

# Silicone in the Oil and Gas Industry

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# SILICONE IN THE OIL AND GAS INDUSTRY

## ABSTRACT

Silicone is a class of specialty chemicals that have unique properties that results from its origins at the frontier of inorganic and organic chemistry. This paper will describe the nature of silicone and the physical and chemical properties that make it unique. The relationship and utilization of these properties to applications throughout the petroleum production and refining chain will be discussed.

Historically, the primary use of silicone in the petroleum processing industry has been as foam control agents in applications from exploration and drilling (drilling muds, cements), through production (gas separation, gas treatment, well water injection), to refining (gas treatment, distillation, delayed coking). Silicone effectiveness is so high that it is usually only requires extremely low concentrations of active material to achieve the desired results.

Silicon-based materials are also used in the petroleum industry for other purposes, such as in demulsification, where the unique properties of silicone polyethers have allowed cost effective formulations to be developed for use in some demanding applications by specialist companies in this field.

## 1. INTRODUCTION

### 1.1. SILICONE or POLYORGANOSILOXANE

The term "SILICONE" is very generic and covers the family of organosiloxane polymers. The silicone name was given initially when it was thought that analogies could be found between carbon and silicon chemistry; silicone comes from the analogy with ketone, since the structural unit of the organosiloxane  $-R_2SiO-$  corresponds to the  $R_2CO$  structure of a ketone, but the comparison stops there. The double bond  $Si=O$  is unstable, leading preferably to the formation of single bonds,  $R_2Si-O-R_2Si-O$ , and thus a polymeric compound, while carbon is capable of forming single molecules of the ketone type.

The POLYORGANOSILOXANES are thus polymeric, containing Si-O-Si bonds of the same nature as in silicates, but with organic radicals fixed on the silicon. They occupy, therefore, an intermediate position between organic and inorganic compounds, or more precisely between silicates and organic polymers, and through this dual nature, have fascinating properties. (10)

The most common of these polymers is POLYDIMETHYLSILOXANE, but the methyl radicals along the chain can be substituted by many organic groups, and in particular, hydrogen, alkyl, allyl, trifluoropropyl, glycol ether, hydroxyl, epoxy, alkoxy, carboxy, and amino.

## 1.2. POLYDIMETHYLSILOXANE MOLECULAR STRUCTURE

The molecular structure and some relevant parameters of the Si-O-Si bond explain the unique properties of the polydimethylsiloxane and the differences to expect from the hydrocarbon polymers.

**Table 1 Molecular numerical data**

Bond	Length Nm	Delta electronegativity	Ionic character % (1)	Bond energy kJ/mol (19)
Si-O	0.165 (19)	1.7	50	445
C-C	0.154 (11)	0	0	346
Si-C	0.192 (19)	0.7	12	306

Bond	Rotation barrier kcal (1)
Si-O	<0.2
C-O	2.7
Si-CH <sub>3</sub>	1.6
C-CH <sub>3</sub>	3.6

Bond	Bond angle Degré
Si-O-Si	+142.5 (9)
O-Si-O	+109 (9)
C-C	+112 (11)

The siloxane bond is longer, more polar, and has a higher energy than a C-C bond. The Si-O-Si bond angle is larger than the C-C-C bond angle, and the corresponding O-Si-O bond angle is about the same size as that for C-C-C. Because of this long siloxane bond, this very flat bond angle, and the consequent nearly free rotation of the side groups around the backbone (close to zero for methyl side groups (4)), the siloxane backbone will be able to adopt various orientations, and to present the side groups to their best advantage.

These characteristics, coupled with the low surface energy of methyl groups and the low intermolecular force between methyl groups, determine most of the properties of polydimethylsiloxane.

