Flexible Guiding Systems for Cooling Air

Increase in Mass Throughput and Improved Mechanical Product Properties

In order to avoid bubble ruptures during the production of blown film, the velocity of the cooling air is often reduced, which has a negative effect on the plant efficiency. The use of air guiding systems (AGS) can prevent such bubble instability. A novel air guidance system was developed at IKV in Aachen, Germany, using iris diaphragms in order to increase the cooling efficiency of blown film extrusion and thus improve the productivity of an existing plant.

Flexible air guiding system in blown film allows higher mass throughputs and greater process stability © IKV

The applications of blown film range from simple carrier bags to hygiene and medical articles such as baby diapers or films for adhesive plasters. All film products have in common that they must be produced with maximum mass throughput and must be of the best possible film quality to ensure maximum plant efficiency. Since the mass throughput strongly depends on the amount of heat removed from the bubble, existing cooling systems are being constantly further developed and optimized [1], which also has a positive effect on the ecological impact (**see Box p. 34**).

Principles and Challenges of Blown Film Cooling

Conventional blown film lines use air cooling rings and internal bubble cooling systems to convectively extract heat out of the film by blowing cooled air from outside and inside at the bubble. If heat conduction and heat radiation are neglected, the convective cooling capacity of a cooling ring can be described with equation 1 (**see Box p. 36**) [2, 3]. A major disadvantage of convective cooling is the low heat transfer coefficient α, which correlates with the Reynolds number of the air flow according to equation 2. According to equation 3, an increase in the heat transfer coefficient can be achieved by increasing the flow velocity of the cooling air v at constant density ρ, characteristic length d and dynamic viscosity η of the air [2, 4].

In the bubble expansion zone, where the film is still in a molten state, the film bubble has only limited melt strength, which restricts the cooling air velocity due to bubble instabilities [5]. Due to the risk of bubble ruptures caused by excessive cooling air velocities, machine operators on blown film extrusion lines are often forced to reduce the cooling air velocities, which also negatively affects plant efficiency. One solution to avoid such bubble instabilities is to use air guiding systems (AGS). AGS can be placed on existing cooling rings. These systems guide the cooling air through a specially designed flow gap between the AGS and film bubble (**Fig. 1**). Furthermore, it is possible to use the so-called Venturi effect by narrowing the flow gap. The Venturi effect results from the Bernoulli equation, which states that the specific energy along a streamline is constant [6–8]. Due to the law of conservation of energy, a change in flow geometry leads to a change in velocity of the fluid, which affects the static pressure.

If the flow gap is narrowed, the flow velocity increases, so that the static pressure decreases. By increasing the flow velocity and simultaneously decreasing the air pressure, both the heat transfer and the bubble stability can be increased [11]. In addition, the reduced static pressure allows an earlier expansion of the film bubble within the AGS, resulting in a larger film surface for heat removal. In order to utilize the advantages of the Venturi effect, however, a significant reduction of the flow gap is necessary. Due to different bubble geometries, which depend on the process parameters and the film width, a significant reduction of the flow gap with existing "rigid" AGS is limited.

