TECHNICAL BULLETIN

TEGO® Therm for Thermal Insulation Coatings

Evonik Operations GmbH I Specialty Additives
Business Line Coating Additives

Leading Beyond Chemistry

ABSTRACT

TEGO® Therm is a new product range of tailor-made grades for thermal insulation coatings (TICs) that substantially improve the performance of insulation coatings. The new product range comprises of two microporous silica-based granules, TEGO® Therm HPG 4000 and TEGO® Therm HPG 6806, as well as a waterborne, heat-resistant, polysiloxane hybrid binder, TEGO® Therm L 300. The products allow a formulator to produce insulation coatings with excellent insulation properties & heat resistance, even at temperatures of up to 250 °C. This new technology platform provides excellent performance and sustainability benefits for the use in the engineering, marine and construction sector.

Thermal insulation coatings based on TEGO® Therm products significantly reduce energy loss and contribute to occupational safety as they can significantly reduce the temperature of hot surfaces. They also provide protection against moisture penetration and therefore prevent corrosion under insulation (CUI), which can significantly increase the service life of coated items.

In contrast to conventional insulation systems, such as mineral wool, thermal insulation coatings are easy to apply on complex 3D shapes via spray application, and can also be applied during ongoing operations, giving the benefit of dramatically reducing downtime and maintenance costs.

CONTENT

1. INTRODUCTION OF THERMAL INSULATION COATINGS

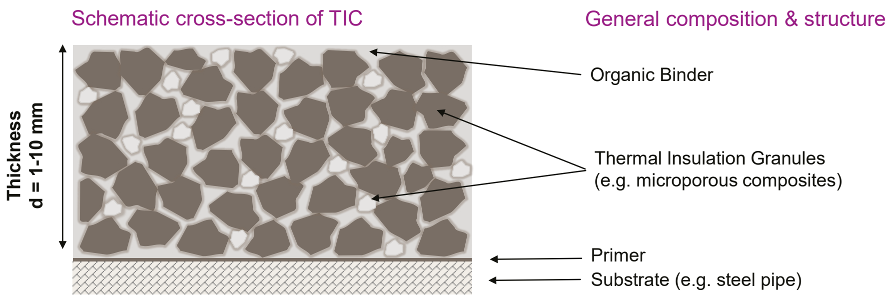
Coating industry trends have driven increased use and interest to develop more efficient and durable thermal insulative coatings. Key areas for this expansion are focusing on the reduction of corrosion under insulation (CUI), increased occupational safety and reduction of energy losses.

Conventional insulation systems, such as mineral wool, are often difficult and time-consuming to apply – appliances and components with complex geometries in particular are often inadequately insulated. Traditional mineral wool also has the disadvantage that the insulation performance is dramatically reduced in the case of moisture infiltration. Condensation of moisture could also result in corrosion under insulation (CUI) and substantially reduced infrastructure lifecycle.

Figure 1. Traditional insulation material and its drawbacks

Thermal insulation coatings have the advantage that they are easy to apply on complex 3D shapes via spray application, and can also be applied during ongoing operations, giving the benefit of dramatically reducing downtime and maintenance costs. Thermal insulation coatings also provide direct protection of the substrate and reduce the risk of condensation & CUI.

Figure 2. Schematic cross-section and general composition of a thermal insulation coating (TIC)



The new product range TEGO® Therm provides high performance insulating fillers as well as a suitable waterborne polysiloxane hybrid binder with high heat-resistance.

The two insulation granules TEGO® Therm HPG 4000 and TEGO® Therm HPG 6806 are both based on a fumed silica core and can be formulated into coatings to achieve high thermal insulative efficiency. The basis of the excellent insulation functionality in coatings is derived from the specially engineered microporous structure, optimized density combined with high hydrophobicity which allows improved filler loading levels, far above conventional fumed silica. The high thermal insulative efficiency comes from an innovative design leading to significant passivation of the three major pathways of heat transfer.

The performance of TICs is also substantially driven by the choice of the organic binder. In combination with the insulation granules the organic binder needs to facilitate high filler loads, excellent adhesion to the substrate as well as good and long-term mechanical stability within the process temperature range.

The waterborne polysiloxane hybrid binder TEGO® Therm L 300 can withstand temperatures of up to 250 °C, while standard binders for TICs can only withstand temperatures no higher than 160 °C. Given its excellent adhesion to various substrates, the polysiloxane hybrid binder ensures particularly resilient coatings. With its excellent compatibility, TEGO® Therm L 300 can also be formulated for make hybrid formulations based on standard acrylic binder technology which can extend the effective temperature range of typical acrylic based binders on the market.

2. TECHNICAL BACKGROUND

2.1 TEGO® Therm HPG based on an advanced microporous composite

Standard un-densified fumed silica, in both untreated – hydrophilic and treated – hydrophobic forms (aka pyrogenic synthetic silica) have been used in the coatings industry for decades as; efficient thixotropes, rheology enhancers, suspension stabilizers, synergistic hydrophobic fillers to enhance corrosion protection along with anti-corrosive pigments across coatings chemistries and segments. These technology offerings have typical critical use levels of 0.5 – 3.0 % by weight on total formulation. Optimization in densification and compaction technology facilitated higher loadings which were employed in industries such as silicone rubber, adhesive and sealants. These grades drive the main functionality of reinforcement, as the densified/compacted options give the nanostructured particle technology a lower thickening component. This change allows for slightly higher loading levels in use compared to the un-densified counterparts.

