



AEROSIL® fumed silica for cable gels

Technical Information 1163

AEROSIL®

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1 Introduction

Fibre optic technology has made enormous progress over the past few years. In almost all areas of modern technology today it is impossible to disregard optical fibres. They are found in communications engineering and data processing for rapid transfer of information, in mechanical engineering for illumination and inspection of cavities and in medical diagnostics where fibre optic cables have proven to be of great value thanks to their flexibility. The economic and technical advantages of these glass-fibre cables over conventional copper cables are (1):

- low installation and maintenance costs
- low raw material costs
- high transfer capacity
- low transmission loss (loss of signal power due to scattering)
- light weight, space-saving
- prevention of cross talk
- high degree of noise immunity, no grounding problems
- safe to use in explosive environment

The main disadvantage of glass fibre cables is the more complicated mechanical connections than those used for copper cable.

With the cost of optical transmitters still relatively high, fibre optic cables are only worthwhile if the transmission distance is more than several hundred meters. A particularly wellknown application for optical fibres is the two marine cables linking the United States with Great Britain and France.

A major requirement for sensitive optical fibres is that they must be able to move freely inside the cable and remain isolated from external forces. Otherwise their transmission loss will increase and the speed of communication will be drastically reduced. This is done using special filler compounds, cable gels, which have been thickened with fumed silicas. In addition to hydrophilic AEROSIL® fumed silica, after-treated (hydrophobic) AEROSIL® fumed silica has also proven to be suitable for this new application.

This brochure describes the use of hydrophilic and hydrophobic AEROSIL® grades as a thixotrope in four different systems for cable gels. It deals in particular detail with the specific differences in rheological properties achieved by AEROSIL® using rheological measurements. Electrical measurements are also described.

2 AEROSIL® fumed silica

AEROSIL® fumed silica is a highly dispersed, amorphous, very pure silica manufactured by high-temperature hydrolysis of silicon tetrachloride in an oxyhydrogen gas flame. The primary particles formed in the AEROSIL® process are virtually spherical and free of pores. During the formation of the primary particles, aggregates are formed which further accumulate into agglomerates. Under shear, these agglomerates can be returned back into smaller aggregates. **Figure 1** shows a transmission electron micrograph (TEM) of AEROSIL® 200, in which the primary particles, aggregates and agglomerates can be clearly seen. Depending on the AEROSIL® grade, the specific surface areas range between 50 and 380 m²/g.

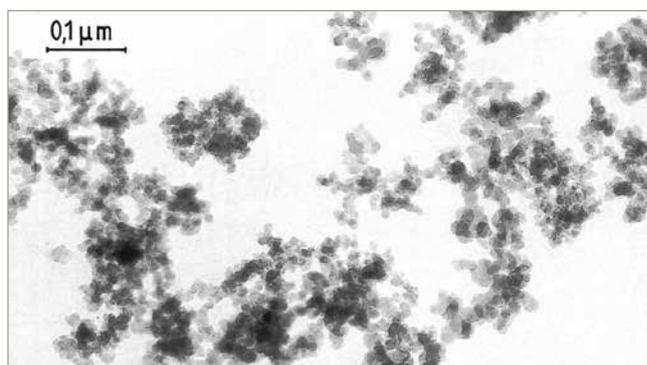


Figure 1
Transmission electron micrograph (TEM) of AEROSIL® 200

Siloxane and silanol groups are found on the surface of the AEROSIL® particles. This latter type of functional group in particular is responsible for the hydrophilic behaviour of untreated AEROSIL®. **Figure 2** shows the surface groups of hydrophilic AEROSIL® grades.

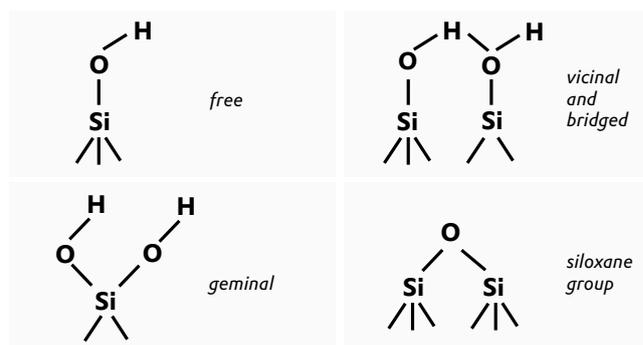


Figure 2
Surface groups of hydrophilic AEROSIL® grades

For basic details and applications of AEROSIL® fumed silica, see Evonik Technical Bulletin 11 (9).

