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Application of Downhole Oil-Water Separation: A Feasibility Study

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تطبيق فصل الماء عن الزيت بقاع البئر

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تم إجراء دراسة جدوى هندسية على حقل نفطي رئيسي يدار بواسطة شركة الواحة للنفط وذلك لتحديد جدوى تطبيق تقنية فصل الماء عن الزيت بقاع البئر، وتحديد الآبار المناسبة بهذا الحقل لتطبيق هذه التقنية. إن استراتيجية الاستنزاف الحالية (أو أي تطويرات مستقبلية) للمكمن GE تؤدي إلى أن إنتاجية الاحتياطي النفطي المتبقي سيتم بزيادة مضطردة لنسبة المياه في الزيت، لذلك فإن فصل الماء عن الزيت في قاع البئر والتخلص من المياه المفصولة تمثل وسيلة هامة لتحسين أداء الحقول الحالية والمستقبلية.

لقد تم تطوير معيّرة لمراجعة خصائص المكمن والبئر أكثر تفصيلا ولتحديد الآبار المرشحة لاحتمال تطبيق هذه التقنية (فصل الماء عن الزيت بقاع البئر). كما تم تحديد المخاطر والمحاذير الموجودة في الآبار المرشحة حيث أظهرت ثمانية عشرة بئراً من أصل أربعة وعشرون بئرا خصائص مميزة للمكمن والبئر وتوافقت مع الشروط الأولية لتطبيق هذه التقنية. إن المعيّرة المستعملة ربما تستعمل لتقييم حقول أخرى بهدف تطبيق هذه التقنية (فصل الماء عن الزيت بقاع البئر). سيتم في هذه الورقة استعراض تصميم أولي لتطبيق طريقة فصل الماء عن الزيت في قاع البئر على ثلاثة آبار.

Abstract: *An engineering feasibility study has been conducted on a major oil field operated by Waha Oil Company to determine the feasibility of applying downhole oil-water separation technology (DHOWS) and to rank the candidate wells within this field on the basis of their suitability for a DHOWS installation. With the current depletion strategy (or any future developments), the nature of the GE reservoir is such that, the remaining oil reserves will have to be produced at high and constantly increasing watercuts. Downhole separation and disposal of produced water present a material opportunity to improve the current and future field performance.*

A screening template was developed to review the reservoir and well characteristics in more detail and to identify a list of candidate wells for the possible implementation of DHOWS technology. Several operational risks and concerns that exist in respect of the candidate wells were identified. Eighteen wells out of twenty four wells demonstrated favorable reservoir and well characteristics and met the initial DHOWS screening criteria. The screening template may be used to evaluate other fields for potential conventional DHOWS applications. A preliminary design of a DHOWS application for three wells is presented in this paper.

INTRODUCTION

It is widely known that the continuous increase in the water-oil ratio hinders the oil production rate, contributes to high operating cost and is a major source of environmental concern to the oil companies. In the past, the response of operators to increasing water production rates was to go up to the top section of

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the reservoir in an oil well away from the rising water, while trying to slow down the advance of water with squeeze cement and cement plug techniques. The oil industry experiences with these techniques have shown mixed results. Meanwhile, if water cannot be stopped and the cost of handling the water and additional other costs exceed the revenue the operator has to abandon the well despite the fact that significant volumes of oil can still be produced.

The Centre for Engineering Research Inc. initiated a feasibility study in 1991 to test a new technique to reduce water-handling costs by reducing the volume of water produced at the surface. This work produced the idea of combining separation and pumping systems downhole and simultaneous injection of the produced water in the same wellbore. Matthews *et al.*[1] presented a novel system for downhole separation and re-injection of produced water in the same well. The technique was applied to two wells in the Alliance field and the results indicated an increase in oil rates. Peachey *et al.*[2] presented a brief summary of field trials completed and the key results achieved, including oil production increases, water reduction, predicted increases in reserves recovery and main factors affecting a successful DHOWS application. Shaw *et al.*[3] indicated that The DHOWS technology could be applied successfully in low risk wells. They defined the risk as a function of workover cost and deferred production; high risk therefore being a prolific well with high workover costs. Scaramuzza *et al.*[4] described the separation system implemented in Grey, Red and Green sands of Barrancas formation, the candidate wells selected, and the results of pilot field trials. Li *et al.*[5] conducted indoor dynamic simulation experiments to test downhole separation and injection technique for a rod pumping well. Jokhio *et al.*[6] reviewed in some detail the economic parameters that affect DHOWS and summarized the characteristics of a waterflood operation that can benefit economically from this technology.