While effective and efficient thermal insulation (with consistent low thermal conductivity) has been a key functionality provided by fumed silica in other industries such as vacuum panels, it was not achieved in coatings, because the requirement in coatings necessitates an ultra-high loading level of >75 % by volume in the finished dried coating. The other key requirement is having an infrared (IR) radiation passivating solution, which fumed silica does not bring alone.

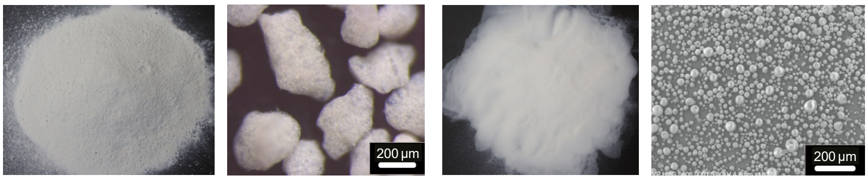
TEGO® Therm HPG 4000 & HPG 6806 are non-combustible, high-performance thermal insulation materials with their developmental roots in the construction sector. Both products are pure mineral insulation materials, based on a proprietary fumed silicon dioxide composite which does not contain fungicides, pesticides, algicides, flame retardants, or binders. This specially engineered materials have a microporous structure formulated to reach an outstanding thermal insulation value. TEGO® Therm HPG 4000 & HPG 6806 can be formulated into coatings to bring high thermal insulative efficiency.

The basis of the superior low thermal conductivity in coatings is derived from the uniquely engineered microporous structure, optimized density combined with high hydrophobicity which facilitates high filler loading levels, far above conventional fumed silica. Ultra-high loading of this mineral-based fillers with a minimized viscosity build-up allows the coating to achieve an outstanding thermal insulation value with spray quality application utility.

Figure 3a. Key physicochemical properties of TEGO® Therm HPG 4000 & HPG 6806

Microporous Composite Granules

TEGO® Therm HPG 4000	**TEGO® Therm HPG 6806**



TEGO® Therm HPG 4000

- Particle size d_{50} ~300 µm
- Superinsulation properties from passivated amorphous SiO_2 core
- High hydrophobicity
- Non-combustible / non-flammable

TEGO® Therm HPG 6806

- Particle size d_{50} ~30 µm
- Excellent insulation properties from amorphous SiO_2 core
- Low particle size for smooth coating surfaces
- Excellent dimensional stability

Figure 3b. Properties and technical information of TEGO® Therm HPG 4000

TEGO® Therm HPG 4000 –
technical data sheet

WB

Purely mineral filler based on silicone dioxide

- superinsulation properties
- high hydrophobicity
- excellent heat & mechanical stability

Typical applications

- Insulation coatings
- Ovens, furnaces, pipelines, incinerators
- Architectural paints

Suitability

waterborne

Processing instructions

Incorporate the product under low shear forces with moderate to high agitation.

Technical information

carbon content	< 2.5 % (without opacifier)
delivery form	free-flowing powder
loss on drying	< 0.5 %
particle size, d_{50}	~ 300 µm
particle size, d_{95}	< 1000 µm
pH- value	6.5 - 8.5
specific surface area (BET)	~ 115 m²/g
tamped density	~ 225 g/l
thermal conductivity at 10°C	~ 0.024 W/m/K

Figure 3c. Properties and technical information of TEGO® Therm HPG 6806

TEGO® Therm HPG 6806 –
technical data sheet

Purely mineral filler based on silicone dioxide

- excellent insulation properties
- low particle size for smooth coating surface
- less thickening and easy to incorporate in coatings

Typical applications

- Insulation coatings
- Ovens, furnaces, pipelines, incinerators
- Architectural paints

Suitability

waterborne

Processing instructions

Incorporate the product under low shear forces with moderate to high agitation.

Technical information

carbon content	~ 3.0 %
delivery form	free-flowing powder
loss on drying	< 1.0 %
particle size, d_{50}	~ 30 µm
pH- value	7.0 - 9.5
specific surface area (BET)	~ 190 m²/g
tamped density	~ 300 g/l
thermal conductivity at 10°C	~ 0.030 W/m/K

Material and morphology of any insulating filler particles will play a strategic role in its impact on the overall thermal conductivity of the coating. The microporous insulation granules provide a very low thermal conductivity due to their low density and their ability to trap air molecules and prevent its movement or restrict it with a torturous path (so-called Knudsen Effect). This provides an excellent thermal insulation property against heat transfer via conduction and convection. TEGO® Therm HPG 4000 also contains an IR opacifier that is effective in limiting heat transfer via radiation.

The new particle design of the both TEGO® Therm HPG grades offers an effective alternative to traditional mineral-wrap and foam-based insulation strategies to eliminate costly maintenance resulting from corrosion under insulation (CUI). Figure 3 a–c summarizes physicalchemical properties of TEGO® Therm HPG 4000 & TEGO® Therm HPG 6806.