AEROSIL® fumed silica can be modified by reacting the silanol groups with suitable compounds such as silanes. For example AEROSIL® R 972 is obtained by reaction with dimethyldichlorosilane; this product exhibits chemically bound dimethylsilyl groups on its surface and can no longer be wetted into water—in other words, it is **hydrophobic**.

3 Cable gels

In 1962 AEROSIL® R 972 became the first hydrophobic silica to be manufactured on an industrial scale. Other hydrophobic AEROSIL® grades are now available, produced by similar methods using corresponding silanes. **Figure 3** provides a summary of these and highlights the difference between them and hydrophilic AEROSIL® grades according to the schematically represented surface groups. All hydrophobic AEROSIL® grades bear the suffix “R” to indicate their water-repellent character.

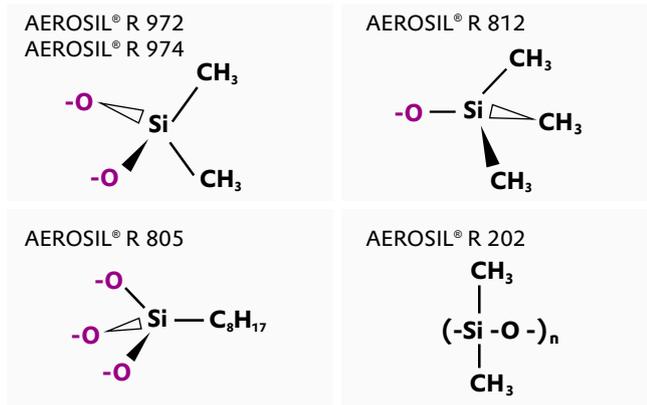
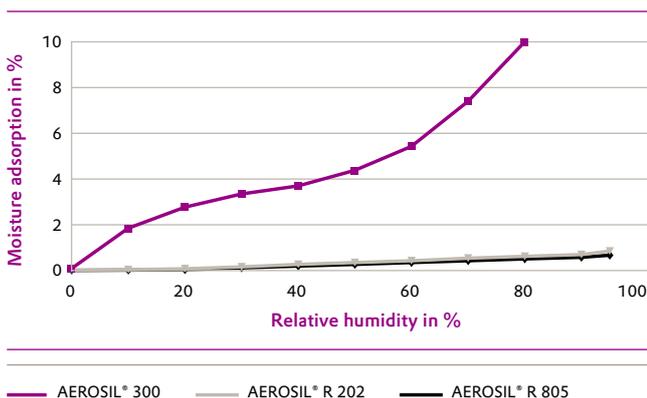


Figure 3
Surface groups of hydrophobic AEROSIL® grades

The hydrophobic nature of aftertreated AEROSIL® grades compared with AEROSIL® 300 can be illustrated by means of moisture adsorption in increasingly humid conditions. **Figure 4** shows the corresponding isotherms.

Figure 4
Adsorption isotherms of various AEROSIL® grades at room temperature (small samples)



Cable gels are oil-based filling compounds which are used in fibre optic cables to protect the sensitive optical fibres.

The basic components of cable gels are mineral, silicone, polybutene, paraffin or polypropylene glycol oils and thixotropes, which are used in concentrations between 1 and 20%. In addition, other additives such as microcrystalline waxes, polymers, organic thickening agents and antioxidants can also be used.

The requirements for cable gels vary greatly and are briefly described below (5, 6, 7):

The purpose of the cable gel is to isolate the optical fibres (glass fibres) from external forces. It should ensure that no tensile and compressive forces are exerted on the sensitive glass fibre, because mechanical stress increases transmission loss, thereby considerably reducing transmission speed. In order to maintain the mobility of the optical fibres in the cable jacket, a low-viscosity cable gel would be preferable, although such material would be mechanically unstable in a cable structure. On the other hand, a high-viscosity system would reduce the ability of the cable to move quickly, thereby preventing it from reacting to any change in stress.

For this reason, thixotropic gels are preferred as filling compounds as they do not yield while at rest but will temporarily fluidize during mechanical motion. In this way, they successfully isolate the optical fibres from major mechanical effects.