The inert low surface energy methyl groups mask the high intermolecular forces associated with the inorganic silicate-like backbone. (11)

### 1.3. POLYDIMETHYLSILOXANE PROPERTIES

**Table 2 Unique properties of polydimethylsiloxane**

Unique PDMS Properties	TYPICAL VALUES	UNITS	Temp	Comments	Ref
Low Surface Tension	20.3	mN/m	20°C	70 mm <sup>2</sup> /s PDMS	19
Critical surface tension of wetting	24	mN/m	20°C	100 mm <sup>2</sup> /s PDMS	19
Water contact angle	110	Degree	RT	fluid baked on glass at 300C	19
Low surface shear viscosity	<10	10exp-6.g/s	20°C	high mol.weight fluid (10exp7)	19
Characteristic pressure (p*) (for intermolecular interaction)	341	J/cm <sup>3</sup>	20-207°C	mol. Weight (10exp5)	20
Pour point	<-50	°C		up to viscosity fluid 100,000cSt	10
Glass transition	146	K			19
Coefficient of adiabatic compressibility	101.1 x 10exp(-12)	cm <sup>2</sup> .dyne-1	20°C	viscosity fluid 1000cSt	10
Solubility of N2	0.16	cm <sup>3</sup> /g	25°C	760mmHg / viscosity fluid 20cSt	
Solubility of O2	0.184	cm <sup>3</sup> /g	25°C	760mmHg / viscosity fluid 20cSt	
Viscosity dependence of temperature	Low				10
Thermal degradation	>343	°C		pure polydimethylsiloxane Mn=111,500	21
Oxidative Stability	10	Hr	250C	gelling time in layer of 3 cm thickness	10
High flash point	>320	°C		viscosity fluid > 1440cSt	10
Dielectric constant	2.8		20°C	viscosity fluid 440cSt	10
Loss factor tan delta	1.2 x 10exp(-4)		20°C	viscosity fluid 800 cps	10
Specific resistance	4 x 10exp(15)	ohm.cm	20°C	viscosity fluid 440cSt	10
Dielectric strength	120	kV/cm	20°C	viscosity fluid 50 cps , 6kV/s	10
Vapor pressure	5 x 10exp(-5)	torr	100°C	viscosity fluid of 30,000cSt	10
Insoluble in water	<1ppm			viscosity fluid >10 cSt	22
Biodegradability	14	%		14C - PDMS of viscosity 200cSt	22
Bioaccumulation	no potential for			viscosity fluid > 10 cSt	22
Chemical degradability in soils	evidence for			C14_PDMS of viscosity 200 cSt	22
Low toxicity- in aquatic media	no adverse effect			viscosity above 10 cSt	22
Low toxicity- in aquatic media	very limited toxic effect			viscosity above 10 cSt	22

The molecular characteristics described above explain the bulk properties of polydimethylsiloxane:

- small variation of physical properties with temperature and molecular weight:
- low freeze point
- low pour point
- low glass transition temperature
- low temperature dependence of viscosity
- liquid behavior up to unusually high molecular weight
- high gas permeability
- high compressibility
- water insolubility
- resistance to thermal and oxidative degradation
- chemical inertness

It also explains the surface properties of polydimethylsiloxane:

- low surface tension
- low interfacial tension with hydrocarbons
- low surface shear viscosity
- low cohesive strength

These surface properties are of critical importance in the success of polydimethylsiloxane, but also of siloxanes substituted with other organic molecules like fluorinated siloxanes or siloxane polyether block copolymers, in applications like antifoaming or demulsification.

#### **1.4. THE ORGANICALLY SUBSTITUTED SILOXANE**

Substituted (with something other than methyl groups) siloxane polymers retain part of the properties of the polydimethylsiloxane, depending on the degree of substitution of the methyl groups, and the type of substituents attached. Replacing methyl groups with polyether groups, for instance, can increase the hydrophilicity of the resulting silicone polyether, and allow the adjustment of the hydrophilic-lipophilic balance to any desired value, while still maintaining the essential features of the siloxane backbone.

