PROFESSIONAL TECHNICAL PAPER
ONLINE PRESENTATION
24 - 25 OCTOBER 2020

Practical Approach to Adapt Flash Point Requirement of Synthetic Based Mud

Novrendi Saragih[*1], M Alfianoor Yudhatama[1]

[1]Well Construction and Intervention, Pertamina Hulu Mahakam
* Email: novrendi.saragih@petamina.com;

Abstract.
In respect to risk of fire hazard, understanding of drilling fluid flash point is a critical factor in handling and use of synthetic based mud (SBM) throughout drilling of a well. It must be ensured that any fluid going thru the rig circulation system has flash point higher than the maximum anticipated flow line temperature of the drilling fluid or the maximum anticipated ambient temperature, whichever is the greater. A more rigorous condition by Pertamina Hulu Mahakam (PHM) requires, instead of the SBM, but the base oil used to build the SBM must have flash point value of minimum 10 ^{o}C over the maximum flow line mud temperature during drilling operations.

Smooth fluid 05 (SF-05), base oil produced by Pertamina Refinery Unit V Balikpapan was introduced to PHM drilling operation as a competitive replacement to the existing EDC 95-11 base oil. Study had performed to iterate SBM formulation using SF-05 that provide optimal drilling performance while maintain level of health and safety to operation. The SF-05 flash point is turn out to be approximate with the anticipated maximum flow line temperature while drilling main reservoir section in TUNU field, with safety margin less than 10 ^{o}C, thus not conform with PHM initial requirement. In order to proceed the job safely using SF-05, further assessment was done and more fit for purpose and practical approach was taken while still maintaining safety requirement.

Considering the base oil in its stand-alone form has never been used as drilling fluid and SBM as drilling fluid was formed by an emulsion of water, solids, additives and a base oil as prime portion, the flash point of SBM is expected to be higher than the flash point of its pure base oil. Several SBM formulations using SF-05 base fluid that was prepared in laboratory had shown flash point high enough to provide safety margin of 10 ^{o}C above the flow line temperature. This enable the drilling operation using SBM based on SF-05 is carried out safely. With such approach, a specific Job Risk Assessment (JRA) is developed and some additional practices as control measures were applied in the field. Furthermore, this practical approach is now being adopted to update the company's standard requirement.

Keyword: flash point, smooth fluid, base oil, synthetic based mud, safety, emulsion, drilling, optimization,

1 Introduction

SBM commonly used in well drilling operation presents risks of operation hazard that should be clearly identified and controlled to promote safety to personnel, environment and asset. One of the common hazard related with operational safety that shall be considered is the flammability or combustibility of the fluid. Referring to the U.S National Fire Protection Association (NFPA), a flammable liquid is defined as a liquid whose flash point does not exceed 100°F, when tested by closed-cup test methods, while a combustible liquid is one whose flash point is 100°F or higher, also when tested by closed- cup methods.
A liquid's flash point is defined as temperature at which sufficient flammable vapors have evaporated to allow for ignition and the propagation of flame when exposed to an ignition source, thus the higher the flashpoint, the lower the risk of accidental ignition of the fluid. Generally, flammable liquids are not recommended as drilling fluids as these will usually ignite and burn easily at normal working temperatures, while combustible fluid may be used for drilling operations with appropriate precautions.

As main constituent in the SBM system, the base oil characteristic will mostly define the final mud properties including the level of the SBM flammability or combustibility. PHM had strictly prohibited the use of crude oil or diesel oil to prepare any drilling or completion fluid due its low flash point and other properties present potential hazard to personnel and/or rig equipment. PHM had also established main requirements in regard with the choice of base oil:

- The base oil flash point shall be 10 ^{o}C over the maximum flow line mud temperature.
- In regard with handling of SBM, monitoring the fluid temperature must be available at the closest point as possible from the hole outlet.
- A temperature mud alarm shall be operating with an alarm setting equal to the flash point of the base fluid less 10 ^{o}C.
- A safety factor of 10°C was added in order to account for hotter than anticipated downhole temperatures resulting in higher than expected flow line temperatures or a compositional change in the fluid.

The extensive drilling experiences in Mahakam area had shown that existing EDC 95-11 base oil is being capable to meet those requirements. When the SF-05 base oil was introduced, it was noticed that it has lower flash point compare to EDC 95-11. Therefore, a specific assessment and treatment is required to justify the suitability to the operation. Typical properties of SF-05 compared to EDC 95-11 are shown in Table 1.

