Journal of Petroleum and Gas Engineering Vol. 2(5), pp. 93-98, May 2011
Available online at http://www.academicjournals.org/JPGE
ISSN 2141-2677 ©2011 Academic Journals

Full Length Research Paper

Application of piezoelectric energy generated from quartz plus semiprecious metals on wax deposition control

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Accepted 29th March, 2011

The primary focus of this research is to develop a tool using semi-precious metals and quartz for preventing or eliminating wax deposition in production and transport system. It also focuses on explaining the mechanisms of using piezoelectric energy generated from mixtures of semi-precious metals and quartz to prevent wax deposition. Five samples of waxy crude were sourced from Niger Delta and characterized for the purpose of this experiment. Quartz was sourced from Bauchi State of Nigeria while two semi-precious metals, zinc and lead sourced from Jos Metallurgical Development Centre, Plateau State of Nigeria were used. The metals were grounded to smaller sizes and mixed with the quartz. Molten aluminium was used to fabricate the tool. The tool was then fixed into the flow line. Each of the crude samples was flown through the flow system under reduced temperature and pressure (below its wax appearance temperature) and the quantity of wax deposited was recorded before the tool and after the tool. The results show that immediately after the condenser, higher percentage of wax deposit was recorded but as the fluid pass through the fabricated tool the quantity of deposits reduced drastically. This is an indication of effectiveness of the fabricated tool in preventing wax deposits along the flow lines. It was also noticed that the effectiveness is more pronounced with zinc plus quartz crystal with over 32% success in achieving deposit reduction on the most potential problematic crude sample while lead achieved only 17.9% success on the same sample.

Key words: Piezoelectric material, piezoelectric energy, semi-precious metals, wax appearance temperature, wax deposition.

INTRODUCTION

Wax deposition in petroleum reservoirs and production equipment has been a continuous problem for hydrocarbon industry. It can occur and present a lot of problems in oil production, transportation and storage. These cause the reduced crude oil pumping rate, severe startup problems after shutdown and wax deposition. As oil development sites move to deeper and therefore colder water, the appearance of wax deposition on pipe walls and other production facilities becomes inevitable. Therefore, finding economic, technical and environmentally friendly solutions for the prevention, management, and remediation of wax deposition problem has become a necessity. Among the two existing handling methods of wax crudes, Removal (curative) and Preventive methods (Ajienka, 1990), preventive may be the best. Within the preventive methods are mechanical, chemical, electrical, thermal and combination of others. Of recent, there emerged the use of magnetic technology for the control of wax deposition (Nguyen et al., 2001).

The choice of any method of treatment depends on the severity of the problem, operational environment, and the location in flow system where the deposition takes place. However, none of the methods are without limitations. For example the chemicals are expensive, environmentally hazardous. They are also very sensitive, and can work effectively only on specific crudes. Thermal

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treatment such as hot oiling can cause formation damage and contraction/expansion of facilities.

Although efforts were made in the past to use semi precious metals and quartz to generate piezoelectric energy to prevent wax deposition (Enercat Tool), the application of locally sourced materials (from Nigeria) for this purpose and the technical processes has not been reported in the literature. Therefore the major challenge in this work was to explain the technical processes involve in using piezoelectric energy generated from mixtures of semi-precious metals and quarts to prevent wax deposition in production and transport system.

REVIEW OF MECHANISM OF PIEZOELECTRIC ENERGY ON WAX DEPOSITION CONTROL

A survey of literature shows that tremendous amount of research work has been done ranging from experimental studies to analytical and simulation studies in order to predict, manage, prevent and treat wax deposition in oil wells, flow lines and in gathering tanks. Also substantial literature on wax composition, factors affecting its deposition and the effect of its deposition on the economy of production, processing, storage, and transport operations have been published.

Factors affecting wax deposition

The mechanism and extent of wax deposition in a flowing system have been studied by many researchers (Jessen et al, 1958; Tronov, 1969; Patton et al., 1970; Armenskii et al., 1971; Bott et al., 1974; Eaton et al., 1976). The basic factors that contribute to the extent of wax deposition in flowing system include: flow rate, temperature differential, cooling rate, and surface properties.

