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RESEARCH AND APPLICATION OF HIGH-PERFORMANCE DRILLING FLUID SYSTEMS IN VIETSOVPETRO JOINT VENTURE

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Summary

Since 2015, starting with the KGAC system, the authors of Vietsovpetro have diligently researched and rationally combined conventional and modern drilling fluid (DF) systems. As the result, the KGAC was upgraded to the KGAC Plus. Then, during the testing and application of the KGAC and KGAC Plus systems to more than 100 wells, some adjustments to the system composition were made and KGAC Plus was improved to KGAC Plus M1. Particularly, Polyhib was used instead of NaOH and AKK to regulate the pH degree and prevent the clay from swelling. Not satisfied with the achievement, the Vietsovpetro team continued to study and test to advance KGAC Plus M1 to KGAC Plus M1*, which has greatly improved the drilling quality and efficiency at Vietsovpetro.

Key words: Water-based drilling fluid, clay inhibitive chemicals, anti-bit balling (anti-accretion) chemicals, borehole stability, thermal stability.

1. Drilling fluid system KGAC

1.1. General information

The KGAC drilling fluid system uses two inhibitors (FCL, AKK) of the traditional FCL-AKK system and two inhibitors (KCl, Glycol) of the advanced KCl/glycol system. In KGAC, FCL inhibits by dispersion mechanism, AKK by flocculation, KCl by binding K^+ ions, glycol by forming a film around the clay components. All 4 inhibitory agents are compatible with each other and with other components such as xanthangum, PAC-LV, lubricants, etc. in the KGAC system. After the laboratory test, the KGAC drilling fluid system was applied at 2 wells of Vietsovpetro with very good results, significantly reducing complexity and non-production time. Its calculated economic efficiency yielded a million dollars. Since then, the KGAC system has been widely used in more than 50 wells of Vietsovpetro.

1.2. Laboratory testing results of drilling fluid system KGAC

The KGAC drilling fluid system is analyzed, tested and compared to 3 systems of FCL/AKK, Glydril, Ultradril.

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All the drilling fluid systems are prepared on freshwater base. Their parameters are measured at 25°C before heating. Then, the samples were hot rolled in a roller oven at 130°C for 40 hours. After heating, the parameters are re-checked, especially the swelling degree of clay (clay inhibition test).

Testing results of main parameters are shown in Table 1 and Figures 1 - 3

Table 1. *Parameters of drilling fluids systems before and after heating*

No.	System	Fluid loss		YP		$Gel_{1/10}$	
		Before heating	After heating	Before heating	After heating	Before heating	After heating
1	GLYDRIL	5	5	33	30	7/9	7/8
2	ULTRADRIL	5	5	43	39	8/12	7/11
3	FCL/AKK	4.5	8	7	9	3/5	1/2
4	KGAC	5.2	5.7	28	26	9/11	8/12