During the filling of the cable by coextrusion, the cable gel should have as low viscosity as possible to ensure that it can be injected smoothly and without excessive pressure. After filling, it should retain sufficiently high viscosity, have a specified yield point and exhibit sufficiently high elasticity. This will ensure that the cable gel does not drip out of the cable if the cable moves or is exposed to high temperatures under pressure. The yield points of cable gels are generally between 35 and 140 Pa, depending on the requirement.

The thixotropic properties of cable gels should also remain constant at temperatures as low as -50°C , and no oil separation should take place at temperatures up to 70°C .

The cable gel prevents water from penetrating into the space between the optical fibres and the cable jacket. Finally, the cable gel used must not have an adverse effect on the electri-

cal properties of the oils. **Figure 5** shows the design of a DIN fibre optic cable (loose fibre bundle technology).

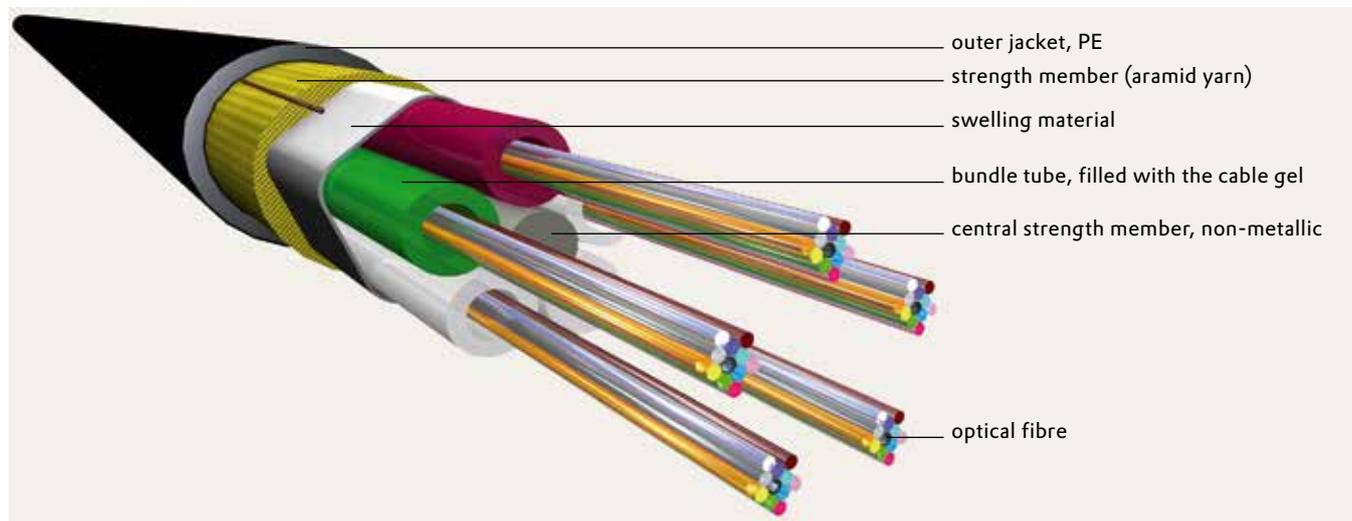


Figure 5
DIN cable construction. 5 bunched wires with each 12 optical fibres

Picture: HUBER+SUHNER GmbH

4 Rheological and electrical properties of different thickened oils for cable gels

4.1 Test methods

Four different types of oils used in cable gels were selected for the tests:

- **Mineral oil Drakeol® 35**
(Penreco, USA)
- **Polybutene Napvis® DE 10**
(BP, UK)
- **Silicone oil Baysilon® M 1000**
(Bayer, Germany)
- **Polypropylene glycol**
(molar mass ~ 700 g/mol), (Aldrich, USA)

The following AEROSIL® grades were used:

- **AEROSIL® 200**
- **AEROSIL® R 972**
- **AEROSIL® R 974**
- **AEROSIL® R 202**
- **AEROSIL® R 805**

Four of the five AEROSIL® grades tested were hydrophobic because prevention of water penetration to the optical fibre is important. Additionally, a blend of AEROSIL® 200 and AEROSIL® R 202 in the ratio of 1:1 was tested in order to determine whether the properties of the oils can be further improved by using this blend.

Using a laboratory disperser (Cowles disc, $d = 5$ cm), the silicas were first thoroughly wetted into the various oils at 6% and 12% at 1000 rpm and then dispersed for 5 minutes at 3000 rpm. The air bubbles introduced into the system by the dispersion process were removed by vacuum.

