Neuburg Siliceous Earth

as an IR-absorbing additive in LDPE

and PE/EVA greenhouse films

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VM-1/0318/06.2018

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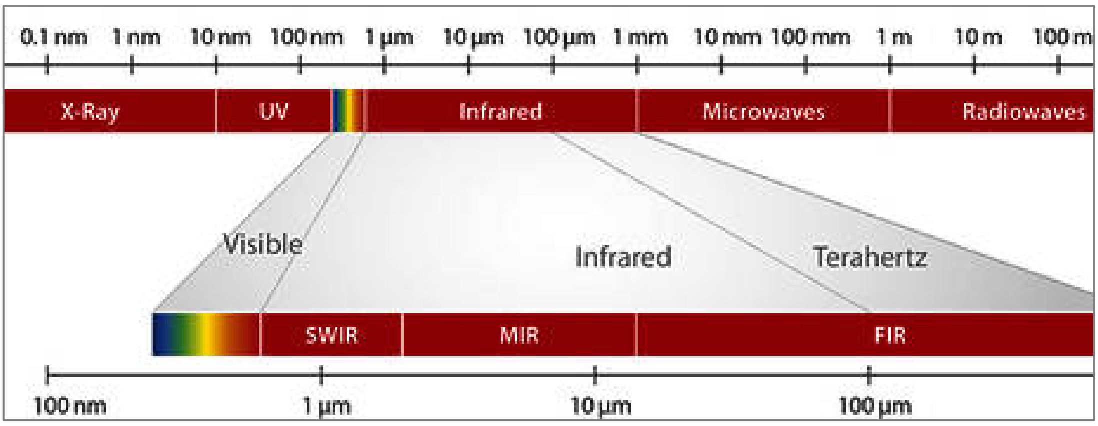
1 Introduction

Greenhouses create an optimal environment for plant growth and allow earlier harvesting and longer periods of growth.

Light transmission in the photosynthetically active range (PAR) should be as high as possible, whereas a good thermal barrier effect is desired in the infrared range.

The following chart shows the electromagnetic spectrum:



Sunlight provides radiation ranging from 290 nm (UV range) past the visible range to the near-infrared range (approx. 3000 nm).

The spectral range of 380-720 nm corresponds to visible light. Plants use it for photosynthesis. The term photosynthetically active radiation (PAR) is also used for this range.
However, measurements frequently only focus on the range from 400-700 nm.

The second important spectral range for greenhouses is in the mid-infrared range from 7-13 µm. This wavelength range represents the heat radiated from the ground into the atmosphere – also known as terrestrial heat radiation – which is lost, particularly at night. A polyethylene film cannot prevent this loss as it is largely transparent for IR radiation in the relevant wavelength range. Adding vinyl acetate as in the PE-EVA copolymer produces some improvement, albeit not to the same extent as mineral additives with IR barrier.

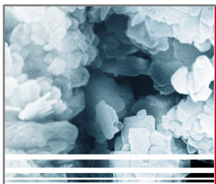
Fine-particle mineral fillers are used as additives to specifically reduce transmission in the film's IR range and so to improve heat retention without noticeably reducing transmission in the PAR range.

This study examines the possible use of Neuburg Siliceous Earth as an IR absorber in greenhouse films.

The optical properties, transmission in the PAR and IR ranges, and IR efficiency of blown LDPE and PE/EVA films with Neuburg Siliceous Earth are compared to unfilled films without IR absorber.

2 Experimental

2.1 Neuburg Siliceous Earth



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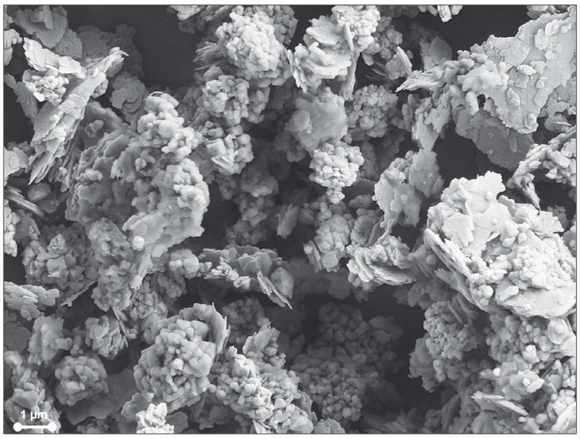
Structure

HOFFMANN MINERAL



A natural combination of corpuscular Neuburg silica and lamellar kaolinite: a loose mixture impossible to separate by physical methods.

The silica portion exhibits a round grain shape and consists of aggregated primary particles of about 200 nm diameter.

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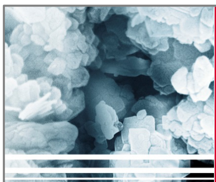

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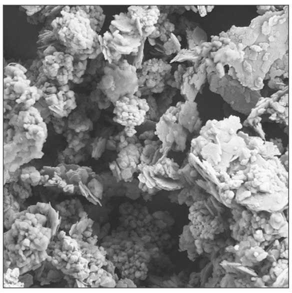
Calcined Neuburg Siliceous Earth

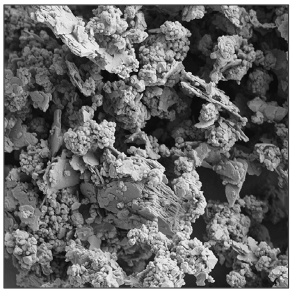
HOFFMANN MINERAL

A downstream thermal process lead to the calcined products SILFIT and AKTIFIT, based on SILLITIN Z 86.



Neuburg Siliceous Earth

Calcination Process →



Calcined Neuburg Siliceous Earth

Additional application benefits, as well as the removing of crystal water included in the kaolinite. The silica part remains inert.

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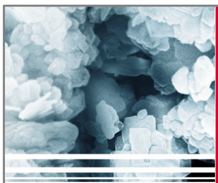
2.2 Fillers and their Characteristics

The table shows a summary of the most important filler properties.



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Filler Characteristics

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	Sillitin V 88	Sillitin Z 89 puriss	Silfit Z 91
Color L*	94	94	95
Color a*	0.1	0.1	-0.2
Color b*	3.8	4.0	0.6
Particle size d_{50} [µm]	4.0	1.9	2.0
Particle size d_{97} [µm]	18	9.0	8.4
Spec. surface area BET [m²/g]	8	11	8

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Sillitin V 88 and Sillitin Z 89 are both relatively color-neutral representatives of classic Neuburg Siliceous Earth. Sillitin V 88 is a coarser variant, while Sillitin Z 89 puriss is a finer type with particularly good dispersion behavior. Silfit Z 91 is a calcined product that is particularly color neutral. Its particle size distribution and dispersion behavior are both similar to Sillitin Z 89 puriss.

2.3 Formulation and Extrusion

In addition to the polymer and filler, the films also contained commonly used proportions of an antioxidant and calcium stearate to act as stabilizers.

The formulation was the same for both types of film:

92.1 %	Polymer
7.5 %	Filler
0.2 %	Calcium stearate
0.2 %	Antioxidant

The compounds were used to manufacture blown mono films with a thickness of approx. 100 µm.

