Controlling the barrier properties of polyethylene terephthalate. A review

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Selected from International Polymer Science and Technology, 41, No. 11, 2014, reference PM 14/3-4/46; transl. serial no. 17308

SUMMARY

Polyethylene terephthalate is one of the most widely used materials in the production of containers and packaging. However, its application is limited by its low barrier properties in relation to oxygen and carbon dioxide. Methods used for the manufacture of containers with improved gas barrier properties are discussed.

Polyethylene terephthalate (Lavsan, PET) is a multifunctional thermoelastic polymer of structural and antifriction designation that possesses a valuable set of service properties: high mechanical strength, rigidity, viscosity, and hardness, low thermal expansion, very good resistance to crack formation, low moisture absorption, a low friction coefficient, excellent wear resistance, and good electrical insulation properties and radiation resistance. Lavsan readily lends itself to machining – milling, turning, drilling, polishing, welding, and end products of Lavsan are noted for good dimensional stability [1–3].

Research into polyethylene terephthalate was begun in 1935 in the United Kingdom by John Whinfield and James Dixon at the company Calico Printers Association Ltd. In 1943, patent applications were submitted and registered on the synthesis of fibre-forming polyethylene terephthalate. In the USSR (in Russia), scientific research in the field of the synthesis of polyethylene terephthalate was begun under the supervision of Academician V.V. Korshak in 1949. Work on industrial technology for the synthesis of polyethylene terephthalate and the production of fibres was done at the All-Union Scientific Research Institute of Artificial Fibres (in Mytishchi) under the supervision of Prof. B.V. Petukhov and Prof. E.M. Aizenshtein, and in 1956, at the same institute, the trial production of Lavsan fibres was begun. On the basis of this work, the industrial production of polyethylene terephthalate and Lavsan fibre was started at the Kursk Chemical Fibre Integrated Works. In 1969–1971, the assembly and start-up of a large-scale plant for the production of polyethylene terephthalate and polyester fibres were carried out at the Mogilev Chemical Fibre Integrated Works (Belorussia) [4, 5].

Bottle-designation, granular PET of grade TVERPET is now being produced by OAO Sibur-PETF (Tver), set up in August 2003, with equipment supplied by the German engineering company Zunner AG.

Fibre and film PET is not being produced in Russia at present. This is associated with features of the Russian polyethylene terephthalate market. In contrast to the world market, where 65% of PET is used to produce fibres, and only 27% to produce preforms, in Russia 95% of all PET entering the Russian market is used to manufacture preforms, and only 3% to produce fibres [6].

Polyethylene terephthalate is an excellent material for the production of packaging and bottles for different
products. PET containers are transparent, possess an attractive appearance, can be produced in different colours, and can take any desirable shape. However, for the packaging of beer and other alcoholic drinks, juices, children’s drinks, and pharmaceutical products, it is poorly suited on account of its low barrier properties with respect to oxygen and carbon dioxide and its lack of resistance to UV rays. In this context, in many countries, work is being conducted on developing polyethylene terephthalate containers with improved barrier properties and low gas permeability values. All these investigations can be divided into three main directions:

1. the creation of multilayer containers, with one layer possessing high barrier properties;
2. the application of a surface coating on one surface of bottles of single-layer PET;
3. the development of single-layer containers containing different components and additives improving the gas barrier properties of the packaging material.

The development of coextrusion technology made possible the effective production of multilayer plastic structures within a single pass on one machine. Coextrusion (coinjection) is a process of simultaneous combined extrusion of more than one polymer by pressing through a forming head with the formation of individual layers connected to each other. The appearance of the coextrusion process promoted an even greater growth of the barrier packaging sector at the end of the 1970s and beginning of the 1980s [7]. Before this, multilayer materials were manufactured by pressing two plastic layers together by means of heat or adhesive. The process was slower and less effective. To this day, pressing remains an important method for the development of multilayer materials, especially combinations of polymers that lend themselves poorly to combined extrusion.

To improve the barrier properties of articles manufactured from polyethylene terephthalate (PET), a multilayer material is proposed, one of the layers of which is a thermoplastic material with low gas permeability. The article contains an inner and an outer layer. The inner layer has two discrete sublayers: one of the sublayers contains polyethylene terephthalate, and the other contains a barrier material made of thermoplastic of the phenoxy type or a copolymer of terephthalic and isophthalic acids and at least one diol. The outer layer contains processed polyethylene terephthalate [8].

Layered material with an inner layer containing a polyolefin (polypropylene or polyethylene), an outer layer containing a polyester (polyethylene terephthalate), and an intermediate layer containing silicon oxide is used for the production of material possessing barrier properties in relation to gaseous ethylene oxide [9].