They can be designed to show low interfacial tension with aqueous solution, while retaining some of the backbone flexibility, low cohesiveness, low surface tension and low surface viscosity of the polydimethylsiloxane. This will be important for their role in demulsification applications, which will be covered later in this paper.

Replacing some of the methyl groups with fluorine-containing alkyl groups, as a second example of direct interest for applications in the oil & gas industry, will yield a high resistance to hydrocarbon solubility, while maintaining a low surface tension. A Trifluoropropylmethyl siloxane of 300 mm<sup>2</sup>/s will exhibit a surface tension of 24 versus 20.4 maximum for Polydimethylsiloxane (7). This will be important for their role in gas/oil separation, which will also be covered later in this paper.

On a broader perspective, it is important to mention that although Polydimethylsiloxane is well known as an unreactive material, it can easily be the reverse with organosiloxane polymers. In fact, many of them are considerably more reactive than their carbon analogue polymers. This is used quite extensively within silicone rubber and sealants, for instance, where acetoxysiloxanes, alkoxy siloxanes, vinyl siloxanes, and methylhydrogen siloxanes are regularly used as the building blocks.

The silicone world is thus very versatile and can exhibit many different behaviors depending on the pending organic groups fixed on the siloxane backbone, while often maintaining a good part of the useful properties corresponding to the polydimethylsiloxane.

For this reason, siloxane polymers have found uses in most industries. Some representative applications are transformer fluids, release fluids, brake fluids, heat transfer liquids, damping fluids, lubricants and high performance greases, flow aids, car polish, shampoo, antifoams, sealants, primers, solvents, dielectric encapsulants, and adhesives.

Most industries, like Automotive, Electric, Electronics, Construction, Textile, Medical, Pharmaceutical, Personal care, Detergent, Polish, Paints & Coatings, Chemical, and Petrochemical industry utilize silicones in many applications, and of course, the oil & gas industry is not excluded.

## 2. ANTIFOAM USAGE THROUGH THE PETROLEUM INDUSTRY

One of the initial and historical reasons for the use of silicone in the oil & gas industry is the need for foam control during the oil and gas separation process, e.g. the need to prevent carry-over of crude droplets within the gas, or carry-under of the gas with the crude.

Many of the other applications of silicone during the crude production and refining process are also for gas-liquid separation purposes; e.g. deoxygenating water for well injection, de-aeration of casing cement, de-aeration and defoaming of drilling fluids, and foam control during glycol scrubbing, amine scrubbing, amine extraction, delayed coking, and other fractionation applications.

The unique properties of silicone have made it an ideal material to meet the demanding needs of antifoam applications in the oil and gas industry for both economic and performance reasons.

### 2.1. FOAMING PROCESS THEORY

A foaming behavior requires the adsorption of a surface-active material (surfactant) at the interface, which will lower the total free energy of the system. Foaming stability nevertheless requires other mechanisms deriving from this adsorption. The main mechanisms are those of film elasticity, viscous surface layer formation, gas diffusion, and electrical double layer repulsion.

Foam is a dynamic medium, always in movement, where the foam bubble is subject to mechanical erosion, stretching and thinning by drainage. The mechanical erosion or the stretching can create an area of rupture if no self-healing process occurs. On this surface weak spot, the concentration of surfactant will be lower, and the surface tension higher, than elsewhere. The resulting gradient will initiate a transfer of surfactants from the surrounding surface layers to equalize the surface tension. Stable foam is foam where the transfer of surfactant will operate at a rate that will allow the underlying layers of liquid to follow the movement of the surfactants and repair the thin spot. This effect is the film elasticity, or Marangoni effect. The film elasticity is therefore the ability of a liquid lamella, i.e. - the foam bubble wall, to resist a localized thinning.

The formation of viscous surface layers, as a secondary effect of adsorption of surfactants, is another important mechanism supporting foam stability. The surface viscosity increase can be supported by intermolecular interaction between the adsorbed surfactants through hydrogen bonding and dipole/dipole interaction.

