reach "better in extended reach drilling."
- Ability to drill more complex profiles.

More over some limitations must be taken into consideration, we are dealing with an advanced and complicated tool with a higher probability of failure of its elements which may requires more tripping to fix or replace. Also, it is very expensive tool in operation or even in case of lost in hole incident. We have to consider that in case of long tangent section or in case of performance drilling, the M.mot supersedes due to higher bit rpm.

METHODOLOGY/COMPARISON STUDY.

This study will compare between rotary steerable system and mud motor with same well profile of two offset wells.

This study is the first step for obtaining the best recommendations of selecting the suitable direction drilling tools for different well profiles and what are the impacts on the next well operation in case of changing the direction drilling tool.

WELLBORE DATA FOR PROPOSED WELL.

Here we display the planned wellbore directional plan for proposed well where we planned to drill 8-1/2" BUS "build up section "from vertical to near horizontal inclination.

TABLE: 1
Directional plan for 8-1/2" section.

MD (ft.)	Incl (°)	Azim Grid (°)	TVD (ft.)	VSEC (ft.)	DLS (°/100ft)
4300.00	0.00	167.00	4300.00	0.00	0.00
4330.00	0.00	167.00	4330.00	0.00	0.00
4400.00	1.40	167.00	4400.00	0.68	2.00
4500.00	3.40	167.00	4500.00	4.02	2.00
4600.00	5.40	167.00	4600.00	10.13	2.00
4700.00	7.40	167.00	4699.00	19.02	2.00
4722.00	7.84	167.00	4721.00	21.37	2.00
4800.00	9.40	167.00	4798.00	30.66	2.00
4830.00	10.00	167.00	4827.00	34.69	0.00
4900.00	12.60	167.00	4896.00	45.50	3.75
5000.00	16.30	170.00	4993.00	64.67	3.75
5100.00	20.00	171.55	5088.00	88.48	3.75
5200.00	23.80	172.01	5181.00	116.50	3.75
5300.00	27.50	172.37	5271.00	148.74	3.75
5398.00	31.20	172.37	5356.00	184.26	0.00
5400.00	31.30	172.37	5358.00	185.06	3.75
5500.00	35.00	172.66	5441.00	225.30	3.75
5520.00	35.70	172.72	5457.00	233.65	0.00
5550.00	35.70	172.72	5482.00	246.71	0.00
5600.00	36.80	172.72	5522.00	268.81	3.70

5700.00	39.10	175.51	5601.00	317.38	3.70
5800.00	41.60	161.20	5677.00	371.44	3.70
5900.00	44.30	157.45	5750.00	430.78	3.70
5983.00	46.50	154.50	5809.00	484.19	0.00
6000.00	47.00	153.98	5820.00	495.15	3.70
6059.00	48.70	152.07	5860.00	535.52	0.00
6100.00	49.80	150.81	5887.00	564.28	3.70
6172.00	51.90	148.68	5932.00	616.86	0.00
6200.00	52.80	147.34	5949.00	637.89	3.70
6220.00	53.30	145.20	5961.00	653.01	0.00
6300.00	55.70	145.20	6007.00	715.66	3.70
6378.00	58.10	143.20	6050.00	779.07	0.00
6400.00	58.80	142.60	6061.00	797.27	3.70
6500.00	61.90	140.30	6111.00	882.38	3.70
6600.00	65.00	138.22	6156.00	970.64	3.70
6657.00	66.8	136.8	6179	1022.65	0.00
6700.00	68.10	133.99	6195.00	1061.68	3.70
6800.00	71.30	132.04	6230.00	1155.12	3.70
6900.00	74.50	130.16	6259.00	1250.57	3.70
7000.00	77.70	130.16	6283.00	1347.45	3.70
7024.00	78.50	129.71	6288.00	1371.31	0.00
7079.00	80.3	128.71	6298	1424.94	0.00
7091.00	80.70	128.49	6300.00	1436.91	0.00
7100.00	81.00	128.30	6301.00	1445.90	3.70

TABLE: 2
Directional plan for 6-1/8" section.

