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The Complicated Challenges to ESP Artificial-lift Application in an Oil-field of Middle-East

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Abstract: *Many oil and gas fields are located at the Middle-East region, especially distributed across Zagros fold belt and Arabic platform slope, most of which were discovered in the 1970s. However, due to the influence of huge reserves, OPEC restrictions, and wars and so on, water-flooding development and artificial lifting are only applied at preliminary status now after long-time natural producing in this region. Moissan Oil Field is located in Iraq and it is of unique regional characteristics in carbonate reservoir lithology and fluid properties. Actually, the artificial lift application of Electrical Submersible Pump (ESP) in this field is also encountered a lot of severe difficulties which will be comprehensively analyzed one by one in details. After that, effective proposal is raised based on geological reservoir, underground well completion, artificial lift design, and operation management and production optimization. The difficulties for ESP application are overcome and the running time of ESP is effectively prolonged.*

Keywords: *Oil Field in Middle East; ESP Artificial-lift; High H_2S Concentration; High GOR; High Bubble-point Pressure; Heavy Formation Water*

1. Introduction

Moissan Oil Field is located at the southeast of Iraq and it is firstly developed at the 1970's. Due to the influence of wars and so on, the oil is produced spasmodically in a natural-flow manner. Chinese company firstly joined the oil field development in the form of Technical Service Agreement as operator at the end of 2010, and the production management of oil field is started in 2011. After that, the oil production rate starts to increase. Along with the decline of reservoir pressure and the increase of water cut, the field trial for the artificial lift application of Electrical Submersible Pump (ESP) starts at the end of 2015. Generally, the application of ESP lifting is still at the initial stage. The resources are scarce and the level is relatively low for related technical services, and there are little experiences for reference [1].

Since 2017, the down-hole ESP system, the surface equipment and the down-hole supporting completion tools are optimized systematically and widely used on site, until now, these technical measures together take the lead in the aspects of stimulation effects and the operation longevity of ESP.

2. Technical Background

2.1 Geological Reservoir Characteristics

Moissan oil Field is actually composed of three oil fields, and they mainly include two development formations. On the top there is the Tertiary Asmari reservoir and its depth is at 2800-3300m. The rock is mainly dolomite and limestone, and there is also sandstone from part to part. The micro fracture is unevenly distributed in some parts and the geological characteristics are complex. Although the sandstone is not continuously distributed, the separate sand body is generally of good grades. The productivity is high and the sand production is common, and screen completion is mainly used in this reservoir.

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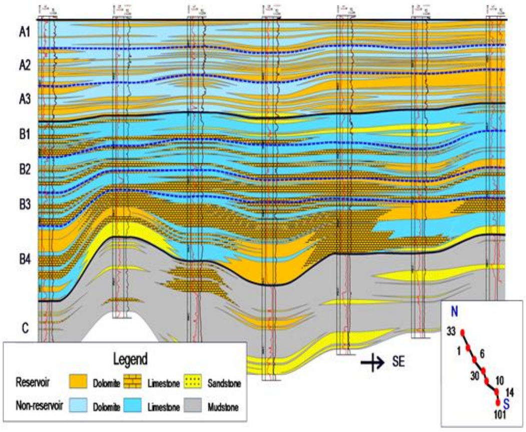

Figure 1: Lithology profile for Asmari oil reservoir formation

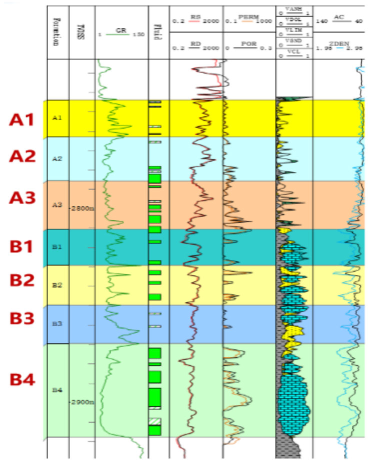

Figure 2: Well logging profile for some production well in Asmari oil reservoir

The main formation at the bottom of Missan field is the Cretaceous Mishrif reservoir. Controlled by both the sedimentary and the diagenetic effects, the formation has a relatively steady distribution laterally, and the vertical physical property varies a lot so there is strong heterogeneity. The reservoir is at depth 3800-4400m with thick limestone, and micro fracture is not very common. Water flooding is applied for oil development and there is no sand produced from wells. Well casing perforation completion is used in vertical well and directional well. Punched pipe completion is mainly used in horizontal well completion and open whole completion is used in other several wells [2].