DevTech Labs, a company engaged in technologies for producing PET bottles, has developed a hybrid system combining coinjection and successive moulding cycles for the production of preforms of barrier PET with 6–9 layers. Such a structure increases the accuracy of production of the layers and accomplishes orientation of the layers for optimising the barrier properties.

Owens-Illinois in Chicago is using a five-layered coinjection of patented passive-active barrier materials for the production of packaging for foodstuffs, from ketchup to beer. Its barrier material, SurShield, includes nylon MXD6 and an oxygen absorber in two ultrathin layers placed between outer layers of PET and a core layer including up to 35% recycled material. It is reported that the barrier against oxygen and carbon dioxide is increased by 40%.

A new polyamide nanocomposite barrier material, Imperm, has been developed by Eastman Chemical Co. (Kingsport, Tennessee) in collaboration with the nanoclay producer Nanocor (Arlington Heights, Illinois). Intended for use in the production of multilayer bottles, the nanocomposite can ensure an antioxygen barrier that is 50–100 times more effective than in the case of PET. Note that nylon MXD6 ensures a 10–20-fold improvement in the barrier by comparison with PET [10].

Film for foodstuffs, manufactured by blow extrusion, contains seven layers. As a barrier to oxygen, the film contains a layer of copolymer of ethylene and vinyl alcohol (EVOH), and the outer layer is formed from material with high heat resistance, such as polyethylene terephthalate (PET), which, along with improved optical properties, also makes it possible to increase considerably the processing rate (the number of working cycles) by comparison with methods known hitherto [11].

The company Constar International is using a three-layer structure with a barrier layer of nylon MXD6 and an oxygen absorber. The given passive-active barrier system, Oxbar, is intended for the production of packaging for juices, hot-packed foodstuffs, and beer [12].

A bottle extruded by blow moulding has been developed, consisting of a first inner layer and a second layer. The first inner layer is made of thermoplastic material of the phenoxy type, phenoxypolyolefins and their combinations. The second layer is made of a foam material including expandable material and a support material. Material of the polyethylene terephthalate group has been chosen as the material for the second layer. When such a bottle manufacturing method is used, an effective thermal barrier reducing any heat exchange through the container or packaging is ensured [13].

The Russian company ZAO Mir Upakovki (St Petersburg) has assimilated innovative technology for the creation of multilayer adhesive-free barrier packaging by injection moulding. The given packaging not only possesses high barrier properties and can replace glass jars and tin cans but also guarantees protection against adulteration owing to its visible
multilayer structure [14].

Gas-protective properties of packaging are particularly important for pharmacological compounds, which can interact with oxygen remaining in the container and entering the packaging from without. The oxygen present within the product, in the free space of the packaging, and in the walls of the packaging after sealing is termed “residual oxygen”. The oxidation of a packaged product can be slowed down by using packaging materials and structures with high “passive” barrier characteristics and combining them with methods for packaging in a modified atmosphere, such as vacuum packing, and/or filling the free space of the packaging with inert gas before sealing. The passive barrier against the penetration of oxygen acts as a physical obstruction which reduces or eliminates diffusional transport of oxygen through the wall of the container but does not interact chemically with oxygen. Such methods of protection are often inadequate for ensuring the required duration of storage and preventing loss of activity of the product. In this context, technology has been proposed for producing heat-shrink plastic film and sheet structures, which includes at least two active oxygen-absorbing layers placed in succession: a layer rapidly absorbing oxygen, with high activity, including a matrix polymer permeable for oxygen and an oxygen absorbent, and a layer of long-lasting action, including a passive high-barrier matrix polymer for oxygen (polyethylene terephthalate) and an oxygen absorber. The production method consists in the successive application of the indicated layers onto a constant polymer substrate from aqueous coating solutions [15]. The authors have proposed that oxygen absorbers be introduced into the packaging material, forming the walls of the container. Such structures are referred to as “active barriers” to the penetration of oxygen, as they not only physically limit the rate of diffusion of oxygen through the barrier but also chemically react with the penetrating oxygen, thereby reducing the real rate of oxygen penetration even more. Such active barriers are most preferable because they potentially can absorb oxygen trapped within the packaging. The lowest rates of passage of oxygen and the most significant improvement in the barrier properties are observed when rapidly reacting parts of the oxygen absorber are introduced into matrix material with the highest barrier characteristics, i.e. material with the lowest oxygen diffusion coefficient. The index of improvement in the barrier properties is defined as the ratio of real oxygen flow through an active barrier layer to the flow through a passive barrier layer essentially made of the same matrix material. The rapidly absorbing active layer, i.e. the inner layer, is produced from heat-shrink polymer with high oxygen permeability (such as a heat-shrink adhesive on an acrylic base, a thermoadhesive of modified thermoplastic material based on cellulose or ethylene–vinyl acetate (EVA) copolymer), into which are introduced oxygen absorber particles dispersed in the matrix polymer or covalently bonding with it. Anthraquinone derivatives can be used as such additives. The oxygen-absorbing layer includes a heat-shrink acrylic polymer, ethylene–vinyl acetate copolymer (EVA), hydroxypropylene cellulose, and other modified plastics based on cellulose or their mixture with polyol, polyvinyl alcohol (PVOH), or a copolymer of ethylene and vinyl alcohol (EVOH) added to it in a quantity of 0.5–50 wt% [15]. Thus, it has been found that the entire three-layer “active-active-passive” structure is suitable for the simultaneous rapid removal of residual oxygen and prevention of ingress of oxygen from the ambient atmosphere for 2 years in order to maintain an oxygen-free atmosphere within the packaging. The final three-layer structure was obtained by extrusion application of a coating from a melt of anthraquinone derivative and acrylic polyhydroxy resin on a PET substrate covered with an aqueous solution of polyvinyl alcohol (PVOH).