7090.00	81.38	214.80	6295.08	0.00	4.20
7184.00	84.37	217.50	6306.74	81.00	4.27
7276.00	86.47	219.73	6314.09	158.50	3.32
7370.00	86.84	221.89	6319.57	235.42	2.33
7429.00	87.34	222.26	6322.57	282.97	1.05
7441.00	88.02	221.58	6323.06	292.66	0.00
7453.00	88.02	221.58	6323.47	302.40	0.00
7529.00	87.61	218.95	6326.38	365.06	2.50
7629.00	87.09	215.49	6331.00	450.35	2.50
7729.00	86.57	212.02	6336.54	538.59	2.50
7829.00	86.07	208.55	6342.96	629.45	2.50
7929.00	85.58	205.07	6350.24	722.58	0.00
7988.58	85.30	203.00	6354.97	779.01	0.00
8029.00	85.68	202.29	6358.15	817.59	2.00
8129.00	86.64	200.52	6364.85	913.72	2.00
8191.98	87.24	199.42	6368.22	974.71	0.00
8229.00	87.24	199.42	6370.00	1010.66	0.00
8251.83	87.24	199.42	6371.10	1032.83	0.00
8329.00	87.67	197.93	6374.53	1108.00	2.00
8429.00	88.24	196.01	6378.10	1206.06	2.00
8529.00	88.80	194.09	6380.68	1304.74	2.00
8629.00	89.37	192.18	6382.27	1403.92	2.00
8674.57	89.63	191.30	6382.67	1449.25	2.00
8729.00	89.63	191.30	6383.02	1503.44	0.00
8741.88	89.63	191.30	6383.10	1516.25	0.00
8829.00	89.38	189.58	6383.85	1603.09	2.00
8929.00	89.09	187.60	6385.19	1702.97	2.00
9029.00	88.80	185.62	6387.03	1802.94	2.00
9118.25	88.54	183.85	6389.10	1892.14	2.00
9129.00	88.51	183.64	6389.38	1902.88	2.00
9175.74	88.38	182.72	6390.64	1949.55	0.00
9229.00	88.38	182.72	6392.15	2002.71	0.00
9262.58	88.38	182.72	6393.10	2036.23	0.00
9329.00	88.57	181.40	6394.87	2102.47	2.00

CASE#1#A: DRILLING 8-1/2" BUS "BUILD UP SECTION" WITH M.MOT.

TABLE: 3
Actual survey for 8-1/2" section drilled with M.mot.

MD (ft.)	Incl (°)	Azim Grid (°)	TVD (ft.)	AHD (ft.)	DLS (°/100ft)	COST	AVG ROP ROT& SLIDE FT/HR	TORT DEG/100FT	DDI
4254.00	1.78	217.55	4145.20	42.00	0.00	1320.6	37.11	1.18	1.7
4316.00	3.21	183.52	4315.05	58.80	1.12	3386.7	37.11	1.18	1.8
4413.00	6.48	163.29	4411.70	66.14	3.84	5325	37.11	1.18	1.8
4504.00	7.61	161.41	4502.02	76.77	1.27	7327.2	37.11	1.18	1.9
4598.00	7.51	162.82	4595.20	88.54	0.22	9350.7	37.11	1.18	2.0
4693.00	7.07	161.22	4689.43	100.01	0.51	11374.2	47.35	1.18	2.0
4788.00	10.54	163.94	4783.30	113.90	3.68	13376.4	47.35	1.18	2.1
4882.00	14.87	161.99	4874.97	133.64	4.63	15357.3	47.35	1.18	2.2
4975.00	17.53	162.71	4874. 97	158.37	2.87	17359.5	47.35	1.18	2.3
5069.00	21.62	161.95	4984.27	188.36	4.36	19361.7	47.35	1.18	2.3
5163.00	24.51	161.86	5052.82	223.36	3.07	21363.9	47.35	1.18	2.4
5257.00	27.95	161.33	5139.00	262.77	3.67	23366.1	47.35	1.18	2.5
5351.00	30.57	160.26	5223.61	306.15	2.84	25368.3	47.35	1.18	2.5
5445.00	33.44	158.62	5305.61	367.00	3.19	27391.8	47.35	1.18	2.6
5540.00	36.40	157.69	5385.31	403.24	3.17	29372.7	47.35	1.18	2.6
5633.00	39.86	157.64	5463.20	456.35	3.72	31396.2	47.35	1.18	2.7
5728.00	42.55	156.30	5536.34	513.92	2.98	33419.7	47.35	1.18	2.8
5823.00	45.99	153.35	5607.81	573.89	4.22	35421.9	45.40	1.18	2.8
5917.00	46.06	151.79	5675.83	633.93	1.20	37424.1	45.40	1.18	2.8
6011.00	46.35	151.41	5741.10	693.62	0.42	38723.4	45.40	1.18	2.9
6072.00	48.50	152.00	5806.16	733.17	3.60	39468.9	45.40	1.18	2.9
6107.00	50.50	153.09	5847.43	756.79	6.29	41428.5	45.40	1.18	2.9