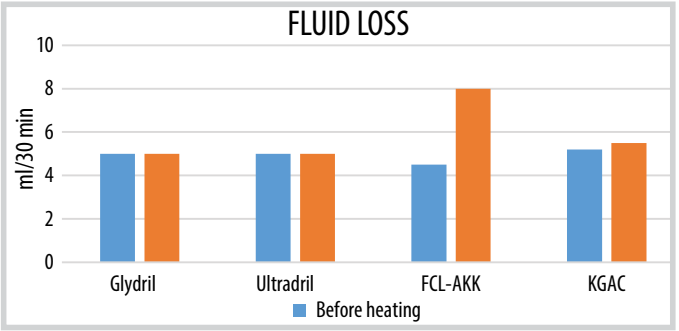

Figure 1. *Fluid loss.*

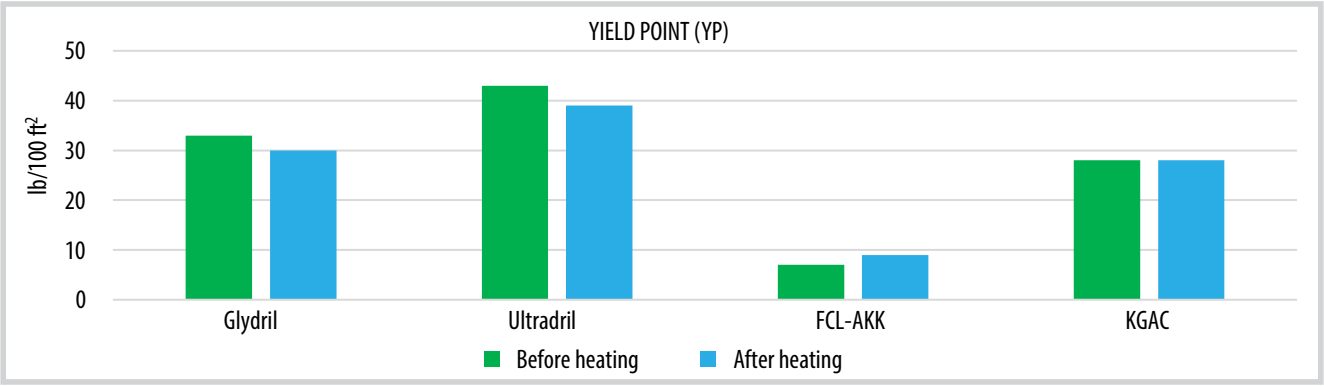

Figure 2. *Yield point (YP) of drill water-based drilling fluid system.*

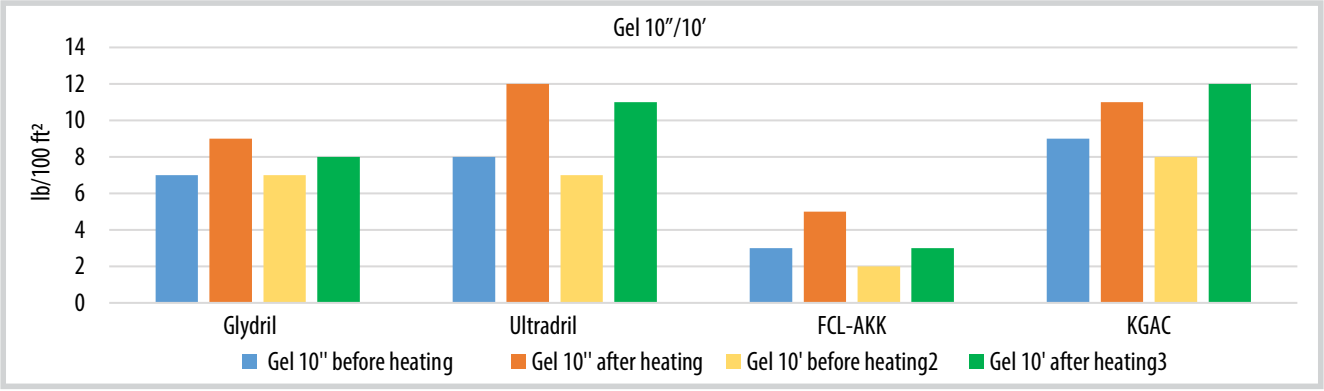

Figure 3. *Gel 10''/10' of drill water-based drilling fluid systems.*

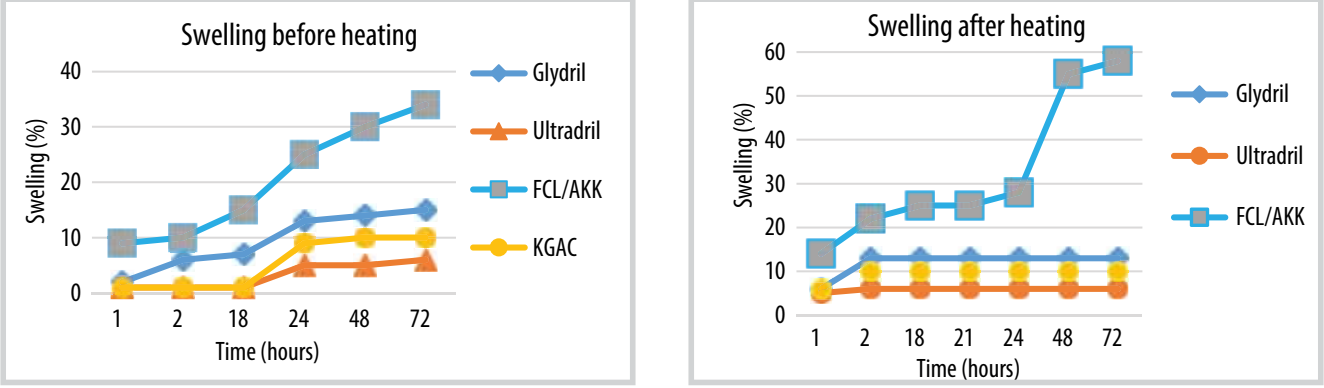

Figure 4. *Comparison of clay swelling between drilling fluids systems (before and after heating).*

The obtained results (Figures 1 - 3) show that the new inhibitor drilling fluid system KGAC is superior to the traditional FCL/AKK and equivalent to Glydril system, which was widely used by contractors at Vietsovpetro's wells, as below.

- Fluid loss: The fluid loss value is equivalent to other systems before heating, while better than the FCL/AKK and comparable to the Glydril after heating.

- Yield point (YP): Both values before and after heating are much better than that of FCL/AKK system, and equivalent to Glydril system.

- Gel: The value shows that the DF is thermally stable after heating, better than the FCL/AKK and equivalent to the Glydril.

The experiment comparing the degree of clay swelling inhibition between some advanced systems is conducted on a swellmeter: The clay sample used is activated clay and compressed at 6,000 psi (408 atm). With geological conditions of Vietsovpetro's wells, the experimental conditions are equivalent to the Oligocene layer containing many active clays. Exposure time of clay core samples in drilling fluid is up to 72 hours.

The new DF system KGAC (Figure 4) has shown high swelling inhibition level, equivalent to and somewhat

Figure 5. *Field tests on Tam Dao 2 rig: There was very little clay adhesion on BHA pulled out, drilled cuttings were well inhibited, dry and nonsticky.*

superior to the Glydril system of MI-SWACO company. The authors conducted a series of experiments with different concentrations and mixing sequences in order to select one recipe that suits the technical requirements of Vietsovpetro.

1.3. Field-test results

From the positive results in the laboratory, KGAC DF system were then applied in 2 wells on Tam Dao 2 rig. The tests at these 2 wells were both successful, achieving technical requirements, lower cost and less negative impact on the environment. Some actual results are presented in Figures 5 and 6.

The actual values of the DF parameters in Figure 6 show that the KGAC meets technical requirements when drilling Vietsovpetro's wells. They fall within design range and are quite stable throughout the drilling period. After successful field tests, in 2015, KGAC system was widely applied in many wells of Vietsovpetro with positive results.