Rheological measurements

The Haake RV 20 tester using the CV 20 N measuring system was utilized for the rheological measurements. Rotational measurements were obtained using PK 20.4° and PK 30.4° cones and oscillation measurements were obtained using the Q 30 plate (clearance 1 mm) with a deformation of 5% at a constant temperature of 25 °C. The following ramp function in the rotational measurements was determined after initial shearing (18 sec. at 1 s^{-1} and 18 sec. at rest).

In the first test, the shear rate was increased linearly within 2 minutes from approx. 0.3 s^{-1} to 10 s^{-1} , held constant for 1 minute at 10 s^{-1} , and decreased linearly within 2 minutes from 10 s^{-1} to approx. 0.3 s^{-1} .

The flow curve (down) was used to calculate each yield point in accordance with the Casson regression model; the viscosities were also calculated at 2.5 s^{-1} using the flow curve down).

In a second test sequence (to determine the recovery of viscosity) the substances were first subjected to shearing at 1 s^{-1} for 0.5 min., then at 100 s^{-1} for 0.5 min. and again at 1 s^{-1} for 0.5 min. The oscillation measurements were carried out as a function of frequency. To do this, the frequency was increased from 0.1 Hz to 9.8 Hz at a constant deformation of 5%. These measurements were used to calculate the loss and storage module.

4.2 Rotational and oscillatory measurements

The measured yield points and viscosities of the various samples are shown in Tables 1 and 2.

The hydrophilic type AEROSIL® 200 exhibits the highest yield points and viscosities in the nonpolar mineral, silicone and polybutene oils as compared with the hydrophobic AEROSIL® grades.

In the case of AEROSIL® 200, despite a 12% concentration, hardly any thickening and thixotropic effect was noticeable in the polar polypropylene glycol. The highest yield points and viscosities were observed when the hydrophobic grade AEROSIL® R 202 was used.

Table 1

Yield points and viscosities of Drakeol 35 (mineral oil) and Baysilon M 1000 (silicone oil), thickened with 6 % and 12 % different AEROSIL® grades.

mineral oil			silicone oil		
silica grade and concentration	yield point in Pa	viscosity at 2.5 s ⁻¹ in Pas	silica grade and concentration	yield point in Pa	viscosity at 2.5 s ⁻¹ in Pas
6 % AEROSIL® 200	198.0	116.0	6 % AEROSIL® 200	461.0	218.0
6 % AEROSIL® R 972	4.0	4.0	6 % AEROSIL® R 972	1.0	4.0
12 % AEROSIL® R 972	93.0	66.0	12 % AEROSIL® R 972	1.0	17.0
6 % AEROSIL® R 974	30.0	19.0	6 % AEROSIL® R 974	2.0	8.0
12 % AEROSIL® R 974	519.0	257.0	12 % AEROSIL® R 974	29.0	51.0
6 % AEROSIL® R 202	24.0	16.0	6 % AEROSIL® R 202	2.0	7.0
12 % AEROSIL® R 202	180.0	110	12 % AEROSIL® R 202	22.0	40.0
6 % AEROSIL® 200 AEROSIL® R 202 (1:1)	106.0	53.0	6 % AEROSIL® 200 AEROSIL® R 202 (1:1)	83.0	55.0
6 % AEROSIL® R 805	92.0	48.0	6 % AEROSIL® R 805	82.0	54.0
mineral oil	0.0	0.135	silicone oil	0.0	0.960

Table 2

Yield points and viscosities of Napvis DE 10 (polybutene) and polypropylene glycol, thickened with 6 % and 12 % different AEROSIL® grades

polybutene oil			polypropylene glycol		
silica grade and concentration	yield point in Pa	viscosity at 2.5 s ⁻¹ in Pas	silica grade and concentration	yield point in Pa	viscosity at 2.5 s ⁻¹ in Pas
6 % AEROSIL® 200	670.0	560.0	12 % AEROSIL® 200	0.3	0.9
6 % AEROSIL® R 972	4.0	66.0	12 % AEROSIL® R 972	0.3	0.7
6 % AEROSIL® R 974	14.0	87.0	12 % AEROSIL® R 974	0.3	0.8
6 % AEROSIL® R 202	22.0	85.0	6 % AEROSIL® R 202	30.0	18.0
			12 % AEROSIL® R 202	54.0	50.0
6 % AEROSIL® 200 AEROSIL® R 202 (1:1)	144.0	88.0	12 % AEROSIL® 200 AEROSIL® R 202 (1:1)	5.0	10.0
6 % AEROSIL® R 805	83.0	149.0	12 % AEROSIL® R 805	10.0	10.0
polybutene oil	0.0	25.0	polypropylenglycol	0.0	0.110

The flow curves in Figures 6 and 7 graphically illustrate this fact once more. All samples show pseudoplastic flow behaviour. The samples thickened with 6% AEROSIL 200 (mineral oil) and 6% AEROSIL® R 202 (polypropylene glycol) also exhibit distinctive thixotropy.