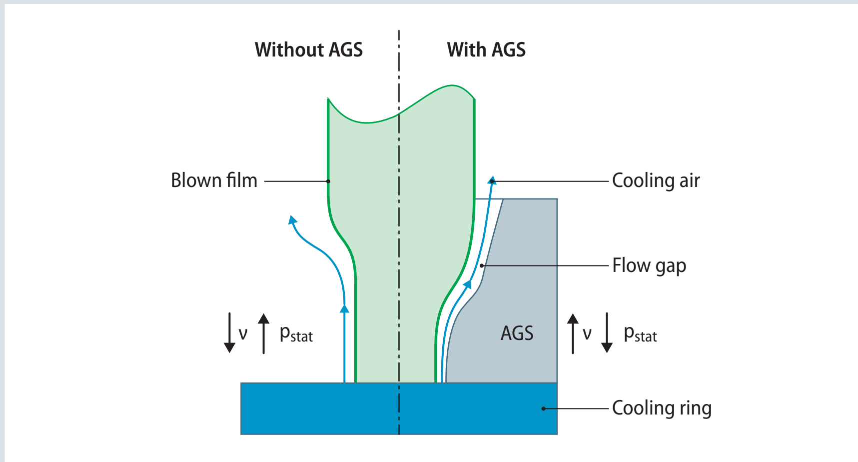

Fig. 1. Venturi effect within an air guiding system (AGS) Source: [9, 10]; graphic: © Hanser

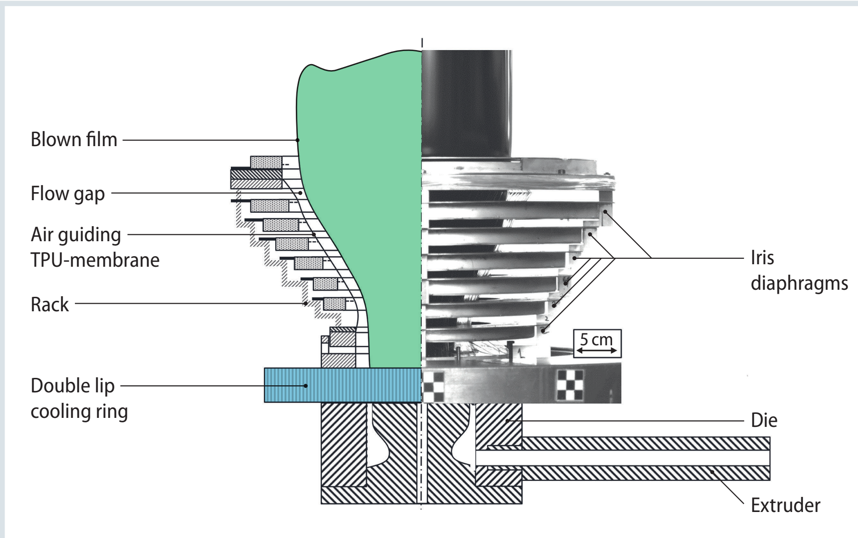

Fig. 2. Schematic diagram (left) and process-integrated AGS (right) in blown film extrusion [10]

Source: IKV; graphic: © Hanser

Development of a Flexible Air Guiding System

For this reason, IKV has developed a flexible air guiding system for blown film extrusion with the aim of increasing the cooling capacity and thus the productivity of an existing blown film extrusion line. This publication deals with the question of how the developed air guiding system influences the mass throughput as well as the film properties such as film thickness variation, mechanics and shrinkage.

Figure 2 shows schematically the area of the bubble expansion zone of a blown film extrusion line, including the flexible air guiding system developed at IKV. The flow gap between the system and film bubble can be adjusted with a transparent and flexible membrane, made of a thermoplastic polyurethane (TPU) of type Desmopan 3690AU from Covestro AG, Leverkusen, Germany. The transparency of the membrane is necessary to set the narrowest possible flow gap between the film bubble and the membrane in order, on the one hand, to make the best possible use of the Venturi effect and, on the other, to be able to adjust the flow gap during extrusion. Six iris diaphragms staggered one above the other are used for fast and radially symmetrical adjustment of the membrane.

Plant Engineering and Design of Experiments

The tests described below were carried out on a blown film extrusion line at the IKV pilot plant. The extrusion line consists of two single-screw extruders (type: KFB 45/600 (L/D=24), manufacturer: Kuhne Anlagenbau GmbH, St. Augustin, Germany) with a 45 mm screw diameter. The screws are 3-zone screws with shear and mixing elements. The dosing of all extruders is carried out by a gravimetric dosing unit (manufacturer: Plast-Control GmbH, Remscheid, Germany). The »