2.2 Fluid Physical Properties

Physical properties of reservoir fluids in Missan oil field are complex: high reservoir temperature, high reservoir pressure, and high bubble pressure, high GOR, heavy formation water, ashpalten deposition and fluid emulsion phenomenon, make the ESP application extremely difficult.

In reservoir environment, formation fluid can flow smoothly. However, at the ground condition, the oil gravity is large and the flow viscosity increases obviously which will cause large power consuming in lifting process. At the same time, reservoir fluids have obvious emulsification and deposition properties which will greatly influence the flowing in well bore, pump, and tubing, especially impact significantly on the temperature control of ESP’s motor and the performance of ESP running life. At present, emulsification is the main phenomenon to be avoid in oil field development [3].

Reservoir fluid contains corrosive gases, and this require that well casing, production tubing and completion tools that should have adequate erosion resistance. CO_2 partial pressure in Asmari reservoir is 0.0248-0.2207MPa, and H_2S is of low content. CO_2 partial pressure in Mishrif reservoir is 0.6276-1.5103MPa, and H_2S partial pressure is 0-0.8138MPa, which has strong corrosivity towards equipment.

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Formation water in Missan oil field has density of about 1.15g/cm3. This will cause large power consuming and will increase the erosion of well casing, completion tools and underground equipment. Therefore, the components of ESP need higher insulation level for erosion and the systematically calibration on the shafts of pump, intake sub, protector and motor[4]. At the same time, the requirement for small size motor's performance is very serious. However, these factors are easily to be ignored in lifting design, which will lead to many difficulties in the construction and production process.

Table 1: Data for two reservoirs and the fluids in Missan oil field

Reservoir	Crude Oil Density of stock tank	Saturation Pressure @90°C	Gas Oil Ratio	B_{os}	Oil Viscosity @35Mpa/90°C	Formation Water Density	Cl-	CO_2	H_2S	N_2	Gas Gravity	BS&W	Initial Static Pressure	Current Static Pressure	Reservoir Depth	Reservoir Temperature
	g/cm^3	Mpa	m^3/m^3	-	cp	g/cm^3	mg/l	Mol %	Mol %	Mol %	-	%	Mpa	Mpa	m	°C
Asmari	0.9219	18.10	102	1.36	3.4	1.1522	169690	0.1-1.52	0-0.4	0.4-1.33	0.8995	0 -70	34.5	29.6	3200	95
Mishrif	0.9183	18.34	124	1.46	1.6	1.1456	145856	3.4-7.2	0.4-2.5	0.4-2.1	0.9122	0-50	44.8	26.9	4200	118

2.3 Well Bore Configuration

The cap rock is salt and gypsum, which is commonly distributed with various thickness at depth range 2000-2900m. The pressure factor for salt layer is 2.2-2.3g/cm3, but the overlie target formation is of normal pressure system. These characteristics lead to many problems: well casing has many layers with great strength and small inner diameter; the difficulties for completion outside well casing are increased and the quality cannot be guaranteed.

Production casing mainly use 28 PPF 6.625 inch, and others use 32 PPF 7 inches for completion. At the same time, some producers are completed and put into production at 1970's, and the casing is damaged and mended many times during these long-term operation, so it has poor integrity and the inner diameter is small. The completion is mainly casing of 5.5 or 4.5 inches after casing patch.

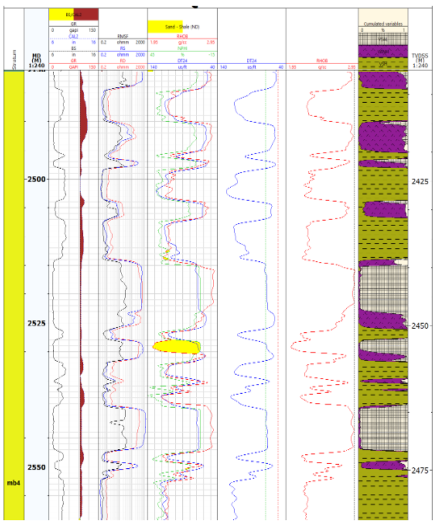

Figure 3: The longitudinal profile of gypsum bed formation cross salt formation

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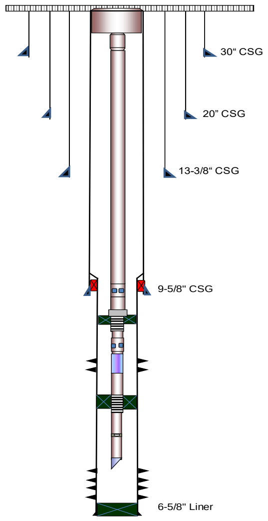