Figure 6
Flow curves of mineral oils thickened with different AEROSIL® grades

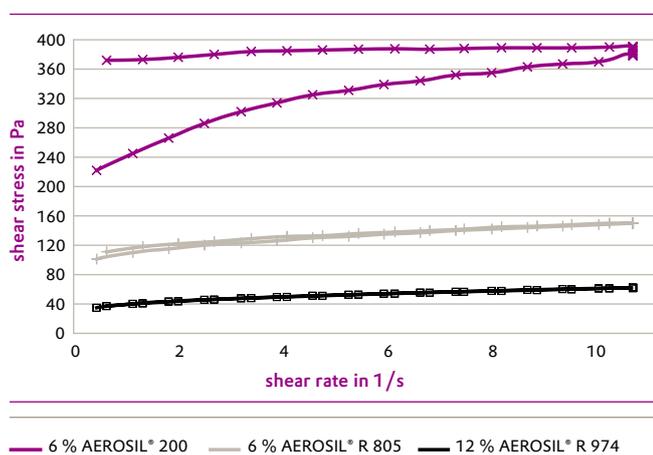
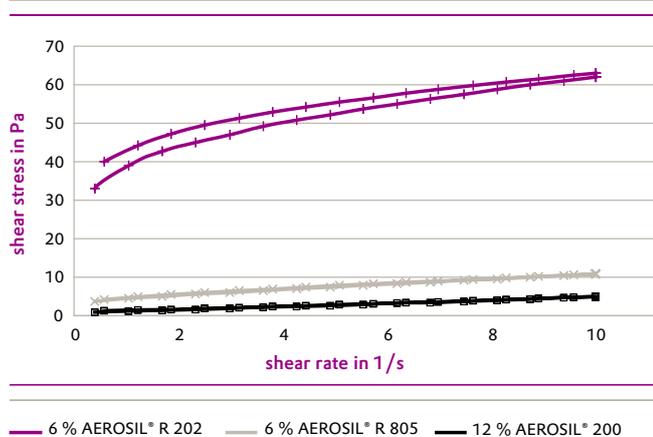


Figure 7
Flow curves of polypropylene glycols thickened with different AEROSIL® grades



The following paragraphs explain the thickening effect of AEROSIL®, which depends on the polarity of the oil, as well as the mechanisms of thickening and thixotropy of the different silicas in liquids. The specific test results are also discussed.

The thickening and thixotropic effect result from the formation of a three-dimensional network of AEROSIL® particles in the system. With the addition of shearing forces (shaking or stirring), the network is broken down, depending on the intensity and duration of the stress, and the viscosity is reduced accordingly. At rest, the network reforms and the system recovers to its original viscosity.

The interactions between the silanol groups of different AEROSIL® particles are responsible for the formation and stability of the network. The hydrogen bonds between the AEROSIL® particles have their full effect in nonpolar liquids such as hydrocarbons or polydimethyl siloxanes. As soon as the liquid molecules exhibit a greater or lesser affinity to the silanol groups as determined by their structure, solvation of the AEROSIL® particles occurs and with it destabilisation of the spatial network. For this reason the thickening of polar liquids such as ethanol or water, or in this case polypropylene glycol, is only possible with relatively large quantities of hydrophilic AEROSIL® grades.

If we now compare the thickening effect of the hydrophobic AEROSIL® grades in the three non-polar oils, the highest yield points and viscosities are achieved in all three oils (mineral, silicone and polybutene oil) when AEROSIL® R 805 is used, while AEROSIL® R 972 exhibits only a minimal thickening effect.