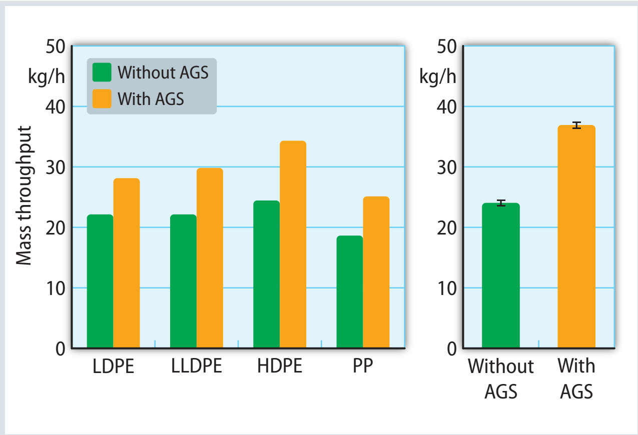

Fig. 3. The use of the AGS developed at IKV leads to increased mass throughputs compared to the conventional process (left average values, right process points, see text) Source: IKV; graphic: © Hanser

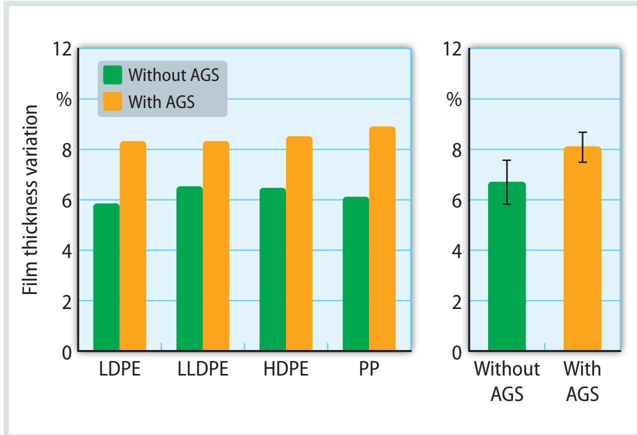

Fig. 4. With the AGS the film thickness variations are higher compared to the conventional process Source: IKV; graphic: © Hanser

melt is fed from the extruders into a radial spiral distributor with a diameter of 80 mm. For the investigations a die gap of 1.5 mm with a land length of 8 mm is used. The used materials are an LDPE (2102 N0W), an LLDPE (6118) and a HDPE (FO4660) from Sabic Europe B.V., Geleen, Netherlands, and a PP (Moplen EP 310 D) from Basell Polyolefine GmbH, Frankfurt/Main, Germany. Depending on the process point, the mass throughput of the plant varies between approx. 15 kg/h and 40 kg/h. For each material, with and without AGS, the design of experiment is based on a full factorial test plan with two variation levels (**Table 1**).

Mass Throughput and Film Thickness Variation

The results of the test series are summarized in the diagrams: **Figures 3 to 8** on the left show the average value from all investigated process points with and without the air guiding system. All shown values are significant. To illustrate the high significance, the right-hand diagram in each picture shows an exemplary process point from the test design (LDPE at BUR = 3.2, film thickness 60 µm, blower output 100 %, T_{Melt} = 200 °C; process parameters **see Table 1**).

With the developed AGS, it is possible to adjust the membrane to the bubble geometry during operation. As a result, the Venturi effect can be induced by the machine operator, independently of the process point. Compared to the conventional blown film process without AGS, the mass throughput can be increased by approx. 30 % on average for all investigated materials (**Fig. 3**). Depending on the process point, even an increase of up to approx. 60 % is possible.