Figure 4: Typical well configuration of natural producing well

3. Challenges for Lifting by Electrical Submersible Pump

3.1 Restrictions from Pump Setting Depth

In Missan oil field, there are mainly three challenges concerning the pump setting depth: ① The produced GOR is 100-124m3/m3, and the bubble point pressure is higher than 18MPa. This is positive in the natural flowing period of oilfield development, however, in the ESP artificial-lift period, the considerable gas inside the down-hole tubing and pump due to high GOR will be easily over the gas handing capacity of ESP's pump, and may frequently cause gas-lock inside pump to tripped the ESP system. Therefore, the pump should be set as deep as possible in the well to minimize the influence of degasification. Based on simulation analysis, the limit pump setting depth should be at least 2100m even if gas compressor is deployed. ② The depth of salt and gypsum layer in Missan oil field is 2000-2900m, the Asmari reservoir is just below this layer. For producers in this reservoir, the cementing quality outside the casing is not good and the casing protection should be especially paid careful attention to. Therefore, ESP has to be set deeply in this salt and gypsum layer as well. ③ The production casing is of common carbon steel which is not anti-corrosive, but the erosive gas content in underground fluid is high, so that as the comprehensive completion system, the pump conveyed by tubing with production packer or can system, has to be deployed and set as deep as possible to protect the well casing against corrosion.

3.2 Restrictions from Pump Assembly Dimension

On one hand, influenced by possible extrusion of the salt and gypsum layer above, well casing is selected with thick wall, so the well borehole is of small size. Most wells in completed by 6.625 inch 28 PPF C-75 or L-80 liner, and there is little application worldwide. On the other hand, the small-size ESP assembly which is adaptive to small-size liner cannot meet the mainstream lifting capacity of 450-1000m3 per day (underground condition) in the oil field in general. This kind of configuration of small well-bore diameter but with high production rate, there is no application practice in the oil and gas industry worldwide.

Challenges are as follows: ① The pump motor which are of small size, high horse-power and high temperature tolerance is hard to manufacture, and there is few product series for selection in the world. ② In some production well, the power of single motor cannot meet the requirements, and dual motors in cascading manner have to be used which actually increase the weak spots and risk for ESP system insulation. ③ The water cut may vary much during the service cycle of ESP, and the oil production rate may also very much after stimulation. These require that the pump should have a large range of delivery capacity. ④ In the small-size packer, the space for cable penetrator and oil tube is limited. This also

ISSN 2706-655X Vol.4, Issue 2: 14-23, DOI: 10.25236/IJFET.2022.040203

increases the requirement for the connection quality between cable and penetrator. ⑤ There are no mature over-cable packer products worldwide now which are adaptive to the small-size well bore. ⑥ Application of large-size round cable is restricted by the limited space.

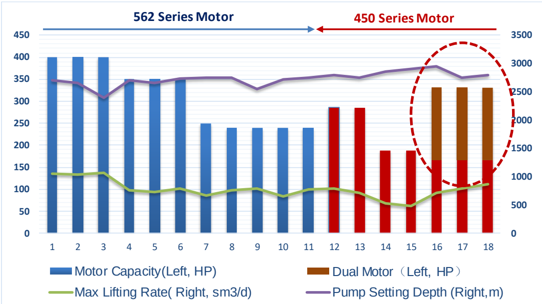

Figure 5: Motor type and configuration design of ESP for producers in a batch of installations

3.3 Restrictions Form Formation Pressure and Temperature for Underground Equipment

Initial formation pressure is higher over 43MPa in Missan oil field, and in some region with low recovery factor, the formation pressure is still higher than 35MPa, as demonstrated by figure 6. At the same time, the formation temperature is also very high.