Piezoelectric effect

Piezoelectricity is the ability of some materials (notably crystals and certain ceramics, including bone) to generate an electric potential in response to applied mechanical stress. This may take the form of a separation of electric charge across the crystal stress. If the material is not short circuited applied charge induces a voltage across the material. The piezoelectric effect is reversible in that materials exhibiting the direct piezoelectric effect (the production of an electric potential when stress is applied) also exhibit the *reverse* piezoelectric effect (the production of stress and/or strain when an electric field is applied). The effect finds useful applications such as the production and detection of sound, generation of high voltages, electronic frequency generation, microbalance, and ultra fine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution, the scanning, probe microscopes and everyday uses such as acting as the ignition source for cigarette lighters and push-start propane barbecues. Now it has found application in hydrocarbon industry.

MATERIALS AND METHODS

Piezoelectric materials

Piezoelectric material produces an electric charge when subjected to a force or pressure. The piezoelectric material such as quartz or polycrystalline barium titanate, contain molecules with a symmetrical charge distribution. Therefore under pressure, the crystals deform and there is a relative displacement of the positive and negative charges with the crystals. In this research work, quartz crystal is used, being one of the most stable piezoelectric materials. Figure 1 shows the displacement of electrical charge due to the deflection of the lattice in a naturally piezoelectric quartz crystal. The larger circles represent silicon atoms, while the smaller ones represent oxygen.

Mechanism of piezoelectric effects

In a piezoelectric crystal, the positive and negative electrical charges are separated, but symmetrically distributed, so that the crystal overall is electrically neutral. Each of these sides forms an electric dipole and dipoles near each other tend to be aligned in regions called Weiss domains. The domains are usually randomly oriented, but can be aligned during poling (not the same as magnetic poling), a process by which a strong electric field is applied across the material, usually at elevated temperatures.

When a mechanical stress is applied, this symmetry is disturbed, and the charge asymmetry generates a voltage across the material. Figure 2 shows the crystal structure and charges distribution in piezoelectric material.

Piezoelectric materials also show the opposite effect, called converse piezoelectric effect, where the application of an electrical field creates mechanical deformation in the crystal. The lack of conclusive literature data on the effects of piezoelectric energy on the phase behaviour of paraffins can be explained by the complex nature of crude, in which a lot of components, having different chemical and physical properties are found.

Experiments

Crude oils

Five samples of waxy-crudes (Dead Oil) were collected from different oil fields in Niger Delta, Nigeria. Addax Petroleum Nigeria provided three samples of crudes (samples OSS-1, OSS-2, and OSS-3) while Shell Petroleum Development provided the remaining two samples (A&B) for the purpose of this research. The specification of the samples remained undisclosed by the donor companies.

Measurement of STO properties

The densities of samples were determined using hydrometer method. The API was determined using ASTM D287. The specific gravities were measured at 60^{o}F using ASTM D1298. The corresponding pour points were measured following the standard

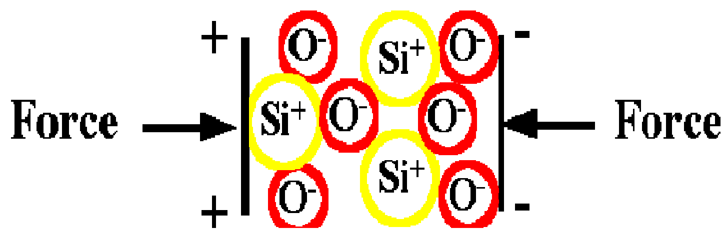

Figure 1. Displacement of electrical charge due to the deflection of the lattice in piezoelectric quartz crystals.

