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NEW ULTRATHERMIC FILMS FOR GREENHOUSE COVERS

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ABSTRACT: Thermic greenhouse covers are plastic films that block infrared (7–14 μm) radiation to reduce the risk of frost when the greenhouse is not heated and to reduce the energy consumption when a heating system is used. The standard mineral fillers (calcined kaolin), which have been normally used to increase the IR opacity of LDPE and other greenhouse films, accelerate the photodegradation of the film as well as moderately increase the haze and diminish the light transmission. In this work, we present a new family of mineral fillers that do not accelerate photodegradation, do not lower the light transmission, and give low or high haze, depending on what is required. With these mineral fillers, the optical properties can be optimized and the IR effectiveness can be reached, thus giving a new generation of ultrathermic films (UT). Using them as greenhouse covers, heat energy savings between 5% and 10% can be achieved.

KEY WORDS: agricultural film, greenhouse, tunnel, blown film, LDPE, EVA copolymer, EBA copolymer, infrared, mineral filler, optical properties.

INTRODUCTION

IT IS KNOWN that growing vegetables under tunnels or greenhouses covered with the so-called thermic films [plastic films opaque to infrared (IR) radiation, specially between 7 and 14 μm] have a greater vegetative development, earlier harvests of greater quality and more abundance [1–5]. These advantages are greater as the plastic cover is more opaque in the mentioned interval of infrared radiation and, at the same time, more transparent to the visible part of the

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Figures 1–5 appear in color online: http://jpf.sagepub.com

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solar spectrum – the light used for the photosynthesis process. Other additional advantages of these films are the reduction of risk of frosts when the greenhouse is not heated, or an important reduction of the energy consumption when a system of heating is used; both improvements are due to the lower heat losses by radiation.

Most of the films or plastic sheets transparent to the visible light are, to a certain extent, opaque to the IR radiation considered. However, LDPE films, the most used material for this application, are very transparent to these wavelengths. In order to palliate this disadvantage, the industry has developed compounds that prevent, at least partially, the losses of heat from the interior of the greenhouse to the sky. The low price of the raw material, its good processability (films of up to 20 m wide can be obtained), its high mechanical resistance, its facility of UV stabilization and its low creep are some of the reasons why this material is widely used for agricultural shelters.

Two solutions are adopted to improve the IR opacity of LDPE films:

- The use of fillers or additives, preferably of mineral type: silica, synthetic or natural silicates (talc, mica, kaolin), carbonates (of calcium or calcium–magnesium), sulphates (of calcium or barium), hydroxycarbonates (hydrotalcite), hydroxysulphates (alunite), hydroxides (of aluminum or magnesium), etc. [6–8].
- The use, by blending or coextrusion, of copolymers of ethylene and vinyl acetate (EVA) or butyl acrylate (EBA). These copolymers show IR absorption bands in the above said wavelength range.

Both solutions have their advantages and disadvantages. The EVA and EBA copolymers moderately increase the thermicity, the transmission of visible light, diminish the haze, and increase the compatibility of organic additives; but they increase the accumulation of dust and the blocking of films; additionally, they can harm some mechanical properties, especially creep, when they are used in hot climates. The use of suitable thermal fillers increases the thermicity more effectively, increases the haze, slightly reduces the light transmission, and does not diminish the initial mechanical properties; but they can have an important negative effect on the photodegradation of the films.

Historically, the industry has used both solutions well, individually or combined, depending on the conditions of use (radiation, temperatures, necessity of turbidity and light transmission, etc.). Thus, it is possible to find in the market some compounds based on LDPE, EVA copolymers (up to 18% of VA) and EBA copolymers (up to 8% of BA), with mineral
filler contents between 0% and 10% in weight. The copolymers with higher VA content are used for the intermediate layers of multilayer films. In areas of Mediterranean climate (low cloudiness, high irradiation, short rain), films of LDPE have been used historically due to their best mechanical properties at high temperatures, and their lower dust accumulation – also, since light transmission is not a limiting factor, films with higher haze are preferred. In more humid climates (high cloudiness, low radiation, frequent rains), the clearest film is preferred since the limiting factor is light transmission and haze of the films is not necessary, since the natural light is diffused due to cloudiness. Additionally, dust accumulation is not a problem since it is washed off by the rain.

The mineral fillers used nowadays have some important limitations: they accelerate the photodegradation of the film, moderately increase the haze and diminish the light transmission, or they are really expensive. In this work we present a new family of mineral fillers that do not accelerate photodegradation, do not lower the light transmission and give low or high haze, depending on what is required; and they thus show a positive cost–performance balance.

**EXPERIMENTAL**

**Materials and Blown-film Preparation**

The polymeric materials used in this work were LDPE (Alcudia PE-033, Repsol-YPF), and EVA copolymers (Alcudia PA-500, 4% VA and Alcudia PA-570, 14% VA). The MFI of all of them was 0.3 g/10 min.

The compounds were prepared in a twin-screw extruder, Werner & Pfleiderer ZSK-25.

The films for the optical and IR properties study were produced using a lab-scale Covex mono-layer extrusion blown-film line. All the films were made using the same processing conditions: 1.2 mm die gap, output of 12 kg/h, film thickness of 200 μm, frost-line height around 25 cm, blow-up ratio (BUR) of 2.33 : 1 and a drawn-down ratio (DDR) of 2.5 : 1.

The films for the field trial were produced using a Covex three-layer co-extrusion blown-film line. All the films were made using the same processing conditions: 1.2 mm die gap, output of 80 kg/h, film thickness of 200 μm, frost-line height around 70 cm, BUR of 2.5 : 1 and a DDR of 2.5 : 1.
Optical Properties

Light transmittance and haze were measured using a hazemeter, Gardner Haze-Plus, according to EN 2155-5 and EN-2155-9 standards, respectively.

