

Gels in polyethylene films

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In the purest sense, a “gel” is a three-dimensional polymer network of sufficient crosslink density that prevents it from flowing. In practice, however, the term “gel” is also used to describe a variety of visual defects in films. Such defects can include crosslinked polymeric gels, non-crosslinked polymeric gels and nonpolymeric defects such as fibers, dust, additives and moisture. Nonpolymeric gels are typically introduced from external sources.

Key point

- Gels prevent flow, create weak spots and cause optical defects

Type of gel	Common causes	Distinguishing features
Point gels	<ul style="list-style-type: none"> ▪ Crosslinked resin ▪ High molecular weight resin that hasn't melted ▪ Foreign resin ▪ Inorganic agglomerates ▪ Dirt, dust or die build-up ▪ Oxidized resin 	<ul style="list-style-type: none"> ▪ Glassy ▪ Glassy ▪ Various colors ▪ Opaque, sandy ▪ Black or brown ▪ Yellow, orange, brown, black
Arrow-shaped gels	<ul style="list-style-type: none"> ▪ Melt index (MI) variation or too low melt temperature in a blend ▪ Interlayer flow disturbances in coextruded film 	<ul style="list-style-type: none"> ▪ Arrow-shaped flow lines
Gel flurries	<ul style="list-style-type: none"> ▪ Occasional release of higher molecular weight resin from the secondary separator of a low density polyethylene (LDPE) reactor 	<ul style="list-style-type: none"> ▪ Shower of clear, translucent gels that appear randomly on the film
Irregular-shaped gels	<ul style="list-style-type: none"> ▪ Foreign resin ▪ Degraded resin ▪ Dirt, dust or die build-up ▪ Oxidized resin 	<ul style="list-style-type: none"> ▪ Various colors ▪ Yellow, orange, brown, black ▪ Typically black, brown ▪ yellow, orange, brown, black
Fiber gels	<ul style="list-style-type: none"> ▪ Nylon, PP fibers ▪ Wood ▪ Paper, cellulose ▪ Cotton 	<ul style="list-style-type: none"> ▪ Fibers that can be melted ▪ Brown irregular chip, non-melting ▪ Colored, fibrous, non-melting ▪ Colored string, non-melting
Fisheyes gels	<ul style="list-style-type: none"> ▪ Moisture or excessive humidity 	<ul style="list-style-type: none"> ▪ Lens-shaped gels with “fisheyes” at both ends

Visual examples of gels

Figures 1 to 8 show visual examples of various gel types as viewed under an optical microscope.