It is only with a concentration of 12% that AEROSIL® R 972 comes close to a yield point of 93 Pa in mineral oil, which is comparable to the yield point of 92 Pa at a 6% concentration of AEROSIL® R 805. In comparison to AEROSIL® R 972, AEROSIL® R 974 is more effective in terms of thickening in all three non-polar oils. This is due to its greater surface area of 170 m²/g as compared to 110 m²/g for AEROSIL® R 972 with the same functional surface groups. The physical mixing of AEROSIL® 200 and AEROSIL® R 202 in a ratio of 1:1 also produces very high yield points and viscosities in mineral, silicone and polybutene oils.

The following mechanism can be used to explain the rheological effect of hydrophobic AEROSIL® grades.

The functional groups on the surfaces of AEROSIL® R 805, AEROSIL® R 202, AEROSIL® R 972 and AEROSIL® R 974 as shown in Figure 3 interact both with each other and with the binding agent, creating especially Van-der-Waals-linkages among the silica particles. As before, a three-dimensional network structure results which increases the viscosity and imparts thixotropic characteristics to the system. The remaining silanol groups support this mechanism in non-polar systems by forming hydrogen bonds, whereas in polar systems they are shielded by the functional groups, particularly those of AEROSIL® R 805 and AEROSIL® R 202.

This model explains the superior thickening effect of AEROSIL® R 202 and AEROSIL® R 805 as compared with AEROSIL® 200, AEROSIL® R 972 and AEROSIL® R 974 in the polar polypropylene glycol and other polar systems such as epoxy resins and vinyl ester resins (3, 4).

The methyl groups on the surface of AEROSIL® R 972 and AEROSIL® R 974 are probably too short to achieve the same effect as those of the larger functional groups of AEROSIL® R 202 and AEROSIL® R 805.

The current results show that the measured viscosities and yield points of the four different oils vary significantly when different AEROSIL® grades are added. For example, it is necessary to have 12 % AEROSIL® R 972 and only 6 % AEROSIL® R 805 to achieve the same yield point in mineral oil. Oscillation measurements were used to determine if there are additional explanations for these differences other than the rheology models already discussed. These measurements make it possible to demonstrate that, only by the addition of AEROSIL® fumed silica to the various oils can visco-elastic properties result.

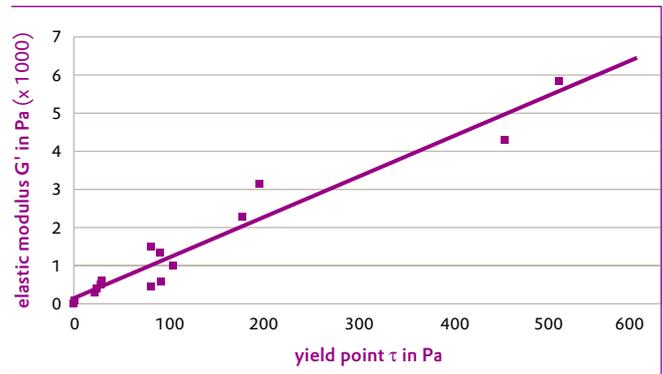
Table 3 shows the measured loss and storage modulus for the mineral and silicone oil and the loss factor $\tan \delta$ calculated at an angle velocity of 10 s^{-1} . Loss modulus G'' is a measure of the viscous component, whereas storage modulus G' is a measure of the elastic component in the system. For the sake of clarity, the two moduli have been calculated at a constant angle velocity of 10 s^{-1} and not shown as a function of the angle velocity. Loss factor $\tan \delta$ is the ratio G'' / G' ; if it is greater than 1, the viscous components in the system are greater, and if it is smaller than 1, the elastic components are greater.

The test results in **Table 3** show, that when the AEROSIL® grades are used, different viscoelastic properties can be obtained in the thickened oils.

Figure 8 shows that there is a good correlation between the elastic properties and the yield points of the thickened mineral and silicone oils. In these oils, as the storage modulus G' increases, so does the yield point.

Figure 8

Correlation of elastic modulus and yield point of oils thickened with various AEROSIL® grades



Beyond that, the loss factors $\tan \delta$ are less than 1 for all samples with high yield points and greater than 1 for all samples with low yield points.

Based on these measurements the following additional mechanism is being suggested for rheological effect. When the thickened oil is suddenly subjected to shearing forces, the three-dimensional network of silica particles reacts because of its elastic properties and absorbs the deforming energy. Initially, there is resistance against being deformed; the system indicates solid-like behaviour. For elastic like behaviour to occur, we must assume that the hydrophilic AEROSIL® particles exhibit hydrogen bonding while the hydrophobic AEROSIL® particles react due to Van-der-Waals attractions. Furthermore, we must consider also steric circumstances.