The aim of this feasibility study is to determine the technical and economical justification to use the downhole oil-water separation system in the GE reservoir, to rank candidate wells within this field on the basis of their suitability for a DHOWS installation, and to develop a screening template that can be used in the evaluation process of oil fields for potential DHOWS applications.

RESERVOIR CHARACTERISTICS

The suitability of the GE reservoir for DHOWS application was studied in terms of the observed/demonstrated reservoir behavior. The GE reservoir has been under primary recovery operations since 1964. The succeeding sections individually examine each of the following reservoir characteristics: reservoir description, drive mechanism, production history, and water disposal/injection zone potential.

Reservoir Description: The GE reservoir is located in the upper part of the G limestone, a formation present in most areas of the Sirt Basin. The formation lithology/depositional environment can be classified as a nummulitic-shallow shelf carbonate sequence with an aggregate formation thickness of 1500 to 1700 ft in the highs and over 2000 ft in the troughs. The reservoir interval is comprised of a shoaling upward sequence defined by 4 main reservoir units. Table 1 presents reservoir

Table 1. GE reservoir – reservoir unit facies/lithologic descriptions.

Name	Dominant facies	Dominant texture	Vugs
Shoal 1	Wackestone w/ whole numulites	Mud- dominated packstone (45 %) + Grainstone (20 %)	15 % Touching 35 % Separated
Shoal 2	Nummulitic wackestone + nummulitic packstone	Mud-dominated packstone (45 %) + Grain-dominated packstone (30 %)	20 % Touching 20 % Separated
Shoal 3	Nummulitic packstone	Grain-dominated packstone (60 %) + Mud- dominated packstone (25 %)	30 % Touching 15 % Separated
Shoal 4	Nummulitic packstone +bryozoan packstone	Grain-dominated packstone (50 %)	10 % Touching 15 % Separated
Lower 1	Bryozoan packstone	Grain-dominated packstone (65 %)	5 % Touching 30 % Separated
Lower 2	Bryozoan packstone	Grain-dominated packstone (65 %)	0 % Touching 10 % Separated
Lower 3	Nummulitic packstone	Grain-dominated packstone (50 %) + Grainstone (40 %)	10 % Touching 30 % Separated
Basal	Nummulitic packstone + packstone w/ Large Nummulites	Grainstone (85 %)	~0 % Touching ~0 % Separated
Sub-basal	Not defined	Not defined	

unit facies/lithologic descriptions. The GE reservoir is a highly undersaturated oil reservoir producing under the influence of a strong natural water drive. In spite of the strong natural water drive, there has been significant decline in reservoir pressure over the last 37 years. Also, available pressure data indicate that the pressure decline is not uniform over the entire reservoir volume. Historical and recent RFT data suggest that there are pressure differentials existing across some of the lower reservoir sub-units.

DHOWS Suitability: The reservoir drive mechanism is highly favorable for DHOWS applications. Presences of bottom water drive as well as edge water drive affecting reservoir performance suggest the following two potential DHOWS water disposal/injection options:

1. Into formerly oil producing sub-units that have watered out under the influence of the edge and bottom water drives;
2. Into the reservoir sub-units which comprises a portion of the connected water aquifer responsible for the water influx.

In either case, the water disposal/injection will, most probably, help to supplement the already strong natural water influx and the reservoir pressure.