Containers for pharmacological compounds should withstand the process of sterilisation by irradiation, but most polymeric materials change their properties when exposed to UV rays. A plastic multilayer container has been proposed for the storage of sterile composites that consists of three layers: a polymeric layer, a gas barrier layer, and an adhesive layer. The container can include five or six layers: inner and outer layers of polymer (polyolefin or polyester – PET), which are in direct contact with the composite and with the surrounding medium, a central gas barrier layer, and two intermediate adhesive layers, each of which ensures adhesion of the polymer layer to the central gas barrier layer. In the proposed invention [16], the inner layer of the container is made of polypropylene, whereas the outer layer includes a mixture of polyolefins: linear and branched. The branched polyolefins contain an alkene – polyoctene. They are used in a ratio of 5–25%. The outer and inner layers include antioxidants approved by the European Pharmacopoeia, such as butylhydroxytoluene, ethylene bis[3,3-bis[3,11,1-dimethylethyl]-4-hydroxyphenyl]butanoate, Irganox 1010®, Irganox 1330®, Irganox 1076®, Irganox168®, and others. Ethylene vinyl alcohol (EVOH) or polyamide (PA) comprise the gas barrier agent of the central layer. EVOH has a flow index of 1–5 g/10 min, a density of 1.19 g/cm³, a melting point of 183°C, a glass transition temperature Tg of 69°C, and a gas permeability with respect to oxygen P02 of 0.4 mL 20 μm/(m² day atm). The adhesive layer of the agent can be formed from ADMER® compounds, which are produced by Mitsui Chemical, such as, for example, ADMER QB 501 E® [16].

In spite of the improvement in the consumer properties of multilayer containers, they have a number of significant shortcomings:
1. Recycling and reprocessing are problems. As most multilayer materials contain more than one type of plastic, they cannot simply be collected and processed, for example together with high-density polyethylene or PET [7].

2. The most significant shortcoming of multilayer containers is their higher cost (by comparison with single-layer packaging) – the equipment for the production of multilayer PET bottles costs, on average, twice as much as normal equipment [17].

3. The extrusion technology is complex. Another widely used method for controlling the barrier properties of polyethylene terephthalate containers is the application of coatings on their inner or outer surface. This is a relatively new barrier technology, which essentially consists in a normal blown PET bottle being filled with a special gas mixture, which, when exposed to external microwave radiation, is converted into a plasma state and deposited in a microscopic layer on the inner walls of the container. By an alternative method it is possible to apply a coating on the outer wall of the bottle as well, by placing it in a gas-spray chamber. Both methods of coating application are characterised by the creation of a thin but very effective barrier layer preventing the penetration of gases through the walls of the packaging. On the other hand, when the container is deformed, particles breaking away from this brittle inner barrier may enter the product. Therefore, at this time, a major problem in the application of an additional coating that is slowing down its wide use is the mechanical damage to the barrier layers during pasteurisation or transportation [18].

A third method for increasing the barrier properties of PET is to introduce into the raw material different additives reducing the “transparency” of polyester for gases. Such additives may be the same barrier materials developed for multilayer containers. The main limitation of such application is the harmlessness of the barrier additives for foodstuffs when they come into direct contact [18].

A polymer composite intended for the production of food containers has been produced that includes polyethylene terephthalate, titanium oxide, and iron oxide. The mass ratio of titanium to iron oxide amounts to 150:250. The method for producing the polymer composite for the production of food containers, including polyethylene terephthalate, titanium oxide, and Fe₃O₄, includes the following stages:

i. the production of terephthalate and ethylene glycol;
ii. the addition of titanium oxide and Fe₃O₄;
iii. the polymerisation of the obtained reaction mixture;
iv. the pelletisation of the polymerised reaction mixture;
v. increase in the molecular weight of the obtained polymer in a subsequent process of solid-phase polycondensation.