6199.00	51.49	152.96	5870.15	820.52	1.04	43430.7	45.40	1.18	3.0
6293.00	54.09	152.64	5928.03	887.10	2.78	45432.9	45.40	1.18	3.0
6387.00	55.90	149.13	5984.87	954.33	3.61	47435.1	45.40	1.18	3.0
6481.00	59.86	146.84	6038.80	1021.80	4.68	49458.6	42.30	1.18	3.1
6576.00	63.70	143.31	6088.77	1090.38	5.20	51460.8	42.30	1.18	3.1
6670.00	67.32	140.67	6133.70	1157.74	4.62	53377.8	42.30	1.18	3.1
6760.00	69.44	136.85	6205.83	1220.62	4.60	55486.5	42.30	1.18	3.1
6859.00	71.51	132.19	6238.93	1286.00	4.90	57510	42.30	1.18	3.2
6954.00	74.57	128.31	6266.66	1344.67	5.06	59512.2	42.30	1.18	3.2
7048.00	78.19	124.42	6288.81	1398.80	5.58	60555.9	42.30	1.18	3.2
7097.00	79.76	123.03	6298.18	1659.00	4.24	63942.6	42.30	1.18	3.3

CASE#1#B: DRILLING 8-1/2" BUS "BUILD UP SECTION" WITH RSS.

Here we have drilled 8-1/2" BUS "build up section" using RSS to achieve the same directional plan, also we started from vertical at the beginning of the section till near horizontal at the end of the section.

We calculate the next four factors for the section drilled with RSS, we observed that the direct rental cost of the RSS at the end of the section is 161,191 USD and the AVG ROP is 52.45 FPH where the AVG touristy is 0.7 deg/100ft where the directional difficulty index is between 1.6 to 3.2 as per below table.

TABLE: 4
Actual survey for 8-1/2" section drilled with RSS.

