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## **The importance of temperature index and the relation to thermal class of materials und system**

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## **BecFluid 9902 - a new ester based insulating liquid**

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# Safety and Environmental Aspects in the Use of Impregnating Materials

By Majdi Al-Masri, Günter Hegemann

## Introduction:

The secondary insulation of electrical devices, such as motors and transformers, is important for several reasons, for example, the mechanical stability, the electrical insulation and protection of coil winding against dust, moisture and chemicals. Thereby, leakage currents or short circuits can be avoided so that safe and reliable electrical products can be produced. Therefore, the manufacturer of such devices gets these materials for secondary insulation (SI) and has to apply and transform them by means of a chemical curing process, in the course of which liquid materials become solid thermoset. The varnish or resin, which is provided for this purpose, is a more or less highly reactive material. It is unstable and tends to transform into a stable state. This transformation can happen spontaneously and violently. Such impregnating materials may be solvents containing varnishes or resins containing less solvents.

Besides the risks resulting from the spontaneous reaction, the materials themselves have a certain risk potential. These are to be found in the material safety data sheets (MSDS). The purpose of this paper is to show where the risks are and how can they be minimized.

## Risks:

There are two conventional classes of SI materials curable to form thermosets.

**Varnishes:** They contain polymers which are usually free of danger materials that are dissolved in a solvent. Solvents are usually the dangerous components of varnishes.

**Resins:** They are 100% systems by definition, despite containing some solvents. Resins are very often used for SI made of unsaturated polyester. They consist of a solution of polymeric unsaturated polyester and a co-monomer, which is the component that determines the hazardous potential. Other resins are epoxy resins and polyurethane resins and the corresponding curing compounds which frequently have to be declared as dangerous materials.

In addition, inert fillers resins may contain further substances like catalysts, hardeners, accelerators, inhibitors, stabilizers and additives for different effects. All these materials may also be classified as dangerous materials. Relevant information can usually be found in the MSDS.

Depending on current condition of SI materials, there may be different kinds of risks.

## Manufacturing:

Risks during the manufacturing of such materials are not subject of this paper because they are to be avoided in the chemical plant and the respective manufacturer is responsible for the elimination of these risks. Also, the chemicals manufacturer is obliged to provide information on any known and expected risks related to the materials and how can they be avoided.

As mentioned above, risks and hazards can differ according to the conditions under which the materials are and the way they are stored and applied.

## Transportation:

After the manufacturing process, the product has to be transported to the customer. This is mostly be done by train and lorry. In this case, the main danger arises from collision produced from traffic accidents in which the liquid insulating materials are set free as a result of container damages.

As most liquid insulating materials have a flash point, there is a great risk for a fire and even explosion. In addition, there is a health risk to people trying to aid, for instance, members of the fire brigades. And there are great risks to the environment, especially to surface water and its inhabitants (micro organisms and fish), and to ground water, especially when used as water supply for people.

There are lots of governmental rules, regulations and laws dealing with the transportation of dangerous goods. They start with the type of containers; the accompanying documents and the labelling of containers and the lorry; the construction and supervision of the technical state of the lorry and its special equipment; the special training of drivers and the supervision of driving times by means of special registered equipment; and they reach as far as to rules guiding the route and traffic hours, such as the avoidance of tunnels, which are not allowed to be passed during peak traffic hours. During bad weather conditions, the transportation of dangerous goods may even be forbidden. There are also regulatory rules on which substances are not allowed to be transported in the same lorry, because they may react in case of an accident. All these regulations serve to avoid accidents and to minimize the consequences if an accident happens in spite of all precautions.

But potential accidents happen not only on the road. There is another source of danger: This is the untimely start of the gelling and curing of the transported material. Under warm weather conditions and in warm regions in general, the tem-

perature in the loading space of a lorry may easily reach 50 to 60°C. The storage time at such a temperature may be quite short, and if the transport takes too long, the curing reaction may start spontaneously even without the addition of a hardener. This is very dangerous because such reactions are producing large amounts of heat. They result in a rise of pressure and then a bursting of the containers. The fumes set free due to a high temperature may be toxic and may be ignited. In addition, other containers would be heated by this fire and may burst. Therefore, some products have to be transported in refrigerated lorries, or alternatively, transportation has to be arranged during the night.

#### **Storage:**

When the material has reached its destination, it usually has to be stored. Also, the untimely start of the gelling and curing process in the containers is a major problem at this stage. This is for the same reasons as the reaction that may occur in the course of transportation. Therefore, storage should take place in a cool place, away from other inflammable substances. The storage time that is guaranteed by the manufacturer can be extended by cool storage. Reducing the environment temperature of the SI materials during the storage by 10°C, can double their specified defensibility time.

Attention should always be paid to the guaranteed storage time, because the probability for an untimely curing is growing from day to day after its expiry. Therefore, materials with expired guaranteed storage time should be removed from the storing place and discarded. Otherwise, there is a danger that the scenario described above for transportation is growing, with much heavier consequences for the whole factory. Therefore, the rule "first in – first out" should be followed consequently.

As most SI materials are more or less flammable in liquid state, the dangers of an external fire are increased when these materials are involved. Therefore, they should be stored in a place that is out of reach of an accidental fire in the area. This also helps avoid the spread of a fire that is started in the resins store.

#### **Application:**

The untimely curing reaction is also a risk in the application stage, though for different reasons. One reason is that the turnover of the impregnating bath is too low so that the gel-time may have become so short that the pot life at ambient temperature is so short that the whole resin will start to gel.

The reasons for the lowering of gel-time may be that the content of inhibitors and stabilizers are greatly reduced due to the fact that the content of the bath is too old. Another reason for untimely curing may be catalytic effects of substances brought into the bath unwillingly, for instance, bare copper and copper alloys like bronze and brass, especially in the form of fine chips with fresh surfaces. Also, iron oxide in the form of rust is able to accelerate gelling of an activated unsaturated polyester resin.

The risk of gelling of an impregnation bath can be overcome by regularly testing the gel-time of resin. There should be a plan on how to stabilize the bath content by the addition of an inhibitor, without making the resin unusable. The manufacturers of the resins can establish such plans and supply the user with the necessary inhibitor.

In the application stage, the fire risk comes from possible external ignition sources. As the impregnating materials mostly have a flash point, it is necessary to draw off the vapours of solvents or co-monomers so that the lower explosion limit is not reached in the surrounding of the impregnating equipment. Also, all electrical devices of the impregnating equipment itself and in the surrounding should be selected to meet the requirements of the Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations.

Another source for sparks, which could ignite the fumes of an impregnating material, is static electricity. The source for such sparks can be unexpected, for instance, insulating rubber soles of shoes, but also static electricity generated when refilling the bath with the resin.

Special attention has to be paid to the curing oven. The solvent of the impregnating varnish or parts of the co-monomers of unsaturated polyester resins are driven off. Also, here it is important to keep the concentration of the fumes under the lower explosion limit to prevent an explosion of the oven. This can be achieved by continuous exchange of the heated air so that the critical concentration of flammable substances cannot be reached.

During the application of SI materials the customer has to handle the resin and also the auxiliary products, such as hardeners and accelerators. Therefore, there are also the hazards connected with these materials. When activating an unsaturated polyester resin with hardener – in most cases a peroxide – and an accelerator – in most cases a heavy metal salt – it is important never to bring these two components in contact in the concentrated form. The activation has to be done in the

right sequence: firstly by thoroughly mixing in the accelerator and then by adding the hardener. If any of these materials is spilled, it is absolutely essential to follow the instructions given in the MSDS for the uptake and disposal of the spilled materials.

There is also a risk of fire when an air-drying varnish is used for impregnation. If a cloth is contaminated with such a material, this may auto-ignite by the oxidative drying of the varnish which is an exothermic reaction setting free enough energy to ignite the rag. Until final disposal, it has to be kept away from air either in a well-closed container or even under water.