Production History: Initial production from the field began in 1964. Production peaked at 250 MB/D of oil and immediately went on decline. This is coincident with the first observation of significant water production in the field during 1966. During the early 1980's a program of well shut-ins/cutbacks was executed, reducing produced liquid volumes to ~140 MB/D. In the late 1980's early 1990's, reservoir liquid withdrawal rates were increased to ~300 MB/D and maintained to the present day. After 36+ years on production, at steadily increasing watercuts (which have been in excess of 75 % since the late 1970's), some 250 MB/D of water from the reservoir is being produced to surface for separation, treatment, and eventual disposal. Given the vintage of the producing wells, there are some concerns regarding the mechanical integrity of the wellbores. The producing field water cut and the large absolute volumes of produced water brought to surface are both clear indications that the GE reservoir warrants further consideration as a potential DHOWS application candidate. Reservoir and fluid properties of GE reservoir are presented in Table 2.

Oil Reserves. With a recovery factor of 40+ % of OOIP realized to date, it is important to consider what amounts of incremental oil recovery are still available to the existing primary recovery operation. Under existing primary recovery operations, and even in the case of numerous possible developments for incremental recovery, a considerable amount of the reserves is still left to be recovered for the next 30 years (to 2030); all of these results confirm that a more thorough assessment of potential DHOWS applications in the GE reservoir is warranted.

Table 2. Reservoir and fluid properties of GE reservoir.

Reservoir properties		
Top GE	2670-2770	ft kb
Initial pressure (datum)	1176	psig @ 2410 ft ss
average pressure (datum)	764	psig
Reservoir Temperature	131	^{0}F
Field average free water level	2610	ft ss
Structural dip	0.5	^{0}
Closure (main)	2342	ft ss
Reservoir productive area	5660	acres
Oil properties		
Reservoir oil density	0.81	g/cc (at 1176 psig, 131 ^{0}F)
Stock tank oil density	0.83	g/cc
Oil viscosity	2.59	cp (at Pi)
B_{oi} (flash separation)	1.038	RB/STB
B_{ob}	1.046	RB/STB
Solution GOR	41.2	SCF/STB
Separator gas gravity	1.046	(air=1)
Oil compressibility	6.75	10^{-6} psi^{-1}
Bubble point pressure	140.3	psig (131^{0}F)
Initial formation water Properties		
Chlorinity	6134-9800	ppm
Salinity	15000-19440	ppm
Resistivity	0.466-0.381	Ohm.m (at 68^{0}F/20^{0}C)
Density	1.01	g/cc (68^{0}F/20^{0}C)
Viscosity	1.052	cp (68^{0}F)

Water Disposal/Injection Zone Potential: Several proximal but unproven water disposal/ injection zones have been identified that require further evaluation before they can be considered acceptable for DHOWS applications.

WELL CANDIDATE CATEGORIES

The following sections evaluate the suitability/ applicability of DHOWS with respect to the well characteristics under consideration. It is important to remember that in assessing a well's suitability for DHOWS applications, its characteristics must be assessed several times, and a suitable candidate well must be shown to meet or exceed the minimum acceptance criteria for each of the well characteristics that are considered. The GE reservoir wells are divided into 9 different categories as presented in Table 3.

Table 3. DHOWS candidate well group descriptions.

Category	# Wells	Description
A	54	currently producing from the GE
B1	16	previously produced from the GE currently not on production
B2	6	previously produced from the GE have been recompleted in a reservoir above the GE currently not on production
B3	5	previously produced from the GE have been recompleted in a reservoir above the GE currently on production
B4	11	previously produced from the GE plugged and abandoned
C1	23	penetrates, but has never produced from the GE currently not on production
C2	44	penetrates, but has never produced from the GE producing from a reservoir above the GE
C3	27	penetrates, but has never produced from the GE producing from a reservoir below the GE
C4	17	penetrates, but has never produced from the GE plugged and abandoned
Total	203	

Well Characteristics. This part of the evaluation is more quantitative than the evaluation of the reservoir characteristics, and if done thoroughly, and supported by sufficient data, will identify almost all of the inputs required for the evaluation of potential DHOWS.

The well characteristics that have been addressed in this part of the evaluation are as follows: current water cut, offset distance, water disposal/injection zone potential, wellbore size and geometry, well history, wellbore isolation, inflow potential, and artificial lift performance.