Gas diffusion from small bubbles with high internal pressure into larger ones with lower internal pressure is one cause of instability and stress within the foam. (12) If this gas diffusion through the bubble wall is reduced because of the presence of adsorbed surfactants, it will result in foam stabilization.

Electrical double layer repulsion is specific to aqueous foam stabilized by an ionic surfactant. The repulsion forces will prevent thinning of the bubble wall through drainage over a certain limit ( $2.5 \times 10^{-8}$  -  $20 \times 10^{-8}$  cm) (13)

## 2.2. ANTIFOAM THEORY

An antifoam is a chemical that will prevent foam formation. A defoamer is a chemical that will knock down or disperse existing foam. While there is a distinct difference between these two actions, the chemical interactions are similar and many, if not most, silicones are effective as both an antifoam and as a defoamer. Therefore, these terms are often used interchangeably.

Any chemical aiming to be an antifoam will have to interact with the stabilizing surfactants and as many as possible of their stabilizing factors. A given chemical will thus behave as an antifoam if it is more surface active than the foam stabilizing surfactants. It can then enter the foam bubble wall and destroy the film elasticity, and/or drop the surface viscosity, and/or facilitate gas diffusion, and/or neutralize the electrical double layer repulsion.

Two modes of action have been recognized (15): the antifoam droplet after entering the liquid/gas interface will either spread over the surface or form mixed layers with the stabilizing surfactants. Both approaches will enable the antifoam, based on its intrinsic properties, to alter some of the stabilizing factors: film elasticity, surface viscosity, gas diffusion or double layer repulsion.

The conditions required to enter an interface can be translated in terms of surface tension (ST) and interfacial tension (IFT) between the antifoam (A/F) and the foaming medium (F).

$$E = ST(F) + IFT - ST(A/F) > 0$$

The conditions to spread on an interface, can also be translated in a similar function:  
 $S = ST(F) - IFT - ST(A/F) > 0$

Insolubility of the antifoam in the foaming medium is not a must, but highly desirable if efficiency at low concentration is expected. The main advantage is that all the antifoam concentrates at the available interfaces. In addition, a chemical used for antifoam purposes has a low surface tension, and can become a foam promoter at relatively low concentrations when soluble in the foaming medium. Shearer demonstrated this for polydimethylsiloxane of low viscosity in oil (14).

Chemical inertness in the foaming medium is also a preliminary requirement for the candidate antifoam.

Finally the droplet size of the antifoam is critical to its efficiency. No antifoam will be efficient forever. This is not due to a chemical material change since only physical modification occurs during the antifoaming process, but rather to droplet size change. The distribution of the antifoam droplets will change every time they contribute to burst a new foam bubble; both coalescence and droplet size reduction will occur, leading to droplets either too big to be present in a foam lamella, or too small to create a significant weak point in the bubble wall. The very small droplets can also resolve into micelles and essentially become invisible to the antifoaming process.

## 2.3. SILICONE ANTIFOAM

Looking at the preliminary requirements and the intrinsic properties necessary for a chemical to behave as an antifoam, it is striking to recognize the nice match with polydimethylsiloxane properties.

### 2.3.1. FOR NON-AQUEOUS FOAM

In gas/oil separation, crude distillation, or delayed coking, polydimethylsiloxane benefits from:

- High surface activity
  - Low surface tension : max 20.4 mN/m
  - Low interfacial tension with oil: 2.8-4.8 mN/m (11)
- Low intermolecular interaction
  - High gas permeability
    - A silicone rubber is 10 to 100 times more permeable to gas than natural or butyl rubber (6)
  - Low surface viscosity of  $< 10 \times 10^{-6}$  N s /m (11)
- Inertness