Challenges form formation pressure and temperature for underground equipment are mainly as follows: ① The mainly popular pressure rating for ESP fittings and well completion tools is 35MPa worldwide, such as underground pressure/temperature sensors and production packer, and some tools' pressure rating can even exceed 35MPa, but the tools are few which can work long term in environments with pressure over 35MPa [5]. ② When there is abnormal circumstances underground, such as emulsification, sand plug, or difficult ESP star, the pressure range for well intervention is narrow and the risk for ESP damage is high. ③ The climate temperature on the surface is also high and the temperature can even exceed 53℃ in the summer of this region. There is also sand storm on site in summer and the heavy raining in winter, the extreme weather causes a severe challenge for the smooth running of pump equipment on the ground. For example, in order to reduce temperature impact, air conditioner is used to some equipment cooling which are actually of "outdoor type". ④ The power of ESP's motor is already very large, and the temperature toleration of motor is very crucial concerning the working environment. The motors which can work in the underground small spaces with large power are not common at all on the market.

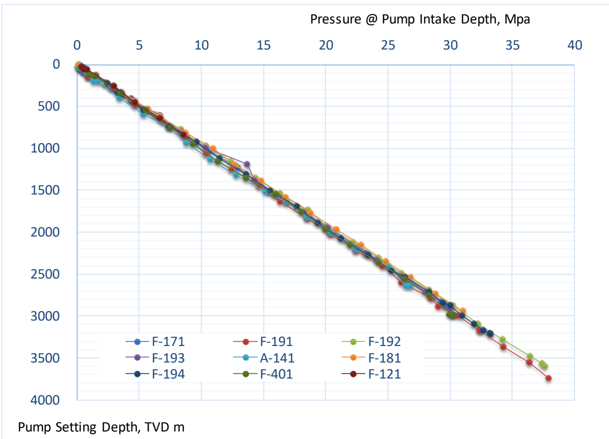

Figure 6: Well-bore pressure monitoring results during a batch of ESP installations

3.4 Restrictions from Formation Water Density

Formation water density is relatively high in this area, and the problem will be complicated considering the small-size pump assembly, the relatively high delivery capacity and pumping lift-head.

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Details are as below: ① The pump assembly has to be started at high power even at the initial pump starting period with low flow-rate, otherwise, the pump may have to be started unsuccessfully or in system vulnerable condition which may cause low running life, high operation cost, or low production efficiency. ② The load of underground cable is increased, and the voltage loss on unit length of cable is increased. The cable insulation becomes weakened. ③The water cut will increase with the development of oil field, and the power required will become larger. Therefore, the motor power need to cover large range accordingly but which is hard to realize for the design of ESP. All the situations above once happened in Missan oil field before, if ignored, more serious results may happen with many lessons.

3.5 Restrictions from Oil Emulsion

The wax content is 2-3.2%, and the asphalt content is 4-7.5% in the oil. In some region, the asphalt content is 8-10%. Analysis shows that asphalt is the main influential factor for emulsification of well bore fluids.

The characteristics of emulsification in Missan oil field are: ① Few production wells are influenced by emulsification in Asmari reservoir, and lots of production wells are influenced by emulsification in Mishrif reservoir. ② Analysis by experiments and production monitoring shows that the production well is more sensitive for fluid emulsification when water cut is 35-55%. ③ In some blocks of Mishrif reservoir, formation pressure drops much and reaches below the asphalt envelope, emulsification happens a lot in these blocks and it is relatively hard to dispose. ④ Experiment analysis shows that the emulsification is of water-in-oil type.⑤ In some wells, the fluid viscosity at well head can reach as high as several thousand mPa•s or even higher. Emulsification can lead to the production fluctuation of wells, and the production can only be recovered sometimes with necessary well interventions [6].

Emulsification will cause bad influence for the lifting-head by ESP. Firstly, the flowing in wells will face uncertainties, such as higher current and temperature of ESP's motor, and the lower lifting-head and delivery capacity of pump. Sometimes, the pump body or the well bore may be stuck, so the pump may not be able to work at all. Secondly, the flow friction will increase due to the emulsification of fluids, and the flow may cease which will badly and indirectly influence the running life of ESP. Emulsification is also in positive correlation with the water cut of production, and it is hard to be eliminated in the life cycle of oil field development [7].

3.6 Restrictions from Sand Production

There is sand production from most of the wells in Asmari reservoir. The physical property of formation is good in some region, and there is obvious sand production in these area. The sand prevention technique must be applied in well completion. The resistance of abrasion and shock for ESP assembly must be considered as well [8].

3.7 Restrictions from Cable Insulation Problem

Figure 7 and figure 8 show the insulation test results during ESP installation for some AWG 4 type cable in the early stage and it demonstrates that: cable insulation resistance drops rapidly when it enters the salt and gypsum layer and the insulation situation is actually too serious to handle during the whole life cycle of ESP running.