MD (ft.)	Incl (°)	Azim Grid (°)	TVD (ft.)	AHD (ft.)	DLS (°/100ft)	COST	AVG ROP FT/HR	TOR DEG/100 FT.	DDI
4127	8.41	48.14	4124.17	61.70	1.86	4754.75	51.60	0.74	1.6
4218	11.60	36.46	4213.78	77.08	3.87	9457.25	51.60	0.74	1.7
4308	14.51	38.77	4301.44	96.56	3.24	14159.75	51.60	0.74	1.8
4398	16.50	44.83	4388.17	119.75	2.39	18914.50	51.60	0.74	1.9
4489	18.78	44.53	4474.88	146.67	2.66	23617.00	51.60	0.74	2.0
4579	21.10	45.02	4559.48	176.81	2.58	28319.50	51.60	0.74	2.1
4669	22.62	42.80	4643.01	209.60	1.92	33074.25	51.60	0.74	2.1
4760	25.93	39.92	4725.95	245.81	3.86	37776.75	51.60	0.74	2.2
4850	28.85	40.80	4805.86	285.73	3.27	42479.25	51.60	0.74	2.3
4940	31.09	42.30	4883.82	329.21	2.65	47234.00	51.60	0.74	2.3
5031	33.04	42.91	4960.93	376.36	2.17	51936.50	51.60	0.74	2.4
5121	34.66	42.73	5035.67	425.23	1.80	56639.00	51.60	0.74	2.5
5211	36.34	42.27	5108.94	476.10	1.89	61393.75	55.40	0.74	2.5
5302	38.29	41.81	5181.31	529.70	2.16	66096.25	55.40	0.74	2.6
5392	39.73	42.65	5251.24	584.79	1.70	70903.25	55.40	0.74	2.6
5484	42.09	44.03	5320.77	643.64	2.75	75553.50	55.40	0.74	2.6
5573	43.19	44.68	5386.24	702.74	1.33	80308.25	55.40	0.74	2.7
5664	43.04	44.49	5452.67	763.77	0.22	85010.75	58.40	0.74	2.7
5754	43.41	44.22	5518.25	824.20	0.46	89713.25	58.40	0.74	2.8
5844	42.28	43.15	5584.24	884.06	1.49	94468.00	58.40	0.74	2.8
5935	42.34	43.39	5651.53	943.87	0.19	99170.50	58.40	0.74	2.8
6025	43.41	43.91	5717.49	1003.76	1.25	103873.00	58.40	0.74	2.8
6115	44.57	44.29	5782.24	1064.95	1.29	108627.75	58.40	0.74	2.9
6206	46.67	45.64	5845.88	1128.66	2.32	113330.25	58.40	0.74	2.9
6296	47.33	46.89	5907.26	1193.32	1.32	118032.75	58.40	0.74	2.9
6386	50.30	48.36	5966.52	1260.13	3.46	122787.50	58.40	0.74	2.9
6477	50.68	49.86	6024.42	1329.64	1.31	127490.00	58.40	0.74	3.0
6567	53.51	51.16	6079.71	1400.17	3.41	132192.50	51.00	0.74	3.04
6657	56.82	52.22	6131.11	1473.73	3.86	136947.25	51.00	0.74	3.07
6748	61.37	53.17	6177.84	1551.60	5.10	141649.75	51.00	0.74	3.09
6838	63.30	53.73	6219.62	1631.19	2.34	146404.50	45.00	0.74	3.12
6929	65.75	53.59	6258.76	1713.27	2.75	151107.00	45.00	0.74	3.14
7019	69.23	53.21	6293.21	1796.35	3.87	152204.25	45.00	0.74	3.17
7040	70.34	53.00	6300.47	1816.04	5.55	153719.50	45.00	0.74	3.17
7069	71.50	50.84	6309.95	1843.42	4.06	156332.00	45.00	0.74	3.18
7119	74.49	49.26	6324.57	1891.12	7.27	158787.75	45.00	0.74	3.19
7166	78.42	48.30	6335.58	1936.98	8.96	161191.25	45.00	0.74	3.20

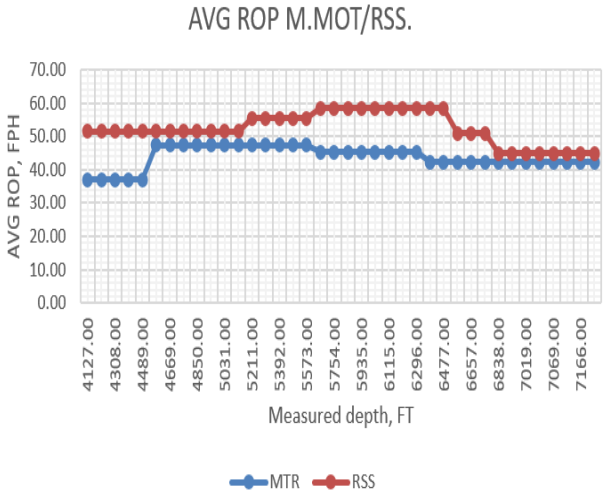

CHART: 1 AVG ROP M.mot/RSS.