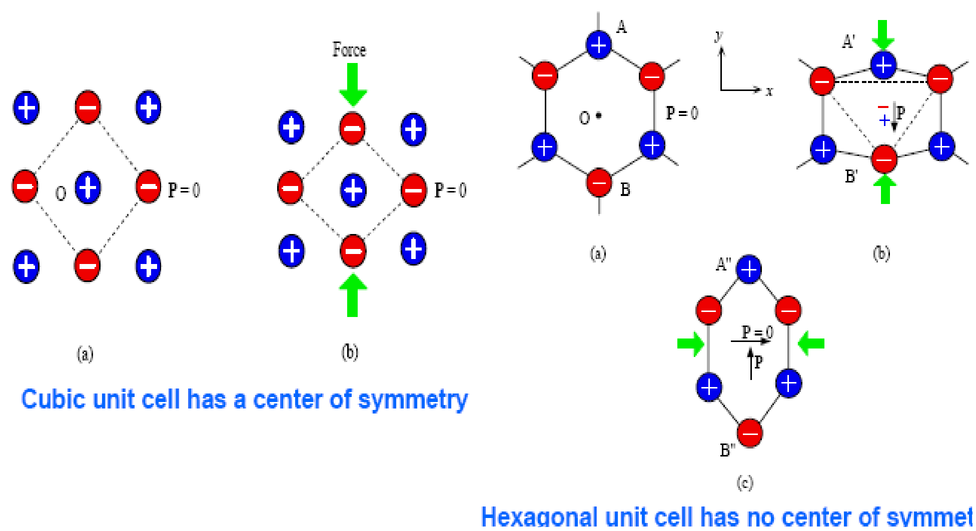

Figure 2. Crystal structure and charges distribution of piezoelectric material.

ASTM D97 procedures. The kinematic viscosities were determined using ASTM D-4624. The results obtained in the above analysis are in Table 1.

Fabrication of the tool (Aluminum Jacket)

Aluminum jacket was fabricated using molten aluminum. The inner pipe has its internal diameter very close to the external diameter of the Pyrex glass through which the crude was passed. The external aluminum jacket is shorter but has wider internal diameter. The space between the external and internal jacket and the tight cover, created space for putting the mixture semi-precious metals and grounded quartz particles (Figure 3).

Wax deposition experiment

Quartz was grounded to crystal form using crushing machine and added to semi-precious metals (zinc, lead and cobalt) which were also chopped into pieces. Each of this mixture (zinc +quartz and zinc + lead) was put in the fabricated tool and covered with aluminum lid. The tool was then fixed in flow line. An electric ring heater in the oil tank was used to heat each of the oil samples to about 75°C to dissolve all the wax and other impurities in the crude. The oil was then flown through the coolant where it was allowed to cool below its wax appearance temperature (WAT). The flow was re-circulated using boaster pump for 18 h, after which the system was stopped.

The temperatures were recorded with six thermocouples and a recorder (meter). Four thermocouples recorded the upstream and downstream temperatures of the oil and the water; one thermocouple was placed inside the oil reservoir for temperature control, and the other was placed in cold water reservoir for recording the temperature. A rotometer was used to measure the flow rate of waxy crude along the flow line.

Prior to each use, the equipment was cleaned by pumping technical grade toluene through it for one hour. The system was then drained and air dried. The Pyrex glass tubing was tilted to allow easy draining of oil by gravity. However, since there is a limit to which a glass can be tilted, an opening was provided in the flow line closed to the oil tank and a valve fixed. A foot pump model "Bee" was used to push out any oil that could not come out as a result of imperfect tilting of the Pyrex glass. The coolant pump was turned on and the flow rate was adjusted with a flow control valve to give the desired oil temperature drop along tubing. As the ring heater was turned on, the system was allowed to reach thermal equilibrium. This took about 30 min. An electronic temperature controller, model Jetec, JTC-903 was used to maintain the temperature of the oil in reservoir at 70°C (180°F). The oil temperature at the condenser was set at 70°C and the outlet temperature at 15°C (50°F). Then the flow was measured and adjusted to the proper rate. The flow was

Table 1. Properties of samples OSS-1, OSS-2, OSS-3, A and B.

S/N	Test	Test Method	Unit	OSS-1	OSS-2	OSS-3	A	B
1	Pour Point	ASTM D 97	^oC	-6	-8	-2	3	-12
2	Cloud point	ASTM D 2500	^oC	13	7.5	14	-	-
	Viscosity @							
	40		Cst	5.91	10.4	12.4		
3	60	ASTM D445		3.22	6.03	8.24	3	-12
	80			1.09	0.93	2.36		
4	Wax Content	UCP 46	Mass%	8.19	5.27	8.61	<5	<5
5	SG	ASTM D287	^oF	0.9174	0.9063	0.9477	0.8817	0.8717
6	Density	HYDROMTER	Kg/l	917	906	948	-	-
7	Heat of combustion(gross)	ASTM D240-02	MJ/kg	33.18	40.24	38.13	-	-
8	Heat of combustion(net)	ASTM D240-02	MJ/kg	31.29	38.27	36.22	-	-