Table 1. Typical Base Oil Properties of EDC 95-11 and SF-05

	EDC 95-11	SF-05
Density	0.814 SG	0.825 SG
Aromatic , % wt	< 0.01	< 0.05
Flash Point (PMCC)	115-120 ^{o}C	80-85 ^{o}C (Minimum guaranteed 75 ^{o}C)
Aniline Point	90 ^{o}C	82 ^{o}C
Auto ignition point	> 220 ^{o}C	240 ^{o}C
Fire Point	> 120 ^{o}C	91 ^{o}C
Sulphur	< 1 ppm	Max 40 ppm

The statistical data of several maximum flow line temperature recorded during drilling the reservoirs section in Mahakam field are shown in the Table 2 below. The wells in swamp area are referring to wells located at shallow water of Tunu field in Mahakam delta where drilling were accomplished by swamp barge rig, while the wells in offshore area refer to well at deeper water depth where drilling were accomplished by jack up rig at South Mahakam, Bekapai, and Peciko field.

Table 2. Statistical Data of Maximum Mud Temperature Recorded at Flow Line

Well	Estimated bottom hole static temp (BHST), degC	Depth, in mTVD	Maximum recorded flowline temperature (degC)	
			During drilling	After Logging
Swamp area (water depth ± 3.5-5 meter)				
TN-A	138	3601	90	70
TN-B	148	3935	88	74
TN-C	139	3641	84	70
TN-D	137	3588	86	71
TN-E	138	3604	88	71
Offshore area (water depth ± 35-60 meter)				
JM-A	141	4519	73	66
JM-B	151	4060	70	64
JM-C	148	4262	70	63
BG-A	109	3448	77	-
BG-B	109	3373	76	-
PK-A	140	4229	75	63
PK-B	138	3710	75	-

If we compare to field data above, the SF-05 flash point characteristic was not meet the rigorous requirement of the PHM where the SF-05 base oil flash point range is less than the expected maximum flow line temperature during drilling, especially when drilling well at swamp area.

To conduct drilling operation safely with SF-05 as base fluid used for the SBM drilling fluid, a more fit for purpose and practical approach was considered to define flash point requirement of drilling fluid. Industrial Recommended Practice (IRP) Volume 14 - Non Water Based Drilling Fluid issued by Canadian DACC's (Drilling and Completion Committee) [2] set the requirement of flash point according to the drilling fluid that passes the rig circulation system, and it is not regulating the flash point of base oil as standalone additive. It is considered as a more realistic condition of drilling operation where the fluid that is heated up inside the wellbore, return back to the surface at flow line and being exposed to open system is in form of SBM as an emulsion of base oil, additives and water, rather than base oil alone.

2 Methodology

Setting up the flash point requirement to the SBM instead of to the base oil is more realistic approach, however, precautions have to be applied ensuring not to jeopardize the safety requirement. To apply the new approach, specific assessment was done to identify the associated risks and the requirement of mitigation measures. Pilot SBM formulation was prepared using SF-05 and EDC 95-11 with mud density of 1.20 SG and 1.40 SG as typically used in drilling operation, as base line for the flash point measurement. The flash point measurement was performed using Pensky-Martens Close Cup (PMCC) method as per ASTM D93. The test was performed in drilling fluid contractor laboratory and also compared to an independent laboratory at LEMIGAS, Jakarta with the summary in Tabel 3.

Table 3. Flash Point Test of Pilot Formulation SBM and SF-05

	SF-05 base oil	SBM using SF-05		SBM using EDC 95-11	
Density	0.82 SG	1.20 SG	1.40 SG	1.20 SG	1.40 SG
Oil to water ratio (OWR)	-	70/30	70/30	70/30	70/30
Heat Aging Temp (degF)	-	284	284	284	284
Heat Aging, Hours	-	16	16	16	16
Initial (I)/ Static (S)/ Rolling (R):	-	R	R	R	R
Test Result at Contractor Laboratory					
Last Temperature recording	80 ^{o}C	106 ^{o}C	N/T	106	N/T
Observation	Flash	No flash	-	No flash	-
Test Result at LEMIGAS Laboratory					
Last Temperature recording	-	100 ^{o}C	100 ^{o}C	100 ^{o}C	100 ^{o}C
Observation	-	No flash	No flash	No flash	No flash

The test result shown that flash point of SBM prepared with SF-05 is exceeding the flash point of the pure base oil and also exceed the maximum expected mud flow line temperature with sufficient safety factor of minimum 10 ^{o}C.

2.1 Associated Risk

The associated main risk considered during the use of hot SBM drilling fluid is risk of fire incident due to combustibility/flammability of the fluid. There are two tasks that involves circulating hot SBM drilling fluid from bottom of the well to return at surface: (1) Circulating the mud during drilling the section and (2) Circulating the mud after completion string set on bottom (after logging at static condition). Technical evaluation was done based on the highest flow line mud temperature as shown in Table 2 and it was concluded that the most critical task will be the circulation during drilling operation of the reservoir section. Nevertheless, handling pure base oil in surface facility also to be considered for the anticipation of maximum expected ambient temperature, to ensure the base oil is safe to be stored at open system mud pit or tank.