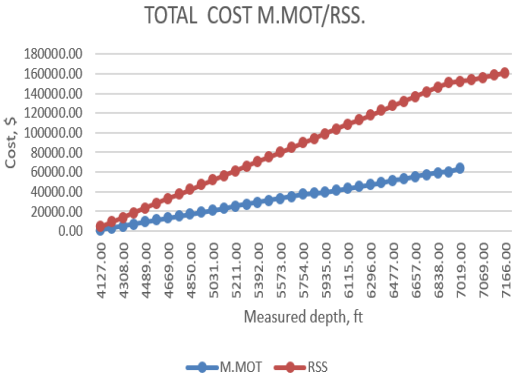

CHART: 2 Tool Cost M.mot/RSS.

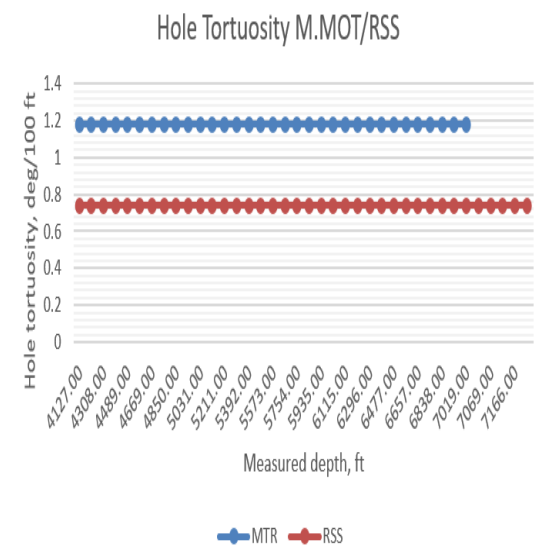

CHART: 3 Hole Tortuosity M.mot/RSS.

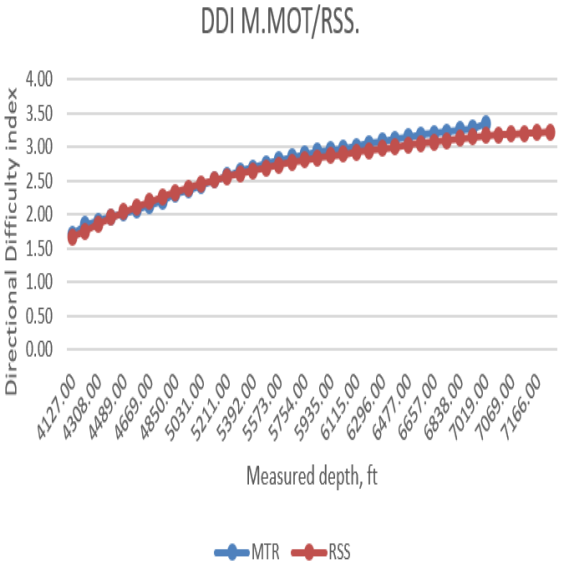

CHART:4 DDI M.MOT/RSS.

CASE#2#A: DRILLING 6-1/8" HZ SECTION "HORIZONTAL" WITH M.MOT.

In this case we have drilled 6-1/8" horizontal section 'using mud motor to achieve the directional plan in table: 2, where we are horizontally steering thru the reservoir section,We follow the same previous procedure in calculating the 4 factors affecting the study, we got the below data and actual survey

TABLE: 5
Actual survey for 6-1/8" section drilled with M.mot.