Figure 1: Point gel - a gel formed by a foreign resin/body



Figure 2: Point gel - a gel due to dust or sand contamination

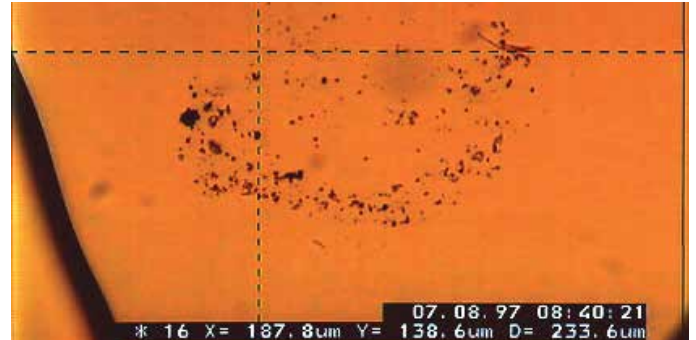


Figure 3: Arrow-shaped gel - a gel with arrow-headed flow lines

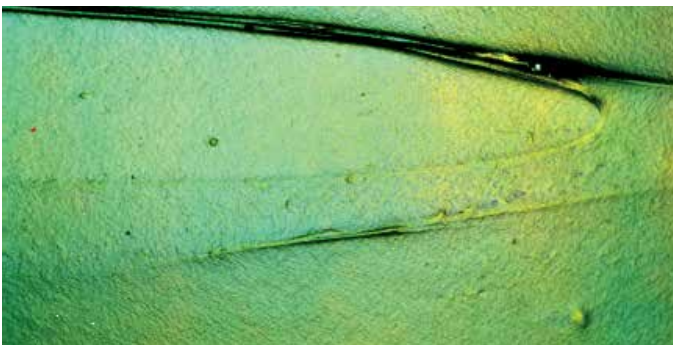


Figure 4: Gel flurries - a gel that appears randomly on the film

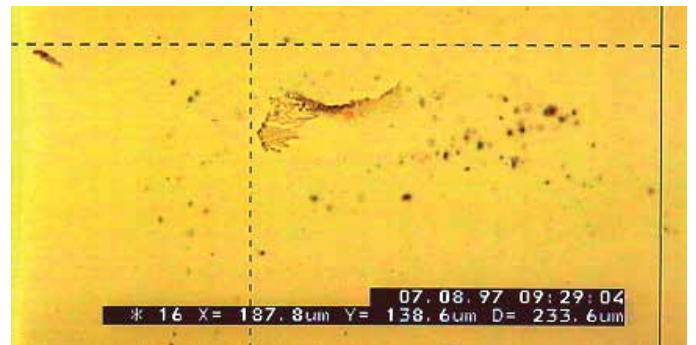


Figure 5: Irregular-shaped gel - a gel formed due to foreign resin, oxidized polymer, dirt, etc.