3 Results

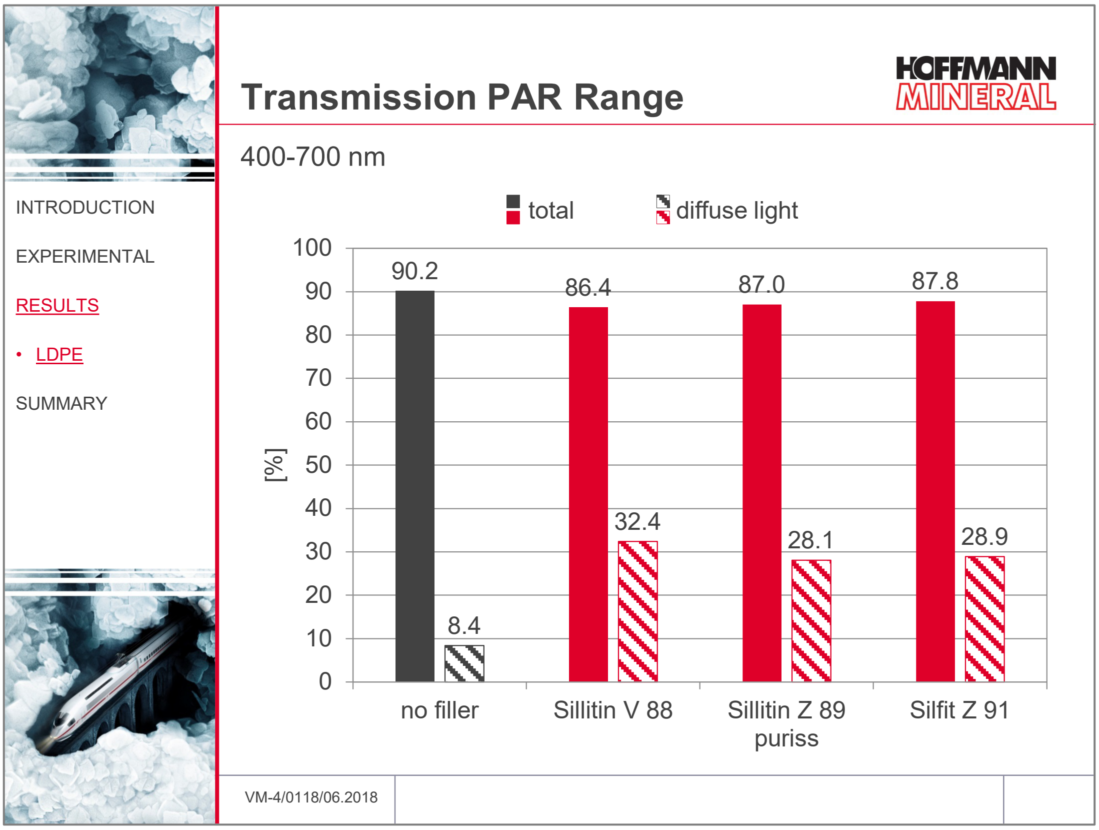
3.1 LDPE Greenhouse Film

Properties of the used LDPE type

- Polymer: Riblene FM 34 F from Versalis
  - Density: 0.924 g/cm³
  - MFR: 3.5 g/10 min
  - Additives: slip agent erucamide and antiblock agent
  - Recommended for blown film application
  - Grade with good balance between processability, mechanical and optical properties

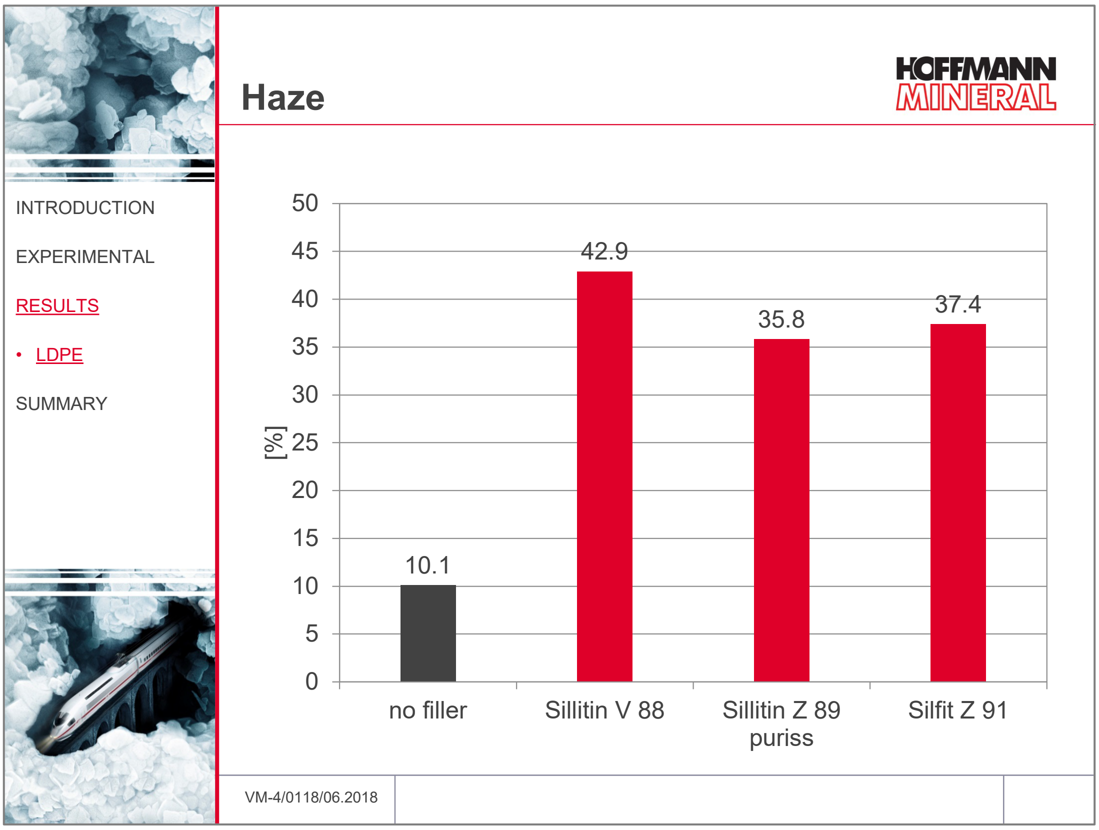
Transmission in the PAR Range

Transmission in the spectral range of approx. 400-700 nm is an important property in greenhouse films. This wavelength range is the part of the solar radiation spectrum that plants use for photosynthesis. Transmission in this spectral range, which is also known as the PAR (photosynthetically active radiation) range, therefore needs to be as high as possible.
A distinction between direct and indirect/diffuse light is also important. Too much direct light, especially in regions exposed to strong sunlight, is damaging to plant growth. Mineral fillers can cause more widespread and even scattering of the light, which positively impacts plant growth.



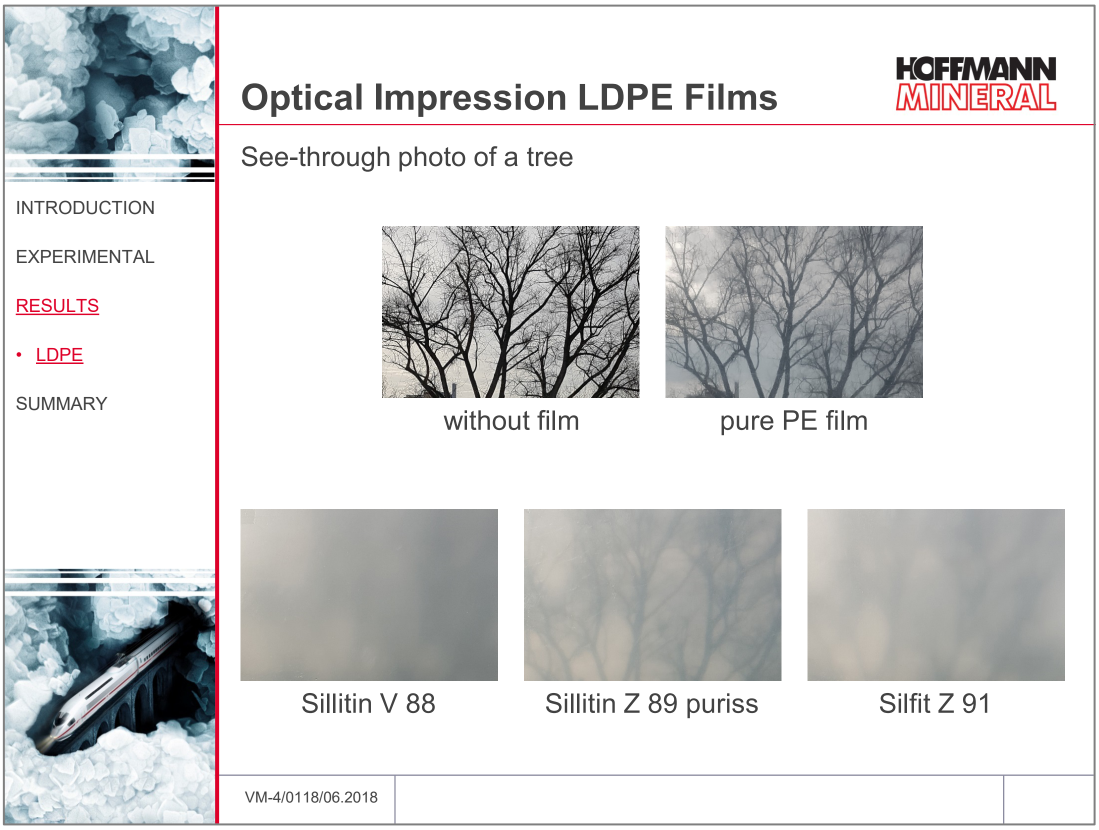
As expected, the film without filler demonstrated the highest total transmission. The addition of filler only reduces transmission marginally – the loss when using the finer fillers Sillitin Z 89 puriss and Silfit Z 91 is slightly less than that caused by the coarser Sillitin V 88.
The diffuse proportion of the film without filler is approx. 8 %. This proportion increases to approx. 29 % when the finer filler types Sillitin Z 89 puriss and Silfit Z 91 are used. The coarser Sillitin V 88 has the highest diffuse proportion, of approx. 32 %, and thus achieves the strongest scattering of light.