Table 3

Elastic modulus G' , loss modulus G'' and $\tan \delta$ of Drakeol 35 (mineral oil) and Baysilon M 1000 (silicone oil) at 10 s^{-1} , thickened with 6 % and 12 % different AEROSIL® grades

mineral oil				silicone oil			
silica grade and concentration	elastic modulus G' in Pa	loss modulus G'' in Pa	$\tan \delta$ (calculated)	silica grade and concentration	elastic modulus G' in Pa	loss modulus G'' in Pa	$\tan \delta$ (calculated)
6 % AEROSIL® 200	3150.0	810.0	0.26	6 % AEROSIL® 200	4300.0	1050.0	0.24
6 % AEROSIL® R 972	110.0	100.0	0.91	6 % AEROSIL® R 972	5.0	40.0	8.00
12 % AEROSIL® R 972	590.0	610.0	1.03	12 % AEROSIL® R 972	50.0	105.0	2.10
6 % AEROSIL® R 974	600.0	220.0	0.37	6 % AEROSIL® R 974	70.0	110.0	1.57
12 % AEROSIL® R 974	5850.0	4500.0	0.77	12 % AEROSIL® R 974	500.0	510.0	1.02
6 % AEROSIL® 200 AEROSIL® R 202 (1:1)	1000.0	210.0	0.21	6 % AEROSIL® 200 AEROSIL® R 202 (1:1)	450.0	310.0	0.69
6 % AEROSIL® R 202	400.0	245.0	0.61	6 % AEROSIL® R 202	60.0	110.0	1.83
12 % AEROSIL® R 202	2300.0	2000.0	0.87	12 % AEROSIL® R 202	300.0	510.0	1.70
6 % AEROSIL® R 805	1350.0	610.0	0.45	6 % AEROSIL® R 805	1500.0	700.0	0.47

At rates of deformation higher than the yield point, the silica particles move in the shear field and disarrange each other, assuming a configuration that is adverse to a normal thermodynamic conformation. Under these higher shear rates, the thixotropic oil indicates predominantly viscous behaviour and begins to flow. After removing the shearing deformation, the elastic properties of the visco-elastic system dominate. The energy, which is absorbed by the elastic deformation, is released and the three-dimensional network of silica particles forms again. The yield point recovers almost to its original value.

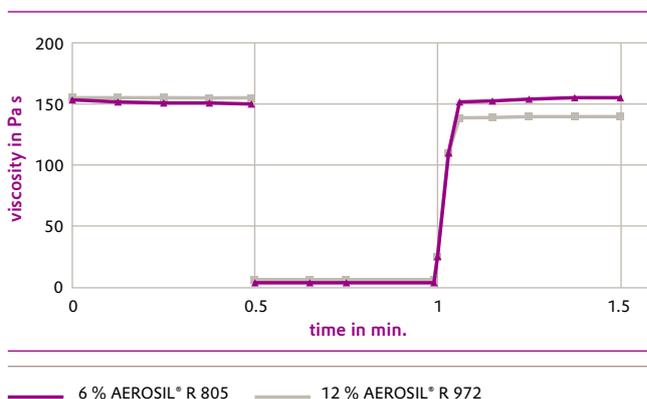
The mixture with 12 % AEROSIL® R 972 and 6 % AEROSIL® R 805 in the mineral oil are compared below in greater detail. The yield points are almost identical at 93 Pa and 92 Pa, which means that AEROSIL® R 805 is about twice as effective as AEROSIL® R 972 in terms of yield point. This is because the mineral oil thickened with 6 % AEROSIL® R 805 has a higher storage modulus G' of 1350 Pa compared with 590 Pa for 12 % AEROSIL® R 972. At the same time, loss factor $\tan \delta$ is 0.45 for the sample with AEROSIL® R 805 and 1.03 for AEROSIL® R 972.

Obviously, the higher elasticity of the mixture thickened with AEROSIL® R 805 is caused by the octyl groups on the surface. As discussed earlier, these groups react due to Van-der-Waals forces. The methyl groups on the surface of AEROSIL® R 972 are obviously too short to achieve the same large particle-particle interactions. With this model, we can explain why AEROSIL® R 805 is about twice as effective as AEROSIL® R 972 in terms of yield point.