TEGO® Therm HPG grades have an unique property balance of high hydrophobicity properties along with high silanol density to create a compatible filler solution well suited for water-based coating environments.

2.2 Overview of waterborne silicone binder TEGO® Therm L 300

The new TEGO® Therm L 300 is a waterborne, heat-resistant polysiloxane hybrid resin that meets all the requirements of a sustainable formulation. It is free of organic solvents and features a significantly reduced VOC content from production to application.

TEGO® Therm L 300 can withstand temperatures of up to 250 °C, while standard acrylic-based binders for TICs can only withstand temperatures no higher than 160 °C. Given its excellent adhesion to various substrates, as well as high compatibility with various binder types such as waterborne acrylics, TEGO® Therm L 300 ensures particularly resilient coatings.

Products from the TEGO® Therm line can be combined with one another and with other product lines, depending on the specific application to extend an existing formulation performance; whether to extend temperature stability – the binder may be utilized, to extend the low conductivity performance – the TEGO® Therm HPG 4000 granule may be utilized and to reduce cracking – the TEGO® Therm HPG 6806 may be utilized.

Figure 4a. Key physicochemical properties of TEGO® Therm L 300

Heat-stable Binder

TEGO® Therm L 300

- Liquid waterborne silicone hybrid binder with solid content ~ 50%
- Broad compatibility with acrylic emulsions
- Superior heat stability (up to 250°C)

Figure 4b. Properties and technical information of TEGO® Therm L 300

TEGO® Therm L 300 –
technical data sheet

WB

Silicone polyester resin, hybrid polysiloxane dispersion

- broad compatibility with acrylic emulsions
- excellent heat stability
- outstanding adhesion to various substrates

Typical applications

- Insulation coatings
- Heat-stable coatings
- Matrix for insulation particles (TIC)

Suitability

waterborne

Processing instructions

Prior to use, agitate with low shear forces.

Solubility

Water

Technical information

appearance	milky liquid
delivery form	dispersion
non-volatile content	46 - 54%
pH-value	4,5 - 7,0
viscosity at 23°C (as supplied)	50-500 mPas

Technical data sheet

Regulatory information

2.3 Basics of thermal insulation and thermal conductivity

The thermal conductivity (λ) is the property that describes the ability of a material to conduct heat. In contrast to the thermal resistance (R-value), the thermal conductivity refers to the specific property of the insulating material which does not depend on the thickness of the insulation layer.

Measuring the thermal conductivity is a commonly used technique for the characterization of the insulation performance of TICs. Since the thermal conductivity depends on the temperature, it is important to determine the λ-value for the target process temperature.

Equation a) Thermal conductivity λ and b) thermal resistance (R-value)

a) $\lambda = q \frac{d}{\Delta T}$ [mW/m K]

with d: thickness of the specimen (m); T: Temperature (K) and q: heat flow rate (W/m²)

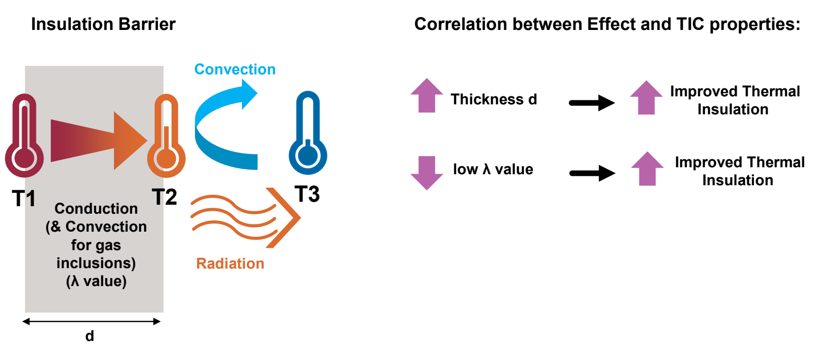
b) $R = \frac{d}{\lambda}$ [K m² /mW]

The thermal conductivity of a material or a coating mainly depend on three phenomena that are depicted in figure 5:

- **CONDUCTION:** Heat transfer between substances that are in direct contact with each other
- **CONVECTION:** Heat transfer by the movement of fluids (liquid or gases)
- **RADIATION:** Thermal energy transmitted through empty space by radiation (mainly in the infrared range)

TEGO® Therm HPG grades are designed to provide a torturous pathway for air in the same way that silica aerogels perform the same function. However, it significantly differs from silica aerogels in composition (as TEGO® Therm HPG 4000 contains an IR opacifier), particle formation, structure modification, and treatment of the final granules which addresses the three pathways of heat transfer mentioned above. TEGO® Therm 6806 is a uniquely produced spherical silica particle with high internal porosity and high hydrophobicity. Its 30-micron spherical shape is helpful as a synergist for any formulation to reduce cracking, while supporting the low conductivity performance.