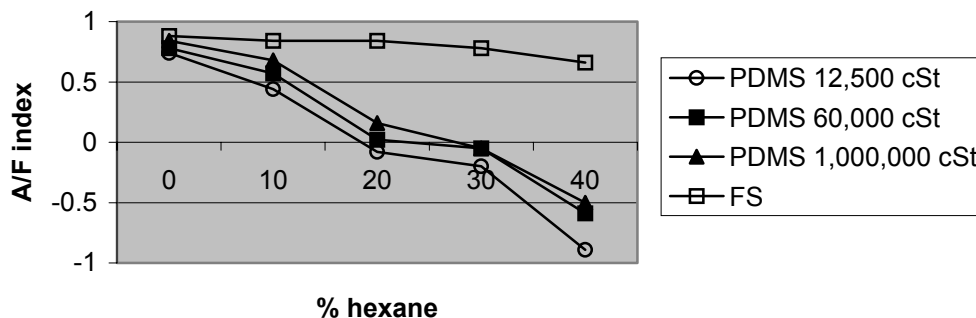
These properties are almost perfect match with the requirements. Only the insolubility requirement can become problematic if not addressed correctly.

Two specific applications are discussed below and should give the reader an idea of the considerations and usefulness of silicones as processing aids in non-aqueous environments.

#### GAS/OIL SEPARATION

The insolubility of polydimethylsiloxane (PDMS) in a live crude is not automatic. Depending on the gas/oil ratio and the type of crude and gas, the solubility of the silicone will vary with molecular weight and with substituent groups. The antifoam efficiency variations have been demonstrated by Callaghan, Hickman, Lawrence and Melton under lab test conditions, at ambient pressure, when hexane (the nearest equivalent to the gas present in live crude, e.g. ethane, propane, butane) was mixed in different ratios within a stabilized crude, and antifoam efficiency of PDMS 12,500 cSt, 60,000 cSt, and 1,000,000 cSt, and a fluorosilicone were tested (8). Figure 1 shows some of this data.

**Figure 1: The effect of crude oil dilution by hexane upon the A/F index**



If FH is the foam height in a sparge test, the antifoam A/F index is equal to  $\{FH(0\text{ppm}) - FH(5\text{ppm})\}/FH(0\text{ppm})$ .

When the percentage of hexane increases, the lower viscosity PDMS antifoam loses efficiency and eventually becomes a profoamer, while the higher viscosities of PDMS maintained efficiency better and coped with higher hexane concentrations, while the fluorosilicone was able to handle the highest hexane ratios. In all cases, the lab results suggest that the higher the viscosity of the PDMS, the higher the efficiency will be, even when low gas/oil ratios are considered. (8)

This lab data has not been directly correlated with the field, but the general observation that higher viscosities work better at higher gas/oil ratios has been observed. Therefore, a PDMS of 60,000cSt and above is generally recommended to cope with higher gas/oil ratios. If a step change is required, the first one can be expected by a move from 12,500cSt to 60,000cSt, and then to 600,000cSt or 1,000,000cSt, with a final step change being the use of fluorosilicone. As with any antifoam, the economics of effective dose rate vs. material price determine the final choice, although material handling should also be considered. To make the higher viscosity materials easier to handle, many are now available pre-dispersed in solvent.

When a suitable silicone has been selected, the concentration of active silicone required is usually in the range of 1 to 10 ppm for PDMS and 0.5-2ppm for fluorosilicone. This is of course depending on many parameters; the residence time in the separator being a critical one, along with other ones linked to the crude characteristics and process conditions.

#### DELAYED COKING

In this process, not only does the solubility of the antifoam need to be addressed, but also the thermal stability. The temperature of this thermal cracking process can go up to 450-500C, while its full cycle time is often about 24 hrs. Although the thermal stability of silicone is quite high, in absence of air, initial thermal decomposition of PDMS starts around 300°C. A thermal breakdown of the silicone polymer will thus occur under the coke drum operating conditions. This thermal breakdown is manifested by molecular rearrangement, which generates volatile cyclic siloxanes and progressively reduces the molecular weight of the initial polymer.