In addition to the mass throughput, the variation of the film thickness must also be investigated as an important quality parameter. The tests showed that the developed AGS leads to an average increase in film thickness variation of approx. 3 % (**Fig. 4**), or even less depending on the process parameters (in **Fig. 4 right** e.g. only approx. 1.5 %). One possible explanation for the increase in film thickness variation is the wrinkling of the air-guiding membrane. During the tests with the developed AGS it turned out that a wrinkle-free clamping of the TPU membrane was not possible, so that an inhomogeneous flow gap between the membrane and the film bubble was created. Areas with a large flow gap lead to lower flow velocities and thus to a worse cooling performance than areas with smaller flow gaps. In theory, the film bubble is stretched longer in the extru-

Savings Potential for Cooling

The continuous optimization of the cooling performance not only results in increasing mass throughputs, it also enables more sustainable packaging products due to energy savings. The most commonly used material for blown film is polyethylene (PE). Compared to other polymers, it has a particularly high specific heat capacity of approximately 2.1 kJ/(kg·K). At a processing temperature of 180 °C, for example, approx. 168 kJ/kg of heat must be dissipated when the PE film cools down to a temperature of 100 °C at the end of the bubble expansion zone. For a medium-size blown film extrusion line with a mass throughput of 700 kg/h, this requires a thermal cooling capacity of approx. 33 kW.

In practice, for extrusion lines with such mass throughputs, use is made of cooling units with a cooling capacity of 100 kW, which in total (cooling ring and internal cooling) provide approx. 7500 m^3/h of cooling air at a temperature of 7 °C. The difference between the process heat to be thermally dissipated and the cooling capacity is all lost power. The electrical power consumption of such cooling units is approx. 35 kW at usual efficiencies. If the cooling capacity is increased by 10 %, e.g. by optimized systems, the energy efficiency of the blown film line can be increased to such a level that, at 7200 operating hours per year, 25,000 kWh (corresponding to a CO_2 equivalent of approx. 15 t) can be saved per blown film line. Per kilogram of a produced blown film, this means a saving of only 2.97 g of CO_2, but with approx. 2.28 million tonnes of plastic being processed into film for packaging applications in Germany, this gives an industry-wide CO_2 savings potential of several thousand tonnes.

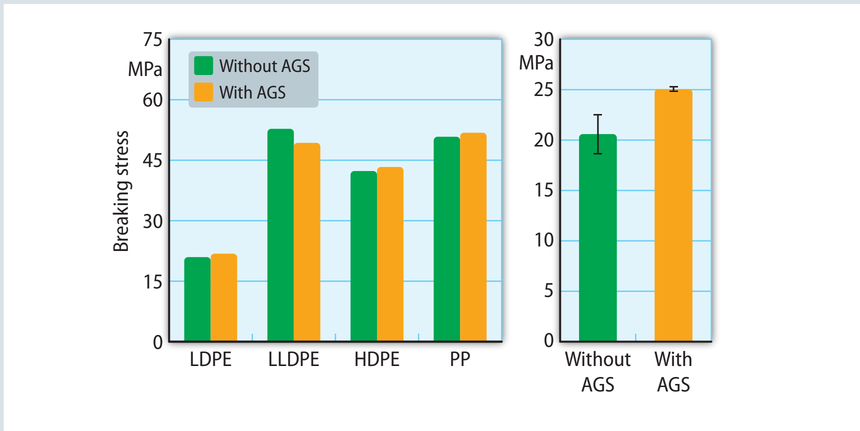

Fig. 5. Breaking stresses: On average, the values increase with the use of an AGS; in the case of LDPE (right), for example, there is an increase of approx. 5 MPa Source: IKV; graphic: © Hanser

sion direction in areas of a large flow gap, which leads to thin points in the film.

Mechanical Film Properties

While the film thickness variation is moderately increased by the AGS, the air guiding system has a positive influence on the mechanical properties. Breaking stress and elongation were determined with a universal testing machine (type: Zwick Z10, manufacturer: Zwick GmbH & Co KG, Ulm, Germany) in a test procedure according to DIN EN ISO 527–1. The clamping length of the film samples, which were loaded at a constant traverse speed of 200 mm/min, was 50 mm.