Figure 5. Basics of thermal insulation



2.3.1 Equipment types to measure thermal conductivity (λ) in TICs

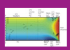
Due to the thin coating film thicknesses in centimeters or millimeters, in comparison to other insulation types, along with the low thermal conductivity values; there are several instruments available to measure thermal conductivity (λ) in coatings. Some key learnings when measuring thermal conductivity that formulators should take into consideration to minimize error and recording misleading results:

- Sample **preparation** (geometry and temperature as well as humidity conditioning). Consistent sample size, thickness and maintaining consistent – proper environmental test condition is important for accurate, consistent, and reproducible results.
- Influence of **pressure** on measurement methods between two surfaces. It's important to have good contact and often some sanding of the surface is needed for very rough or textured surfaces to maximize a firm connection having no air interface between the contact probe and the coating surface. Air gap/interface with give false results often higher thermal conductivity results.
- **Warm up of the sample** during measurement.
- Influence of **temperature difference** on measurement method, within the sample between two plates.

In coatings, often two main equipment types are used and there is a further discussion to high-light some difference between heat flow meter and guarded hot plate are noted here:

- A Heat Flow Meter has a sensor, providing an electric voltage as function of the heat flow that exists within the specimen at given surface temperatures and specimen thickness. It calculates the thermal conductivity based on an assumed linear function between the sensor signal and test temperature (mean temperature of the tool) as well as the heat flow density. The sensor signal however is not entirely a linear function of the test temperature and the heat flow density. It also depends on the thermal conductivity and specimen thickness. It is an indirect measurement method which depends heavily on the known boundary conditions and the degree of similarity of relevant properties (conductivity and thickness) between the calibration specimen and the specimen to be tested.
- A Guarded Hot Plate apparatus measures the energy that flows through the specimen at given surface temperatures on the sensor-plates with a given specimen thickness. With these values, it directly calculates the thermal conductivity and thermal resistance irrespective of material and thickness. Therefore, it does not require calibration and shows long-term reliability. It will have no errors even after years of operation. (source: Lambda Messtechnik GmbH Dresden)

Figure 6. Measurement technologies available to determine thermal conductivity λ depending on temperature

	Operation Principle	Parameter	Application
Guarded hot Plate	  $\lambda = \frac{d \cdot U \cdot I}{A \cdot \Delta T}$ U = voltage [V] I = electricity [A]	Effective range λ [mW/m·K]: 1 - 2500 Measuring time [hour]: ~ 4 - 24 Sample size min./ max. [mm x mm]: 150 x 150 x 10 / 500 x 500 x 120 Reproducibility [%]: < 0.5 (most < 0.2 %) Measurement accuracy [%]: < 1 (most < 0.7 %)	• Production quality assurance • Reference measure method • Temperature dependent therma conductivity
Heat Flow Meter	 d = thickness [m] A = area [m²] Q = heat flow [kg/m² * s³] ΔT = temperature difference [K] $\lambda = \frac{d \cdot Q}{A \cdot \Delta T}$	Effective range λ [mW/m·K]: 19 - 190 Measuring time [hour]: ~ 1.5 - 2 Sample size min./ max. [mm x mm]: 120 x 120 / 250 x 250 thickness not assigned Reproducibility [%]: < 0.5 Measurement accuracy [%]: < 4	• Production development/ screening • Max sample size needed • Temperature resistance of the sample of > 50 °C

2.4 Fabrication of Thermal Insulation Coatings

TEGO® Therm HPG 4000 & TEGO® Therm HPG 6808 granules can be incorporated into a coating to provide excellent thermal insulative performance, reduced flammability due to the non-combustible silicon dioxide composition, and improved hydrophobicity that allows open vapor diffusion while limiting water penetration and conductivity in the coating. To make the coating, it would require a suitable waterborne binder into which the insulation granules can be incorporated through mixing, then coated on a substrate through a spray applicator.

As the d_{50} of TEGO® Therm HPG 4000 is approx. 300 microns and the distribution ranges from 1–1000 microns, it is important to make sure the sample removed from a container is homogeneously distributed for consistent low thermal conductivity performance. To achieve this, it is recommended to properly rotate the sample container before taking samples for formulation. In a production environment it is recommended to use such a device as a 3 axial powder mixer like a Turbula mixer which rotates container on 3-axes. This point becomes moot if the entire container is used in the batch. It is also important to avoid putting back unused portions of samples taken out of the container.

TEGO® Therm HPG 6806 with a smaller d_{50} of approx. 30 µm does not require a homogenization step before being used.

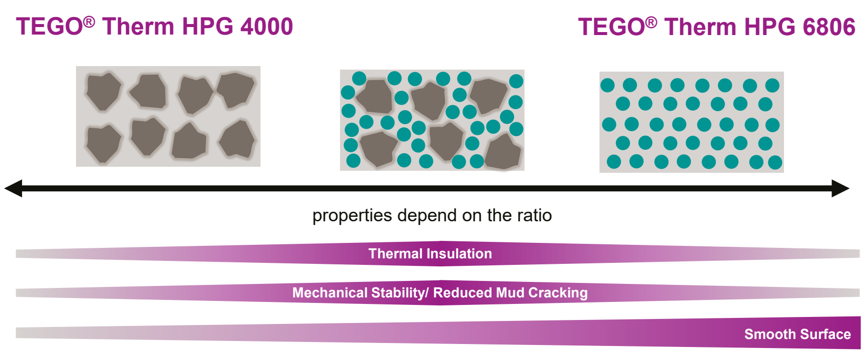
Guided formulation for the fabrication of the thermal insulation coatings based on TEGO® Therm HPG insulative granules are shown in figure 7. Depending on the heat-resistance requirements of the thermal insulation coating, recommendation of the suitable binder or blends of binders are given.