1.4. Initial economic efficiency

To initially evaluate the economic efficiency of the KGAC, the authors make a comparison between the cost

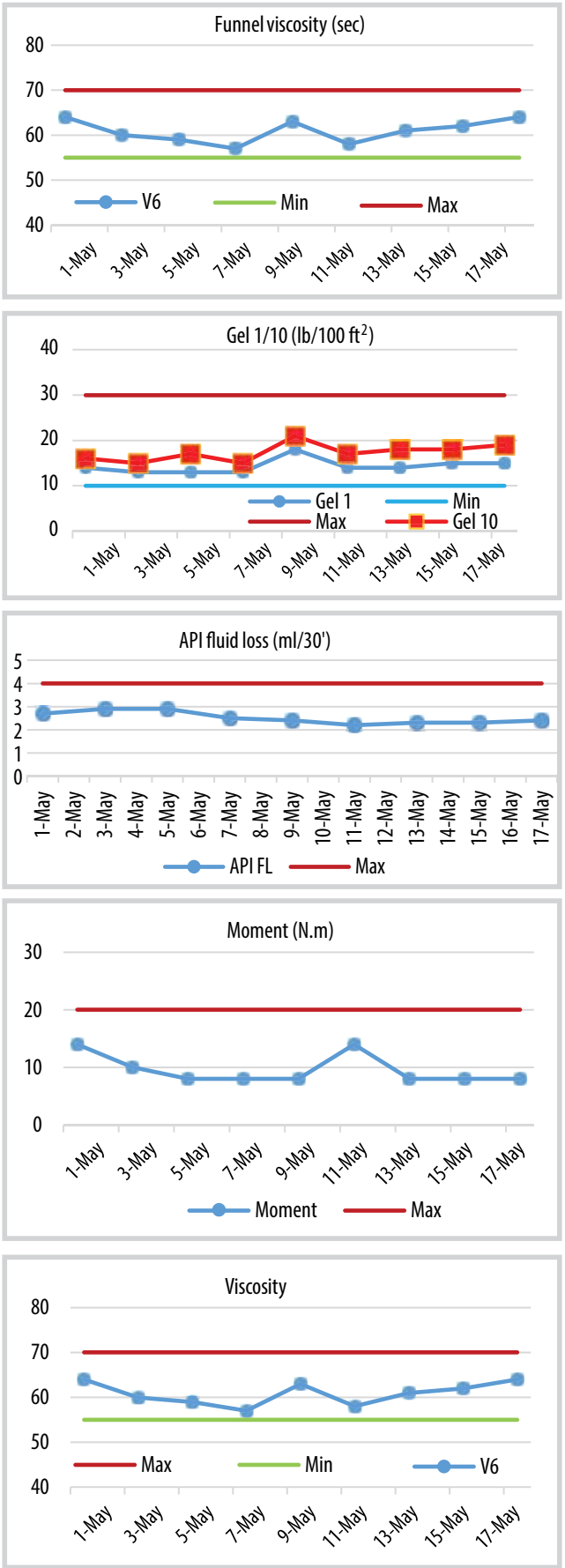

Figure 6. *Actual parameters of KGAC DF when applied to well drilling.*

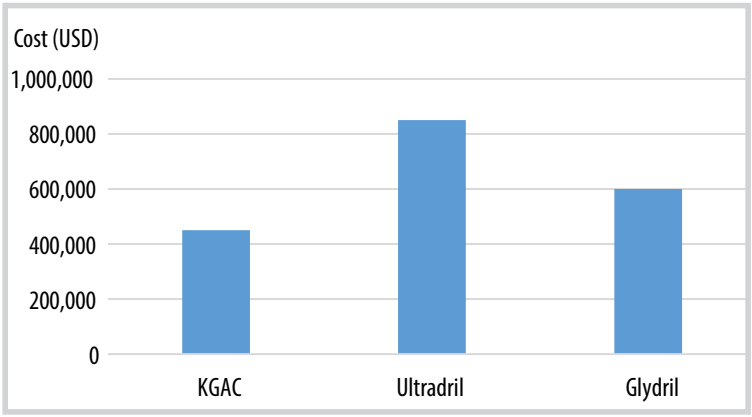

Figure 7. *Cost comparison of DF systems.*

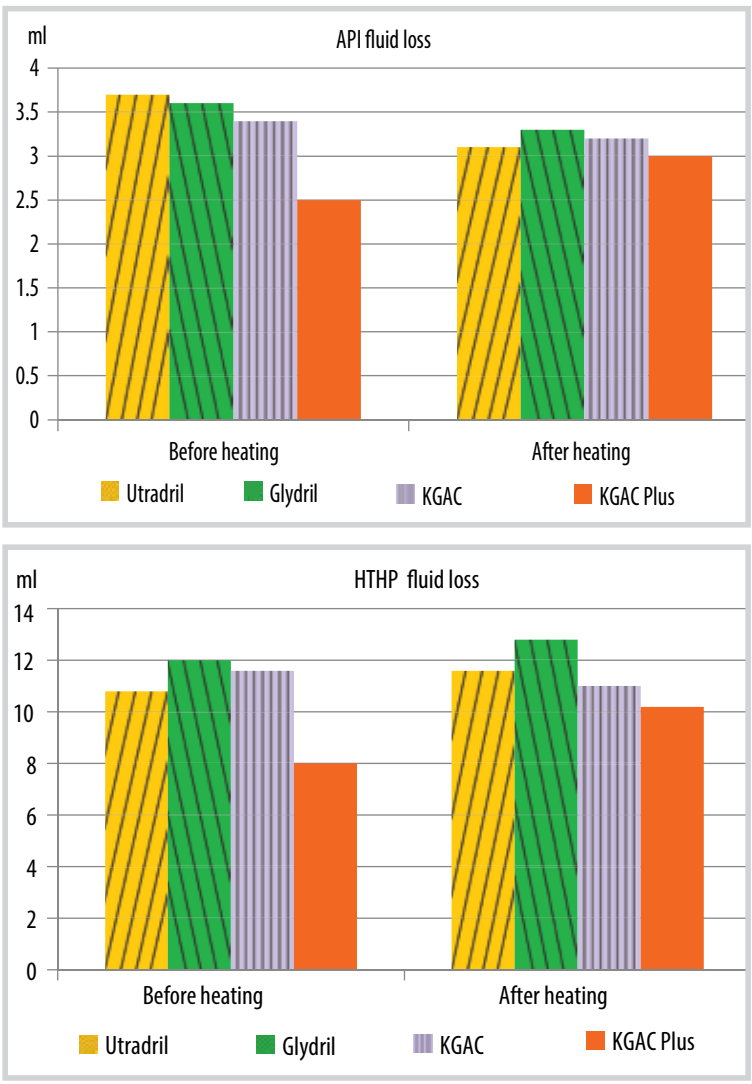

Figure 8. *API and HTHP fluid loss of DF systems (before and after heating).*

of DF service at well A1 (using Glydril system) and that of self-service construction at well A2 (using KGAC system). These two wells are drilled by the same rig in similar geological conditions (Figure 7).