#### **Health risks:**

When handling varnishes or resins and their auxiliary components, there may also be a health risk from the direct contact with these substances. They are also described in the MSDS. The substances can be absorbed by the skin without harming them, whilst they may damage the skin. There may be direct toxic effects or toxic effects after accumulation by long term contact. The uptake may happen by inhalation or by direct swallowing. The first case may happen when smoking a cigarette that is held by contaminated fingers, the latter by eating or drinking in the place where these substances are handled and used. One of the most important things in this respect is never to fill such materials in bottles or containers that are normally used for beverages. And each container, cask or bottle has to be immediately labelled correctly. Interchanging such substances can have catastrophic consequences.

One health risk caused by many substances – well known for this are epoxy resins – is sensitisation and allergization. Therefore, the direct contact with such substances has to be avoided.

#### **Risk for environment:**

The risk of contaminating the environment does not only exist during transportation and storage but also during the handling process.

This could occur by means of spilling the products. This could lead to both the contamination of the soil and ground water. In this respect, the water-borne varnishes have to be handled with special care. They can easily penetrate the soil until they reach the ground water because they are soluble in water. From there, they may be transported over long distances. Rain helps to wash the material into the ground water, but also into surface water, such as rivers and lakes. It is of great importance whether they have toxic effects on the organisms

in the water or whether they are biologically degradable.

Another contamination concerns the atmosphere. Varnishes contain about 50 % of volatile organic substances (VOCs). These VOC's are usually flammable and toxic compounds. The worldwide consumption of varnishes for secondary electrical insulation is about 40 000 to/year. That means that 20 000 tonnes of VOCs are set free during the impregnating process. Unsaturated polyester resins, which have to be heated during the heating process, emit about 20 % of co-monomer by means of evaporation. By an annual use of 20 000 to worldwide for electrical insulating purposes 4000 to of VOCs are set free per year. In total, there is a potential of 24000 tonnes of VOCs worldwide per year. To avoid the contamination of the atmosphere with these VOCs, the emissions generated during the impregnating process have to be decontaminated, either by thermal or by catalytic oxidation to carbon dioxide and water.

#### **Future possibilities to reduce risks:**

There are possibilities to reduce the risks connected with the impregnation of electrical machines to form a SI. Some SI manufacturer developed successfully unsaturated polyesters, which do not need co-monomers for the formation of thermosets. These monomer-free (MF) unsaturated polyesters are low viscous polymers without any monomers or VOCs. They are declared as non-hazardous materials with extensive consequences. There are no transportation and storage problems. There is no fire hazard because they do not have a flash point lower than the decomposition temperature. Therefore, there is no explosion limit to be considered. Due to the special curing mechanism there is practically no risk of untimely gelling and curing even at temperatures up to 50 and 60°C. And there are no significant health risks in handling these resins in the right way.

Nevertheless, in the MSDS there are instructions that spilling has to be avoided. The reason is that in Europe, every spilling of any liquid chemicals necessitates the exchange of soil as a consequence. And in handling this replacement, it is necessary to use the same things like gloves and safety goggles as it is the case when handling any other chemical material.

During the curing process, between 1 % and 5 % of these resins are set free as fumes. These fumes are VOCs. They result from the fact that every organic material is decomposed to a certain extent when heated especially if it contains oxygen donor component like peroxide. The amount and composition of these fumes depends on the curing conditions

and the construction of the electrical machine. For standard conditions the composition of these fumes is well known.

**Conclusion:**

The listing of risks and hazards in the use of secondary insulating materials might give rise to the impression that their use is very dangerous. When safety instructions outlined in the MSDS as well as regulations and laws are disregarded, this impression may be true. Nevertheless, the manufacturers of varnishes and resins are working hard to reduce such hazards. Known risks can be avoided. To improve safety, resin manufacturers are looking for new possibilities to reduce the risk potential in materials that are used today and they are different in the capability of achieving this aim.

# The importance of temperature index and the relation to thermal class of materials und system

By Gunther Baumgarten

## 1 Temperature index (TI)

In data sheets of electro insulation materials you will find many interesting figures. One of these is the temperature index. The temperature index is given as a figure without any unit and very often without any further explanation. The intention of this paper is to discuss the kinds of temperature index and the relation to thermal classes of materials and systems.

### 1.1 Theory

To understand the theory of temperature index (TI) some assumptions have to be made prior to further discussions:

- The decomposition of the electrical insulation is the limiting factor of the lifetime of the electrical equipment.
- The decomposition is following the kinetic rules of a chemical reaction.
- Nearly all decomposition reactions of electrical insulating materials are following a chemical reaction first order or pseudo first order.

All reactions first order will give a straight line in a log-time – reciprocal absolute temperature – graph.

This allows us to make forecasts to the behaviour of a material due to temperature and time.

### 1.2 Characteristics of influence to a TI

The general problem is to determine the reaction velocity of the decomposition reaction. In most cases it is impossible to determine concentrations of components. To solve this problem defined test method and defined endpoint criteria are used.

Several temperature-time data are ob-

tained und put into a log-time – reciprocal absolute temperature – graph. A regression line is calculated and the line is extrapolated to a defined time.

#### 1.2.1 Test method

The test method has to reflect the main stress of an insulating material during its lifetime. The common main stresses are voltage stress or mechanical stress.

Example: intended use: wire enamel - test method: proof voltage

#### 1.2.2 Endpoint criteria,

The end point criteria should reflect level of decomposition acceptable to the insulation material.

The value 50 % of the initial value is very often used, but there are also a lot of fixed values in use.

#### 1.2.3 Extrapolation time

The extrapolation time should be the intended time of use of the equipment.

Examples:

For an electrical machine industry 20.000 h is very often used, this is about two years and three month.

But there are other possibilities due to the use of the equipment:

- A coffee grinder is running about 50 h in total during a period 20 years.
- The generator of a car is used for about 3000 h during its existence. During the same period of time the starter is used for less than 50 h.
- On the other end a transformer or generator of a power plant hat to run for more than 25 years, that's about 200.000 h

### 1.3 Summary

A temperature index without any further explanations is useless.

There is not one temperature index for a material, there can be defined as much TIs as desired.

It is important to know:

- Which test method was used and does this method of test reflect the main stress.
- Is the endpoint criterion in line with the requirements of my equipment.
- How long is the active time of an equipment during its life, and is this reflected by the extrapolation time.

This can only be done by the manufacturers of the equipment, but most TIs are produced by manufacturers of the materials.

To solve this problem, IEC 60216-2 [1] is giving common accepted methods of test and endpoint criteria for materials and its intended use.

IEC 60216 is using an extrapolation time of 20.000 h if not otherwise stated.

## 2 Thermal class

The thermal class is classifying a material or system into a given temperature range. It is always linked to the intended use of a material and the main stress to a material.

### 2.1 Thermal class of a material

The thermal class of a material is equal to the numerical value of the recommended maximum continuous use in degree Celsius. The materials are classified into groups with defined temperature ranges.

## 2.2 How to get from a Temperature index to the thermal class of a material

The first item to clarify is the intended use of a material. With this knowledge it is possible to search for a common accepted method of test and end end-point criteria.

**Table 1 – Thermal classes according to IEC 60085**

Temperature	Index	Thermal Class
≥90	<105	90
≥105	<120	105
≥120	<130	120
≥130	<155	130
≥155	<180	155
≥180	<200	180
≥200	<220	200
≥220	<250	220
≥250	<275	250

If there is no common accepted method, the supplier and purchaser have to agree on a method by their best knowledge and experience.

The TI obtained after the thermal endurance experiment is classified in to one of the defined thermal classes in IEC 60085 [2].

If there are already established materials for the intended use, with field experiences, the procedure according to IEC 60216-5 [3] should be used to classify a new material in conjunction with an established one.