MD (ft.)	Incl (°)	Azim Grid (°)	TVD (ft.)	VSEC (ft.)	DLS (°/100ft)	COST	AVG ROP FT/HR	TOR DEG/10 0 FT.	DDI
7256	83.13	122.41	6321.83	1510.47	2.15	2002.2	18.60	1.07	3.27
7350	86.17	122.04	6330.59	1560.37	3.26	2832.9	18.60	1.07	3.29
7389	87.22	121.98	6332.84	1581.01	2.70	4025.7	18.60	1.07	3.3
7445	85.05	122.06	6336.61	1610.64	3.88	5154.6	18.60	1.07	3.31
7498	85.43	121.06	6341.01	1638.28	2.01	6155.7	18.60	1.07	3.32
7545	88.7	121.47	6343.42	1662.64	7.01	8030.1	18.60	1.07	3.33
7633	88.89	120.42	6345.27	1707.88	1.21	10053.6	38.10	1.07	3.34
7728	88.15	118.97	6347.72	1754.92	1.71	12077.1	38.10	1.07	3.36
7823	87.65	117.79	6351.20	1800.05	1.35	14079.3	38.10	1.07	3.38
7917	87.97	117.56	6354.80	1843.67	0.41	16081.5	38.10	1.07	3.39
8011	90.06	117.00	6356.43	1886.75	2.31	18105	38.10	1.07	3.41
8106	90.37	117.00	6356.07	1929.76	0.37	20064.6	38.10	1.07	3.42
8198	90.93	116.44	6355.03	1971.01	0.75	22109.4	38.10	1.07	3.43
8294	90.37	113.98	6353.94	2011.89	2.63	24111.6	38.10	1.07	3.45
8388	90.19	112.98	6353.48	2049.34	1.08	26135.1	38.10	1.07	3.46
8483	89.75	113.78	6353.53	2087.04	0.96	28201.2	38.10	1.07	3.47
8580	86.85	113.77	6356.41	2126.12	2.99	30203.4	38.10	1.07	3.49
8674	88.21	113.66	6360.46	2163.89	1.45	32205.6	41.40	1.07	3.5
8768	87.22	113.57	6364.21	2205.52	1.06	34229.1	41.40	1.07	3.51
8863	87.22	115.54	6368.81	2240.19	1.02	36252.6	41.40	1.07	3.52
8958	90.19	115.25	6370.96	2280.17	3.21	38254.8	41.40	1.07	3.54
9052	89.32	114.85	6371.36	2319.97	1.02	40257	41.40	1.07	3.55
9146	88.95	225.44	6372.78	2359.91	0.74	41833.2	41.40	1.07	3.56

CASE#2#B: DRILLING 6-1/8" HZ SECTION "HORIZONTAL" WITH RSS.

In this case we have drilled 6-1/8" horizontal section using RSS to achieve the same directional plan in an offset well and we got the below data.

TABLE: 6
Actual survey for 6-1/8" section drilled with RSS.

MD (ft.)	Incl (°)	Azim Grid (°)	TVD (ft.)	VSEC (ft.)	DLS (°/100ft)	COST	AVG ROP FT/HR	TOR DEG/10 0 FT.	DDI
7090	81.38	214.80	6295.08	20	4.20	5005.5	25.60	0.52	1.07
7184	84.37	217.50	6306.74	80.53	4.27	9904.5	25.60	0.52	1.68
7276	86.47	219.73	6314.09	157.65	4.32	14910	25.60	0.52	1.98
7370	86.84	221.89	6319.57	234.57	3.30	31630.5	25.60	0.52	2.15
7684	87.74	208.58	6334.49	507.31	4.24	36476.3	25.60	0.52	2.51
7775	86.05	210.68	6339.42	590.46	2.96	40044	25.60	0.52	2.58
7842	85.93	208.53	6344.10	651.64	3.21	45049.5	25.60	0.52	2.62
7936	85.80	206.94	6350.88	738.65	2.69	50055	25.60	0.52	2.68
8030	85.44	204.50	6358.06	826.8	2.62	55113.8	53.10	0.52	2.73
8125	86.78	202.36	6364.51	917.16	2.65	60066	53.10	0.52	2.78
8218	86.92	200.15	6369.62	1006.68	2.38	65124.8	53.10	0.52	2.83
8313	86.70	198.52	6374.90	1098.98	2.73	70130.3	53.10	0.52	2.87
8407	88.60	196.43	6378.76	1190.91	3.00	75135.8	53.10	0.52	2.91
8501	89.46	194.32	6380.35	1283.6	2.42	80141.3	53.10	0.52	2.95