Fortunately, this molecular rearrangement is not instantaneous and has been found to vary inversely with molecular weight. The thermal stability of PDMS 60,000cSt and 600,000cSt have been analyzed and compared at 400°C, after 2 hrs in a nitrogen atmosphere, by TGA and GPC, in Table 3.

**Table 3 Thermal stability of PDMS 60,000cs and 600,000cs**

PDMS type	Before thermal degradation		After thermal degradation		
	Mn	Polydisp.	Mn	Polydisp.	Weight loss
DC200/ 60,000cSt	82,070	2.18	55,747	6.11	33.70%
DC200/ 600,000cSt	155,462	2.21	91,110	4.38	18.30%

In the conditions of the test, the Mn of the PDMS of 600,000cSt after thermal degradation is still higher than the Mn of the PDMS 60,000cSt prior to thermal degradation. The weight loss, through generation of volatile siloxane, was also smaller. Both the higher residual molecular weight (remember that for an antifoam to be effective it must be insoluble, and that the higher the PDMS molecular weight, the lower the solubility) and the greater amount of material left as a liquid after the test

would point to the 600,000 PDMS being the longer-lasting antifoam for this application. This is manifested by a lower required addition rate in the refinery. This has been demonstrated in several processes, with a comparable required addition rate of ½ or less of the 600,000 as compared to the 60,000.

From an application standpoint, the antifoam is typically dispersed in kerosene or another suitable solvent (to aid in handling and in dispersion within the coker) and then added to the delayed coker at a dose level from 2 to 20 ppm active, depending on the severity of the foaming issue in the particular coker, which varies based on feed composition and specific coker operating conditions. The antifoam is added in one of two locations. The most common is to the top of the coker drum, sometimes as a coarse spray to improve coverage. This delivers the defoamer directly to the top of the foam head. The caution with this method is to add the chemical as far from the gas outlet as possible to minimize any entrainment with the coker gas.

The second addition point is at the inlet to the coker furnace. This has the advantage of eliminating entrainment and the further advantage of decreasing coke buildup in the furnace tubes (more on this below). The disadvantage of this addition point is that the defoamer is exposed to elevated temperatures and will begin breaking down before it ever reaches the liquid/gas interface. This reduces overall chemical efficiency.

As for the increased furnace tube performance, there are two theories as to why this occurs, although neither has been proven. The first is that as the vacuum resid is heated in the furnace, gas is generated, which in turn creates foam. This foam cokes out on the tube wall relatively quickly. The PDMS helps control this foam, and therefore, decreases coke buildup. The second theory is that the PDMS acts as a kind of release coating for the furnace tubes, decreasing the amount of coke that “sticks” to the tube wall. PDMS is used as a release coating in many other industries.

### **2.3.2 FOR AQUEOUS FOAM**

Examples of this are in gas scrubbing by glycols or amine solutions, in drilling muds, in deaeration of casing cements, and in deaeration of water for well injection, polydimethylsiloxanes benefit from their:

- High surface activity
  - Low surface tension
- Low intermolecular interaction
  - High gas permeability
  - Low surface viscosity  $< 10^{-6}$  N s /m (11)
- Inertness
- Water insolubility, independent of a cloud point

However, the low interfacial tension required with the foaming medium to obtain a good spreading of the antifoam on the bubble wall interface is not really met with a silicone fluid. It is rather a silicone fluid compounded with hydrophobic silica, which provides the high efficiency expected in aqueous foam. The silicone fluid is now the carrier; it will meet the requirements to enter in the interface, and deliver the dispersed hydrophobic silica, which will burst the bubble by a de-wetting mechanism. (16)

A silicone antifoam compound is normally used in its emulsion form at 10% or 30% w/w at concentrations corresponding from about 1 to 10ppm of active compound. An

emulsion is an ideal way to deliver an insoluble active into an aqueous foaming solution. Nevertheless, the stability and the efficiency of the final emulsion can vary quite dramatically, depending of the type of active compound, the silica treatment, the type of stabilizer additives used, and the droplet sizes distribution obtained during the emulsification process.