## 2.3 Thermal class of a system

The first item to clarify is the intended use of an insulating system. General considerations how to test a system could be tested can be taken from IEC 60505 [4]. For systems in the area of rotating machines or transformers, system tests according to IEC 61857-21 [5] can be used.

The experiment itself is constructed like a TI-experiment. Several temperature-time

data are obtained und put into a log-time – reciprocal absolute temperature – graph. A regression line is calculated. A figure accordingly to a TI is calculated and the TI is classified into one of the thermal classes.

## 2.4 Relation between thermal class of a material and a system

There is no direct relation between the class of a material and the behaviour of the material in a system.

According to IEC 60085, the class of a material is determined by thermal endurance tests following the instruction in IEC 60216 and the class of a system is determined by systems tests following the instruction in IEC 60505.

The main reasons why the thermal class of a material cannot be used for system are chemical and physical interactions between the components of a system during production and use. In practise positive and negative synergetic effects can be observed.

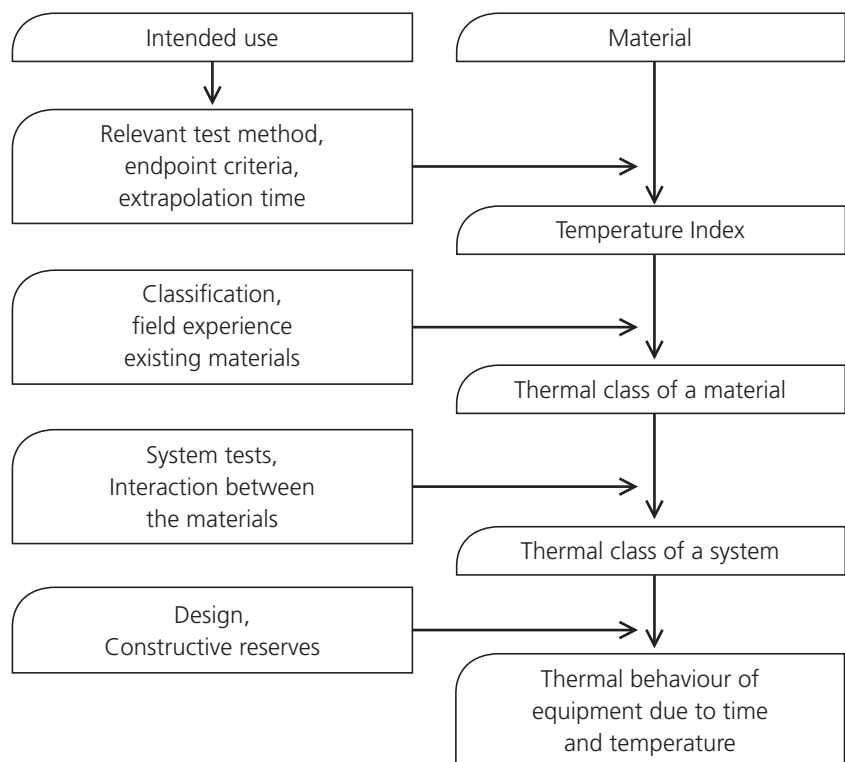
A class 155 material may fit into a class 180 systems without problems. On the other end, if materials are chosen by inexperienced designers of equipment or unknown incompatibilities are occurring, even class 200 materials may fail in a class 180 system.

### 3 Influence of the design to the lifetime of an equipment.

The last step in this discussion is the relation between established and tested systems to the real design of a equipment or machine.

The correlation between systems and real equipment is based on well-established and conservative designs. If an unusual design is used, or equipment is pushed to the technical possible borderline this correlation may become invalid. In such a case the equipment itself has to be tested.

### 4 Conclusion



## 5 References

- [1] IEC 60216-2 Electrical insulating materials - Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials - Choice of test criteria
- [2] IEC 60085 Electrical insulation - Thermal evaluation and designation
- [3] IEC 60216-5 Electrical insulating materials - Thermal endurance properties – Part 5: Determination of relative thermal endurance index (RTE) of an insulating material
- [4] IEC 60505 Evaluation and qualification of electrical insulation systems
- [5] IEC 61857-21 Electrical insulation systems - Procedures for thermal evaluation – Part 21: Specific requirements for general-purpose models - Wire-wound applications

# Advances in monomer free unsaturated polyester technology

By Michael Glomp

In meanwhile more than 10 years many experiences in the processing of monomer free unsaturated polyester resins (in the following also referred to as MF resins) were gathered. 10 years, in which new types were developed and successfully introduced into the market. At present MF resins are used in all areas of electrical devices.

It was a decade in which the comparatively young group of unsaturated polyester resins gained market maturity, a good reason for a review on the history of the MF resins and the presentation of new insights.

## 30 years ago...

It was back in 1978 when Dr. Günter Hegemann, former director of R&D for trickle and impregnating resins at Dr. Beck GmbH, started investigations on substitutes for styrene, the most common monomer in unsaturated polyester resins. He closed with the conclusion that although alternative monomers exist, eventually their advantages were eliminated by serious disadvantages. The logical consequence has been the development of a new type of unsaturated polyester resins for which no monomers were used at all. Despite this recognition it still took some years before the development finally started.

In cooperation with BASF Ludwigshafen a team of scientists started research to realize the idea of a monomer free unsaturated polyester resin. Finally, in 1996 the research came to a successful result. The first monomer free trickle and impregnation resin based on unsaturated polyester, Dobeckan® MF 8001 was introduced into the market. It met great interest at several users due to its environmental, health and safety benefits and its mild odour. Concern with respect to the resins viscosity of 30.000 mPas prevented the resins success. It was the successor product Dobeckan® MF 8001 NV, that in the end was the first triumph for the new group of unsaturated polyester resins. With this version the viscosity was reduced significantly down to 7.500 mPas and new applications were entered.

Dobeckan® MF 8001 NV was not just the first commercial success for MF resins but more important an affirmation for a whole approach and first proof that the MF technology will have a great share in the supply of electrical insulation resins. Further developments which met particular market needs followed and resulted in a comprehensive portfolio of monomer free resins.

Currently 6 groups make the MF portfolio, as shown in table 1.



Dr. Hegemann's report on the substitution of styrene was published in beck isolier technik, issue 53 from 1978

**Table 1:**

Name Dobeckan®	Description	Use
MF 8001 NV	Polyester;	Stators of motors and generators
MF 8001 UV-2	Elastic, environmentally friendly product for general purpose use	Transformer
MF 8004	Polyester-imide	Alternator
	Tough-elastic, environmentally friendly product for applications with high maximum thermal and mechanical loads	Servo motor
MF 8044	Polyester-imide	Generator
MF 8044 UV	Tough-elastic, environmentally friendly, high reactive product for applications with high maximum thermal and mechanical loads	Power tools
		Special applications
MF 8005	Polyester;	Small transformer
	Elastic, environmentally friendly product with very low viscosity, general purpose use	Universal drive
MF 8006	Polyester-imide	Generator
	Elastic, environmentally friendly, high reactive product for applications with high maximum thermal and mechanical loads	Transformer
		Special applications
MF 86..	Polyester/Polyester-imide	Drive
	Tough-elastic, environmentally friendly, product with superb thermal conductivity	Generator