In fact, during well completion, the highest cost is typically the 12¼" and 8½" sections (when drilling through active clay formations). Through the wells, on average, about 1,000 m^3 of DF must be used to drill this stage. Using the KGAC solution system can save about USD 160,000 compared to the Glydril.

2. KGAC Plus drilling fluid system

2.1. General information

The Vietsovpetro drilling fluid team continued their research and added the encapsulation inhibitor chemical HyPR-CAP, which is analogous to ID-CAP D in the Glydril system or ULTRACAP in the Ultradril system. This chemical is compatible with other components of the KGAC and the KGAC Plus system was created, which has the quality equivalent to the best water-based drilling fluid system currently used on the Vietnamese continental shelf. In the first year of use, the KGAC Plus drilling fluid system successfully maintained its cost-effectiveness, reaching more than USD 2 million. In 2018, two drilling fluid systems KGAC and KGAC Plus were certified for ecological and environmental safety and awarded a gold medal by the World Intellectual Property Organization (WIPO).

2.2. Laboratory testing results of KGAC Plus system

Encouraged by the success of the KGAC system, the authors have investigated adding a new encapsulation inhibitor component HyPR-CAP with different concentrations and mixing processes. Compatibility, stability of DF parameters, inhibition ability, thermal stability, lubricity, etc. were studied in comparison with ULTRADRIL and some other advanced DF systems. Testing results are shown in Figures 8 - 10.

From Figures 8 - 10, we can see that:

- API and HTHP fluid loss are better when compared to other systems.

- Rheological properties and lubricity of KGAC Plus system are improved compared to KGAC and equivalent to Ultradril.

- The inhibition ability of KGAC Plus system is improved compared to KGAC and comparable to Ultradrill.