Haze



Film haze proved to be similar to the diffuse transmission proportion. The film without filler was relatively clear, as expected, with 10 % haze, whereas the haze increased strongly with the addition of fillers. However, the finer filler particles in Sillitin Z 89 puriss and Silfit Z 91 caused less haze than the coarser particles in Sillitin V 88.

Optical Impression of the Films

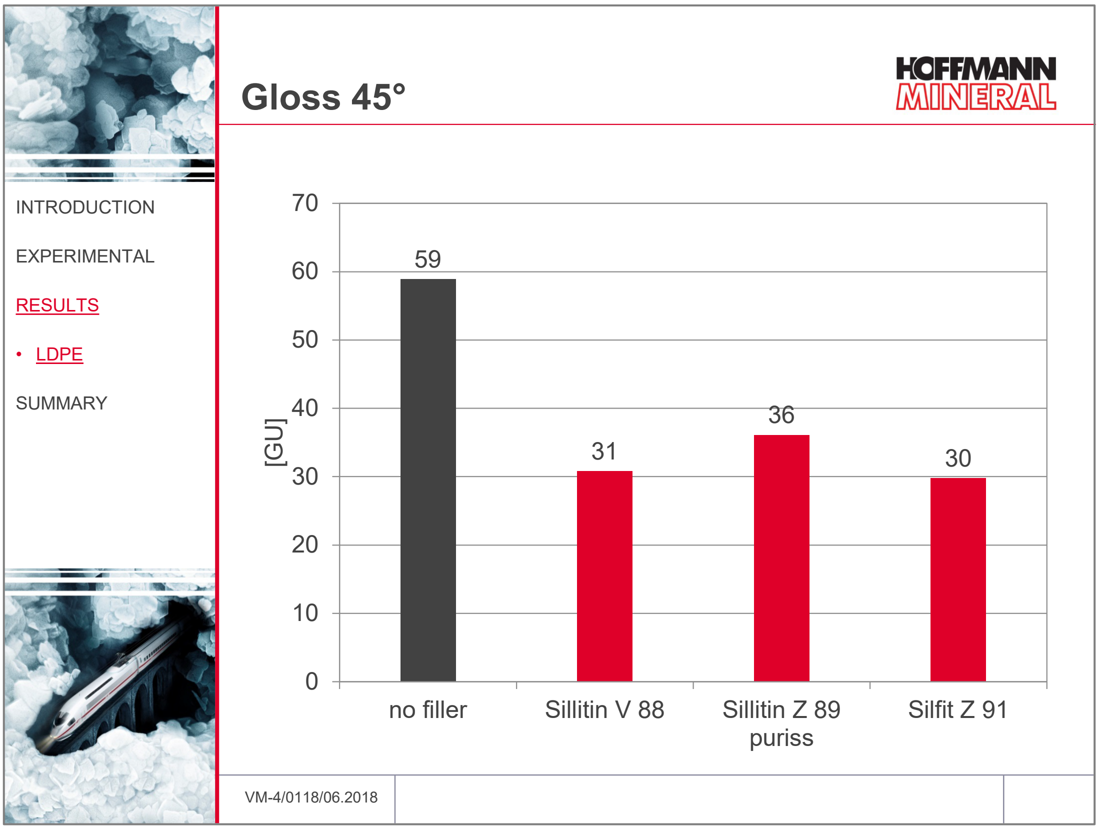


The optical impression of the LDPE films is very consistent with the measured haze. Looking at the same subject through the films shows that Sillitin Z 89 puriss produces the clearest picture among the films with filler, whereas Sillitin V 88 causes the most haze. Silfit Z 91 is somewhere between the two.

This is partly due to the particle size of the fillers and partly to the thermal post-treatment (calcination) of the filler.

Coarser particles such as those in Sillitin V 88 scatter the light more strongly, making the film seem milkier than the finer products Sillitin Z 89 puriss and Silfit Z 91 with the similar particle size. The difference between these two products is caused by the calcination of Silfit Z 91. During the process, the kaolin content is converted into calcined kaolin which makes the film look milkier.

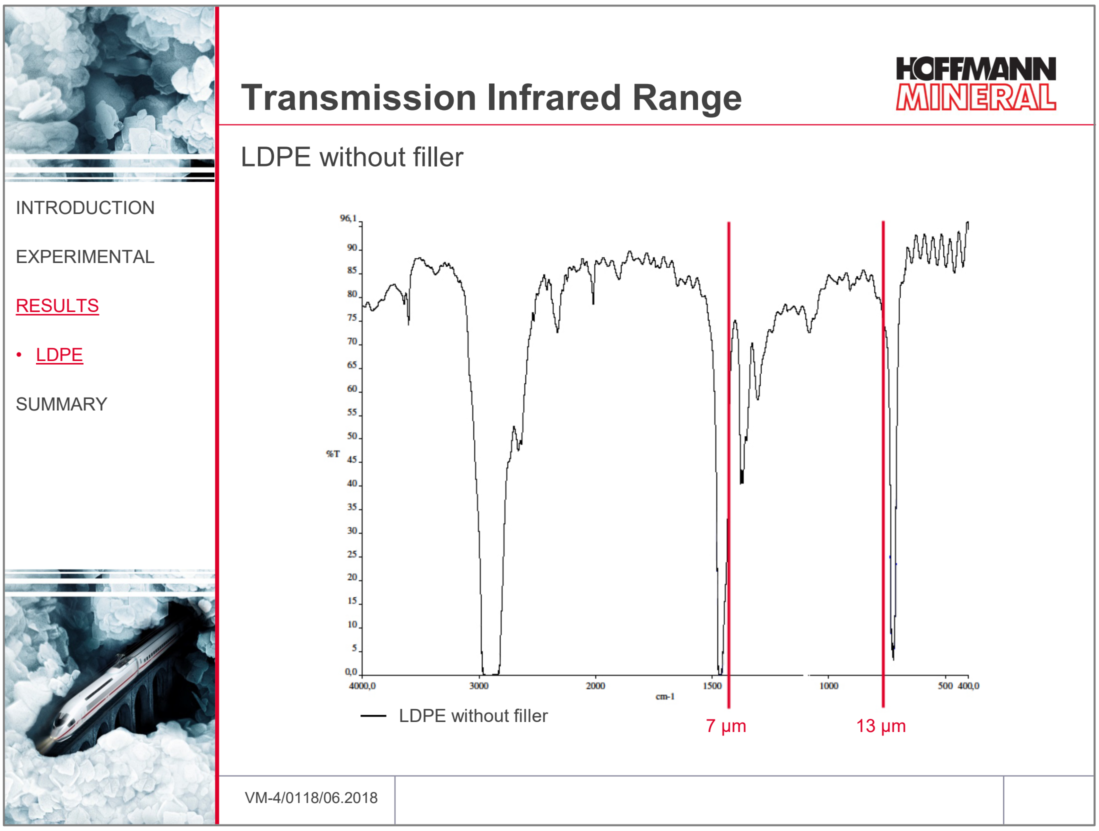
Gloss 45°



Gloss was determined at an incident angle of 45°. Adding the filler caused it to drop by approx. 30 units – the films with filler are more mat than the film without. Sillitin Z 89 puriss demonstrates the highest gloss and thus the least matting effect, which correlates well with the low haze.