2.2 Mitigation Measures

Assessment on risk of fire and its mitigation measures were developed based on the fire triangle theory. For a fire to start, three elements must be present simultaneously:

a) Combustible material (solid, liquid or gas).
b) Supply of air (oxygen) that is necessary for the combustion process.
c) Introduction of ignition source (flame, spark, static electricity, heat, etc.).

Figure 1. Fire Triangle

When handling or using SBM as drilling fluid regardless the type of base oil, the following had been applied as minimum precautions and safety measures as per stipulated in the company requirement:

a) Fixed foam extinguishing system and flammable gas detectors is available on board the rig.
b) "Explosion proof" electrical equipment as per Hazardous Area Classification Zone 2 requirement.
c) Temperature sensor at the closest point as possible to the hole outlet is available and provided with continues recording.
d) Permit to work system is in-placed and followed.
e) QA/QC is done to the batch of SBM and base fluid that will be delivered to the rig.
f) Emergency drill / exercise is regularly done and well documented/evaluated.

g) Competent and trained essential key personnel are assigned on-site.

Therefore, the working environment has been conditioned to low risk level while always keeping the awareness that the associated hazards are not fully eliminated. With the higher flash point of SBM that can be obtained using SF-05, the risk level is able to be maintained in low level with some new control measures that was never done before:

a) In well design or preparation stage, systematic flash point test was performed to the SBM drilling fluid built from SF-05. No flash in temperature minimum of 100 – 106 ^{o}C (or as required to respect the minimum 10 ^{o}C above the maximum expected flow line temperature).
b) Socialization of new associated hazard and risk to all crew (i.e. reviewing the MSDS of the SF-05, emphasizing the lower flash point, and the how to handle it properly)
c) The temperature of mud out at flow line will be announced by rig PA system every 1 hour, when it had reached the level of ≥ 70 ^{o}C.
d) Temperature mud alarm setting will be set at 96 ^{o}C (refer to lowest temperature test 106 ^{o}C - 10^{o} safety factor.
e) Avoid storing pure base fluid on mud pit if the pit temperature is expected to reach the flash point of SF-05 minus safety factor of 10^{o} C, i.e: 70 ^{o}C
f) Checklist for mitigation measures monitoring.

Additionally, a detailed JRA was created to describe the detail risk and as a checklist for the involved party prior to and during the job/task execution. Based on JRA performed, the residual risk level could be categorized in acceptable range.

3 Result and Discussion

Field trial using SBM built from SF-05 was conducted to evaluate the mud performance as well to monitor the consistency of the flash point throughout the operation. The wells are drilled using swamp barge rig, provided with non enclosed mud pit and mud flow line, no dedicated base oil tank was on rig. The base oil was stored inside tank on a dedicated support barge specialized to transport and store liquid SBM. Prior drilling the first well (TN-N), fresh built SBM was prepared in liquid mud plant on shore base where the flash point was again measured in laboratory for reference in the field. The profile of well for the trial is shown in the Table. 4.

Table 4. Profile of wells for field trial

No.	Well	OH size	Depth (mMD/ mTVD)	Section length	Well Profile	BHST
1	TN-N	8 ½"	4592 / 3739	2925 m	J-shape, Max inclination 37°	142 ^{o}C
2	TN-AA	8 ½"	3622 / 3440	1982 m	S-shape maximum 34° inclination then drop to 0°	134 ^{o}C
3	TN-AB	8 ½"	3883 / 3786	2870 m	J-shape, max inclination 13°	140.5 ^{o}C
4	TN-AC	8 ½"	3856 / 3810	2542 m	J-shape, max inclination 14°	141 ^{o}C
5	TN-G	8 ½"	4012 / 3655	2474 m	J-shape, max inclination 25°	139 ^{o}C

A check list was implemented to ensure mitigations already in place during the drilling operation. The example of mitigations action check list for well TN-G is shown in figure 1.