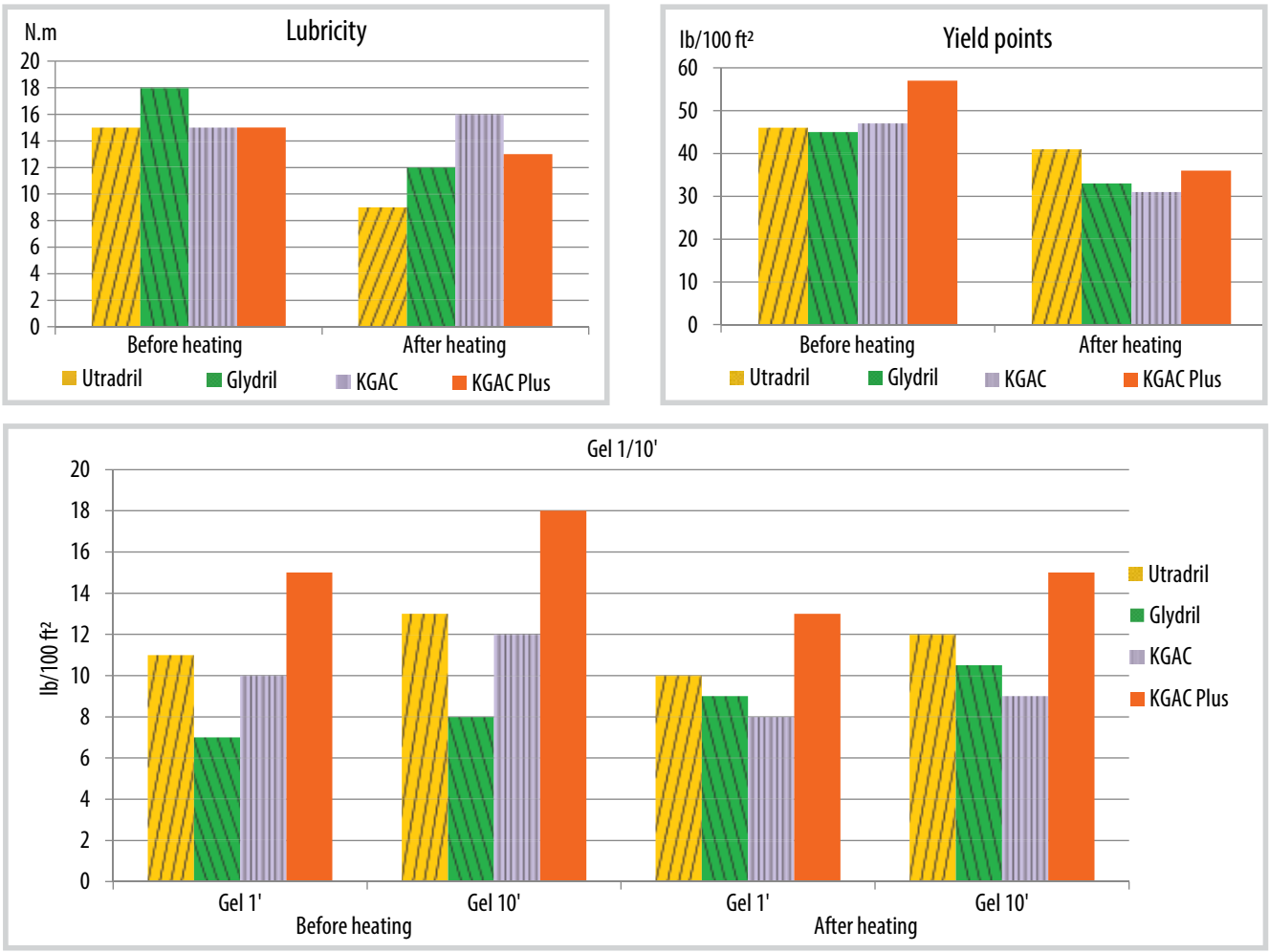

Figure 9. *Rheological properties (YP, Gel) and lubricity of DF systems.*

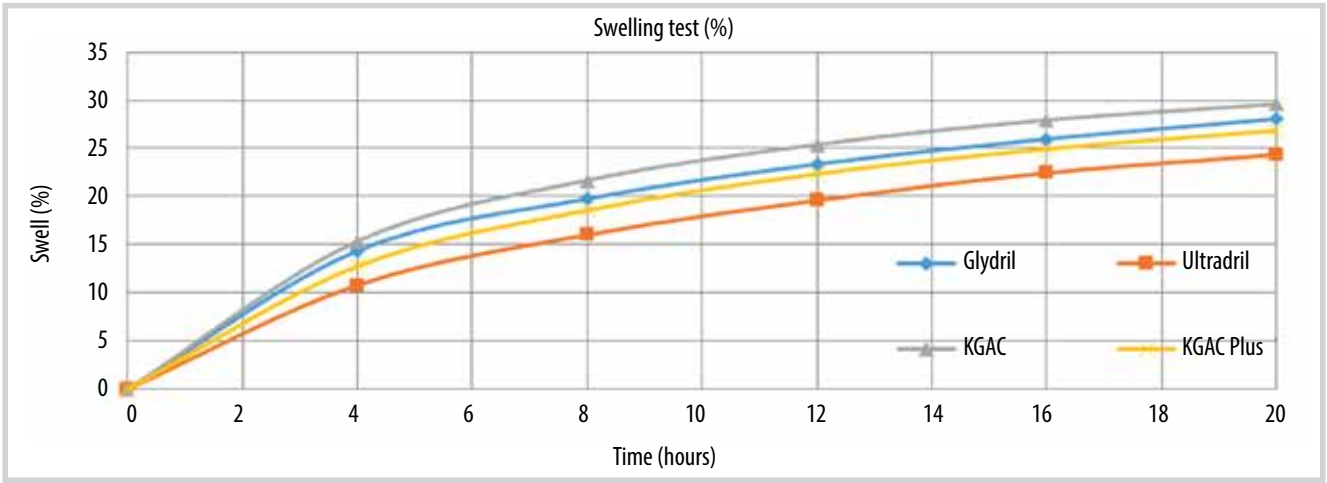

Figure 10. *Inhibition ability of DF systems.*

2.3. Field test results

The KGAC Plus DF system was successfully field-tested for drilling 2 wells using Tam Dao-03 and Cuu Long rigs. No complications or problems occurred during the drilling and casing of these wells.

Figure 11 shows that the parameters of DF KGAC Plus during field tests are stable within the design values.