### Viscosity and Penetration of MF Resins

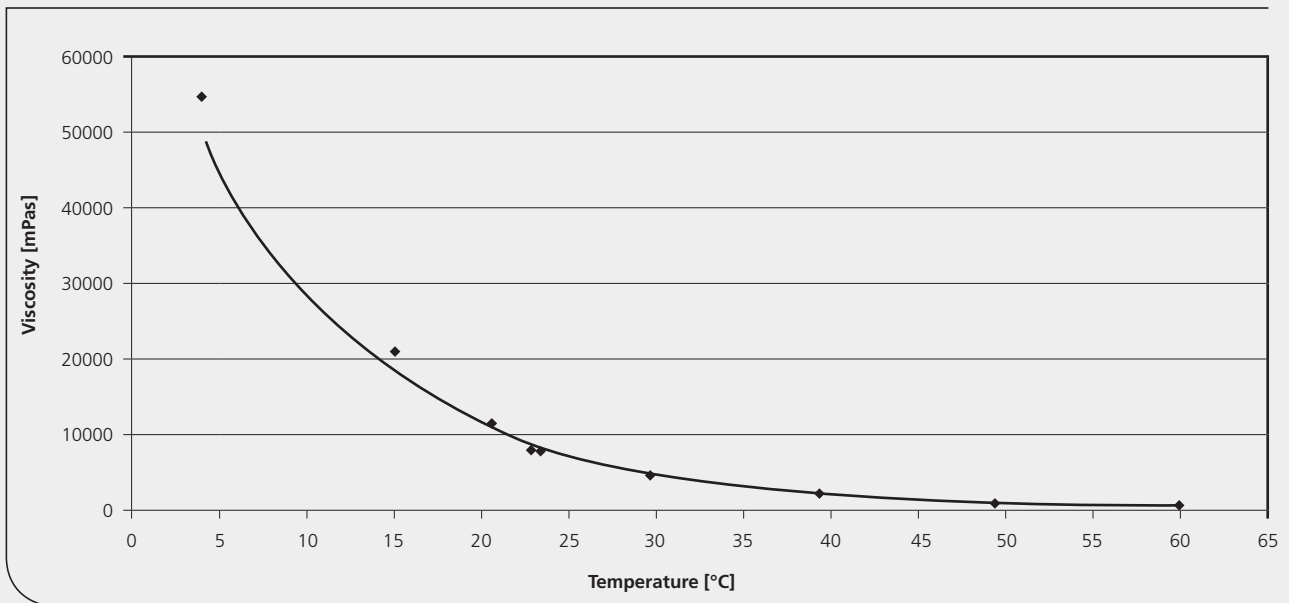
As no monomers with very low viscosity are used for MF resins, this group of electrical insulation systems is higher in viscosity than conventional resins. Very often this fact is being used as an argument against monomer free resins and equated to with bad penetration properties. At first the relation between viscosity and penetration seems logical, but certainly the penetration of a resin into a winding structure does not depend only on its viscosity. On the contrary other properties must be considered also.

As a kinetic factor, the viscosity is a measure of the resistance of a fluid to being deformed. The viscosity is equivalent to the reciprocal value of the fluidity. A higher viscosity is often

perceived as a greater thickness of a liquid, which is caused by molecular friction in movements relative to each other. This results in cohesion of the fluid and its resistance against deformation. The larger the molecules are, the higher the friction and the stronger the resistance against deformation. Hence the viscosity of the small monomers like styrene, vinyltoluene, diallylphtalate and diacrylate is low compared to the large polymers of the polyester based resin.

Molecular motion is higher at elevated temperatures. With the increased mobility of each molecular fraction the fluid viscosity drops. Illustration 1 shows the viscosity of Dobeckan® MF 8044 dependence on the temperature.

### III. 1: Viscosity-temperature-graph of Dobeckan® MF 8044



Resins are able to penetrate a winding structure as a result of two mechanisms. Initially resin flows into the structure due to the relative speed of resin and the part and the tendency of the resin to keep its energetically favourable form. In fine structures, the capillaries, the resin is also sucked upwards against gravity. The cause of this movement, known as the capillarity effect, is surface tension between fluid and solid substrate. The dependence is well expressed in the equation for the penetration height in capillaries:

$$h = \frac{2\sigma \cdot \cos\varphi}{\rho g r} \quad \{1\}$$

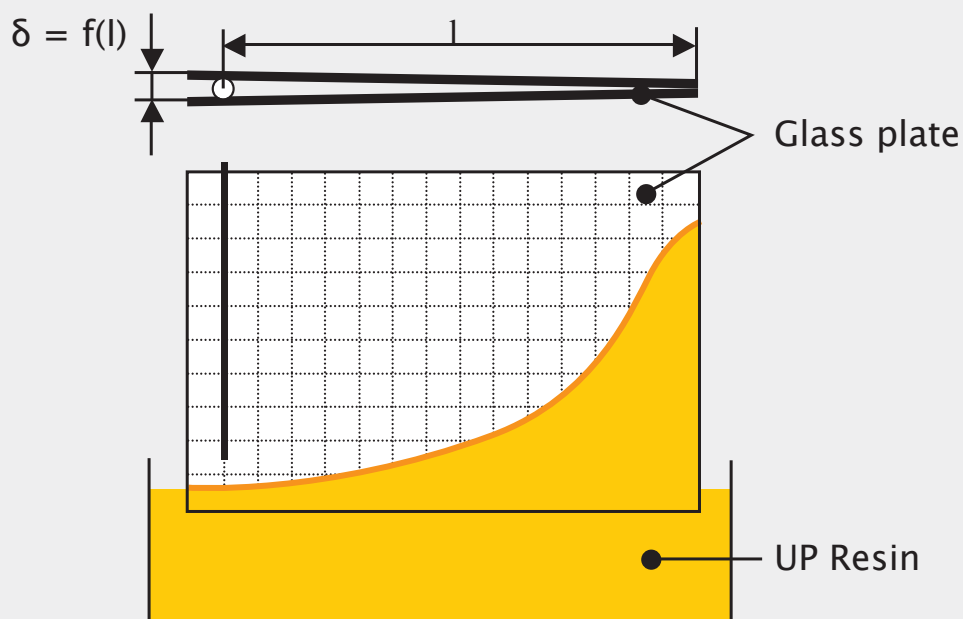
h: penetrated height  
 $\sigma$ : Surface tension  
 $\varphi$ : Contact angle

$\rho$ : Density of fluid  
g: Gravity acceleration  
R: Radius of capillary

By implication, the thermodynamic factor, surface tension and the contact angle, help to assess a resin's ability to penetrate winding structures.

Statvars used as a standard for processing tests the MF resins were found to have very good penetration. Despite the high viscosity it was seen that even small capillaries were completely filled with resin. Hence experiments in the application department laboratory of ELANTAS Beck GmbH were conducted to compare the ability of monomer-free resins and conventional resins to penetrate small structures. The confirmation of the very good penetration was gained from an easy but very demonstrative test in which two glass plates were bonded together. At the one end, a wire with 1 mm thickness was laid in between the glass plates so that a gap with the size d occurred. Depending on the distance from the wire this gap got thinner unless it was completely closed at the opposite side (see illustration 2).