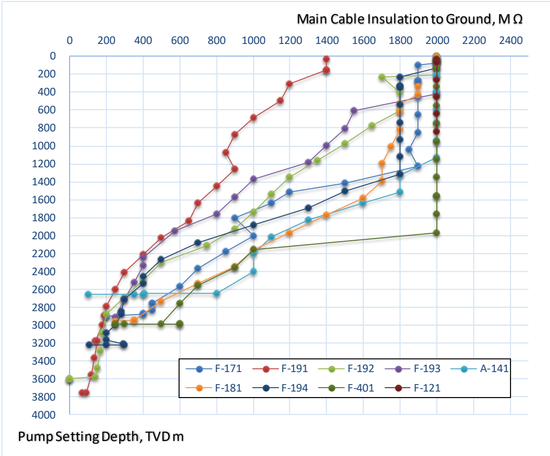

Figure 7: Insulation test trend for cable against ground during a batch of ESP installations

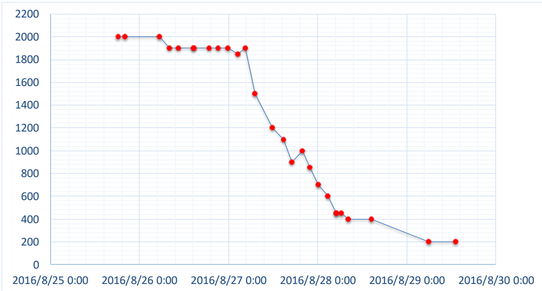

Figure 8: Cable integrity Ph. to ground resistance insulation in a well running in whole (MΩ)

4. Integrated Key Techniques for Successful ESP Application in Missan Oil Field

Concerning challenges above, many techniques with innovation are applied in Missan oil field.

4.1 Integrated Design in the Multi-Disciplinary Perspective

Making each design in the multi-disciplinary perspective, concerning such as well site construction, grid power supply, diesel power generation, the variable frequency speed regulating device (VSD), the pulse filter package against harmonic for sine wave output, cable penetrator/feed through of wellhead/packer, lead cable, pump type, motor protector, down-hole sensor, well completion tools, reservoir productivity/water cut forecast and so on. In this way, the strength of each discipline will be brought into play, and the integrated reliability of technical scheme will be increased. Actually, this process also seriously tests the capacity in technology and cooperation of the team.

4.2 Systematically Strength the Torque Configuration for Each Part of ESP System to Overcome the Problems of Sand Producing, Heavy Water and Serious Power Fluctuation

Four aspects in details: ① The fluctuation and even losses of power supply grid frequently dash the mechanical strength of ESP system, so redundant space is especially important in the system design. ② For sand production prevention: firstly, premium screen is used to well completion tools in sandstone formation; secondly, in pure sandstone formations with good physical property, the negative-pressure perforation operation is somewhat avoided. ③ Concerning the challenges caused by high density of formation water, the assumption of well bore fully-filled with formation water is to calibrate the ESP components' strength and motor's capacity as basic designing. ④ Optimization design concerning alloy material, innovated flow type of pump, dual protectors configured, and pod system deployed in some special wells, cable protector to whole production tubing string, tungsten-carbide wear bushing designed in the bottom of motor shaft, to improve the performance of ESP system.

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4.3 Improving Power Supply Quality from both the Upstream and Downstream of VSD

Three key details for this solution: ① Concerning the bad power grid in Iraq, the lack and fluctuation of power resources, diesel generators are adopted for power supply in some region. One generator is for use and the other is spare in case of sudden accident for the first one which is controlled smoothly through synchronization panel. This proposal improved the quality and steadiness of power supply which is especially crucial for the smooth operation of ESP. ② Concerning harmonic interference of power grid and water cut increasing in the oil field, one-to-one VSD is innovatively allocated in Missan oil field. [9]