DHOWS Watercut Threshold: The physical limitations of the liquid-liquid hydro-cyclone separation process determine the minimum producing watercut required for efficient separation of the produced oil-water stream. By setting a minimum of 75% threshold watercut for consideration of DHOWS applications (single stage separation) in candidate wells producing from the GE reservoir, Figure 1 shows water cut cumulative frequency.

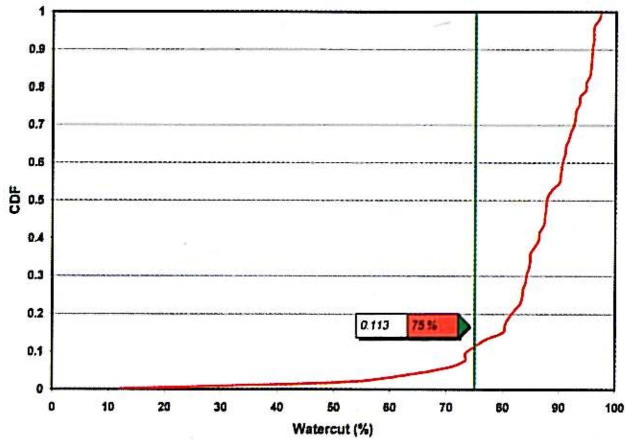

Fig. 1. Watercut cumulative frequency.

Production Zone and Water Disposal/Injection Zone Offset: The consideration of offset distance is more of assessing operational risk to which a candidate DHOWS application might be subjected, as opposed to determining whether or not a candidate DHOWS application is possible (unlike for current watercut, wellbore size, and water injection zone potential). Within individual candidate wells, as was the case for the candidate reservoir as a whole, a larger offset distance is preferred as it tends to mitigate/lessen the operational risks associated with: 1. cooling of downhole motors in the specific case of GE producers which are configured with ESP's and whose DHOWS applications under evaluation would maintain the current method of artificial lift – this can be "shrouded" away, but may reduce the maximum amount of horsepower and flow capacity of the gallery of bypass tubes that are available for a candidate DHOWS.

2. re-circulation of disposed/injected water into the production zone in the near wellbore region. Figure 2 shows offset distance cumulative frequency for GE reservoir.

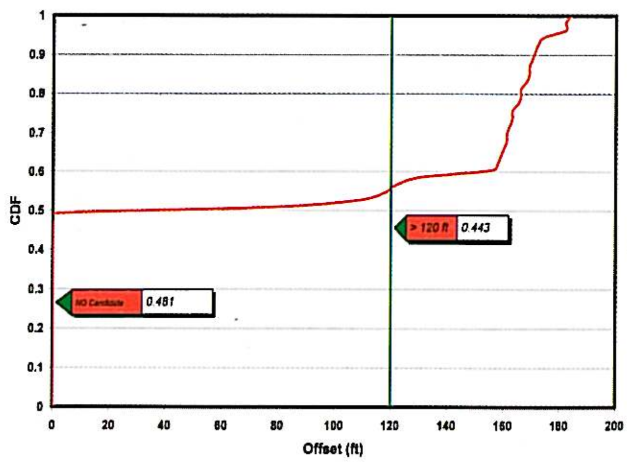

Fig. 2. Offset distance cumulative frequency.

Water Disposal/Injection Zone Potential: The assessment of water disposal/injection zone performance addressed two important considerations:

(1) design constraint(s) for potential DHOWS applications in respect of the candidate water disposal/injection zone.

(2) characterization of the relationship(s) which govern the water disposal/injection rate accepted by the candidate zone.

The candidate water disposal/injection zone performance has the largest impact on the specifications for DHOWS equipment designs, most notable of which are:

(1) It determines the number of injection and (if necessary) production pump stages.

(2) It establishes minimum horsepower requirement.

(3) It influences overall equipment length and determines the required offset distance between producing and disposal zones which is required to avoid the necessity for equipment designs with shrouded motor sections.