Figure 7. Guiding formulation for waterborne thermal insulation coatings

Peak temperature	150 °C	200 °C	250 °C
TYPE OF COATING	**ACRYLIC**	**ACRYLIC + SILICONE**	**SILICONE**
DRYING/CURING MECHANISM	**AMBIENT DRYING**	**AMBIENT DRYING AND CURING AT HIGHER TEMPERATURES**	
TEGO® Therm L 300	–	40	60
Acrylic Resin (e.g. MOWILITH® LDM 6119)	60	20	–
Polyvinyl alcohol sol., 20 % in demin. water (e.g. Kuraray Poval™ 3–80, 3–83, 4–88)	12	12	12
TEGO® Therm HPG 4000	15	15	15
TEGO® Therm HPG 6806	10	10	10
Viscosity Adjustment Water, demineralized	3	3	3
Total	**100**	**100**	**100**

To achieve an optimized filling load and performance properties of the TIC it is recommended to use a mixture of TEGO® Therm HPG 4000 (with coarse particles) and TEGO® Therm HPG 6806 (with finer and more spherical particles). If a smoother surface of the TIC is required, the ratio of TEGO® Therm HPG 6806 vs. TEGO® Therm HPG 4000 could be increased (see Fig. 8).

Figure 8. Properties of TIC depending on the applied ratio of TEGO® Therm HPG 4000 and TEGO® Therm HPG 6806

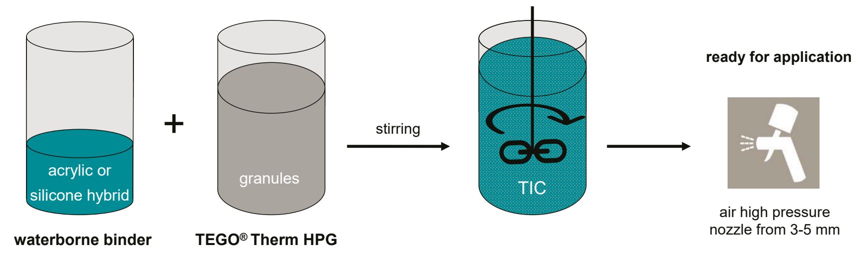


To incorporate the TEGO® Therm HPG granules into a waterborne coating; figure 9 highlights a basic incorporation/dispersion flow chart .

The mixing time for the lab formulation should be conducted with a propeller stirrer (starting from 300 rpm to no more than 2500 rpm) less than 4–5 minutes to minimize physical break-down of the insulative fillers under shear. It is vital that shear forces are minimized, which has direct relation to the thermal insulation properties of the coating. When incorporating TEGO® Therm HPG into the waterborne binder, formation of vortex in the vessel is critical to quickly incorporate insulation granules, which greatly helps minimize mixing time. It is also important not to re-introduce the unused portion back into the sample container as this can begin to change/shift the granule distribution of what is in the container. This shift over time and repeated re-introduction of unused portions of sample back into the container could result in inconsistent overall performance (stability and rheology).

TEGO® Therm HPG 4000 and/or TEGO® Therm HPG 6806 should be added to the formulation in small quantities while stirring (standard personal protection equipment for dust should be maintained). During the addition of granules, the speed of rotation must be increased continuously in small steps up to 1200 rpm. It is important to avoid excessive shear which can irreversibly destroy the particle structure. In formulating, it is important to avoid use of wetting and dispersing additives to prevent that the open porous structure of the particles is penetrated by the binder.

Figure 9. Incorporation of TEGO® Therm HPG granules in TIC formulation



COATINO® Campus Video-Link

We also maintain that there will be differences observed in the final thermal conductivity performance of the coating when applied by hand draw down and by spray, so we recommend the spray application to achieve the lowest and most consistent thermal conductivity values. The use of larger spray gun nozzle sizes (4–5 mm) are suggested. Minimum air pressure recommended for the spray gun is approx. 5 bar (80 Psi), the distance between the substrate and the nozzle is recommended to be at approx. 30–50 cm (1–1.5 ft). The TIC is thixotropic in nature, hand mixing is recommended before pouring the coating in the spray hopper. Please do not add water before adding it into the spray hopper as that may result into sagging, this is applicable, especially for vertical application.

A formulating hint when developing thermal insulation coatings, it is important to keep in mind the granules loading needs to be adjusted by the surface area, not by equal weight. When comparing the different TIC granules, formulator should balance the formulation and adjust the TIC loading by surface area and not formulate all test systems with the same loading by weight as surface areas and bulk densities are very different between thermal insulation granules.