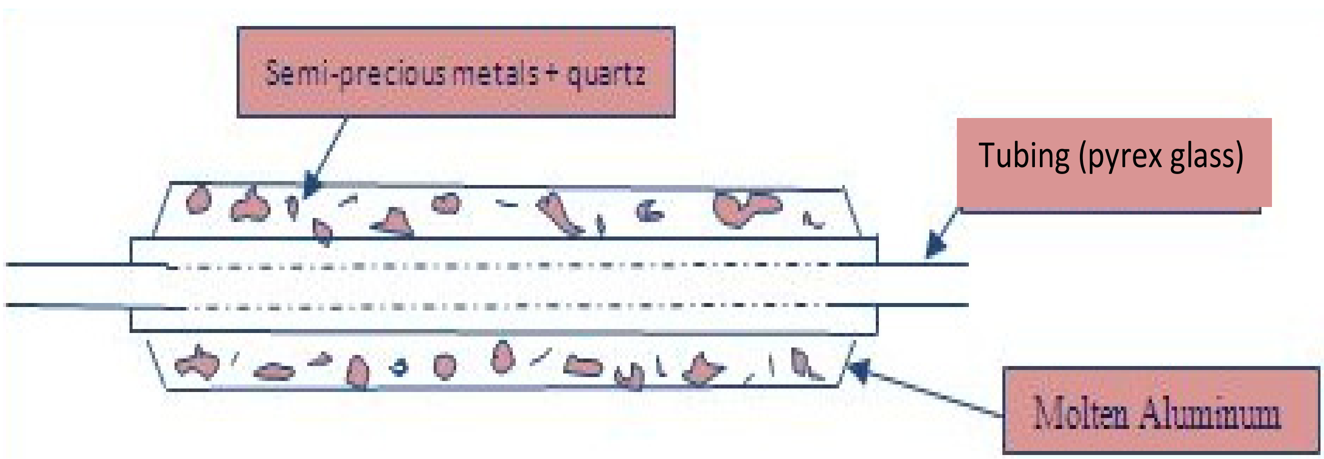

Figure 3. Detailed diagram of the fabricated tool.

continued for 18 h. As the flow continued, the temperatures of the inlet and outlet were taken to ascertain the effectiveness of the improvised condenser. Then, the flow was stopped. In the first instance, it was zinc + crystal quartz in the fabricated tool. The cold water was maintained at $0^o \pm 0.5^oC$ in an insulated 7 liters reservoir. The flow rate of the coolant (water) was measured using SOCAM flow meter model ISO4064. PEDROLLA 0.5 Hp pump model PKM60 was used for the continuous circulation of the crude oil and the coolant in the flow system.

At the end of the experiment the glass tubing was drained at ambient temperature, and then cut into sections, each about 14 cm long. The deposited wax was melted out of the tubing by heating the preweighed sections at 180^oF (82^oC) for 10 min. The amount of mass lost by the tubing was compared with the weight of the wax obtained. The difference was considered to be due to the volatization of lighter components. The same process was repeated for samples OSS-2 and OSS-3. The readings were taken and the obtained results compared. At the end of each experiment, the oil reservoir and the flow system were flushed using toluene and air dried before the next sample is re-run.

After the three samples were ran, the fabricated tool was removed, loosed, and zinc and crystal quartz were poured out and the tool thoroughly cleaned. Lead plus crystal quartz was then placed in the tool and replaced back into the flow line. The experiment was run again for all the three samples (OSS-1, OSS-2 and OSS-3). The same procedure was followed as did with zinc plus crystal quartz.

RESULTS AND DISCUSSIONS

Stock tank oil properties

Table 1 summarizes the measured densities, pour point, cloud points, and viscosities of samples OSS-1, OSS-2, OSS-3, A and B. As can be seen right from the table, sample OSS-3 has the highest molecular weight, asphaltene and wax content and the largest C_{36+} fraction. This gives the clear justification why sample OSS-3 has the highest cloud point (WAT) value as indicated in Table 1. Sample OSS-2 on the other hand, has the lowest asphaltene content and the smallest C_{36+} fraction, thereby, exhibiting lowest clout point (WAT) value. From this analysis it can be understood that samples A and B are not likely to cause much problem to the production system. Also it is obvious that to access the performance of the fabricated tool, the outlet temperature at the condenser is not supposed to be much more than the WAT for each sample.

Compositional analysis

Table 2 summarizes the composition of crude oil samples

Table 2. Results of compositional analysis of waxy crudes.