### III. 2: Set up of test for demonstrating the penetration of capillaries



The plates were put into the resin at a defined depth. A grid on one of the plates was used to determine the penetrated height depending on the distance to the wire. Knowing the distance it was possible to calculate the gap length with equation 2.

$$\delta(l) = 1 \cdot \sin \frac{D}{2l} \quad \{2\}$$

- $\delta$ : Gap length
- $l$ : Distance from the wire
- $D$ : Wire diameter (reference gap length)
- $l'$ : Horizontal gap length

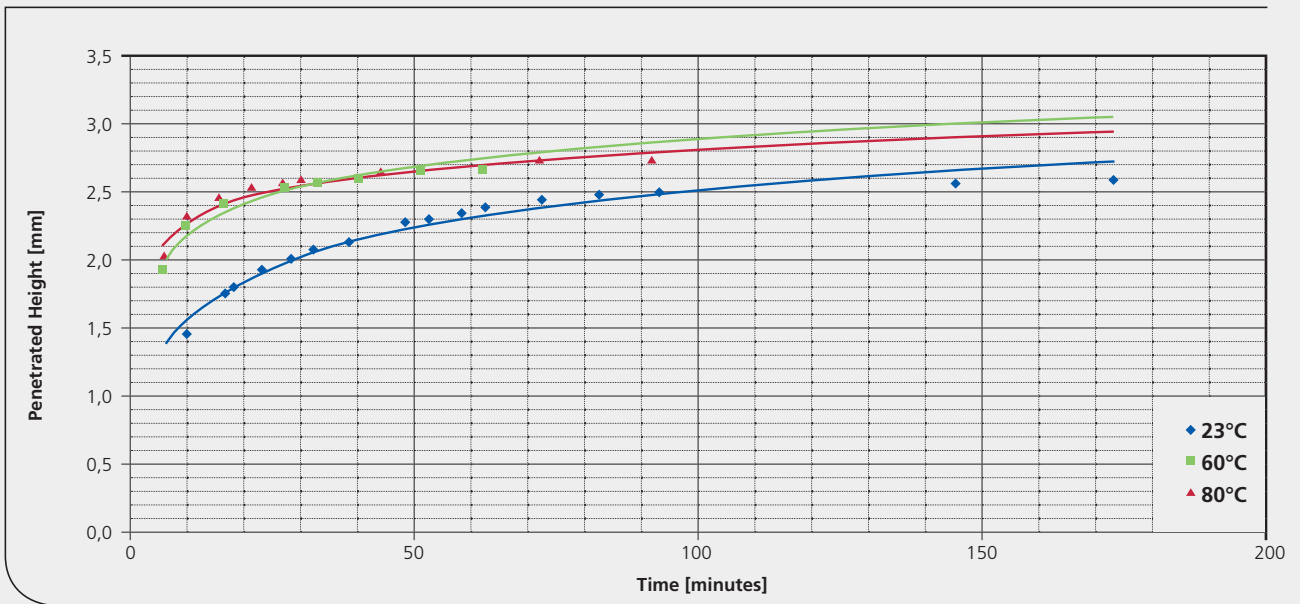
For the determination of the temperature dependence the whole set-up was put into an oven. After thermal equilibrium was achieved, the test was started by immersing the glass plates into the resin. The test results are shown in the illustrations 3 and 4.

The first picture illustrates the varying penetration at different temperatures of Dobeckan® MF 8044. It can be seen that the

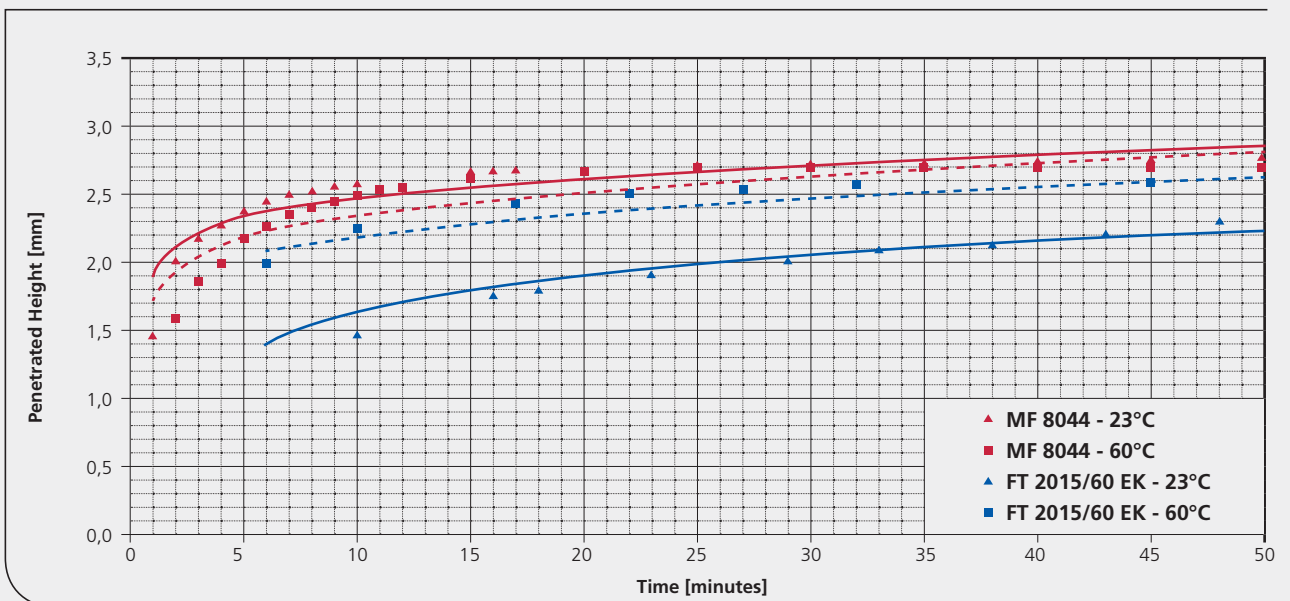
penetration is faster at higher temperatures, which is achieved by pre-heating the parts, whereas the stationary values are almost equal. Furthermore this graph shows the limit of pre-heating parts to improve the resins penetration into the winding. At temperatures above 60°C the effect is negligible. Both curves, measured at 60°C and 80°C respectively, are almost identical. Thus further pre-heating results in neither a better nor a faster penetration of the winding.

Compared to the significantly less viscous Dobeckan® FT 2015/60 EK, the findings of the first test are confirmed. The penetration of the conventional resin initially is better, it penetrates the winding faster. There is almost no difference between the penetration heights at 23°C and 60°C due to the lower surface tension of the Dobeckan® FT 2015/60 EK at elevated temperatures. Even though the conventional resin initially penetrates the winding structure faster, the stationary value is practically identical with a warmed MF resin at 60°C. Though the viscosity of Dobeckan® MF 8044 is higher at 60°C compared to the conventional resins viscosity at room temperature 23°C, 435 mPas instead of 250 mPas, the behaviour is equal due to the better surface tension and the higher contact angle.

III. 3: Penetration height into a slot of 1/55 mm Dobeckan® MF 8044 at different temperatures



III. 4: Penetration height into a slot of 1/55 mm Dobeckan® MF 8044 and Dobeckan® FT 2015/60 EK



The tests proved that an estimation of a resin's penetration capabilities based only on the viscosity is not acceptable. Almost identical penetrated heights were achieved in capillaries despite the significantly higher viscosity of monomer free resins in some of the tests. This effect can be explained with a higher surface tension and contact angle, compared to unsaturated polyester resins based on monomers.

### Increase of Impregnation Efficiency

The above remarks implies that pre-heating parts above 60°C doesn't seem sensible when processing monomer free unsaturated polyester resins. However, processing recommendations for MF resins suggest even higher temperatures, up to 135°C depending on the parts size and construction. This is due to the fact that higher pre-heating temperatures enable an optimized process with respect to winding fill factors, resin consumption and used energy.

The application of conventional, monomer containing resins usually do without pre-heating of the parts. This is prevented by the high volatility of common monomers and concerns with respect to the tank stability. When hot parts are dipped, large amounts of monomers are lost by evaporation. This loss must be compensated by adding monomer to the tank to avoid unacceptable increases of the resin viscosity, hence altering processing conditions with varying impregnation results. A regular tank test is required. Furthermore many conventional systems tend to have continuous polymerization ones the reaction has started. At the very beginning the reaction rate is small, but it increases continually afterwards. Gelling of the resin in the tank is imminent. The monomer free unsaturated polyester resins Dobeckan® MF offer superb tank stability. In practice damage of the resins should not be expected even when parts with high pre-heat temperatures are processed. This fact actually makes a hot-dip process possible and enables the gelling of the resin inside dipped parts.