2.5 Comparison of thermal conductivity in coatings

Figure 10a. Waterborne acrylic formulations with thermal insulation fillers

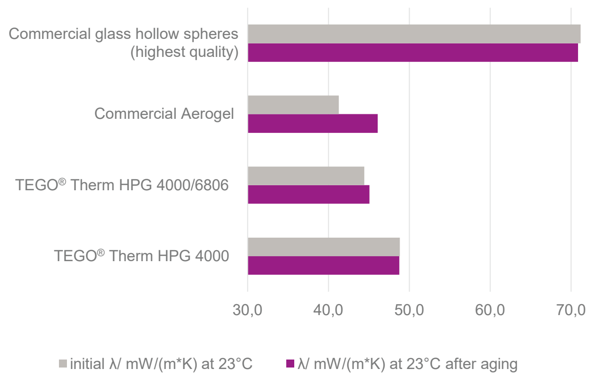
FORMULATION	1	2	3	4
Waterborne acrylic binder*	45.6 %	43.1 %	72.7 %	63.9 %
Water	**24.2 %**	**22.8 %**	**12.6 %**	**18.6 %**
Other components**	0.6 %	0.6 %	0.9 %	0.9 %
Particle stabilizer (PVOH)	**1.0 %**	**1.0 %**	**1.6 %**	**1.4 %**
TEGO® Therm HPG 4000	28.7 %	26.0 %		
TEGO® Therm HPG 6806		6.5 %		
Commercial aerogel			12.1 %	
Commercial hollow glass spheres				15.2 %
Calculated PVC	**78 v%**	**80 v%**	**72 v%**	**79 v%**

*Approx. 50 % water content in used binder systems; **rheology modifier and fibers
Note: Formulations were optimized for lambda performance

Key formulating hints in figure 10a when making TIC with TEGO® Therm HPG technology is the use of the polyvinyl alcohol, as this is very important to achieve the higher loading with the insulation granules in particular. Choice of fibers is also a critical aspect and the particular one chosen for formulations helps to reduce cracking. Increased ratio of TEGO® Therm HPG 6806 is also very effective to reduce cracking. If long term stability is required, use of select biocides may be needed in water-based coatings.

Samples were made by spray application with a standard hopper gun on a 3 mm thick aluminum substrate with a 15 cm x 15 cm surface area. Each layer of approx. 1 – 2 mm wet coating thickness has been dried after spraying under environmental conditions for approximately one day, before the next layer has been sprayed. In total 10 – 15 layers have been sprayed per sample to reach a minimal coating thickness of 1.5 cm. The complete multilayer sample has been dried in an oven at 60 °C for approximately one week with daily weight control. Only samples which did not show a change in weight between 2 measurements have been used in the lambda measurement. Thorough thru – dry is critical for consistent, accurate and reliable Lambda results. Before measurement by GHP method, the coating surface has been polished/leveled in parallel to the blank aluminum bottom side by sanding (excess material has been cut away and not polished to avoid dust penetration inside pores). It is also important to have a full – intimate contact between the measurement sensor and coating surface, with no air barriers or gaps for consistent and reliable results. Uneven or highly roughed surfaces can give false and inconsistent readings, as the air gaps can negatively influence sensor detection.

Figure 10b. Thermal conductivity in waterborne acrylic binder with various insulation fillers before and after heat ageing for 10d at 140 °C



In figure 10b, the waterborne acrylic formulation demonstrates that formulations with TEGO® Therm HPG 4000 and TEGO® Therm HPG 6806 show a good thermal insulation performance with a low increase of lambda with temperature. The combination of both grades shows a synergy effect due to higher loading levels obtainable resulting in a reduction of lambda. The formulation with the combination of both grades shows a similar performance compared to the formulation containing aerogel particles. The formulation containing hollow glass spheres shows a steep increase of lambda with increasing temperature and the highest lambda values of all tested formulations across particle choice.

After aging at 140 °C for 10 days formulations with TEGO® Therm HPG 4000, TEGO® Therm HPG 6806 and glass spheres show minor increases of approx. 1 mW/(m*K) or less over the temperature range up to 150 °C. The formulation containing aerogel increases by 4–5 mW/(m*K) over this temperature range. Measurements are made using the guarded hot plate method.

Figure 11. Images of acrylic-based TIC with varying insualtion fillers after heat aging for 10 d @ 140 °C

Figure 11 shows photos after heat aging of waterborne acrylic with insulation fillers at 140 °C for 10 days. The mechanical stability and dimensional stability performance of the aerogel formulation shows shrinkage, delamination and increase in density by 7 % compared to the other formulations.

Figure 12a. Hybrid waterborne acrylic & silicone binder formulations for higher temperature stability w/ thermal insulation fillers

FORMULATION	6	7	8	9	10
Waterborne acrylic binder*	14.0 %	12.3 %	12.0 %	20.5 %	19.1 %
TEGO® Therm L300 binder*	29.6 %	26.1 %	25.4 %	43.2 %	40.3 %
Water	**26.4 %**	**20.9 %**	**20.4 %**	**23.3 %**	**21.7 %**
Other components**	0.5 %	0.5 %	0.5 %	0.9 %	0.8 %
Particle stabilizer (PVOH)	**1.9 %**	**1.6 %**	**1.6 %**	**2.7 %**	**2.5 %**
TEGO® Therm HPG 4000	27.4 %	30.8 %			
TEGO® Therm HPG 6806		7.7 %	40.1 %		
Commercial aerogel				9.5 %	
Commercial hollow glass spheres					15.6 %
Calculated PVC	**76 v%**	**83 v%**	**80 v%**	**68 v%**	**79 v%**