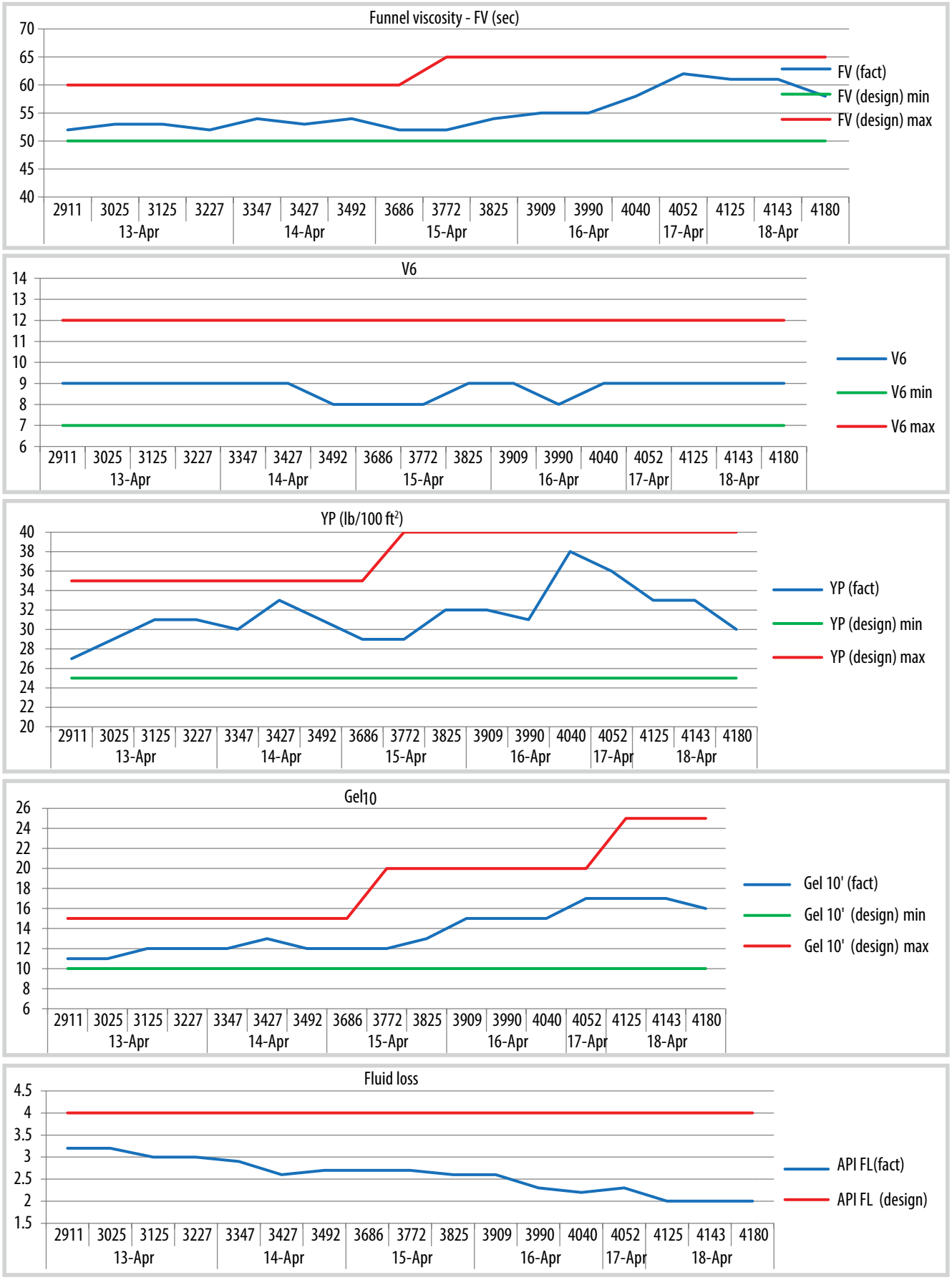

Figure 11. *Parameters of KGAC Plus DF during field tests.*

2.4. Initial economic efficiency

Experimental results show that the quality of the KGAC Plus system is equivalent to Ultradril (the best water-based inhibitive system currently offered by MI SWACO-USA and applied worldwide). Figure 12 shows that the cost of preparing the KGAC Plus system is only about 60% of that of Ultradril. If this system is applied, about USD 300,000 per well can be saved, not counting other factors. With an annual average construction rate of 20 - 25 wells, Vietsovpetro is expected to save about USD 6 - 7 million per year.

2.5. Eco-environment safety certificate of DF systems KGAC and KGAC Plus

After successful application at the fields, samples of DF systems KGAC and KGAC Plus were sent to the Research and Development Center for Petroleum Safety and Environment - Vietnam Petroleum Institute (CPSE VPI) for analysis and assessment of ecological safety level.

The toxicity of these 2 DF samples against marine algae Skeletonema and larvae of Black tiger shrimp Penaeus monodon was assessed in accordance with the quality management standard procedures ISO 9001: 2008 and TCVN ISO/IEC 17025: 2007. Conclusions of CPSE-VPI stated: "Based on the acute toxicity test results against marine algae Skeletonema and larvae of the Black tiger shrimp Penaeus monodon, the KGAC and KGAC Plus DF systems are classified in group E - the best group according to the toxicological classification system OCNS (Offshore Chemicals Notification Scheme, UK)".

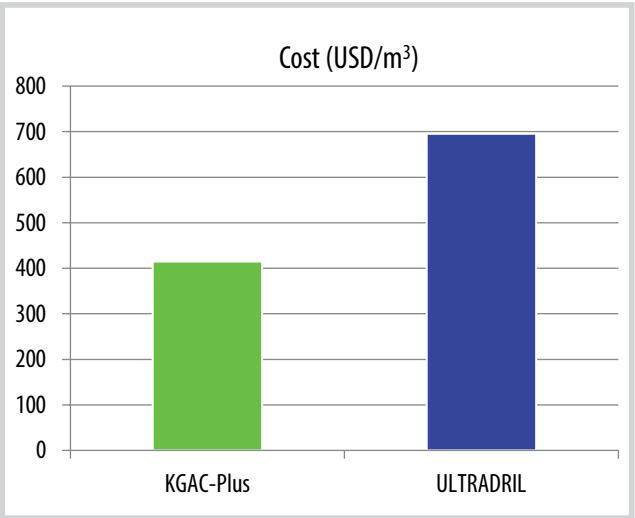

Figure 12. *Cost comparison of KGAC Plus and Ultradril systems.*

3. KGAC Plus M1 drilling fluid system

3.1. General information

KGAC Plus M1 DF system has changed in composition compared to KGAC Plus system. Specifically, Polyhib is used as an alternative to NaOH and AKK to maintain pH value and inhibit clay swelling. Its inhibition mechanism is the formation of ionic bonds by NH_{2+}. KGAC Plus M1 system is being successfully applied to drill more than 100 wells of Vietsovpetro. In 2020, this fluid drilling system won the first prize at the National Technical Innovation Contest (VIFOTEC).

3.2. Laboratory test results of KGAC Plus M1 system

The results of laboratory test on the degree of clay swelling inhibition of KGAC Plus M1 system compared with other systems are presented in Figure 13.

Research and experimental results show that the new inhibitor system KGAC Plus M1 is superior to Vietsovpetro's other KGAC systems and is equivalent to Ultradril of MI SWACO company.

3.3. Field-test results of KGAC Plus M1 system

KGAC Plus M1 system was field-tested at 2 wells with results presented in Figures 14 and 15.

During the drilling of the test well, DF parameters were stable within the allowable design value and met the technical requirements.

3.4. Economic efficiency

Experimental and field-test results show that the quality of KGAC Plus M1 system is equivalent to that of Ultradril (the best water-based DF system available

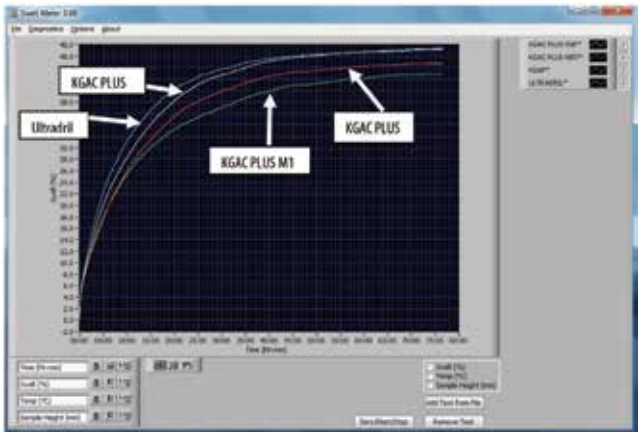

Figure 13. *Laboratory testing results on the degree of clay swelling inhibition of KGAC Plus M1 system compared with other systems.*

Figure 14. *Clean BHA without adhering clay.*

Figure 15. *Drilled cuttings were well inhibited, dry and not sticky.*

currently). KGAC Plus M1 system with cost of 357 USD/m^3 is much cheaper than Ultradril with 698 USD/m^3. Typically, about 1,000 - 1,500 m^3 of inhibitive DF is needed to drill sections with highly active shale. Therefore, if KGAC Plus M1 system is applied, it can save about USD 340,000 - 520,000, not to mention other factors (dilution level, thermal stability, clay tolerance, rig rental time, labor, etc.).