A pre-heat of the part is advantageous in many ways. Due to the higher starting temperature less time is required to cure the parts in the oven. Even though the parts are chilled while dipped in the resin, the temperature is still higher compared to the impregnation at room temperature. The gelling is faster and higher winding fill factors with less secondary drainage are achieved. Of even higher importance is the possibility to gel the resin while the part remains dipped. This process builds cross links between the polyester polymers. With ongoing

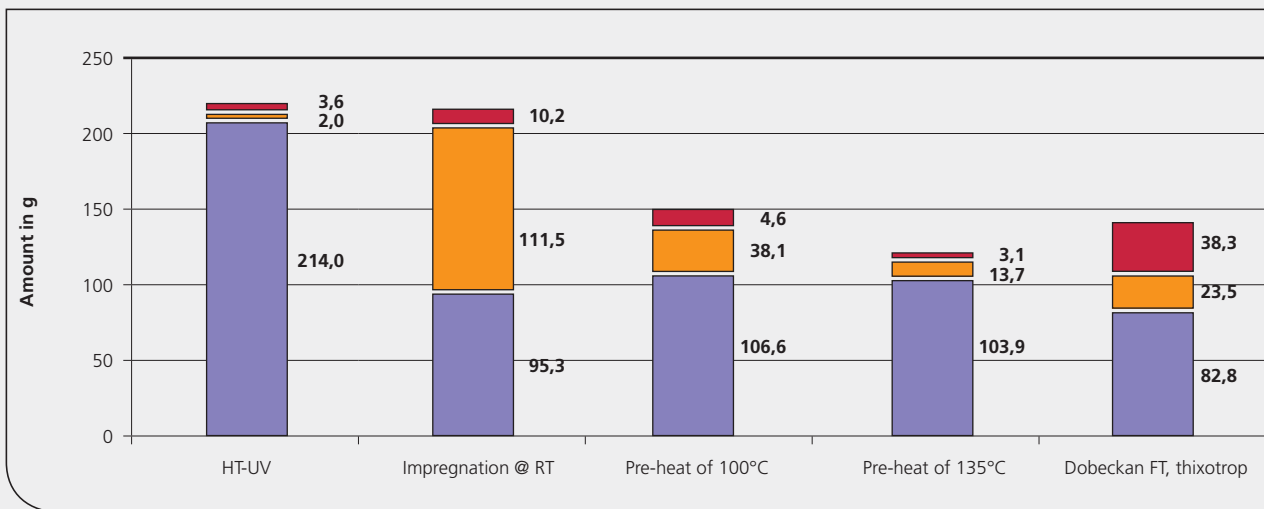
gelling even more molecules are linked together and even larger particles are formed, which can be observed in the increasing viscosity of a gelling resin. The fluidity of the resin decreases continually and associated with the decrease of fluidity the secondary drainage in the curing oven is reduced as well. The resin that does not drains off the part remains in the winding and helps to increase the impregnation quality and the properties of the parts also.

Pre-heating the parts and keeping their higher temperature to gel the resin during the immersion can be considered as the optimal process. The filling of the winding can be controlled by simple variation of dipping time or dipping temperature and the results achievable are comparable to a roll dip process.

Investigations were made in the laboratories of ELANTAS Beck GmbH to determine the impregnation efficiency of different processing. The following illustration 5 breaks down the resin consumption into three segments: the evaporation losses, the secondary drainage and the remaining resin in the winding after cure. All results are based on tests with a 4 pole stator for standard use in size 90. Resins used were Dobeckan® MF 8044 as well as the thixotropic Dobeckan® FT 1052/60 EK, optimised against drainage.

As the first column shows the hot-dip with gelling of resin during dip (HT-UV) is able to fill the winding completely in an electrical machine. A fully filled winding guarantees significantly better thermal conductivity due to the avoidance of trapped air. A customer proved the advanced thermal conductivity in a load test, where pump stators were impregnated by trickling with a styrenated conventional resin and hot-dipping in Dobeckan® MF 8044. During the load test the temperature rise of the trickled stator went up to 125°C and that of the MF impregnated, fully filled winding went up to only 89°C even though both performed identically. In addition to better performance, highly filled windings show better thermo-mechanical properties and are less vulnerable to humidity and destruction by chemicals.

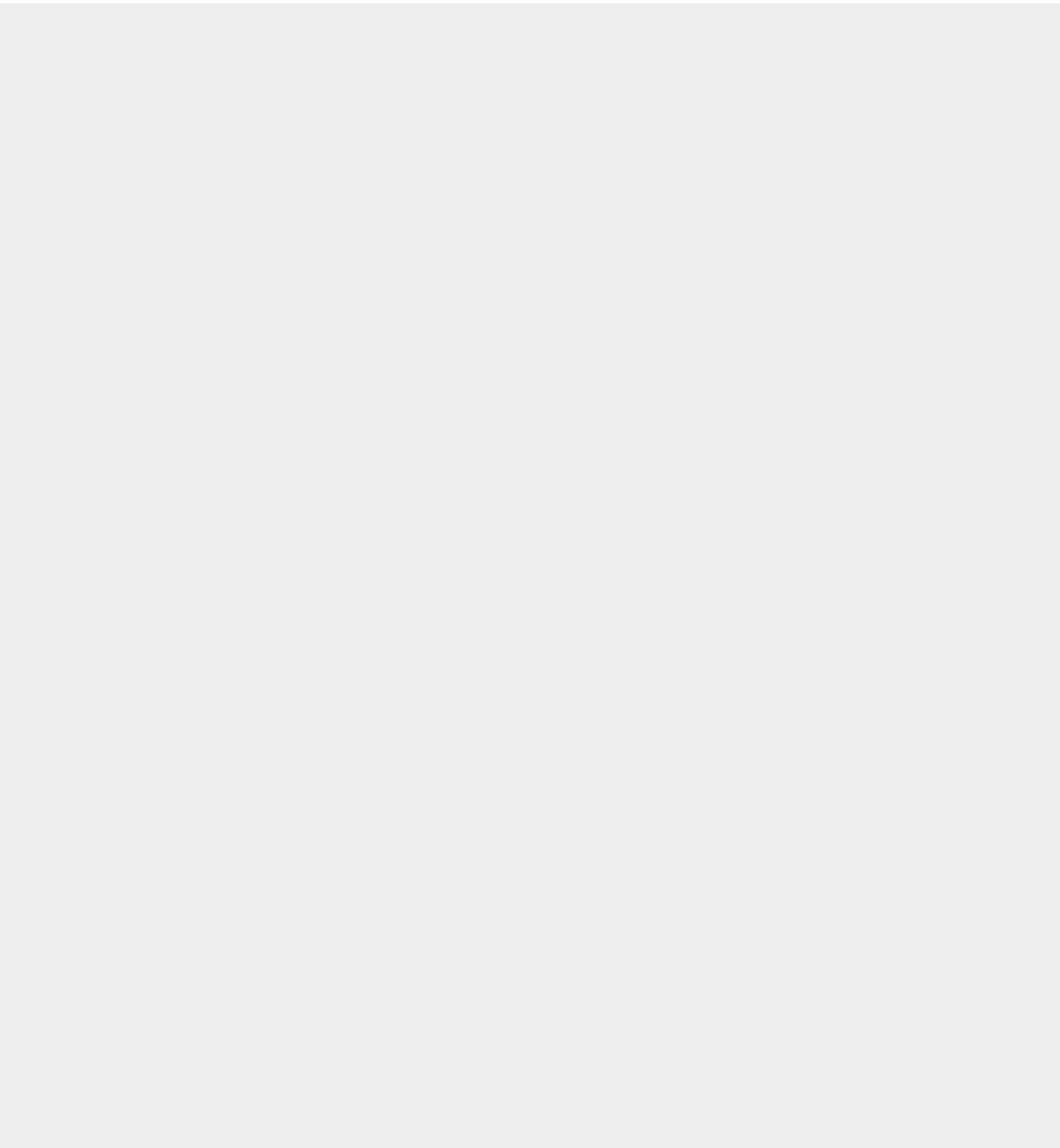
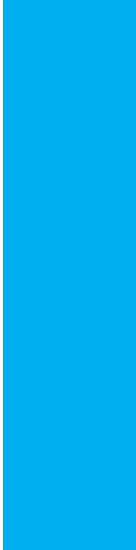
### III. 5: Impregnation efficiency of different methods and resins (Dobeckan® MF 8044 and Dobeckan® FT 1052/60 EK)



Winding fillings achievable without pre-heating are very similar to the results of the conventional impregnation. When the parts are moved into the oven, the resin reduces viscosity with increasing temperature and evidently is sucked into the winding. However, the larger amount of excessive resin on the parts surface causes high secondary drainage, so that this processing is not recommended except for the low viscous Dobeckan® MF 8005.