*Approx. 50 % water content in used binder systems; **rheology modifier and fibers
Note: Formulations were optimized for lambda performance

Figure 12b. Thermal conductivity in waterborne silloxane hybrid binder with various insulation fillers

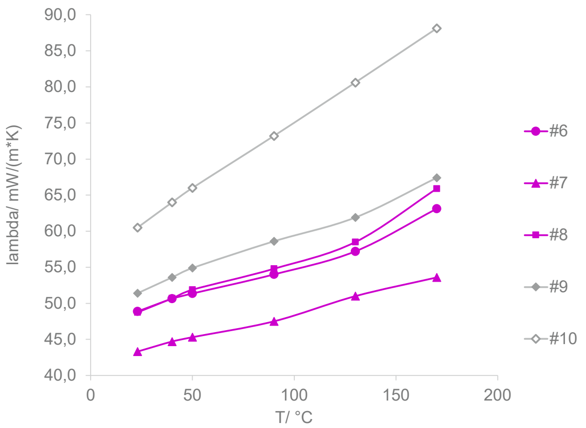


Figure 12a includes formulations in waterborne acrylic and hybrid silicone emulsion for increased temperature stability. Results in figure 12b show formulations with TEGO® Therm HPG 4000 and HPG 6806 blend demonstrate good thermal insulation performance with a low increase of lambda with temperature up to 170 °C. The combination of both TEGO® Therm HPG granules shows a synergy effect due to higher loading levels obtainable resulting in a reduction of lambda. The aerogel-based formulation has been made with a lower PVC to avoid the shrinkage observed within the waterborne acrylic binder system. The formulation containing the glass spheres show similar properties as observed within the waterborne acrylic binder formulation. Thermal conductivity measurements are made with guarded hot plate method.

3. FIELDS OF APPLICATION

3.1 Occupational safety and Safe Touch Performance

Safe Touch Performance illustrated in figure 13 & 14 is achieved with several mm of TIC (formulated with having a λ-value of ~40 mW/(m*K) and IR visualization captures reduced surface temperature of steel pipe removed from 250 °C oven without protective gloves required.

Figure 13. Safe Touch Performance visualized with IR camera

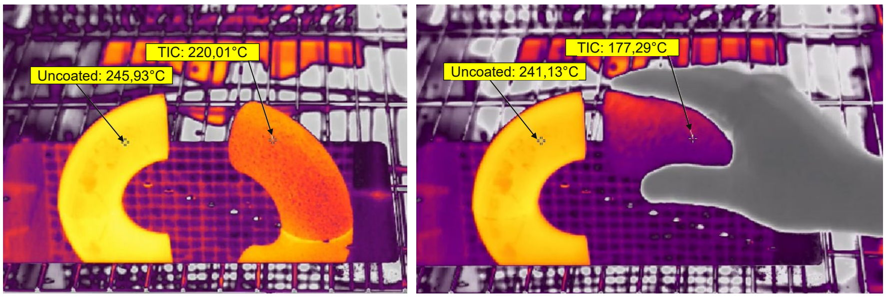
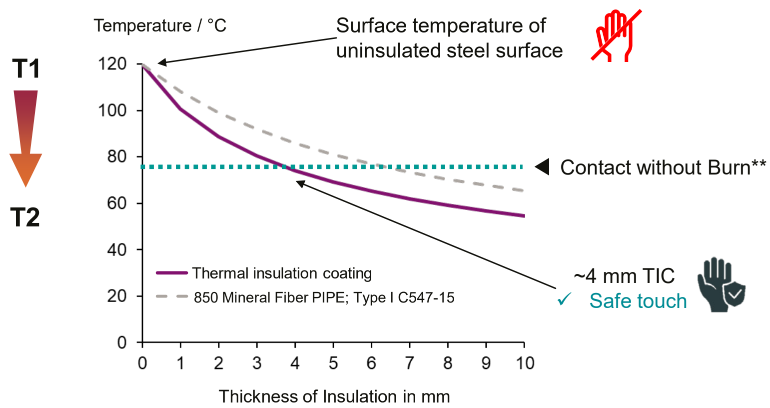


Figure 14. Simulation of Safe Touch Performance for steel pipe, (T1 = 120 °C)



*Calculation based on simulation with NAIMA software 3E Plus, Substrate: steel pipe with 120°C, ambient temperature & no wind speed outside, ε= 0.9 for TIC and Polymer Coating **(Simulation results only show general trend)**

** Safe touch requirements based on DIN EN ISO 13732-1

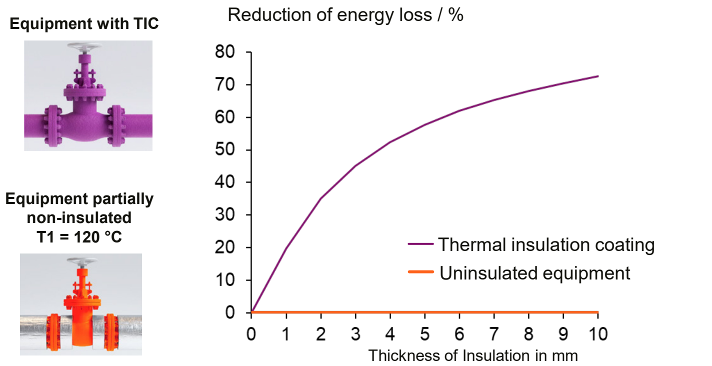
Figure 14 show the simulated decrease of the surface temperature depending on the dried film thickness of the insulation coating. The temperature profile has been simulated with the NAIMA software 3E Plus and the calculation of a steady-state heat transport.