### 3. DEMULSIFICATION

Foams and emulsions have much in common, both being examples of two immiscible fluids, intimately dispersed. In practice, both surface elasticity and surface viscosity are of importance in both these disperse systems. Therefore, as would be expected, demulsification is similar in many aspects to defoaming. In a defoaming process, a gas phase needs to be separated from a liquid phase, which requires interface destabilization and coalescence. Similarly in a demulsifier process, a liquid phase needs to be separated from another liquid phase through interface destabilization, droplet flocculation and coalescence.

The first challenge in the chemical breaking of water-in-oil emulsions is to reach the oil-water interface. The oil has a viscosity that will slow down the diffusivity of material. The hydrophilic-hydrophobic dual nature of surfactant and polyfunctional oil soluble flocculants will help these to concentrate at oil/water interfaces. DIFFUSIVITY, thus MOBILITY, FLEXIBILITY, and INTERFACE ACTIVITY of demulsifiers are thus critical for their efficiency.

The second challenge is the displacement of the stabilizers from the interface by a more surface-active, but yet poorer emulsifying, agent to give a new interface with little resistance to coalescence. An energy barrier builds up easily by accumulation at the water/oil droplet interface of organic solids of high molecular weight, like asphaltenes, resins, and waxes, as well as inorganic solids like calcites. The effectiveness of a demulsifier correlates with the lowering of the interfacial shear viscosity and dynamic interfacial tension at the oil-water interface (17,18). LOW SURFACE TENSION, LOW INTERFACIAL TENSION, LOW INTERFACIAL SHEAR VISCOSITY, LOW INTERMOLECULAR INTERACTION of demulsifiers are thus critical for their efficiency. Thus, it is not surprising that most of the advantages of silicone justifying their superior efficiency as an antifoam can also be applicable during chemical demulsification.

#### SILICONE DEMULSIFIERS

A polydimethylsiloxane has many of the properties needed to work as a demulsifier, but its solubility in oil and interfacial tension with water are high, so a PDMS on it's own is not particularly effective.

Silicone polyethers (SPE's) can address these drawbacks. See Table 4 for a generic SPE structure. The PDMS part of the block copolymer will retain the properties of the PDMS (e.g. low surface tension, low intermolecular interaction, molecule flexibility, low surface viscosity), while the polyether chains attached to the backbone offer better migration to the interface.

SPE's can have many different structures, e.g. different DP's of the siloxane backbone, different amount of polyether on the backbone, and the types of polyether groups (typically EO or EO-PO of varying lengths) fixed onto the silicone backbone. The final copolymer can have an ABA structure, as well as a rake structure.



#### **4. OTHER APPLICATIONS**

Silicones, as PDMS or as substituted siloxane polymers, are regularly used in many other applications further down the petroleum production process.

These have not been covered in this paper, but some other typical applications are:

- Antifoams in many petrochemical processes, such as in BTX extraction by glycols, in solvent de-asphalting, in asphalt transportation, in lubricating oils, in diesel additive packages.
- Vanadium corrosion inhibitors (ash modifier) in gas turbines using heavy fuels.
- Low temperature hydraulic fluids.
- Thermal and dielectric fluids in transformers.
- Greases – particularly when resistance to high temperature, oxidation, or chemical corrosion is required; fluorosilicone greases are also used when better resistance to hydrocarbon solvents or fuels is required.
- Sealing foams and elastomers, particularly as protection against fire and smoke risk in petrochemical plants or offshore Platforms.

#### **5. SUMMARY**

This brief review has examined the relationships between the molecular structure of silicones, their unique combination of properties and their interesting fit with the requirements of the Petroleum industry. The surface properties of silicones (low surface tension, low surface viscosity, low cohesive strength, and high gas permeability), coupled with its thermal and chemical stability and low sensitivity to temperature variations, are the foundations of its success in the Petroleum industry.

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