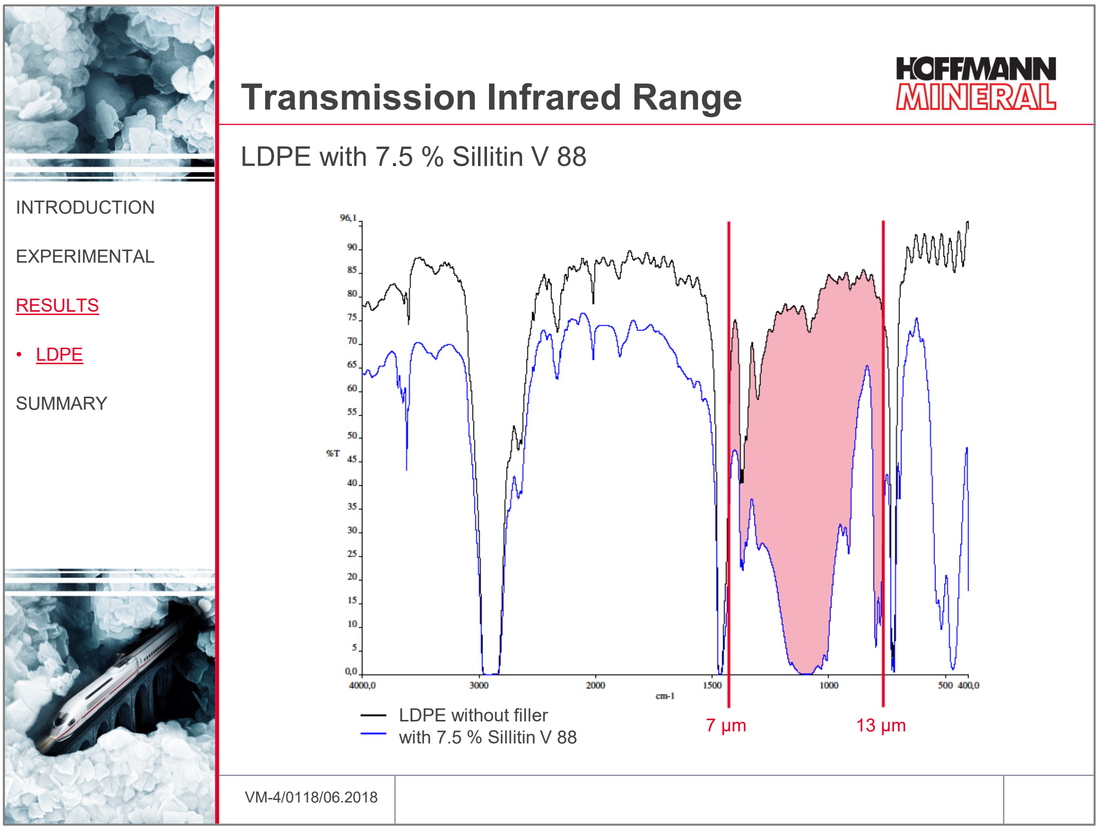
Transmission in the Infrared Range

Particular focus is on the wavelength range from 7-13 µm, equivalent to the wave numbers from 1430 to 770 cm^{-1}, as this range around 10 µm corresponds to the maximum energy radiation from the Earth's surface (terrestrial heat radiation at 15°C or 288 K).

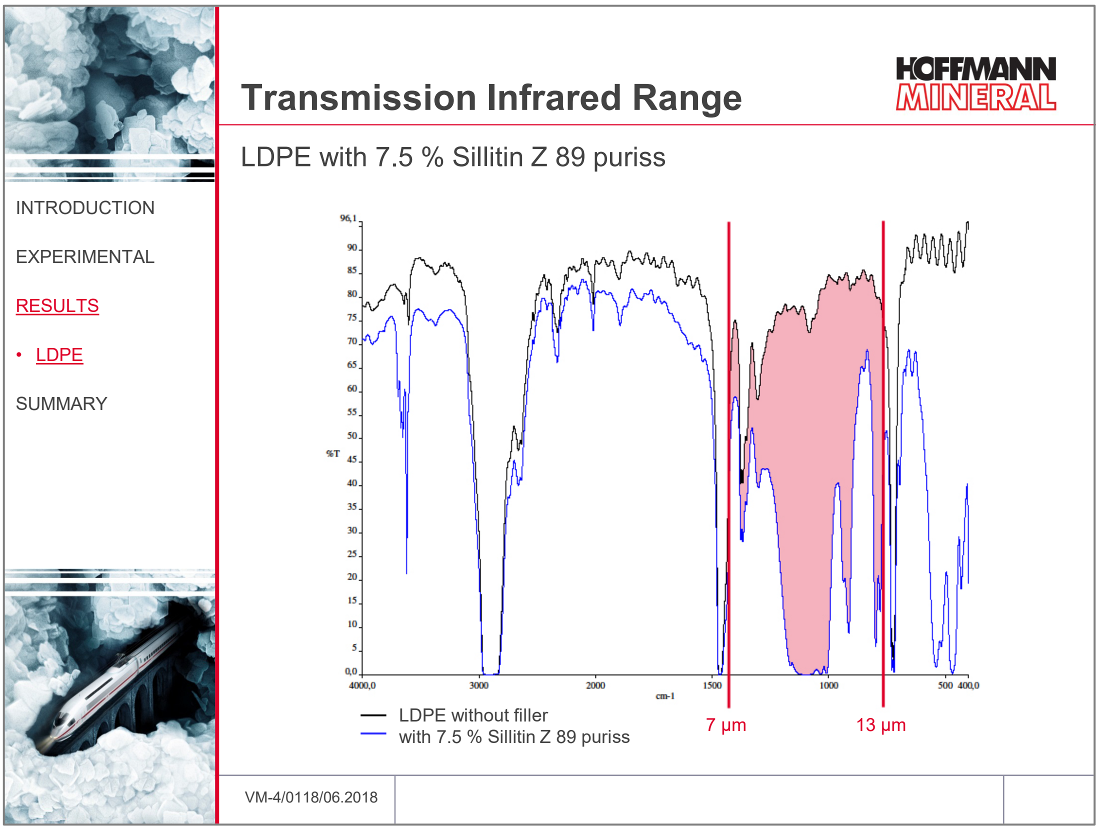


The IR radiation barrier effect demonstrated by the LDPE film without filler was low in the relevant wavelength range.

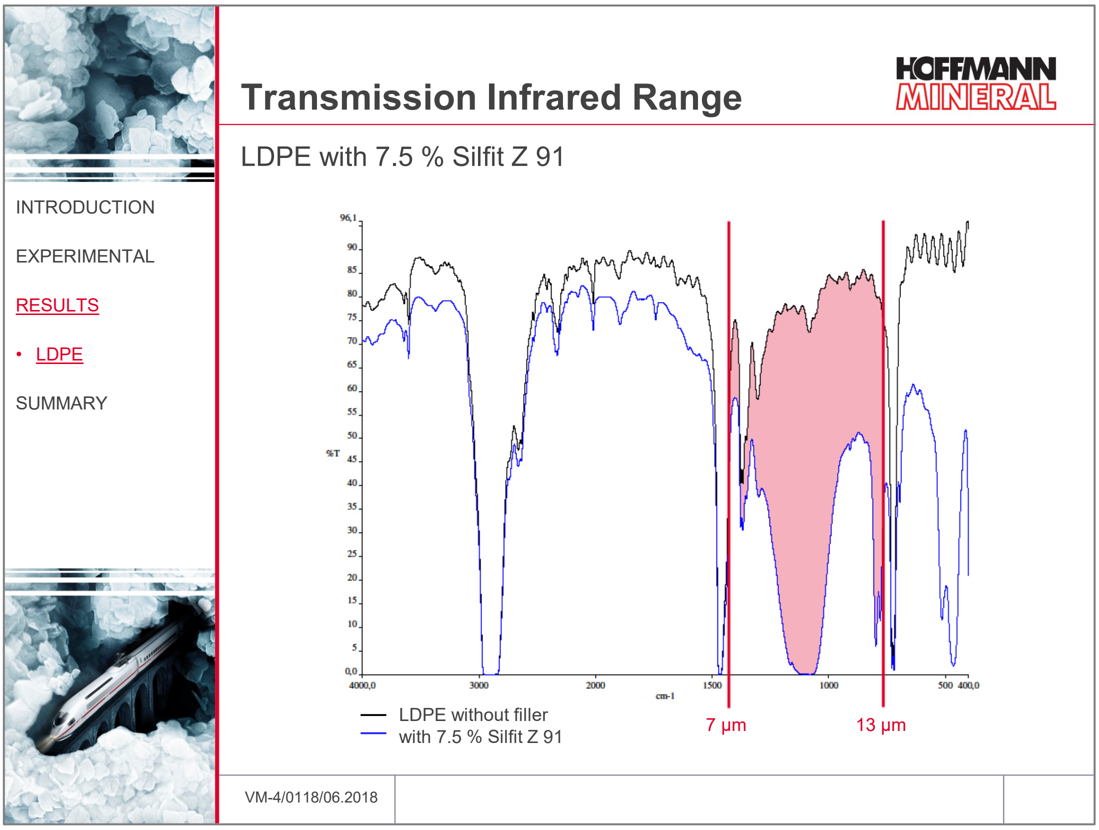
The following three charts feature the transmission curves of the mineral-filled films (blue line), in each case compared to the film without filler (black line). The differential area is shaded red in each case and highlights the barrier performance achieved by the filler.