4.4 Effective Measures Adaptable to the Small-size Well Bore

Concerning the restrictions from small-size well bore, the corresponding measures are taken as follows: ① Motor of 538 series is the main application in Missan oil field in the artificial-lift system of both Asmari and Mishrif reservoir producers, and this also lowers the material inventory. ② For producers with low water-cut and nil H_2S content in Asmari reservoir, motors of 562 series can be chosen, and the setting depth of pump can be lifted into the casing of 9.625 inches to meet the requirement of productivity. Generally, the pump setting depth is optimized at about 2700m, and however the artificial-lift system is recommended to configure the pod system along with production string to protect the casing from erosion. From top to the bottom, the system adaptable for 28 PPF 6.625 inches of liner are optimized as: multifunctional sensor+motor of 538 series+dual motor protectors+pump intake+gas handler+centrifugal pump of 400 series+ pressure sub+pump head sub. ③ Cables are promoted as AWG No. 1 and No. 2 with upgraded insulation material(EPDM) from AWG No.4, and there is metal shell outside for protection, critically 230℃ temperature rating deployed. Practices have proved that these measures effectively guaranteed the long running life of ESP system. ④ The new and dedicated production packers combined with tri-legs cable penetrator are designed solely for the wells of Missan Oil Field whatever the production casing is 9.625 inches or 6.625 inches.

4.5 To optimize the Temperature and Pressure rating of ESP System

Three key points for this solution: ① The electric motor adopts temperature grade of 160℃(refer to the inner temperature of electric motor), and the down-hole sensor adopts technical grade of 50MPa and 150℃. ② In reservoir blocks with high pressure, setting depth of production packer is lifted with the intention to avoid it over 35MPa, especially for packers corresponding to 6.625 inches. ③ Optimize the surface equipment up to highest temperature grade (environment temperature 55℃). NEMA 3R or 4 outdoor type is proposed, and sunshade is also assembled at the same time to avoid direct solar radiation.

5. ESP Application Effect and Related Insights

Practices show that measures above effectively improved the application of ESP and make the steady and smooth application of ESP become actual.

5.1 Operation Effects

(1) In Missan oil field, the service life of ESP which are assembled in 2017 are as shown in figure 9. Among them, underground systems have failed to work in 11 wells and the average running life of these wells are 721 days. The average service life of ESP in the other 21 running wells until January, 2021 are 1184 days and the application results are superior in this region[4,8,10].

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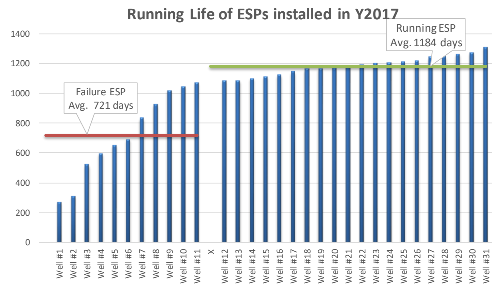

Figure 9: Running days of ESP which are installed in 2017

(2) The motor is the most important component of ESP and are liable for failure, practices show that it can endure the rigorous conditions as well as the high temperature. Figure 10 demonstrates the temperature related to the pump motor operation monitored underground in 2021.

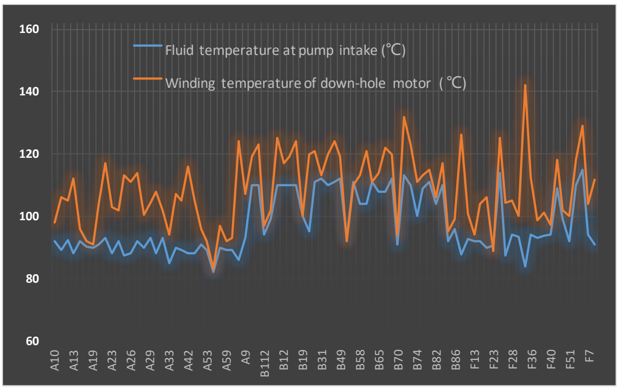

Figure 10: The running temperature of ESP's motors monitored in 2021

(3) During 2018 to 2020, sudden power trips happened frequently dozens of times at a short period. Which cause mechanical shock to pump components and great damage for the electric components' insulation. Practices prove that the improved ESP system can endure such harsh conditions and the excellent running life is obtained as which is shown in figure 9.

5.2 Further Insights

(1) Concerning the various challenges in Missan oil field for application of ESP, it is essential to integrate the professional competences of reservoir engineering, well completion, artificial-lift technique, well intervention management at well-site, production management and so on. Only in this way, can the system integrity and design quality be guaranteed.

(2) The high-temperature resistant electrical components and the shockproof dynamic rotary components are the technical core for successful application of ESP in a special oil field.

(3) As for the negative influence of emulsification, especially for the wells of no production, rigless well intervention such as diesel solving, organic solvent dissolution combined with gas-lift and wellhead parameters adjustment to flow-back the emulsion fluid inside tubing or pump as priority. These techniques have been successfully practiced in Missan oil field.

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