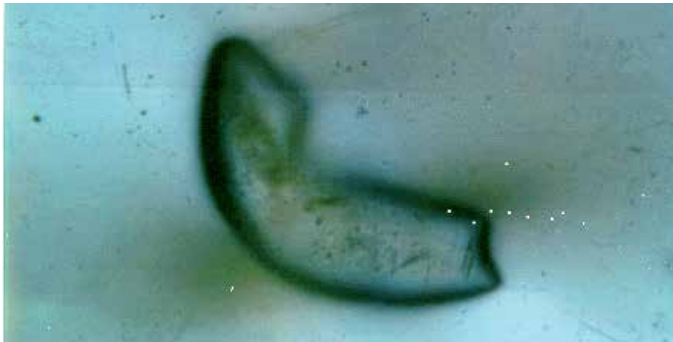


Figure 6: Fiber gel - a gel formed by a cotton fiber

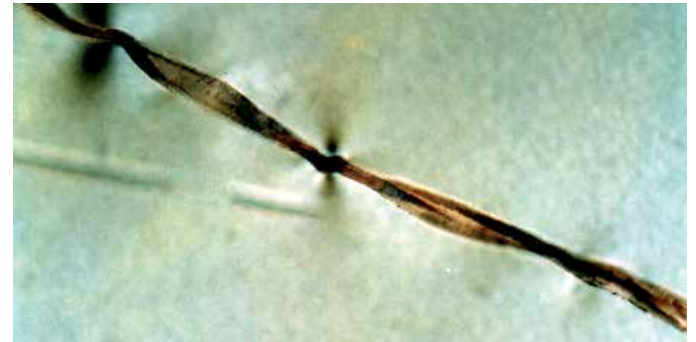


Figure 7: Fiber gel - a gel formed by a wood chip

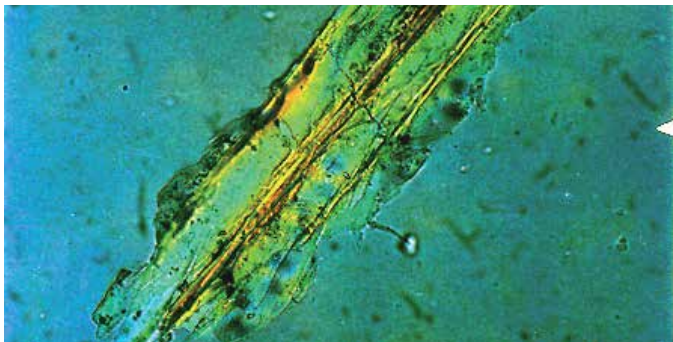


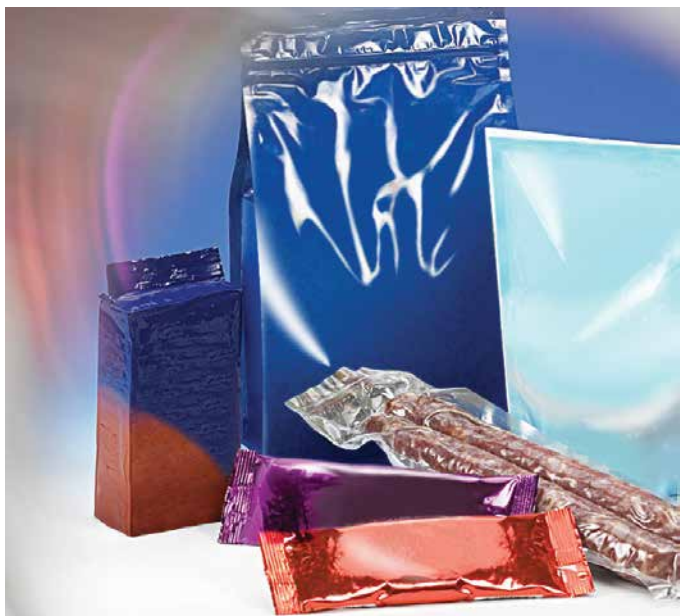
Figure 8: Fisheyes gel - a lens-shaped gel with "fisheyes"



Addressing gel problems in film extrusion

Resolving a gel problem can be time consuming, challenging and expensive, requiring patience and sometimes just good luck. Importantly, these problems should be approached in a systematic and logical manner. This table lists several sources of gels that can be encountered during film extrusion and a corresponding list of troubleshooting tips.

Source of gels	Troubleshooting
Naturally present in the resin or masterbatch, as received	<p>All resins contain gels to some degree. The size and number are largely dependent on (i) the manufacturing process (ii) manufacturing conditions, and (iii) the level of thermal stabilizers in the resin:</p> <p>For gel-sensitive applications (e.g. lamination, surface protection films):</p> <ul style="list-style-type: none"> ▪ Use resins known to contain low gel levels ▪ Consider installing a gel scanning device ▪ Add a suitable antioxidant masterbatch, as necessary
Resins or resin blends with low to moderate levels of thermal stabilization	<ul style="list-style-type: none"> ▪ Replace with resins known to contain low gel levels/appropriate stabilization packages ▪ Add antioxidant masterbatch, as necessary
Unmelted particles arising from insufficient melting or mixing (e.g. poorly dispersed additives/pigments)	<ul style="list-style-type: none"> ▪ Ensure that the additive in the raw material is well-dispersed ▪ Ensure sufficient melt pressure for good mixing ▪ Ensure correct extruder screw design with effective mixing sections/elements ▪ Ensure extruder screw or barrel are not excessively worn ▪ If the cause of unmelted resin is believed to be due to “overpacking” of the screw (in grooved feed extruders), increase the temperature of the cooling water in the grooved feed section
Large melt viscosity difference between resins	<ul style="list-style-type: none"> ▪ Replace the higher-viscosity resin with a lower-viscosity resin ▪ Increase melt temperature and back mixing ▪ Ensure resin with higher melt viscosity is the dominant blend partner, where possible ▪ In coextruded film, change the melt velocity by changing output; hence layer distribution or modify channel dimensions
Excessive melt temperatures leading to crosslinked or degraded resin	<ul style="list-style-type: none"> ▪ Check resin supplier’s recommended temperature settings and adjust accordingly ▪ a persistent high melt temperature indicates excessive shear heat ▪ Modify the structure with easier processing resins ▪ Check the screw for wear and replace, as necessary, or consider using an improved screw design ▪ Reduce output and/or modify the temperature profile to reduce melt temperature
Recycled resin with low thermal stabilization and/or contaminants	<ul style="list-style-type: none"> ▪ Filter contaminants from recycled resin/scrap, where possible ▪ Reduce the amount or eliminate recycled resins ▪ Add antioxidant masterbatch
Carbonized resin from dirty extruder screw/die and/or contaminated screen packs	<ul style="list-style-type: none"> ▪ Remove the screw and disassemble the die, clean thoroughly, use a purge compound as necessary ▪ Replace screen packs more frequently
Die fouling or die build-up	<ul style="list-style-type: none"> ▪ Disassemble the die and clean; remove die build-up
Contaminated resin hoppers, feeders or conveying lines	<ul style="list-style-type: none"> ▪ Ensure resins are completely removed from the hopper/feeder prior to a resin change ▪ Conduct regular inspections of conveying lines and filters ▪ Remove excess dust/external contaminants from raw material bags before emptying into bins



Lamination film



Surface protection film

Importance of measuring gels

The number, size and type of gels can affect film extrusion, lamination and end use:

- Large gels can cause film breaks or reduce the drawdown ability, especially at high line speeds.
- Gels can cause weak spots and reduce mechanical strength and sealing performance.
- Gels can reduce the barrier properties of laminated films, especially those with aluminum foil or metallized films.
- In high-clarity films, gels can reduce optical performance and detract from the aesthetic appeal of the packaging.
- In surface protection films, gels are unsightly and can cause tearing during peeling, resulting in scratches in the surface being protected.
- In lamination films, excessive gel content can cause optical imperfections, printing and sealing problems. Hard crosslinked gels, in particular, can damage expensive printing plates.