Compared to the unfilled film, Sillitin V 88 significantly reduces transmission in the near- and mid-infrared range.



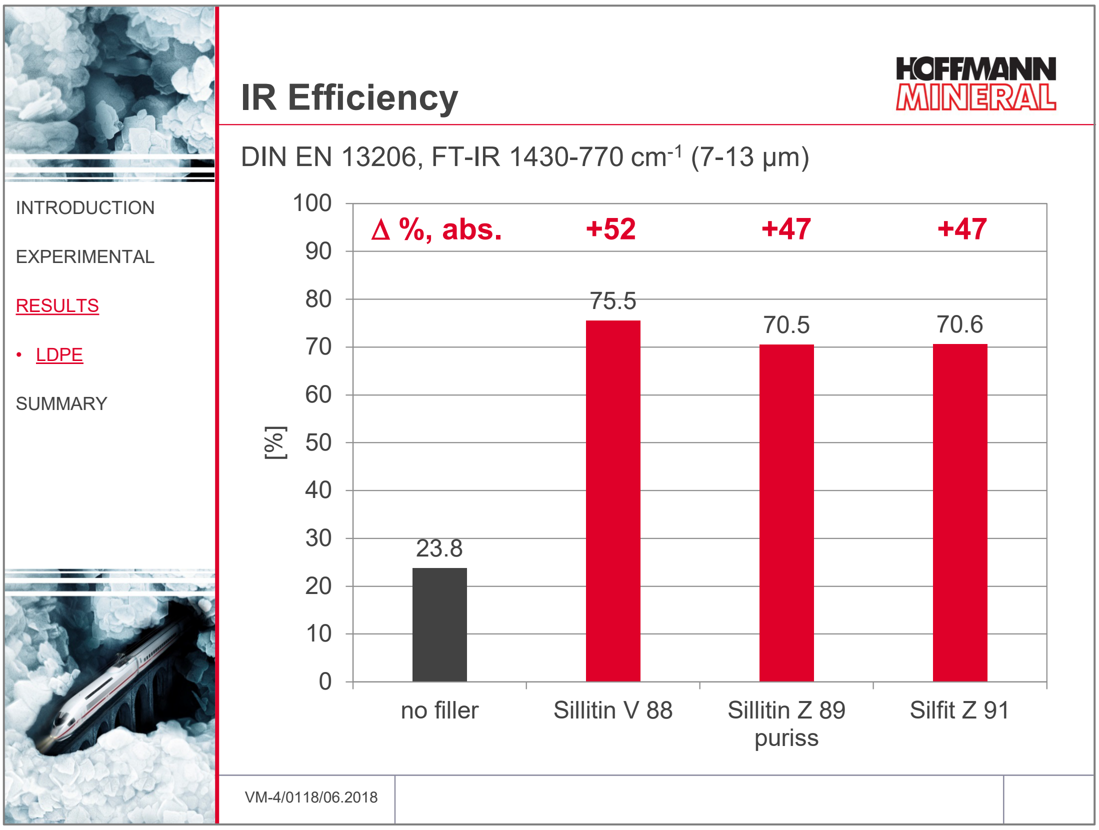
A clear IR radiation barrier effect is also discernible with Sillitin Z 89 puriss. Compared to Sillitin V 88, however, Sillitin Z 89 puriss raises the barrier effect in the shorter wave range < 9 µm, which can be explained by the finer particle size.



The barrier performance of Silfit Z 91 is also good, and stronger in the 11-12 µm range than Sillitin Z 89 puriss with virtually the same fine particle size. Thermal post-treatment is probably the explanation for this difference.

IR Efficiency

IR efficiency as defined in DIN EN 13206 is the percentage that the film blocks in the relevant wavelength range from 1430-770 cm^{-1}.



Unlike the pure PE film with its efficiency of just 24 %, the barrier performance of the mineral filler is 70-75 %. As such, the films with filler have substantially better thermal retention capability.

Compared to the pure PE film, this translates into an improvement in IR efficiency of approx. 47 % when using the finer Sillitin Z 89 puriss and Silfit Z 91 and approx. 52 % in the case of the coarser Sillitin V 88.

Accordingly, Sillitin V 88 is most effective at blocking infrared radiation, which is consistent with the least thermal loss.

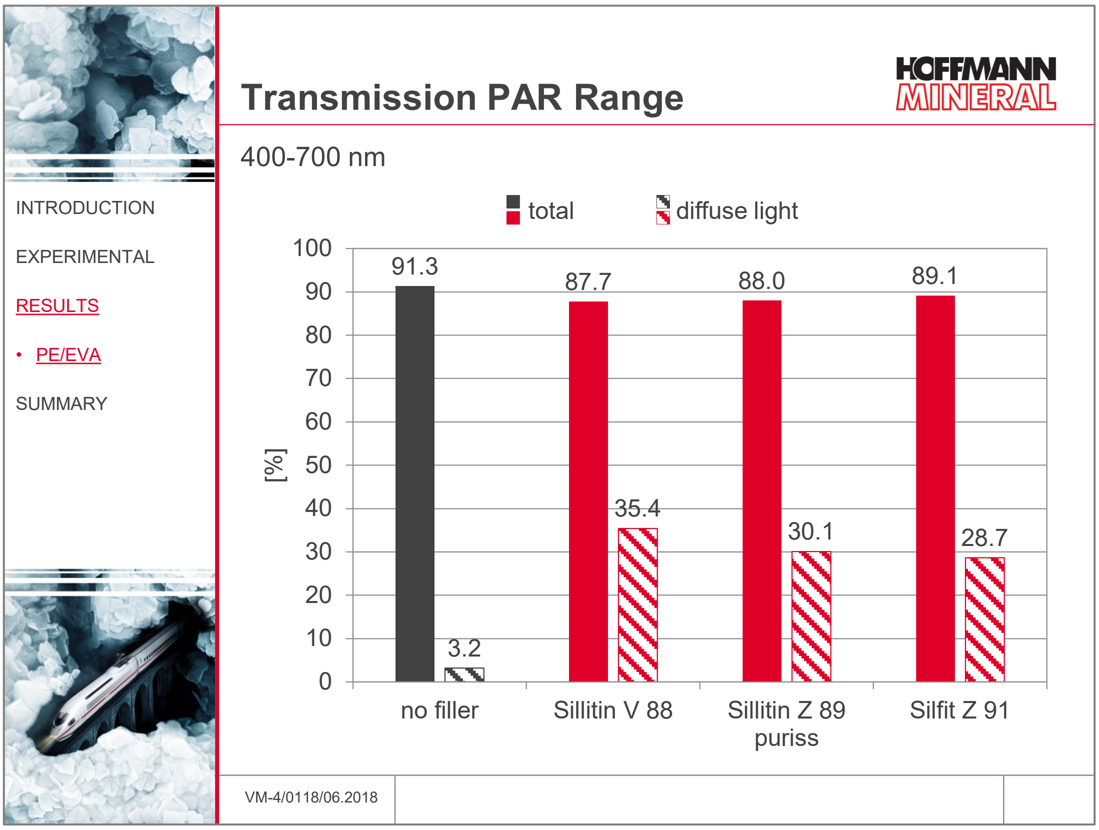
IR efficiency could be increased further, in principle, by using a thicker film or greater concentration of mineral additive.