Zone Characterization: The uncertainty regarding the characterization of the candidate water disposal/injection zones identified at the reservoir level is confirmed from an examination of the DHOWS candidate well data.

Wellbore Size and Geometry: The wellbore size and geometry are important considerations governing the engineering design of potential DHOWS applications. The production casing sizes and setting depths and their relationship with the production and water disposal/injection zones have a direct impact on DHOWS equipment rated capacity. Having completed a review of the well size and geometry of the DHOWS candidate wells, the results can be summarized as follows:

(1) 31 % of the candidate wells lack production casing over the target production zone and as such are no longer considered to be high graded DHOWS candidate wells at this time (potential exists to deepen and install cemented liners in place for the 9 5/8 inch cased wells);

(2) of the remaining candidate wells, 35 % are completed with 9 5/8 inch, 18 % with 7 inch, and 11% with 5 inch casing over the target production zone (the wells completed with 5 inch production casing over the target production zone are not considered to be DHOWS candidates at this time);

(3) the DHOWS candidate wellbores are vertical wells which exhibit little deviations.

Well Workover History: As a part of the screening of an individual well, it is important to review the candidate well's workover/completion history. By identifying problematic wells or wellbore conditions, the likelihood of the long-term success of a DHOWS application can be increased. The cement bond also should be checked as part of casing leakage evaluation.

Wellbore Isolation: The utilization of two or more zones (in most applications) for the production and disposal/injection of reservoir fluids increases the requirement for hydraulic isolation, in the vicinity of the wellbore, between the production casing and surrounding reservoir units.

Inflow Potential: An examination of the candidate well's inflow performance behavior was addressed utilizing several complementary viewpoints. In respect of a final DHOWS evaluation design, a candidate well's inflow performance (IPR) is an integral portion of the nodal analysis that is the basis of any DHOWS design. In this case, the IPR serves to quantify the dynamic behavior of the sole fluid source for a candidate well.

Artificial Lift Performance: ESP systems are the sole artificial lift application present in all of the DHOWS candidate wells. Figure 3 shows ESP run life in the GE reservoir. The installed ESP system

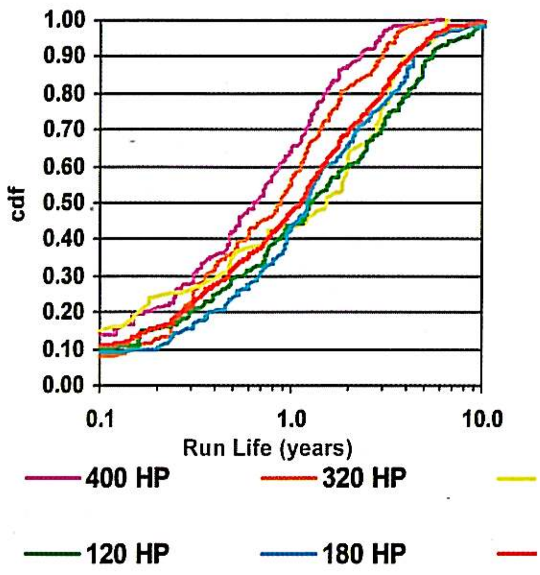

Fig. 3. ESP run life in the GE reservoir.

design, subsequent operation, and logistics in respect of any associated infrastructure will have some effect on the operational reliability of a potential DHOWS application. A DHOWS application equipped with ESP artificial lift system behaves very much like a conventional ESP application except for: (1) the direction of flow out of the pump, (2) the attached hydro-cyclone liners, (3) the extra plumbing to direct the hydro-cyclone overflow to surface.

EQUIPMENT DESIGN AND INSTALLATION

A significant number of operational risks and uncertainties have been identified as part of the evaluation of reservoir and well characteristics (primarily the uncertainty of the disposal/injection zone quality) for the DHOWS candidate wells. To prepare templates for DHOWS equipment designs and installation procedures would be the most appropriate once a water disposal/injection test has been completed on one or more of the candidate wells. To illustrate the impact of key design parameters and their associated inputs/constraints, several preliminary DHOWS equipment designs for a candidate DHOWS well are presented. The analysis has been summarized in the following sections: candidate well ranking, design inputs and constraints, DHOWS designs.