Well : TN-G
Rig : M

	Actions / Control Measures	Comment / Status
New control measures (that was never done before) as below:		
1.	Socialization of new associated hazard and risk to all crew (i.e. socialization MSDS, lower flash point, etc.)	Done on Pre-Spud Meeting TN-G, Re-emphasize on PJSM
2.	Paging system to announce the mud temperature out every 1 hour (*starting after the temperature out > 70 °C*)	Done by Mud Logger
3.	Temperature mud alarm setting set at 96 °C	none, max temp 78 deg C
4.	(*If possible*) to dedicate 1 pit (that is side by side to active pit) to be filled with water for cooling effect against mud temperature in active pit	Done by Mud Engineer & Pump Man
5.	(*If possible*) avoid storing pure base fluid on mud pits	Done
6.	Perform cooling by spraying water on outside area BOP Riser (*if the mud temperatur out > 96 °C*)	none, max temp 78 deg C
Additional control measures to ensure/increase level of confidence (but no direct effect to reduce severity & probability) are as below:		
1.	Flash Point test is performed to SBM (built from SF-05 and also EDC-95-11 as comparison)	Done, no flash was observed with test temperature 106-110 °C
2.	Testing of foam type fire extinguishing system prior start the operation	Done by safety officer
3.	Portable foam type fire extinguisher should be available near the flow line area	Done by safety officer

Figure 2. Mitigations Action Check List

The flow line temperature was continuously measured and recorded with mud logging sensor unit. During drilling the 8 ½" section on TN-N well, the maximum temperature recorded at flow line was 87 ^{O}C. No anomaly was observed related throughout the drilling and completion operation. SBM sample was taken from site and was then tested for flash point check at laboratory in town with result of 100 ^{O}C – 108 ^{O}C. Accordingly, mud flash point was still in comply with 10 ^{O}C above maximum flow line temperature.

Table 5. Summary of Flash Point Monitoring on well TN-N

	Flow line max temp	Active mud	Backloaded Mud after drilling	Active mud after centrifuge
Density of SBM Oil to water ratio (OWR)		1.28 SG 78/22	1.20 SG 76/24	1.20 SG 80/20
Last Temperature recording	87 °C	104 °C	100 °C	108 °C
Observation		Flash	Flash	Flash

Upon completing all five trial wells, all had been performed safely without any issue to the flash point. The SF-05 SBM had consistently provide flash point requirement with adequate safety margin to the flow line temperature. The summary of mud properties and flash point is shown in figure 2 below.

	1. TN-N	2. TN-AA	3. TN-AB	4. TN-AC	5. TN-G
Mud density (SG)	1.20 – 1.25	1.20 – 1.23	1.20 – 1.23	1.18 – 1.31	1.18 – 1.28
OWR, %	74/26 – 79/21	74/26 – 76/24	76/24 – 78/22	77/23 – 81/19	75/25 – 78/22
Yield Point (YP), lbs/100ft2	24-35	19 - 25	19 - 23	22-25	16-21
Plastic viscosity (PV), cP	16-38	19 - 26	24 - 43	23 - 35	19 – 37
LSRYP, lbs/100ft^2	10-11	9 - 11	8 - 11	9 – 10	7 – 9
Gel Strength, sec	13/23 – 20/35	13/20 – 19/34	10/18 – 17/36	13/22 – 16/28	12/23 – 13/25
HTHP FL, ml	2.0 – 4.2	2.8 – 5.2	4.0 – 4.2	4.0 – 4.2	2.0 – 3.8
Electrical Stability, Volt	658 - 1250	600 - 1265	725 - 1200	565 – 1399	501 – 1097
Max Temp Out – °C (during drilling)	87	76	74	85	80
Mud flash point – °C	100	100	100	98	98

Figure 3. Mud Properties of trial wells showing the temperature of flow line

4 Conclusion

Requirement of base oil with high flash point value for building a SBM drilling fluid system is known for the safest conservative approach to prevent risk of fire, however, alter the flash point requirement based on the SBM flash point value should be considered for a good enough and fit for purpose objective. The lesser specification could be considered providing the risks assessment and monitoring were done properly. With proper monitoring and mitigation control measures, no issues related with flash point had been experienced when handling and using SF-05 base oil to build SBM for safe drilling operation in Mahakam field.

References

[1] ASTM D93-18, Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester, ASTM International, West Conshohocken, PA, 2018, www.astm.org

[2] Canadian DACC's (Drilling and Completion Committee), 2014. Industrial Recommended Practice IRP Volume 14 – Non Water Based Drilling Fluid.

[3] Dawoed, Sam. 2007. Fire Protection in the Petroleum Industry. Paper SPE-110521-MS. SPE Annual Technical Conference and Exhibition, 11-14 November, Anaheim, California, U.S.A.

[4] D.F. Jacques, HE Newman and HW Turnbull, 1992. A Comparison of Field Drilling Experience With Low-Viscosity Mineral Oil and Diesel Muds. Paper SPE-23881-MS. IADC/SPE Drilling Conference, 18-21 February, New Orleans, Louisiana.

[5] NFPA 30: Flammable and Combustible Liquids Code, 2018.