Low and high shear tests carried out by means of rotational measurements as a function of time correlate with these results. As shown in Figure 9, the recovery in the mineral oil thickened with 6 % AEROSIL® R 805 was almost 100 % due to its high level of elastic components and "only" about 90 % in the mineral oil thickened with 12 % AEROSIL® R 972. This example also shows that recovery takes place within a few tenths of a second in both substances.

Problem-free extrusion of the cable gels into the cable jacket requires both complete and rapid recovery of the original viscosity after the cable has been subjected to shearing forces. Both properties, which in effect characterise the thixotropic properties of cable gels, can be obtained using AEROSIL® fumed silica.

Figure 9
Viscosity rebounding after shearing deformation of mineral oils, thickened with 6 % AEROSIL® R 805 and 12 % AEROSIL® R 972



4.3 Electrical measurements

The methods used to measure the dielectric properties are described in (8).

The dielectric constant, as measured at 1 MHz and 25 °C, was 2.17 for mineral oil, 2.19 for polybutene oil and 2.67 for silicone oil.

When the AEROSIL® grades tested here are used in these oils the dielectric constant remains practically unchanged. The dielectric loss factor $\tan \delta$ was less than 0.001 in all the samples.

Good dielectric properties are particularly important for filler compounds used in copper cable (8).

5 Physical-chemical characteristics of AEROSIL® fumed silica

Test methods	AEROSIL® 200	AEROSIL® R 202	AEROSIL® R 805	AEROSIL® R 972	AEROSIL® R 974	
Behaviour towards water	hydrophilic	hydrophobic				
Appearance	- fluffy white powder -					
BET surface area BET1 ¹	m ² /g	200 ± 25	100 ± 20	150 ± 25	110 ± 20	170 ± 20
Tamped density ² approx. value	g/l	50	60	60	50	50
Densified material (suffix „V“, „VV“)	g/l	120 ¹²	-	-	-	-
Loss on drying ³ (2 h at 105 °C) when leaving the plant	wt. %	≤ 1.5	≤ 0.5	≤ 0.5	≤ 0.5	≤ 0.5
Loss on ignition ^{4,7} (2 h at 1000 °C)	wt. %	≤ 1.0	4.0 – 6.0	5.0 – 7.0	≤ 2.0	≤ 2.0
pH-value ⁵ (4% „aqueous dispersion“)		3.7 – 4.7	4.0 – 6.0 ¹⁰	3.5 – 5.5 ¹⁰	3.6 – 5.5 ¹⁰	3.7 – 4.7 ¹⁰
C-content	wt. %	-	3.5 – 5.0	4.5 – 6.5	0.6 – 1.2	0.7 – 1.3
SiO ₂ ⁸	wt. %	≥ 99.8	≥ 99.8	≥ 99.8	≥ 99.8	≥ 99.8
Al ₂ O ₃ ⁸	wt. %	≤ 0.050	≤ 0.050	≤ 0.050	≤ 0.050	≤ 0.050
Fe ₂ O ₃ ⁸	wt. %	≤ 0.003	≤ 0.010	≤ 0.010	≤ 0.010	≤ 0.010
TiO ₂ ⁸	wt. %	≤ 0.030	≤ 0.030	≤ 0.030	≤ 0.030	≤ 0.030
HCl ^{8,11}	wt. %	≤ 0.025	≤ 0.025	≤ 0.025	≤ 0.050	≤ 0.100
Sieve residue ⁶ (by Mocker, 45 µm)	wt. %	≤ 0.05	-	-	-	-
Unit weight (netto)	kg	10	10	10	10	10

¹ acc. to DIN 9277

² acc. to DIN EN ISO 787/11, JIS K 5101/20 (not sieved)

³ acc. to DIN EN ISO 787/2, ASTM D 280, JIS K 5101/23

⁴ acc. to DIN EN ISO 3262-20, ASTM D 1208, JIS K 5101/24

⁵ acc. to DIN EN ISO 787/9, ASTM D 1208, JIS K 5101/26

⁶ acc. to DIN EN ISO 787/18, JIS K 5101/22

⁷ based on dried substance (2 hours at 105 °C)

⁸ based on ignited substance (2 hours at 1000 °C)

⁹ special moisture-protective packaging

¹⁰ in water: methanol = 1:1

¹¹ HCl-content is a part of ignition loss

¹² packaging of densified material: 20 kg

The data have no binding force.

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- 9 Technical Bulletin 11,
Basic Characteristics of AEROSIL®

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