Figure 5 shows that the breaking stress in the extrusion direction increases on average when using an AGS. As can be »

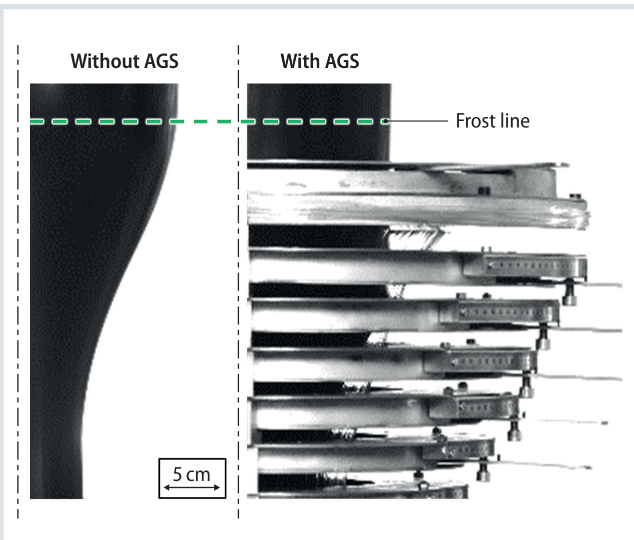

Fig. 6. Compared to the conventional process, the use of the AGS leads to an early expansion of the film bubble Source: IKV; graphic: © Hanser

Process parameter	Unit	Low level				High level			
Blow-up ratio BUR *	[-]	2.4				3.2			
Film thickness d_{Film}	[µm]	60				180			
Blower output P_{Blower}	[%]	50				100			
Melt temperature T_{Melt}	[°C]	LDPE 180	LLDPE 190	HDPE 200	PP 220	LDPE 200	LLDPE 210	HDPE 200	PP 240

** BUR: blow-up ratio*

Table 1. Full factorial design of experiment Source: IKV

The Authors

Lars Kraus, M.Sc., is Group Leader "Process technology Extrusion" at the Institute for Plastics Processing (IKV) at RWTH Aachen University, Germany, and is also mainly responsible for blown film extrusion; lars.kraus@ikv.rwth-aachen.de

Prof. Dr.-Ing. Christian Hopmann holds the Chair of Plastics Processing and is also Head of IKV.

Dr.-Ing. Martin Facklam is Head of the Extrusion and Rubber Technology Department at IKV.

Acknowledgments

The research project 20100 N of the Forschungsvereinigung Kunststoffverarbeitung was sponsored as part of the "Industrielle Gemeinschaftsforschung und -entwicklung (IGF)" by the German Bundesministerium für Wirtschaft und Energie (BMWi) due to an enactment of the German Bundestag through the AiF. We would like to extend our thanks to all organizations mentioned. In addition to these institutions, the authors would like to thank the companies Sabic Europe, Geleen, Netherlands, Basell Polyolefine GmbH, Frankfurt/Main, Germany, and Covestro AG, Leverkusen, Germany, for providing the experimental materials.

Service

References & Digital Version

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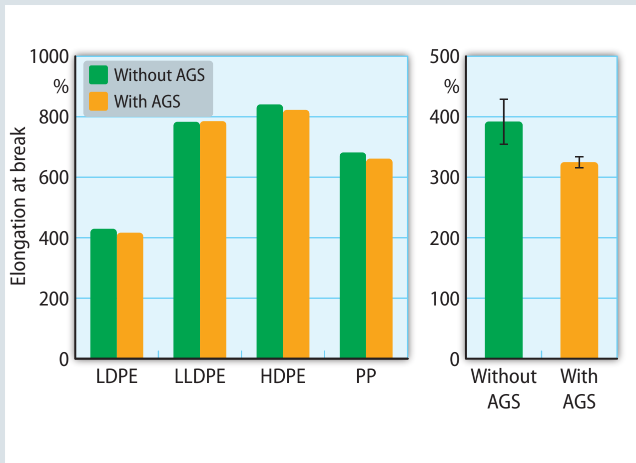