Candidate Well Ranking: The well ranking scheme utilized at this stage of the evaluation was at best only partially quantitative. Ranking characteristics and weights are presented in Table 4. The ranking system was implemented as follows:

Table 4. Category "A" wells – candidate ranking scheme.

Ranking characteristics	Weight (%)
Current watercut	10.0
Wellbore size and geometry	25.0
Water injection zone potential	15.0
Inflow potential	20.0
Offset distance	15.0
Oil reserves	7.5
Well history	7.5

1. Only the well characteristics were addressed by the ranking scheme.

2. For each well and sub-well characteristic (some wells had more than one quantitative characteristic included), as many as 7 possible designations were assigned (NC = no candidate, this well characteristic is of such a state that the well cannot be considered as a candidate without considerable/costly well construction/intervention; blank = no data available, the well can still be considered as candidate based on the other characteristics; 5 to as low as 1 (best to worst) = a numerical ranking approximately ordering the candidate wells with available data for that characteristic into 5 groups where possible).

3. With the aim of maximizing the liquid and associated oil throughput from a DHOWS application, a weighting scheme to combine these rankings into a total score with the largest total score indicative of the "best" DHOWS candidates. (The blanks having been treated as zeroes in the linear combination of the characteristic ranks)

4. The data have been rank ordered according to this total score (as opposed to by well name) to highlight at this preliminary stage of the feasibility study which wells are expected to exhibit the best overall combination of well characteristics when applying DHOWS.

Of the original 54 DHOWS candidate wells, 36 of the wells are believed to exhibit well characteristics that would require to relegate them from immediate consideration. Again, it is the evaluation team's belief that these NC characteristics would require that these candidate wells undergo significant well construction/ modification before the NC was upgraded to a relative ranking. Because of this, they have been dropped from further consideration for this study. Table 5 presents Ranked Candidates. Rather than isolate the top 5 DHOWS candidate wells for further examination, it is decided to select 3 more wells from the remaining inventory of 18 that to some extent were representative of the range of circumstances/well characteristics present in the entire well inventory. The wells selected are as follows: E-001, E-038, E-095.

Design Parameters and Constraints: Before undertaking a DHOWS design, it is somewhat beneficial to document at the first place the relevant design inputs and, where necessary, identify any constraints that might apply in respect of an actual design that must be worked up prior to actually preparing the design. In addition to the well constraints (watercut, wellbore size/geometry, drawdown, fracture pressure, and operational risks

Table 5. Ranked candidates.

Well	Water cut rank	Wellbore. size & G rank	Well history rank	Inflow potential rank	Offset distance rank	Injection zone potential rank	Remainin g reserves rank	Total score
E-001	4	5	5	5	5	4	5	4.35
E-033	4	5	3	5	3	4	5	4
E-035	4	3	5	5	3	5	5	3.9
E-038	4	5	5	4	1	4	4	3.675
E-094	1	5	5	1	5	4	1	3.65
E-278	2	5	5	3	4	2	3	3.45
E-037	1	5	3	4	4	3		3.325
E-095	2	3	5	5	2	5	4	3.275
E-275	1	5	5	2	2	4		3.225
E-036	2	5	3		3	4	5	3.2
E-072	3	3	5		4	5	4	3.175
E-025	1	5	3	3	3	3	2	3.125
E-031	2	5	5		1	5	4	3.125
E-299	1	5	5	2	3	2	1	3.05
E-040	1	5	3		5	2	2	2.875
E-092	2	3	5		2	5	2	2.625
E-054	3	3	3	1	1	3	1	2.55
E-066	1	3	5	1	1	3	1	2.3

– wellbore isolation, wellbore integrity, and artificial lift run life), there are other DHOWS equipment related constraints that must be addressed these are: motor horsepower and bypass tube velocity. Table 6 presents the motor horsepower limitations. It is essential that the relevant constraints be identified and quantified before the design is made in order to ensure that a design that is produced is consistent with the constraints and good engineering practice.