Infrared Spectroscopy

The infrared spectrum of the film was analyzed using a Nicolet 5700 spectrophotometer. The IR average transmittance in the range 7–14 μm was calculated according to EN 13206 standard.

Field Tests

The plastic film tests were carried out in test greenhouses built at the IMAG institute site in Wageningen, The Netherlands, during the winter of 2001–2002. The size of the greenhouses was 5 m width, 4 m length, and 1.5 m height. The greenhouses consisted of three round-arched hoops in longitudinal direction with standard hoop spacing of 2 m and a door in each gable, which was closed during the experiments. The gable walls were insulated on the inner side with bubble-film coated with aluminum on the inner side of the greenhouse. By reflecting the heat radiation in the gables a longer greenhouse tunnel could be simulated.

The greenhouses were equipped with a heating system consisting of white metallic electrical heating pipes filled with oil. These 12 heating pipes with a length of 4 m were installed per tunnel, each having a heating capacity of 500 W. This resulted in a total of 6 kW heating capacity being installed per tunnel to provide 300 W/m² ground area.

RESULTS AND DISCUSSIONS

Over the years, the mineral fillers used to increase the thermicity of LDPE, EVA, and EBA films have been evolving. The first patents and the first commercial films, in the 1970s, mainly used silica, silicates, and hydrated alumina [6]. With time, the extrusion temperatures used by the processors were increasing, and aluminum hydroxide was abandoned, since it decomposes around 180 °C. During the 1990s the most used fillers were silicates, especially calcined kaolin. Calcined kaolin has some important limitations: it accelerates the photodegradation of the film, moderately increases the haze, and diminishes
the light transmission. There are better commercial fillers such as hydrotalcite that do not degrade or affect the optical properties of the film, but they are much more expensive.

In this article we present a recently developed family of mineral fillers that are not degrading, do not lower the light transmission, give low or high haze – depending on what is required, and show a cost-performance balance that is better than hydrotalcite. They are based on mixtures of a borate that is stable in the processing conditions and a compound selected from the group made up of silica, silicates, carbonates, and sulfates [9]. The particle size distribution of the filler and its refractive index is managed in order to obtain the desired haze.

In Figures 1–3 the optical properties (global light transmission and haze) and IR effectiveness of LDPE monolayer films containing different amounts of these new optically-optimized mineral fillers are compared with standard films containing kaolin.

Since the amount of filler content – due to its effect on light transmission and photodegradation of film – is not a limiting factor with this new generation of ultrathermic films (UT), higher IR effectiveness levels (>95%) can be achieved while haze can be around 20% (clear ultrathermic films, CUT) or higher than 80% (hazy ultrathermic films, HUT).

An experimental CUT film was tested at the IMAG Institute in Wageningen (The Netherlands) with excellent results. The experimental film was a three-layer film containing a mineral filler with a refractive

![Figure 1. Light transmission of films with different mineral fillers.](image-url)
index very similar to that of the polymer matrix, in order to not alter the optical properties. It was compared to a three-layer film (EVA 4% VA/EVA 14% VA/EVA 4% VA) without mineral fillers. Optical properties of both films, as well as their thermicity, are shown in Table 1.

The films were installed in two identical walk-in tunnels (Figure 4) equipped with electrical heating and special measurement equipment.
such as pyrometer, air temperature and humidity sensors, and thermocouples to measure substrate and film temperatures. Measurements of all these variables were done with and without heating, with and without water condensation on the film, with clear and clouded sky, and with low and high wind velocity. With these measurements, the overall heat losses (the \( k \)-value) of the two greenhouses were calculated for each situation and the values were used to simulate the energy consumption of a greenhouse during a complete agricultural season.

During one year and even over several growing seasons climatic conditions vary considerably; the effect of those variations can be taken into account with computer simulations. In this case, the software KASPRO,

**Table 1. Optical properties and IR effectiveness of the films tested in The Netherlands.**

<table>
<thead>
<tr>
<th></th>
<th>Light transmission (%) EN 2155-5</th>
<th>Haze (%) EN 2155-9</th>
<th>IR effectiveness (%) EN 13206</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear ultrathermic film</td>
<td>93</td>
<td>19</td>
<td>95</td>
</tr>
<tr>
<td>Reference film</td>
<td>92</td>
<td>17</td>
<td>82</td>
</tr>
</tbody>
</table>

**Figure 4.** Experimental greenhouses.
developed by the IMAG Institute (Wageningen-UR, The Netherlands), was used to calculate the energy consumption for different crops and different climates. It was calculated that a tomato crop under the CUT film uses 8.3% less energy than under the reference film. The effect of condensation on the covering material was considered in the calculation model. Calculations for different crops under both films are shown in Figure 5. Taking into account the price of the gas used for heating, the use of UT films is clearly economically advantageous.

The same experiment was repeated during winter 2003–2004 with CUT and the reference films, as well as with their anti-drip versions.

In greenhouses without heating, such as those used in Mediterranean climates, the main advantage of UT films is that they maintain the warmth of the plant and the soil or substrate better during the night. For these climates with a high percentage of clear days (direct light) the use of very hazy films is recommended. The new mineral fillers permit obtaining HUT with haze values up to 90%, light transmission over 90%, and IR effectiveness up to 97%.

CONCLUSIONS

A new family of mineral fillers has been developed to improve the blocking of infrared radiation in plastic films for use as
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greenhouse covers. It is based on a mixture of a borate and a compound of silica, silicates, carbonates, and sulfates. These mineral fillers are not degrading, do not lower the light transmission of the films and can give low or high haze, depending on what is required. A heated greenhouse covered with these new films needed less energy (8% for a tomato crop in The Netherlands) than a normal thermic film.

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