3.2 PE/EVA Greenhouse Film

Properties of the used PE/EVA type

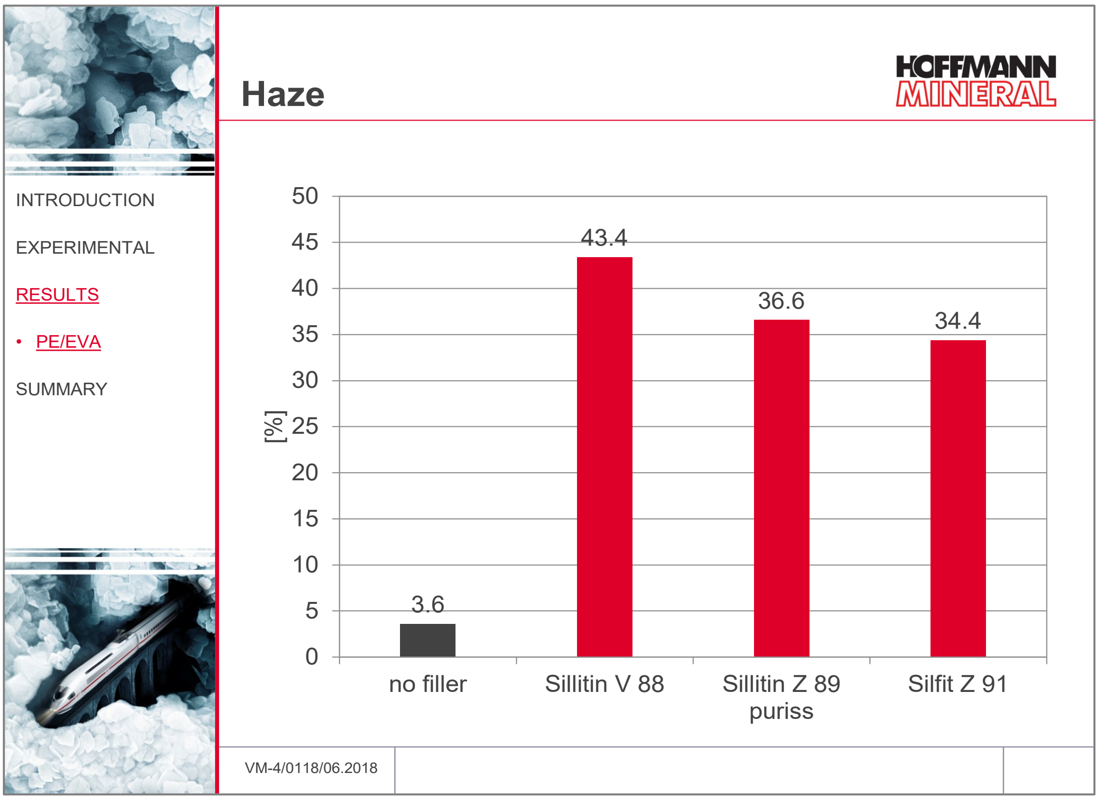
- Polymer: Escorene Ultra FL 00909 from ExxonMobil
  - Density: 0.928 g/cm³
  - MFR: 9 g/10 min
  - Vinyl acetate content: 9.4 wt%
  - Additives: none
  - Suitable for blown film applications
  - Grade with good optical properties

Transmission in the PAR Range



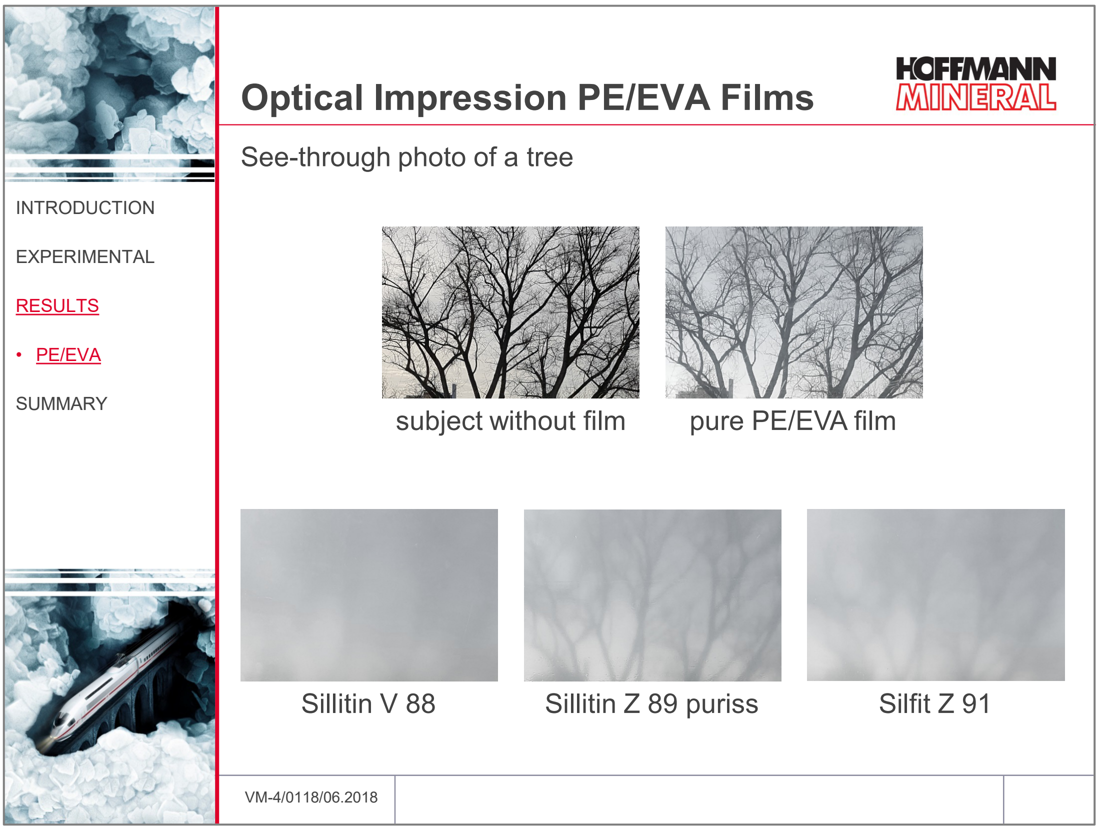
In keeping with the results using the PE film, the PE/EVA film without filler demonstrated the greatest total transmission. Transmission is only marginally reduced by the addition of fillers, whereby here again the finer Sillitin Z 89 puriss and Silfit Z 91 result in the smallest reductions. The diffuse proportion increases from approx. 3 % in the case of the unfilled film to approx. 29 respectively 30 % when using the finer fillers Sillitin Z 89 puriss and Silfit Z 91. The coarser Sillitin V 88 has the highest diffuse proportion, of approx. 35 %, in the PE/EVA film, as well, and thus the strongest scattering of light.

Haze



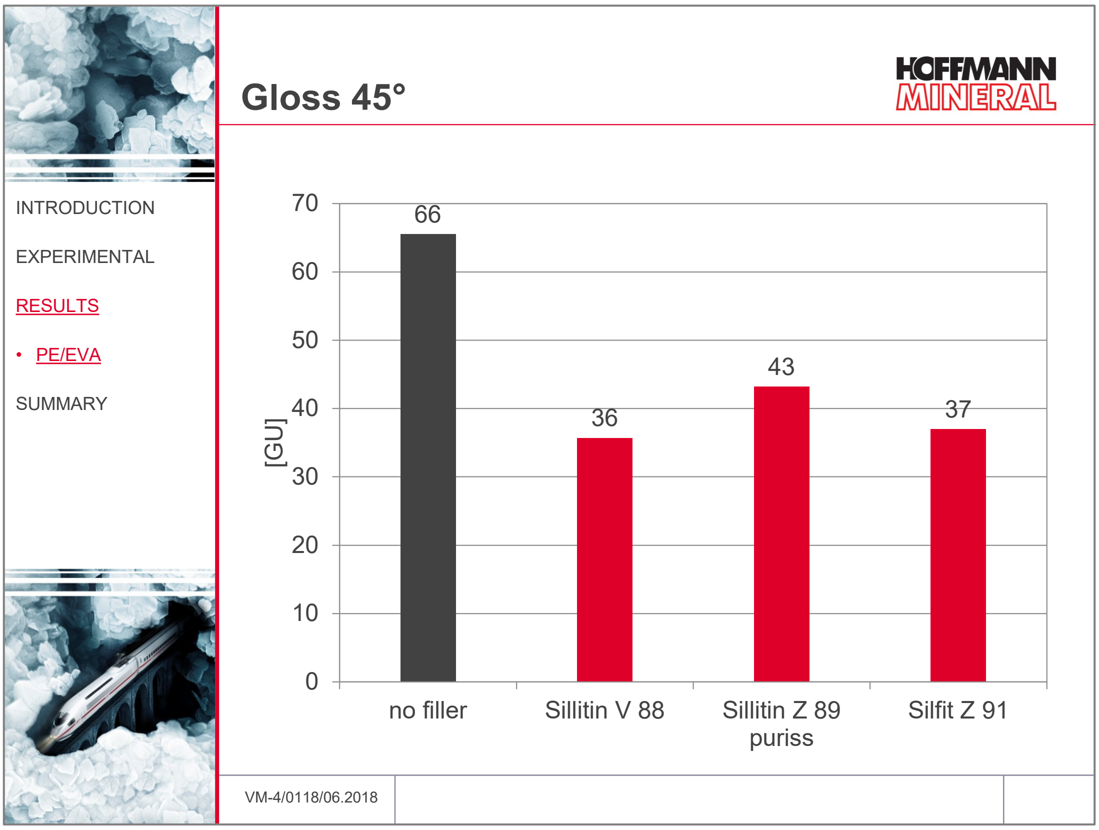
The haze of the film without filler was only approx. 4 %, as expected. Haze increases strongly with the addition of the fillers, whereby it is again the finer filler particle size of Sillitin Z 89 puriss and Silfit Z 91 that produces less haze than the coarser particles in Sillitin V 88.