DHOWS Designs: The preparation of a DHOWS design, like most downhole equipment designs, requires a considerable amount of data and oversight in order to ensure that an internally consistent, reliable, and operable equipment specification is the final result. The DHOWS designs completed in the course of preparing this report were developed as follows:

1. The required design data were collected in a summary input data sheet;

Table 6. Motor horsepower limitations.

Equipment series	Max single motor HP @ 60 hz	Single motor length (ft)	Max total combined HP @ 60 hz	Max # of motors combined	Minimum Casing Size (")
456	150	30.7	450	3	5.5, 7 shrouded
540	250	30.4	750	3	7
562	450	34.9	900	2	9.625, 9.625 shrouded

2. The input data sheets were vetted and the inputs for each data element were compared with data for the DHOWS candidate well population, after which the relevant design constraints applicable to each of the candidate wells were searched and documented;

3. In the absence of accurate injectivity indexes, all designs were created using an estimated value calculated from the medium permeability estimates for the Lower 3 and Basal reservoir intervals;

4. The individual designs were created to maximise the production, within the bounds of the design constraints.

Table 7 summarizes the DHOWS design for this candidate well in relation to the 5 dominant system constraints (CAPsep – hydro-cyclone capacity, HP – motor horsepower, VELbp – bypass tube velocity, DD – drawdown, Pfrac – formation fracture pressure). Figure 4 shows DHOWS Diagram. Having prepared a series of concept proof equipment designs for DHOWS candidate wells, the following summarizes the findings:

Table 7. DHOWS design inputs.

Description	Value	Units
General information		
Casing size	9.625	inch
Casing weight	40 (est.)	lb/ft
Casing condition/impairment/doglegs	uncertain	
PBTD/TOC	2779	ft KB
Liner and interval	NA	ft KB
Tubing size (OD)	3.5	inch
Tubing weight	9.3 (est.)	lb/ft
Tubing landing depth	To be determined	ft KB
Current method of artificial lift	ESP	
Power	To be determined	hp
Voltage available		V
Frequency	50 (est.)	Hz
Producing data		
Formation and type (e.g. carbonate, sandstone, etc.)	Shoal 1 and 2 (carbonate)	
Production perforation interval(s) – MD (1967)	2710-2730	ft KB
Production perforation interval(s) – TVD	2710-2730	ft KB
Anticipated production rate		
Oil rate	1200	BBLD
Water rate	18800	BBLD
Total fluid rate	20000	BBLD
Wellhead pressure (for the casing)	~100	psi
GOR	20	SCF/BBL
Bubble point pressure	140.3	psi
Stock oil density	0.83	g/cc
Reservoir oil density @ 1176 psig, 131 deg. F	0.81	g/cc
Oil viscosity @ 1176 psig, 131 deg. F	2.59	cp
Water density @ 68 deg. F	1.01	g/cc
Bottomhole temperature	131	F
Producing bottomhole pressure @ mpp	487	psi
Producing fluid level from surface (mD)	To be determined	ft KB
Static bottomhole pressure @ mpp	790	psi
Producing wellhead (for the tubing) pressure	~100	psi
Liquid productivity index (estimated)	66.208	BBLD/psi
Abrasives, Scale, CO_2, H_2S, asphaltenes, waxes	H_2S = 5.22% ; CO_2 = 30 %	
Chlorides and concentrations	19 100	ppm
Anticipated water injection zone data		
Formation and type (e.g. carbonate, sandstone, etc.)	Lower 3 and basal – carbonate	
Injection perforation interval(s) – mD	2904-3022	ft KB
Static injection zone pressure @ mpp	895	psi
Sandface injection pressure	To be determined	psi
Estimated fracture gradient	0.65	psi/ft
Injectivity index (estimated)	40.0	BBLD/psi

Notes:
Injectivity index based on mid k of 88md skin –4. Cement will have to be drilled out to access the Lower 3 + Basal zones.