Based on actual consumption, the chemicals cost of KGAC Plus M1 system for 4 field-test wells is USD 933,496, compared to USD 2,467,092 for drilling 4 wells with similar conditions using the Ultradril system or equivalent. Thus, about USD 1,500,000 is saved. On average, annually Vietsovpetro constructs about 20 wells, therefore, it is expected to save around USD 8 million per year.

4. KGAC Plus M1* drilling fluid system

To enhance the quality and effectiveness of the KGAC Plus M1 DF system, Vietsovpetro's DF team has conducted research and experiments to upgrade the system to KGAC Plus M1* DF.

4.1. To improve inhibitive level

Experiments were conducted to find a suitable polyamine inhibitor to replace Polyhib in KGAC Plus M1 system:

Table 2. *Cuttings dispersion test results*

	KCl 7%	Poly-Hib	EC301	VH-258	Ultrahib
Initial mass of cuttings (g)	30	30	30	30	30
Dried cuttings remaining on 150 µm sieve (g)	9.8	23.7	25.2	27.55	24.35
% reserved	**32.67**	**79**	**84**	**91.83**	**81.17**

Base mud UltraFree- MI Vietfree

Figure 16. *Anti-accretion test in KGAC Plus M1 DF system.*

Table 3. *Anti-accretion test in KGAC Plus M1 DF system*

	Base mud	3% Ultrafree	3% Vietfree
Accreted shale (g)	18	0.5	5
Anti-accretion percentage (%)	-	97.2	72

Once extracted from the formation, water will be absorbed into drilled cuttings, causing them to disperse into smaller particles. One function of the inhibitors is to reduce the dispersion of drilled cuttings such that they are large enough to be removed from the shale shaker.

In this experiment, artificial drilled cuttings were made from API bentonite with the size of 2 - 5 mm. A 30 g sample of artificial drilled cuttings was immersed in 450 ml of the test solution and rotated at 120°C for 4 hours in roller oven. Then, the solution and cuttings were filtered through a 150 µm sieve for 2 minutes using a dedicated vibrator. The cuttings remaining on the sieve were dried to a constant weight. The test solution was prepared on a 7% KCl solution, with polyamine chemical used at a 3% concentration. Experimental results are shown in Table 2.

Experimental results indicate that the polyamine inhibitors have a good effect in reserving drilled cuttings, in which the sample containing Viethib-258 is somewhat better than the sample containing Ultrahib. Additionally, it also shows that polyamine chemicals can be used effectively in combination with KCl.

4.2. To improve anti-accretion ability

Figure 16 and Table 3 show that the experimental

Table 4. *DF samples after adding $CaCO_3$ F/M và Celba F/M*

	Tam Dao 01 rig	Tam Dao 03 rig	Cuu Long rig
Before adding			
Mud cake durability (seconds)	26	31	28
Moment (lb.in)	130	145	125
After adding $CaCO_3$ F/M and Celba F/M			
Mud cake durability (seconds)	56	62	61
Moment (lb.in)	95 - 100	90 - 100	80 - 85

Table 5. *Test results of KGAC Plus M1* system*

STT	Parameters	Unit	Results		Requirements
			Before heating	After heating 150°C/16 hours	
1	Density	g/cm^3	1.63	1.63	1.60 - 1.70
2	Funnel viscosity	Sec	76	68	60 - 70
3	API fluid loss	ml/30 minutes	2.8	3.2	≤ 3.5
4	Mud cake	mm	1	1	≤ 1.5
5	V600/V300	-	164/106	121/80	
6	PV	cP	58	41	ALAP
7	YP	lb/100 ft^2	48	39	40 - 50
8	V6		12	11	10 - 14
9	Gel 1/10'	lb/100 ft^2	11/24	10/15	10 - 16/12 - 25
10	pH	-	10	9.5	9.5 ± 0.5
11	Moment	N.m	15	14	≤ 20
12	Content of K^+	g/l	96	93	80 - 100
13	Content of Cl^-	g/l	70	70	≤ 80
14	MBT	Nm	20	22	≤ 35
15	HTHP FL 150°C@500psi	ml/30 minutes x 2	12.2	13.4	≤ 14

Table 6. *DF parameters when drilling 2,846 - 4,627 m*

Section		Parameters								
		γ (g/cm^3)	FV (seconds)	FL (cm^3/30 minutes)	K (mm)	$Gels_{1/10'}$ (lb/100 ft^2)	PV (cPs)	YP (lb/100 ft^2)	V6 (grad.)	pH
2846 - 3033 KGAC + M1*	Designed	1.12 -1.14 ± 0.02	50 - 65	< 3.5	1	8 - 14/9 - 15	ALAP	25 - 40	8 - 12	9 ± 0.5
	Actual	1.14	58 - 61	3 - 3.5	1	8/9	28 - 31	35 - 38	8 - 9	9.5
3033 - 4011 KGAC + M1*	Designed	1.16 ± 0.02	50 - 65	< 3.5	1	9 - 14/9 - 16	ALAP	25 - 40	9 - 13	9 ± 0.5
	Actual	1.15 -1.18	57 - 60	2.6 - 3.0	1	9/12	33 - 35	38 - 42	9 - 11	9.3
4011 - 4445 KGAC + M1*	Designed	1.18 ± 0.02	50 - 65	< 3.5	1	9 - 15/10 - 18	ALAP	25 - 40	9 - 13	9 ± 0.5
	Actual	1.19 -1.23	56 - 59	2.6 - 2.8	1	10/13	33 - 36	40 - 44	10 - 11	9.1
4445 - 4627 KGAC + M1*	Designed	1.20 -1.26 ± 0.02	55 - 70	< 3.5	1	9 - 15/10 - 22	ALAP	25 - 40	9 - 14	9 ± 0.5
	Actual	1.24 - 1.28	57 - 64	2.6 - 2.7	1	10/15	37 - 41	40 - 46	10 - 12	9.0
	BHA with 2 stabilizers	1.27	60 - 64	2.8 - 3.0	1	9/12	33 - 35	38 - 39	9 - 10	9.0