8595	89.01	192.24	6381.61	137.81	2.26	85093.5	53.10	0.52	1.98
8688	89.13	192.28	6383.11	1469.22	1.14	90099	53.10	0.52	3.02
8782	88.92	190.84	6384.71	1562.74	1.55	95051.3	53.10	0.52	3.05
8875	89.07	188.73	6386.35	1655.5	2.27	100057	53.10	0.52	3.08
8969	88.95	189.06	6387.97	1749.35	1.34	105062	53.10	0.52	3.11
9063	88.92	186.14	6389.72	1843.29	3.11	110068	56.20	0.52	3.13
9157	88.83	183.94	6391.56	1937.25	3.34	115127	56.20	0.52	3.16
9252	88.86	182.98	6393.48	2032.15	1.01	120132	56.20	0.52	3.18
9346	89.20	181.21	6395.07	2125.93	1.92	125138	56.20	0.52	3.21

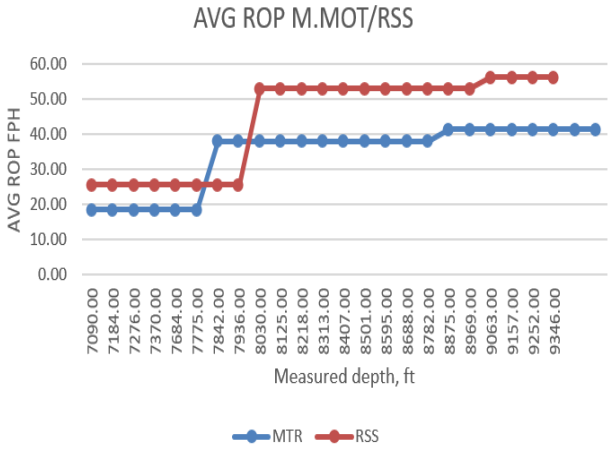

CHART: 5 AVG ROP M.mot/RSS (6-1/8" hole).

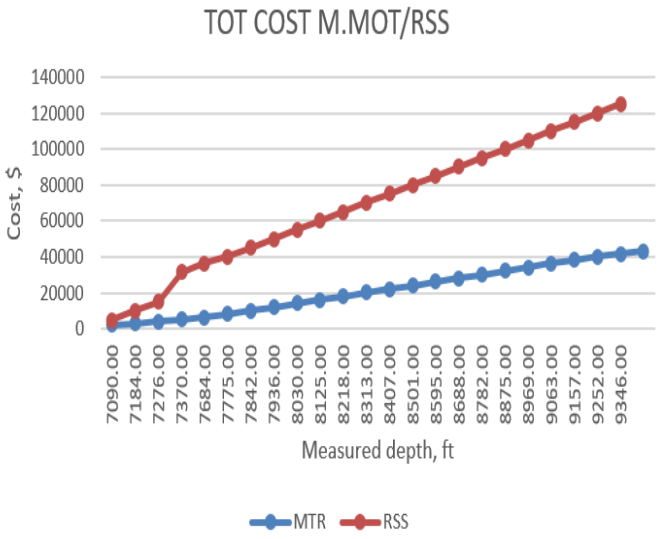

CHART: 6 TOT cost M.mot/RSS (6-1/8" hole).

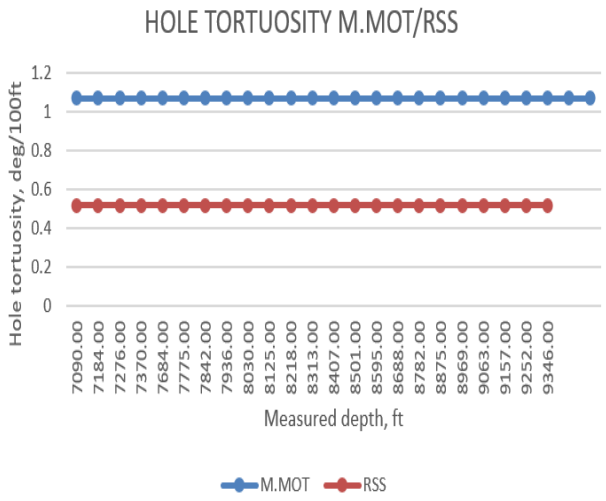

CHART: 7 Hole tortuosity M.mot/RSS (6-1/8" hole).