Techniques to evaluate gels

Film appearance rating

Resin suppliers typically assess the gel levels of production lots against a manufacturing specification using simple quality control (QC) techniques. For film grades, a common method employed worldwide involves a visual inspection of a test film, which is compared against a series of reference films to give a "film appearance rating" (FAR). Although this test does not classify the size, type and number of gels, FAR is generally a reliable indicator of gel levels during normal production conditions. If the test film is not adequately represented by any of the reference films, however, the FAR rating becomes a very subjective measurement and, in extreme cases, irrelevant. Furthermore, as the test is only carried out periodically, any gel problem that might occur between tests is not detected.

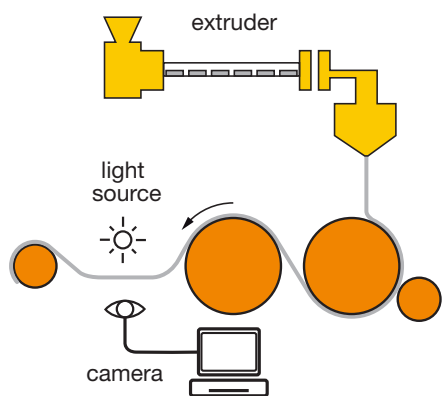
Manual classification of gel number and size

An improvement on the FAR measurement is to manually count the number of gels within certain size ranges that occupy a certain area of test film. The size ranges are often selected to reflect "small," "medium" and "large" gels, which simplifies the setting of the gel specification. Both techniques are relatively labor-intensive, however, and they are performed only periodically using small amounts of resin sample that is assumed to be representative of the production lot. Any gel problem that arises between tests will naturally go unnoticed.

Automated classification using optical scanning devices

The limitations of FAR and manual classification, combined with the increasing demand for "low gel" films, have driven some resin suppliers such as ExxonMobil Chemical to invest in automated optical scanning devices. These devices can detect, record and classify film defects based on size and type. Such devices can be installed in-line to provide continuous monitoring of gels with minimal supervision. An alarm system alerts the operator of a gel upset at the precise time it occurs, which allows corrective action to be taken immediately, thus reducing scrap.

Figure 9: Schematic representation of a film being assessed for gels using an optical scanning device



Optical quality control system

In recent years, the polyethylene film industry has been transitioning to optical scanning systems for quantitative gel measurement. Many of ExxonMobil Chemical's polyethylene plants now employ such devices, made by OCS GmbH (figure 9). A video camera captures images of the film, which are then analyzed by a computerized system. The system looks for areas of film that are darker or alter light differently, which indicates the presence of a gel or film defect. When a gel is detected, its picture is stored and the area of the defect is calculated using a grid system. Often this is expressed as an equivalent circular area, with the degree of circularity allowing streamers and fibers to be detected. For grading purposes, ExxonMobil Chemical has now replaced Film Assessment Rating (FAR) with Total Defect Area (or TDA) as measured by the optical scanning system. For further queries on TDA measurements, please consult your ExxonMobil Chemical sales representative.

Hot stage/FTIR microscopy

Infrared microscopy couples an optical microscope containing a hot stage to an infrared spectrometer. This analytical technique can be employed to determine:

- the melting characteristics of the film defect
- the chemical composition of the film defect based on its absorption of infrared radiation
- the position of the film defect within a multilayered film

Typically, a small piece of film sample containing the defect is cut out and placed on the hot stage. Initially, the sample is slowly heated at a uniform rate (e.g. 10°C/min) and the melting characteristics are monitored through the microscope. The crystallization of the defect can also be monitored in a similar fashion by controlled cooling of the melt. The information provided by an FTIR scan can often help identify whether the defect is a polyethylene, another polymer type, oxidized polymer, inorganic material, cellulosic material, etc.

ExxonMobil Chemical can provide this specialized analytical service for its customers at its world-class global technology centers.

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