The steady-state simulation visualized that the surface temperature of a hot item, e.g. a hot pipeline with an surface temperature of approx. 120 °C could be reduced to an acceptable limit by a TIC layer of approx. 3–4 mm. The simulation results and the shown example helps to visualize the effect of safe-touch performance. However, for the planning of a specific project additional external factors such as wind speed and humidity may influence the surface temperature. Potential burn injuries are also not only the result of the surface temperature, but also the amount of energy transferred and the exposure time. Further information and requirements regarding safe-touch performance are given in the region-specific norms (e.g. DIN EN ISO 13732-1 or ASTM C1055/1057).

3.2 Reduction of energy loss and dew point shift leading to prevention of condensation

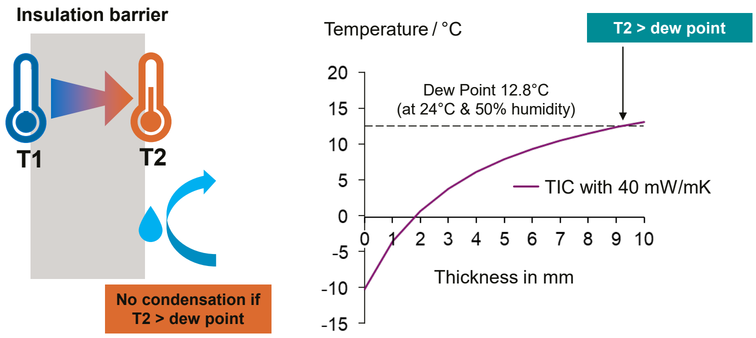
The combined result of a TIC having super hydrophobicity – thermal insulation – dimensional stability across a temperature range shifts dew point as shown in figure 16. With as little as a 2 mm TIC formulated having a λ value of 40 mW/(m*K), a 30 % reduction of energy loss can be achieved over non insulated surface (see figure 15). By shifting the dew point and introducing a temperature gradient/thermal break, the TIC performance with TEGO® Therm HPG 4000 can dramatically reduce the formation of condensation, if not completely, which helps reduce the mechanism driving CUI.

Figure 15. Reduction of energy loss depending on the thickness of TIC in comparison to non-insulation surfaces



*Calculation based on simulation with NAIMA software 3E Plus, Substrate: steel pipe with 120°C, ambient temperature & no wind speed outside, ε= 0.9 for TIC and Polymer Coating **(Simulation results only show general trend)**

Figure 16. Prevention of condensation



*Calculation based on simulation with NAIMA software 3E Plus, Substrate: steel pipe with 120°C, ambient temperature & no wind speed outside, ε= 0.9 for TIC and Polymer Coating **(simulation results only show general trend)**

3.3 Use cases and TIC use with TEGO® Therm HPG in practice

Evonik has established more than a dozen manufacturing site use cases with the commercialized TIC containing TEGO® Therm HPG 4000 and TEGO® Therm HPG 6806 to achieve low thermal conductivity and main three-dimensional stability in both interior and exterior plant use in assorted environments including piping, caustic soda tank and heat exchanger infrastructure for the main typical 3 areas of use including safe touch, energy efficiency and CUI prevention.

4. CONCLUSION

- TIC made with TEGO® Therm HPG 4000 & HPG 6806 demonstrate high performance efficiency due to improved lower thermal conductivity combined with higher hydrophobicity imparting a balanced condensation protection, especially at temperatures above 100 °C.
- TIC made with TEGO® Therm HPG fillers demonstrates improved durability due to the improved 3D stability showing less shrinkage after exposure to heat stress.
- For safe touch and thermal break enhancement driving dew point shift, TIC made with TEGO® Therm HPG fillers demonstrates improved thermal stability performance over other TIC filler technology.
- To overcome cracking behavior which can occur in very highly filled coatings, the TEGO® Therm HPG 6806 offers reinforcement and reduces cracking tendencies supported by its spherical morphology.
- TEGO® Therm L 300 provides an improve heat-stability and could be used in combination with TEGO® Therm HPG grades for temperature range up to 250 °C.

This information and any recommendations, technical or otherwise, are presented in good faith and believed to be correct as of the date prepared. Recipients of this information and recommendations must make their own determination as to its suitability for their purposes. In no event shall Evonik assume liability for damages or losses of any kind or nature that result from the use of or reliance upon this information and recommendations.

Evonik supports you in selecting the best suited product and optimizing current formulations through our Application Technology Group.

Evonik Operations GmbH
Goldschmidtstraße 100
45127 Essen
Germany
Phone +49 201 173-2222
Fax +49 201 173-1939
coating-additives@evonik.com

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