A reduction of secondary drainage is already being achieved at dip temperatures of 100°C for small parts, as shown in the third column and even lower temperatures for larger parts. The improved penetration combined with a faster gelling in the oven reduces the total losses to a smaller extent compared to drainage optimized conventional resins. Nevertheless, the winding is more completely filled and better properties of the device are achieved.

A further optimization is possible even with small sized parts as long as they are pre-heated to higher temperatures. In tests a pre-heat of 135°C was investigated. With such a treatment before impregnation the total consumption can be reduced to values below the consumption of thixotropic impregnating resins with monomers and coincidentally the filling can be increased. Lower evaporation losses and even significantly lower secondary drainage make this process more efficient without fearing that the resin is damaged.



# BecFluid 9902 - a new ester based insulating liquid

By Thomas Jonat

## Introduction:

Electrical transformers are enabling cost efficient transportation and distribution of electrical energy over long distances. The inherent electrical energy losses throughout transformation process lead to heating up the iron core and the copper windings. To manage this thermal energy and to improve overall electric properties most of the transformers are still filled with mineral oil. During a long period there were a lot of substantial improvements made, but the chemical basis could not be changed. Aside the insulating and heat managing base properties of mineral oil are still the same, and can be described in the following sentences:

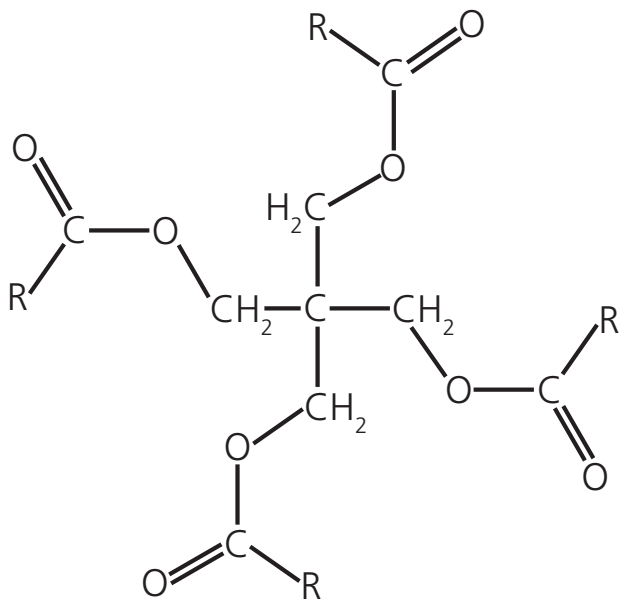
Mineral oil is toxic to living organisms and nearly not biodegradable in the environment. These facts cause a lot of additional costs in case of unexpected escape of the mineral oil into the environment and immense collateral damage to organisms.

In case of fire caused through an internal electrical failure by a shortcut or external fire the mineral oil burns heavily what makes fire fighting very difficult and dangerous and the following damages are immense.

Between these dramatic behaviour in case of faults there are other disadvantages known like corrosive sulphur, sludge formation and water insolubility.

In regard to these facts there are environmental regulations not only in protected regions which indicates to take a look at alternative insulating and cooling liquids.

## BecFluid 9902 – a “new” cooling and insulating fluid



The first substitution used for mineral oil appeared in the 1930s with the introduction of chlorinated aromatic hydrocarbons such as polychlorinated biphenyls (PCB, Ascarel). These liquids were banned because in the case of fire there can highly poisoning dioxins and furans occur and escape to environmental, first most severe registered accident in Seveso, Italy. As an alternative to the PCBs there were developed silicones in the 1970s, followed in the 1980s by synthetic fluids such as polyalphaolefins (PAO) and polyolesters (POE)

offering a very high flash and fire points with less risks of environmental pollution.

The BecFluid 9902 is a polyolester based on pentaerythritol formulated for use in distribution, power and traction transformers and for hybrid technology. Its unique environmental, fire safety, chemical and electrical properties are advantageous versus conventional mineral oils. These excellent properties are well known since 30 years.

## Performance

### a) Fire Safety

The flashpoint is defined as the temperature where you can ignite the equilibrium vapour over a chemical substance from outside by e.g. open fire, electric arc, etc. At the fire point the vapour pressure of a substance and the generated initial energy is on a level where it is high enough for continuous burning.

In comparison to mineral oil BecFluid 9902 has a very high flash and fire point

	Unit	BecFluid® 9902	Mineral oil
Flash point	°C	274	160
Fire point	°C	303	170
Specific heat	J / kg · K	1816	1860
Heat of combustion	kJ / g	36,8	46,0

and is defined as a K-class fluid for use in transformers. Clearly the high fire point of the synthetic ester is the main reason for its resistance to ignition. Further results of ignition tests of mineral oil and synthetic esters have shown that the ester fluids have slower heating rate, another important factor. The low heating rate of BecFluid 9902 is due to the high specific heat and thermal conductivity of the fluid. During the exposition to the torch mineral oil is blackening after a short time. This indicates thermal decomposition with hard to define cleavage products. Synthetic Ester is after much longer exposure only slightly darkened showing that only minimal decomposition had occurred.

One of the most important aspects of the fire behaviour of a material is its tendency to produce smoke and toxic fumes, both of which can seriously hinder the escape of personnel to safety from a fire. In this respect transformer fluids based on PCB's displayed the worst possible characteristics. They are producing dense black smoke containing large amounts of corrosive and acidic hydrogen chloride (HCl) gas together with smaller quantities of highly toxic dioxins and furans. Fire tests with synthetic esters have shown that BecFluid 9902 would not contribute fumes any more hazardous than those already present in a fire, and that smoke emission would be minimal, much lower than that from mineral oil and askarels. The gases produced through a fire with synthetic ester liquids are comparable to wood fumes. Since BecFluid does not contain chlorine it cannot evolve dangerous hydrogen chloride gas or dioxins.

Synthetic Esters like BecFluid 9902 has been tested and approved by insurers and fire authorities for use in transformers located inside buildings and other critical areas without the need for special fire precautions.

#### b) Environmental & Health

In times of increased pressure on the environment it is in our responsibility to choose the most environmentally friendly materials available. BecFluid 9902 is a far better option than both mineral oil and silicone oil with regard to environmental protection.

BecFluid 9902 can be classified as readily biodegradable after OECD 301 test method. It satisfies the dual criteria of 60 % biodegradation occurring within 10 days of exceeding 10 % degradation, and at least 60 % degradation occurring by

day 28 of the test. In fact in the tests 99 % degradation had occurred after day 28.