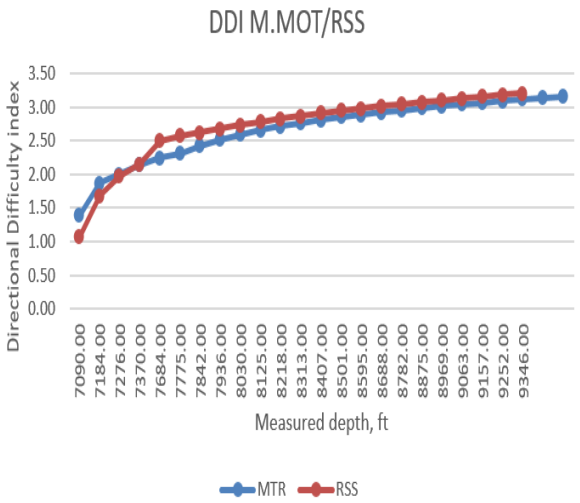

CHART: 8 DDI M.mot/RSS (6-1/8" hole).

RESULTS DISCUSSION

From previous we experienced many cases for directional drilling to evaluate and differentiate between the most common tools used for directional drilling as following.

1- In case of drilling with mud motor (case#1#A & case#2#A).

Drilling with mud motor can achieve a 60% cost reduction due to lower cost per foot for the tool while the AVG ROP in this case was 44 FPH including rotary and slide .

Mud motors showed hole tortuosity ranging from 1.2:1.8 deg/100 ft. which is three times higher than the hole tortuosity achieved by RSS.

While the DDI for mud motor are the same for RSS.

2- In case of drilling with RSS (case#1#B & case#2#B).

The operation cost of RSS showed 250% higher than the cost of mud motor while achieving avg ROP of 52.4 ft/hr. which is 20 % higher than mud motors.

However, the hole tortuosity in case of RSS is ranging from 0.4: 0.8 deg/100ft which is very useful in case we have a plan for logging or completion, both tools showed the same DDI.

CONCLUSION

Based on previous study and actual field data we recommend a wide scale of investigation for a large number of wells to make the correct decision as the choice is not absolute as following.

RSS is the best choice in the following situations.

- The need for higher ROP specially for offshore drilling where the rig daily rate could be 10 times more than onshore and saving rig time is vital.
- Motor sliding could cause a problem like differential stuck, bit failure without getting surface indication in case of tri-cone bit.
- RSS is useful where a hole section passes through a variety of formation types that exhibit different rotary BHA tendencies.
- RSS shows hole tortuosity 3 times lower than M.mot tortuosity which is very helpful in case there is a plan for logging or running open hole completion.
- RSS exceeds in extended reach drilling as reduction in wellbore tortuosity permits further extended reach and easier completion installation within given limits for torque and drag.
- RSS is better in reducing casing wear, reducing drill pipe wear.
- Tool face setting in some formation is a problem where we face a changing reactive torque, this problem doesn't exist in RSS while it is headache in motors.
- torque and drag are higher in case of M.mot than RSS due to higher tortuosity.

Mud motors are better in the following.

- Requires less training and maintenance and more durable.
- Compromising dogleg capability and cost competitiveness.
- Motors could achieve DLS up to 15 deg/100 ft which is not available for RSS.
- Double bend configurations with adjustable bent housings and fixed bent subs allow doglegs up to 20°/100 ft (30 m). Which is much higher than RSS.
- If long tangent section the M.mot is better due to higher bit rpm.
- performance drilling "using motor to enhance ROP",
- High speed/low torque application or low speed /high torque applications are available in motors which gives the variety of choosing the suitable tool for the planned formation
- Less operation cost and lost in hole cost (60%) lower.

Nomenclature

RSS	= Rotary steerable system.
M.MOT	= mud motor.
ROP	= rate of penetration.
DDI	= directional difficulty index.
AHD	= along hole displacement.
DLS	= dog leg severity.
TOR	= tortuosity.
MD	= measured depth.
TVD	= true vertical depth.
INCL	= inclination.
AZM	= azimuth.
BUS	= build up section.

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