chemical samples (Ultrafree, Vietfree) used in the KGAC Plus M1 system reduce the ability of shale to adhere to metal surfaces.

4.3. To improve borehole stability

Improving the shale inhibition ability of KGAC Plus M1 system will contribute to the stability of the borehole. Through research, experiments and testing at wells, the inhibition ability of the KGAC Plus M1* system has been enhanced with polyamine-based chemicals. Moreover, adding materials such as $CaCO_3$ F, $CaCO_3$ M and Celba F, Celba M help to increase durability of mud cake and reduce adhesion moment, ensuring borehole stability suitable for each specific geographical condition.

Experimental results in Table 4 show that, when DF sample is treated with 15 - 20 g/l $CaCO_3$ F/M and 3 - 5 g/l CelbaF/M, the durability of mud cake increases from 30 seconds to 60 seconds and the moment decreases from 140 - 150 lb.in to 90 - 100 lb.in. Vietsovpetro has applied this to process DF for many wells with high efficiency.

4.4. To improve thermal stability

KGAC Plus M1 DF system being applied in Vietsovpetro can withstand temperature up to 130°C. In order to drill wells with temperatures up to 150°C, the authors have found new products that are equivalent to MI SWACO's chemical, such as Oxoscav 5000, PTS 200, Resinex II, Soltex, Driscal D…, which are used intensively and or replace some components in KGAC Plus M1 to form a new system that can withstand temperatures up to 150°C.

Test results of KGAC Plus M1* system in Table 5 show that:

- DF parameters before and after heating at 150°C/16 hours meet technical requirements of the high-temperature wells up to 150°C.

- There is no sticky phenomenon due to thermal destruction of lubricant; torque parameter remains unchanged.

*4.5. Field test results of KGAC Plus M1**

4.5.1. Parameters of DF KGAC Plus M1 in field test*

Table 6 shows that DF parameters in the field test are within design ranges and stability.

4.5.2. Field test results

Drilling parameters in section 2,846 - 4,627 m:

- Average drilling rate: 1,781/71,6 = 24.9 (m/hours);

- Average drilling rate per day: 1,781/7 = 254.4 m

After reaching TD at 4,627 m, tripping and logging were performed without problem.

DF parameters were stable within design ranges; pH value and K^+ ion content remained unchanged after long logging period.

Figure 17. *No bit-balling while drilling.*

Figure 18. *Clean stabilizer.*

Adding Tube Kleen along with lubricant did not cause any increase in DF viscosity or blockage of the shaker screens. However, after a long logging operation, blockage of the shaker screens occurred.

There was no bit- and BHA-balling (Figures 17 and 18).

DF system KGAC Plus M1* using polyamine-based inhibitor (Viethib-258) has been improved in shale inhibition ability; pH and rheology values are stable within technical ranges for drilling Vietsovpetro's wells.

Tube Kleen chemical has effect of anti-sticking on bit and stabilizer, improving mechanical drilling rate through lower Miocene thick shale layer.

Wellbore was stable after 60 hours of logging operation at hole temperature of 112°C. This means that Viethib-258 effectively inhibits clay swelling and helps to stabilize the action of polymers under well conditions. Thereby, dilution rate and consumption of chemicals were reduced compared to the KGAC Plus M1 DF system.

Therefore, the addition of new chemicals to the KGAC Plus M1 system has resulted in a new DF system, the KGAC Plus M1*. Laboratory experiments and field test results of KGAC Plus M1* system with innovative solutions as described above have confirmed the effectiveness of the new DF system. Specifically, clay inhibition ability, anti-accretion and anti-bit-balling effect, thermal stability and wellbore stability have all been improved.

5. Applicability

After being successfully researched and applied in many wells, KGAC Plus M1 DF system has been approved for widespread use in Vietsovpetro's wells. All three newly developed systems, KGAC, KGAC Plus, and KGAC Plus M1, meet all economic and technical criteria while ensuring safety for humans and the ecological environment.

Since 2019, these DF systems have been

widely applied in Vietsovpetro's wells, not only replacing the need to hire external DF services but also providing DF services to other partners.

6. Conclusions

Technical efficiency and applicability of the 4 high-performance DF systems KGAC, KGAC Plus and KGAC Plus M1 and KGAC Plus M1*: All 4 new DF systems are equivalent to or superior in some aspects to current high-quality advanced fluid systems, ensuring good drilling through highly active clay formations and complex geologic conditions. At the same time, all 4 DF systems are suitable for Vietsovpetro's technical conditions and ensure safety for the ecological environment. Depending on stratigraphic and geological conditions, selecting the right DF system helps save costs while still meeting the technical requirements of the well.

Economic and social efficiency: The application of the abovementioned 4 DF systems has achieved high economic efficiency, contributing to solve current problems and difficulties in the context of falling oil prices. Furthermore, Vietsovpetro has trained a team of highly qualified DF specialists capable of executing DF packages for oil and gas wells without hiring external DF services. Especially, it is possible to use materials and chemicals available on the Vietnamese market and completely master the technology to drill complex wells.

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