1. Of 54 Category "A" DHOWS candidate wells, only 18 were deemed to exhibit sufficiently robust wellbore characteristics to be considered for further evaluation at this stage of the examination of potential DHOWS applications;

2. Of the 18 remaining DHOWS candidate wells, only 3 were selected for preparation of detailed proof of concept DHOWS equipment designs;

3. With the exception of well E-038, the remaining DHOWS candidate wells have an equipment related

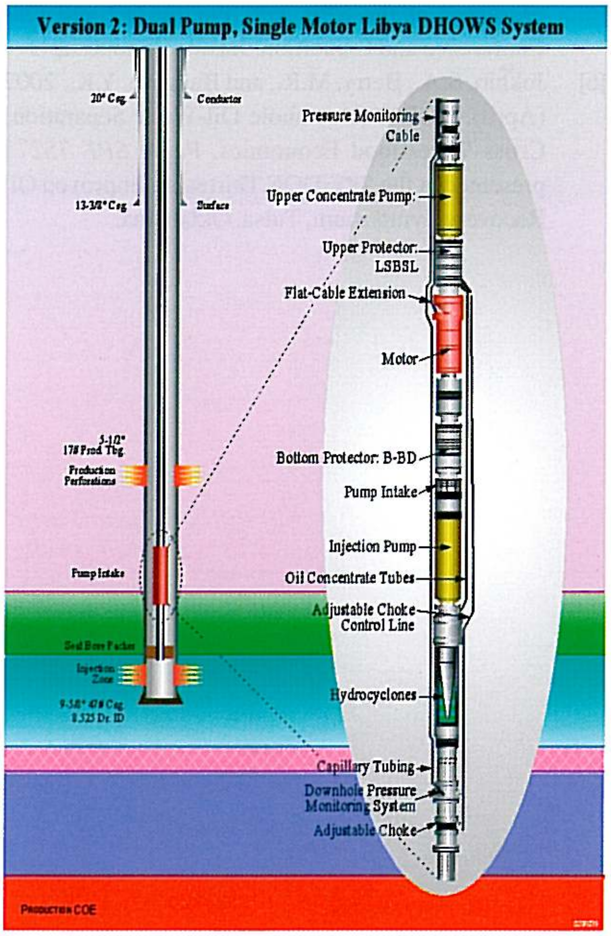

Fig. 4. DHOWS diagram.

limiting design constraint (hydro-cyclone separator capacity);

4. The drawdown limiting design constraint evidenced in well E-038 is not unexpected in the case of DHOWS candidate wells with low PI's;

5. The separator capacity limiting design constraint evidenced in wells E-001 and E-095 is not unexpected in wells with large PI's – especially for small diameter wellbores, (however, not unexpected in large diameter wellbores as well);

6. The design for the well E-095 appears to be extremely robust with minimal anticipated mechanical strain; therefore, a long run life would be anticipated.

CONCLUSIONS

1. Based solely on the DHOWS watercut threshold of >= 75% , some 88.7% of the candidate wells are identified as potential DHOWS candidates;

2. The injection indices, a critical parameter in specification of DHOWS designs, of the candidate wells are not adequately defined by the existing data set, and can only be better defined by undertaking one or more properly designed and executed injection/disposal tests;

3. 31 % of the candidate wells lack production casing over the production zone and, therefore, are not considered as high quality DHOWS candidates – 35 % of the candidate wells are completed with 9.625 inch and 18 % with 7 inch casings, potentially permitting the installation of 20 and 10 MB/D capacity DHOWS systems respectively;

4. The majority of the candidates have some type of downhole obstruction (TOC or bridge plugs) that give rise to some form of operational risk in gaining access to the targeted disposal/injection zone(s);

5. Casing leaks are a persistent and recurring problem and represent an operational risk to the potential DHOWS candidates, these leaks appear to be increasing in frequency with time.

6. Of the 54 candidate wells, 18 demonstrate favourable reservoir and well characteristics and meet the initial DHOWS screening criteria, and have been rank ordered accordingly. The remaining 36 wells exhibited some unfavourable well characteristics which required the evaluation team to remove them from immediate consideration.

ACKNOWLEDGEMENT

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