Optical Impression of the Film



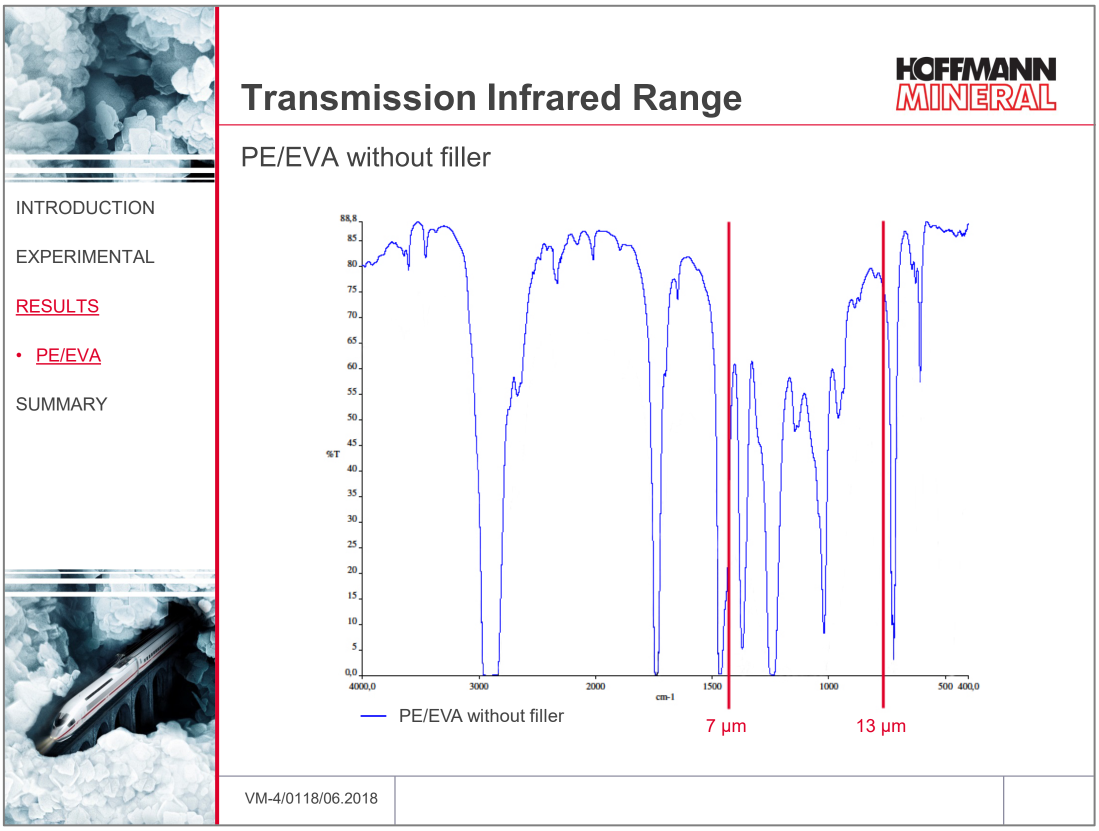
The optical impression of the PE/EVA films is more or less as expected, based on the measured haze properties. Of the films with filler, the film with Sillitin Z 89 puriss again shows the clearest and the film with Sillitin V 88 the milkiest picture.

Gloss 45°



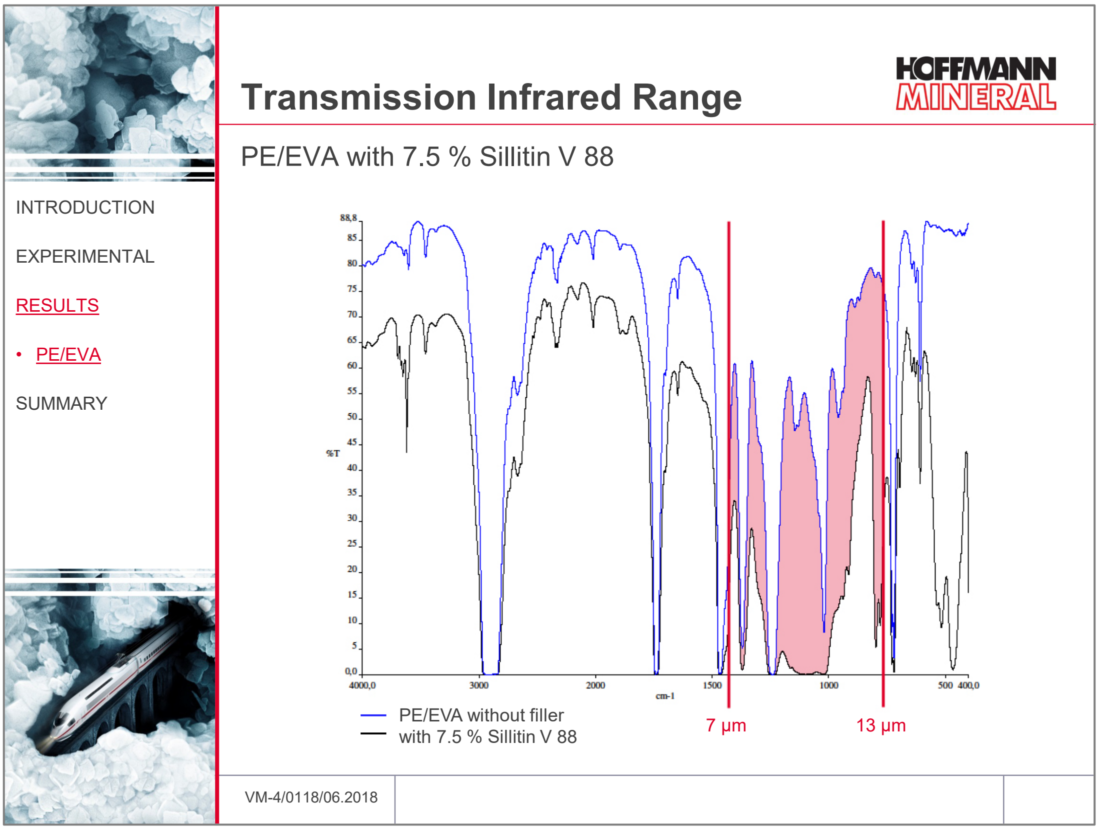
Gloss measured at an incident angle of 45° dropped as a result of adding the filler by approx. 20-30 units – the films with filler are more mat than the film without.