Laboratory No.	LPEC/1/08	LPEC/2/08	LPEC/3/08	LPEC/4/08	LPEC/5/08
Sample code	**Oss-1**	**OSS-2**	**OSS-3**	**A**	**B**
Nitrogen, mole %				0.32	0.14
Light ends, mole %					
C_{2-} Hydrocarbons	60.37	58.73	71.21	70.11	63.4
C3- Hydrocarbons	5.43	5.28	9.32	9.12	7.64
IC4 (Isobutene)	2.99	2.84	1.98	2.18	4.22
NC4 (Normal Butane	1.92	1.67	1.36	1.85	3.98
IC5 (isopentane)	1.13	1.01	0.74	0.97	2.24
NC5(normal pentane)	0.86	0.83	0.38	0.42	1.83
Sum C2 - C5, mole %	72.82	70.43	84.99	84.65	83.31
Light Naphthene (bp<175 ^{o}F) mole %	18.15	16.14	19.86	20.23	16.21
Medium naphtha(175<bp<250℉ mole,%	5.9	5.17	11.43	11.92	5.61
Heavy naphtha 9250<bp<375F mole %	2.1	1.76	9.22	8.96	3.09
molecular weight (g/mol) C6-C10	194	187	223	212	209
Kerosene(375<bp<65^{o}F) mole %	1.3	1.06	7.24	7.28	1.83
Sum C10-C12 mole %	28.15	24.13	47.75	48.39	26.74
LGO (530<bp<650) mole %	0.96	0.87	5.87	5.84	1.27
Molecular weight (g/mol) C28 +	360	298	429	425	330
PGO(650<pb<1049F) mole %	0.68	0.53	3.68	4.13	0.98
Residual Oil (bp>1049F) mole %	0.43	0.36	2.97	2.04	0.64
Molecular weight of C36+ (g/mol)	537	515	693	615	519
Av. Molecular weight of whole oil (g/mol)	164	150	238	185	148

OSS-1, OSS-2, OSS-3, A and B using ASTM D5297 method. From this compositional analysis, information about n-paraffin, iso-paraffins and naphthenes concentration in the dead oils is established. It is also an evident that oils collected from the same field but different reservoir/well has relatively different composition. The differences may be attributed to geological factors and or variation in temperature profiles and production histories for different wells. The implication of the observed variations in oil composition could be interpreted in relation to measured STO property.

Wax deposition experiment

Visual observation of inside of the Pyrex tube (test section) at the end of tests showed that, as the oil flowed up the section, pecks of wax were formed on the pipe wall. Also up the section, a complete continuous film of deposit was observed (solid points) which increased in thickness from there to the top. It was difficult to determine the exact location where the pecks of wax began.

The quantity (in grams) of deposits per time at the section before the fabricated tool was far more than the quantity of deposits inside the tool and even after the crude has passed the tool. The quantity was estimated by visual observation and also was measured using G&G electronic scale model JJ1000. This is also a confirmation that the tool is working effectively. Figures 1 and 2 show the comparism between the percentage wax deposits before and after the samples have passed through the fabricated tool during the test.

Conclusions

1. A tool that controls wax deposition was developed, tested and prooved to be effective in the laboratory.
2. The mechanism of semiprecious metals (Zinc, Colbat and Lead) plus quartz was studied and found to effectively reduce/eliminate wax deposit in the production system through the generation of piezoelectric reaction. Materials (Zinc, Lead and Quartz) were used in their natural form.
3. From this studies, Zinc plus quartz has proven to be more effective than Lead plus quartz crystals. Zinc was able to achieve 32.35% success on sample OSS-3 which is the most potentially problematic crude oil in the samples used for this research work; while lead could achieve only 17.86% on the same sample.
4. Among the five samples collected for the purpose of this studies, two were dropped because early investigations on the sample indicated that they have no potential capability of depositing wax easily. The two samples (A&B) have very low pour point and wax content

(Table 1). Sample OSS-3 was found to have the highest cloud point and wax content (14°C and 8.61 respectively) thereby would cause more flow problems in the production, flowlines and pipelines. This is followed by OSS-1 and the lowest, interms of cloud point and wax content is OSS-2. However, it was generally observed that the major factor in the deposition of wax from crude oil is the temperature falling below its wax appearance temperature (WAT). This is in agreement with the findings of other reasearchers (Agarwal, 1989; Ajienka, 1990 and Armenskii, et al,1971).

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