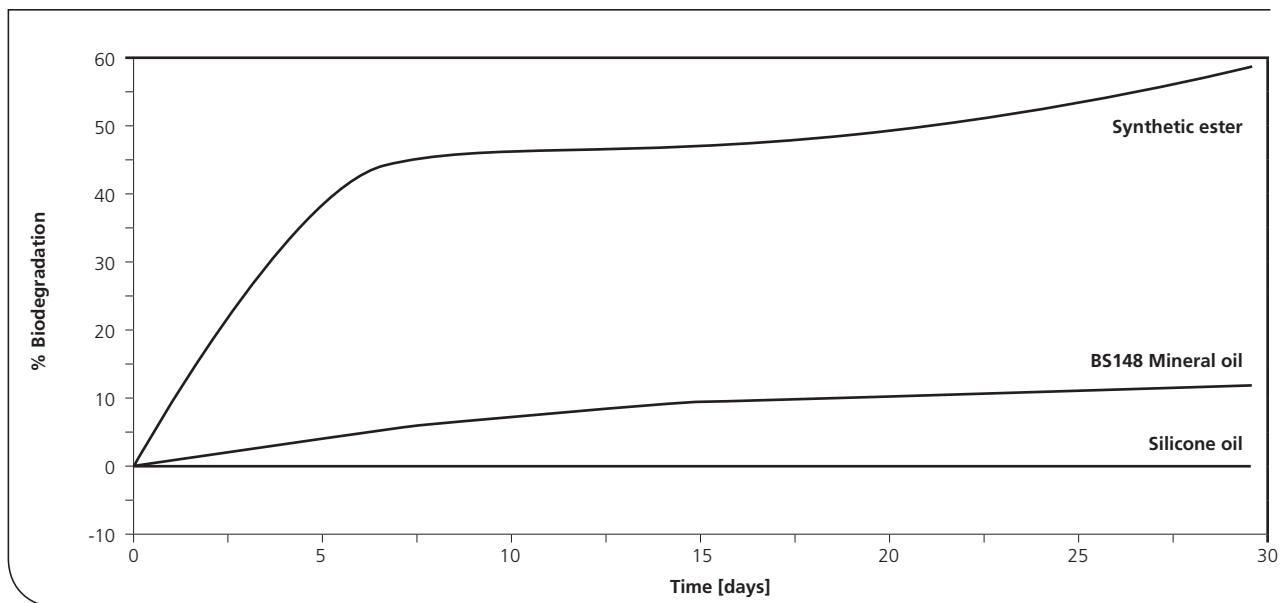
Not only is it important for a transformer fluid to be biodegradable, but it should not represent a hazard to the ecosystem in the short time it remains in the environment. In acute fish toxicity studies synthetic esters showed no mortality or other toxic effects to Rainbow trout and water fleas. In these tests were values measured, which would represent extremely high concentrations of fluid in watercourses and there is no acute risk to aquatic communities by BecFluid 9902 in the unlikely event of a spillage. Furthermore, a sustained gradual release of fluid from a leaking transformer is unlikely to result in concentrations of BecFluid in the water sufficient to create any problems to the aquatic life.

Biological sewage treatment plants use 'activated' or microbially active sludge to break down organic matter within sewage. Contaminating chemicals can destroy these microorganisms and a total cessation of the sewage treatment process may result. This is a very costly and time consuming problem for the sewage treatment industry and water companies act very stringently to avoid such contamination problems by imposing regulations, issuing prosecutions and ultimately fining guilty parties who are proved to be at fault. Mineral oils can reduce the degradation activity in biological treatment plants by destroying the microorganisms or by forming an oil film over them, thus preventing oxygen exchange and hence stopping the sewage breakdown process.

The activity of microbes in activated sludge is measured by their rate of respiration. Hence the behaviour of any potential microbe destroying contaminants can be measured by how the process of respiration is inhibited. In tests carried out by BASF in Germany, synthetic ester showed no effect on the respiratory inhibition of activated sludge up to concentrations of approximately 2000mg/l.

Such high concentrations of BecFluid 9902 are highly unlikely to occur in water or sewage systems and it can be concluded that synthetic esters does not represent a risk to biological treatment plants.

## OECD 301D test on synthetic ester, Mineral oil and Silicone oil



Concern about the contamination of potable and ground-water supplies by industrial chemicals led to the setting up in 1976 of a specialist committee to advise the German Federal Ministry of the Interior on the handling, transport, storage and packaging of water endangering materials. The committee's task was to define the term 'water endangering materials' and to develop a procedure for the classification of such materials.

On the basis of the results of biological and ecotoxicological tests the commission maintains a register of validated water endangering materials.

BecFluid 9902 offers you a transformer fluid, which is biodegradable, non-toxic to aquatic life, will not affect the degradation activity of activated sludge in biological sewage treatment plants and has been evaluated as non-water hazardous by the German Federal Department of the Environment, Umweltbundesamt.

Where transformers are located in close proximity to rivers, canals, lakes, aquatic leisure facilities, sewage treatment works or any other sensitive environment, minimise the risk to that environment by choosing BecFluid 9902.

### c) Moisture Tolerance

The presence of moisture in a transformer deteriorates transformer insulation by decreasing both the electrical and mechanical strength.

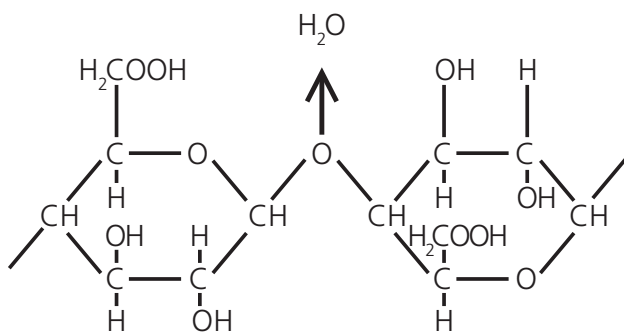
Mineral oils are non-polar substances leading to very low abilities in water uptake. BecFluid 9902 as a synthetic ester has a much higher ability to absorb water in a chemical way without compromising its dielectric properties.

In general, by doubling the water content the mechanical life of the insulation of mineral oil filled transformer is reduced by half. The rate of thermal deterioration of the insulating paper is proportional to its water content. Because of that

ester filled transformers can significantly reduce deterioration of the insulation of transformers.

Moisture inside transformers could appear from the ambient air, what could be controlled by using hermetically sealed transformers. Most of the distribution and power transformers are free breathing for cost reasons.

Water in paper may be found in four states: It may be adsorbed to surfaces, as vapour, as free water in capillaries, and as imbibed free water. Water is catalysing the ageing of cellulose and is an end product of the degradation of the cellulose:



The paper can contain much more moisture than mineral oil. The moisture content follows equilibrium curves shown in many technical publications, and depending on temperatures and local parameters.

Finally the water content is most evident for the electrical behaviour and the ageing of the insulation.

BecFluid 9902 will still be within specification up to a water content of 400 ppm in running transformers. In contrary, mineral oil will be out of specification above just 30 ppm water content. Small amounts of water in mineral oil cause a rapid deterioration in breakdown voltage. In contrary BecFluid 9902 maintains a high breakdown voltage even when moisture levels exceed 500 ppm.

Should the moisture content rise above the maximum in-service limit of BecFluid 9902, the same methods and equipment that are used for removing moisture from mineral oil can also be used e.g. molecular sieves, filtration units, etc.

## Summary

Back to the main topic, the increasing costs for electrical energy can be reduced by using BecFluid 9902 as a new ester based insulating liquid in transformers.

- The working temperature can be raised because of the high fire point.
- The electrical losses through the transportation process can be decreased.
- There is no need for special fire precautions.
- Losses of transformers and damages through fire could be minimised.
- There are no restrictions because of environmental concerns.
- The storage and use of the ester liquid is much less dangerous and complicated.
- The life-time of transformers can be increased through significant reduced aging of the insulation.
- The electrical failures because of moisture content probably occur.
- The maintenance and monitoring costs can be reduced.
- BecFluid 9902 is fully miscible with mineral oil and can be used for retrofilling.

The good experience with synthetic ester since nearly 30 years and the superb properties should conclude to use BecFluid 9902.

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