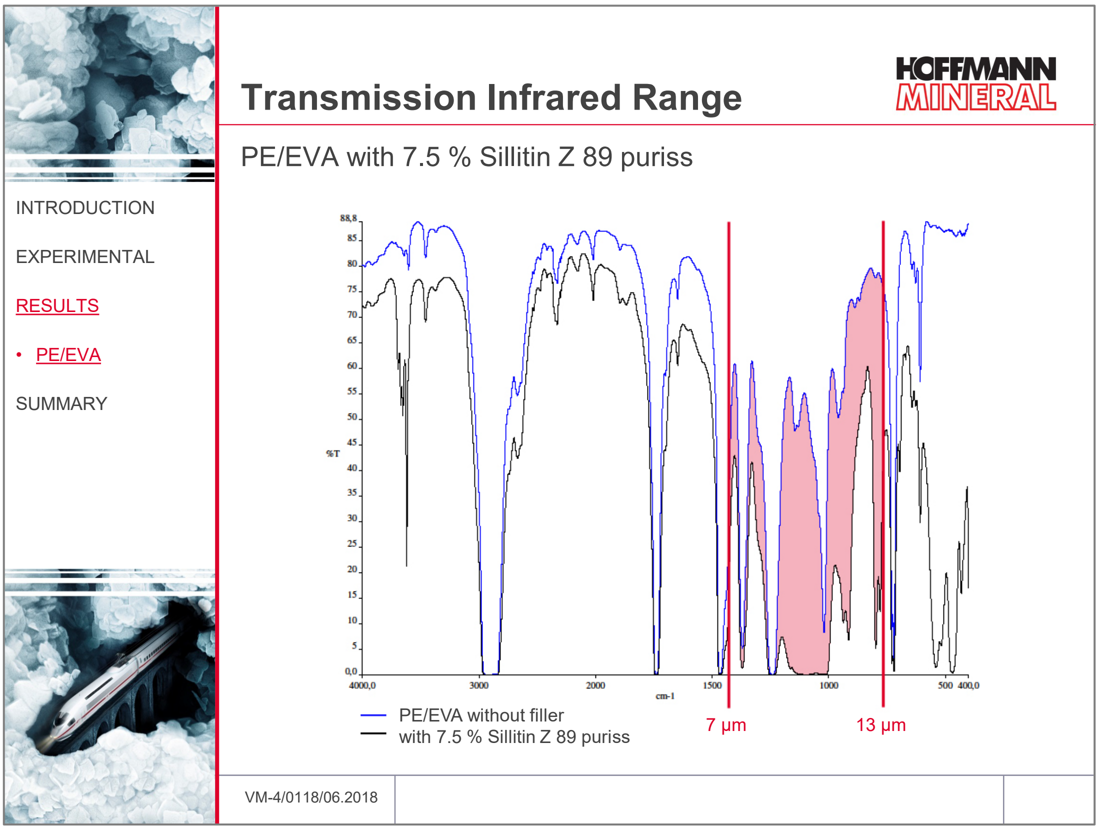
Transmission in the Infrared Range



Even without filler, the PE/EVA film already typically offers a certain ability to block the relevant IR range from 7-13 µm.

The following three charts again compare the mineral-filled film (black line) to the unfilled film (blue line) and show the differential area.





Transmission Infrared Range

HOFFMANN MINERAL

PE/EVA with 7.5 % Silfit Z 91

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• PE/EVA

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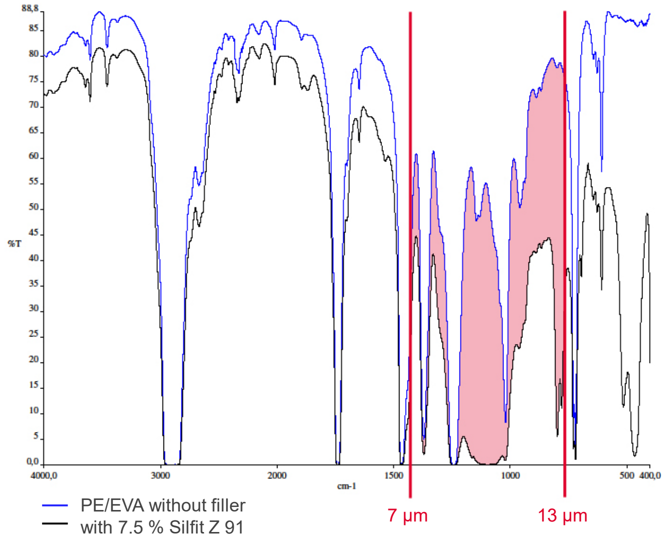

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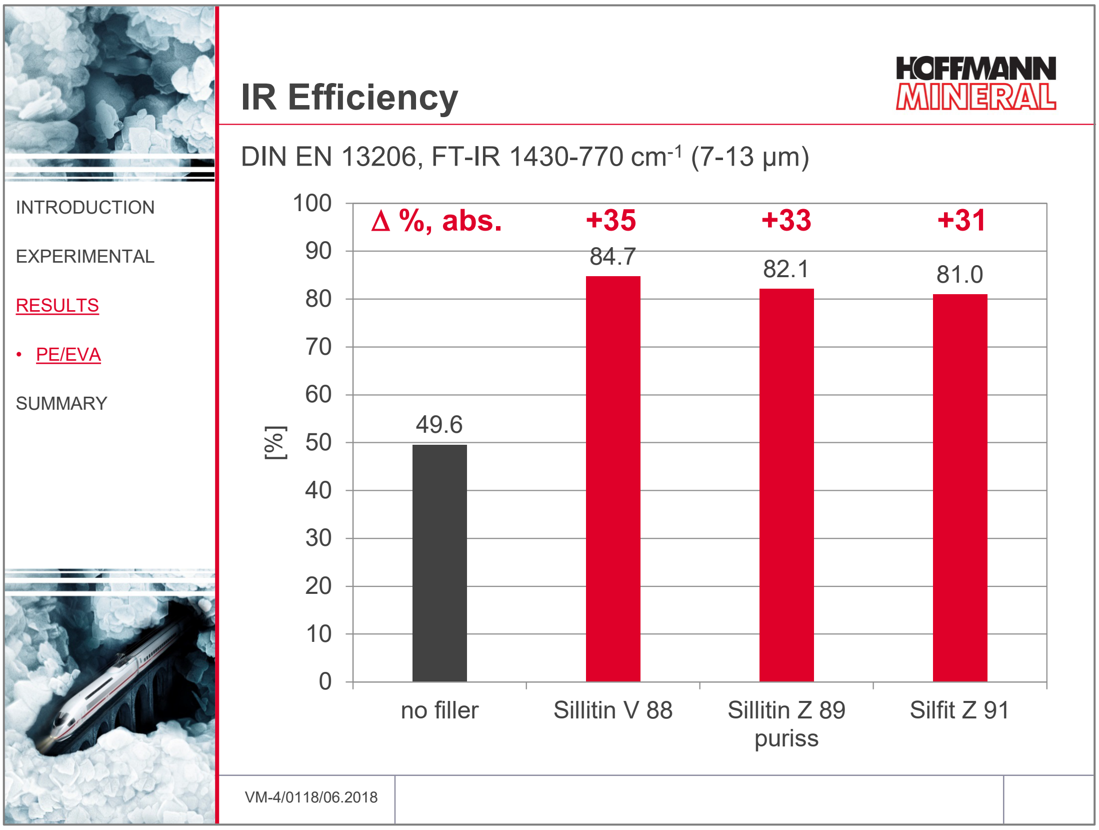
Adding filler significantly improves the barrier performance of the film. As was also the case with the LDPE film, Sillitin Z 89 puriss with its fine particles reduced transmission more strongly in the range of less than 9 µm compared to the coarser Sillitin V 88, while calcined Silfit Z 91 tended to reduce transmission more strongly in the 11-12 µm range.

IR Efficiency



The efficiency of pure PE/EVA film is already approx. 50 %. By adding filler, this performance can be enhanced by further 30-35 % to approx. 80-85 %.

Compared to the unfilled film, this translates into an improvement in IR efficiency of approx. 30 % when using the finer Sillitin Z 89 puriss and Silfit Z 91 and approx. 35 % in the case of the coarser Sillitin V 88.

Accordingly, Sillitin V 88 is most effective at blocking infrared radiation, which is consistent with the least thermal loss.

IR efficiency could be increased further, in principle, by using a thicker film or greater concentration of mineral additive.

4 Summary

Neuburg Siliceous Earth is suitable for use as an IR absorber in greenhouse films based on both PE and PE/EVA.

Compared to unfilled films, light scatter is substantially stronger while total transmission in the photosynthetically active wavelength range remains virtually unchanged, which has a positive effect on plant growth. In addition, IR efficiency is significantly increased and thus thermal loss substantially reduced.

There are only minor differences between the three Neuburg Siliceous Earth products that were examined:

- Sillitin Z 89 puriss: good light scattering and IR barrier, low optical haze
- Silfit Z 91: good light scattering and IR barrier, higher color neutrality
- Sillitin V 88: strongest light scattering and highest IR barrier

Other modifications of Neuburg Siliceous Earth offer the potential for further optimization of greenhouse films.

With additive surface-treated products should have the positive effect of extending life time / improving the weatherability of the films:

- based on Sillitin V particle size distribution: Aktisil Q
- based on Sillitin Z particle size distribution: Aktisil VM 56/89
- based on Silfit Z 91, hydrophobic: Aktifit VM, Aktifit PF 111 and Aktifit Q

Other customized experimental products are available on request.