Fig. 7. Compared to the conventional process, the use of the AGS leads to decreasing elongation at break Source: IKV; graphic: © Hanser

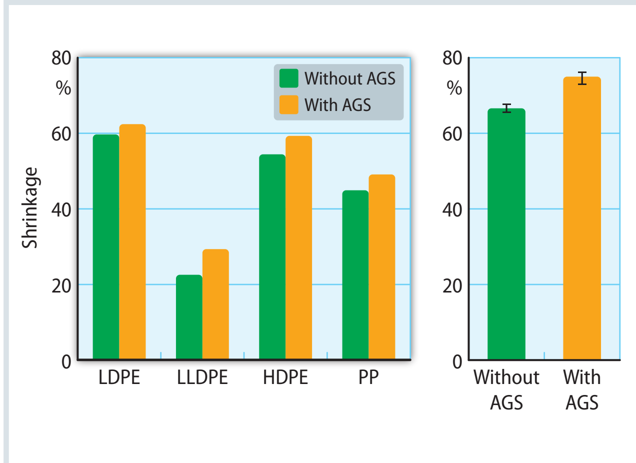

Fig. 8. Compared to the conventional process, the use of the AGS leads to increased shrinkage properties Source: IKV; graphic: © Hanser

Equations

$$\dot{Q} = A \cdot \alpha \cdot \Delta T \quad (1)$$

where: $\dot{Q}$: Heat flow
A : Blown film surface
α : Heat transfer coefficient
ΔT : Temperature difference between the blown film surface and the cooling air

$$\alpha_m = \frac{\lambda}{d} \cdot \mathrm{Nu}(\mathrm{Re}, \mathrm{Pr}) \sim \mathrm{Re} \quad (2)$$

where: λ : Thermal conductivity of cooling air
d : Characteristic length
Nu : Nusselt number
Pr : Prandtl number
Re : Reynolds number

$$\mathrm{Re} = \frac{\rho \cdot v \cdot d}{\eta} \quad (3)$$

where: ρ : Cooling air density
v : Flow velocity of the cooling air
η : Dynamic viscosity of air

seen in **Figure 6**, the use of the AGS leads to an earlier expansion of the film bubble within the AGS, so that the film bubble has already expanded earlier in its width. Until it reaches the frost line, which is defined by the crystallization temperature of the material, the film bubble is still in a molten state and can therefore be stretched much more in the extrusion direction within the AGS than in the conventional process. This results in stronger orientations inside the film, which leads to an increase in breaking stress. At the same time, the orientations ensure that the film is pre-stretched much more than in the conventional process without AGS. As a result, the film can only be stretched to a lesser extent under load, so that the films have a lower elongation at break than conventionally produced films (**Fig. 7**).

This increase in orientation in the extrusion direction can also be visualized by measuring the shrinkage. **Figure 8** shows stronger shrinkage properties of the film compared to the conventional process. At the relevant process point (**Fig. 8 right**), the shrinkage of the film with AGS increases by approx. 10 % compared to the conventional process. The higher the degree of orientation, the higher the shrinkage. This can be attributed to relaxation effects within the film.

Conclusion and Outlook

The development of a flexible air guiding system in blown film production allows a TPU membrane to be adapted flexibly to the film geometry during the extrusion process with the aid of iris diaphragms, which significantly increases the efficiency of conventional cooling rings. In this way, the Venturi effect can be created independently of the process parameters and the used materials. Compared to the conventional process, an increase in throughput of about 30 % on average is possible. However, the thickness variation of the film increases by approximately 3 %. In addition, the breaking stress and shrinking properties are even higher, while the breaking elongation of the blown film is lower.

To simplify the use of the developed AGS in production, a control system for the automatic operation of the AGS should be developed. This includes, for example, concepts that provide for an automatic adjustment of the flow gap to ensure maximum process stability and allow easy start-ups of the process. ■