The invention makes it possible to produce food containers with improved characteristics in terms of absorption and reflection of light, and improved light-protective properties [19]. However, with improvement in the permeability of the packaging, its transparency is lost, which is not always convenient for consumers.

Bottles of thermoplastic polyethylene terephthalate are being increasingly used for the storage of different liquids, in particular for the storage of foodstuffs, such as water, beer, and sugar-containing fizzy and still drinks. The long storage life of milk produced by UHT technology requires certain specific properties of the containers, bottles, or cartons used. In fact, the taste of milk changes when it is exposed to radiation from the UV and/or visible parts of the spectrum. When exposed to such radiation, milk acquires a degraded taste, classified as “milk with a light-affected taste”. A change in taste of this kind is due to breakdown of the vitamin B₂ (riboflavin) contained in the milk by the action of light. The degree of breakdown of this vitamin depends on the intensity of the light source and the wavelength range of this light source acting on the product. It is waves having a length of 350–520 nm that are, it seems, the cause of the indicated breakdown of this vitamin, and consequently the cause of deterioration in the taste of the milk. Technology has been proposed for the production of non-transparent single-layer packaging products based on polyethylene terephthalate intended for the packaging and storage of products, in particular bottles enabling certain types of product, such as milk, to be stored under conditions of protection against radiation from the UV and visible parts of the spectrum. Articles are produced by pressure blowing from a composite including polyethylene terephthalate and 4–40% wt% filler of mineral origin, consisting of white pigment such as titanium oxide or zinc sulphide. Here, the value of normal transfer of light radiation in the wavelength range 350–550 nm through the walls of an article of 0.2–0.5 mm thickness is below 0.25% [20].

A method for producing packaging products includes the production of a polymer mixture of polyactic acid and polyethylene terephthalate and its stirring, heating, extrusion, and blow moulding. The obtained composites possess improved properties, including increased strength, flexibility, breaking elongation, heat resistance, processability, air permeability, and ability to form unsmoothenable folds [21]. This composite can be used to give an aesthetic appearance to packaging.

A composite has been obtained for the production of containers for foodstuffs and drinks that contains the matrix polymer (polyester) and filler. This matrix polymer is produced by the polymerisation of a mixture containing...
dicarboxylic acid and diol. The intrinsic viscosity of the matrix polymer at 30°C in mixed solvent amounts to 0.7–0.9. The filler is an organoclay dispersed in polyamide containing polymerised units of meta-xylendiamine and organoclays in the form of nanofilms. The composite possesses improved gas permeability characteristics [22]. The problem in producing such composites is the limited stability of the organoclay dispersions.

A container with improved barrier properties for the packaging of foodstuffs and drinks is produced by the blow moulding and stretching of preforms of a polyester composite. The polyester composite contains a polyester (polyethylene terephthalate) and a purine derivative as a gas barrier additive of the following composition:

![Image]

The containers possess an improved barrier in relation to carbon dioxide and oxygen, without any reduction in container transparency [23]. However, caffeine and their purine derivatives used as additives may enter the medium of the product, and then the body, increasing the amount of uric acid and urates in the human body. It is also well known that, in an alkaline medium, purine bases undergo keto-enol tautomery, which may cause a deterioration in optical properties and transparency of the packaging.

The comparatively high permeability of polyethylene terephthalate for carbon dioxide limits the use of small-sized PET containers for the packaging of fizzy non-alcoholic drinks. The rate of penetration of carbon dioxide through PET containers amounts to 3–14 cm³/day, or the intensity of losses amounts to 1.5–2% at room temperature, depending on the size of the container. Small containers have a greater ratio of surface area to volume, as a result of which the relative intensity of losses increases. For this reason, PET is currently used for the manufacture of large containers for the packaging of fizzy non-alcoholic drinks. The amount of carbon dioxide retained in the packaged fizzy non-alcoholic drink determines its storage time. It is customary to assume that the storage time of a packaged alcohol-free fizzy drink runs out when the loss of carbon dioxide through the side wall of the container and lid amounts to 17.5%.

To improve the gas barrier properties of PET to molecules of gas, it is proposed that a chemically active additive be introduced, to improve the gas barrier, in a quantity of 0.01–10 wt%. As the active additive, use is made of a compound of the formula R₁OOC–AR–COOR₂, where AR is phenylene and naphthalene, and R₁ and R₂–C₁–C₁₀ are alkyl, phenyl, and naphthyl groups. The proposed container containing the barrier additive makes it possible to increase the storage time of its contents by 20% by comparison with a container without the additive [24]. Thus, the introduction of low-molecular-weight polyesters containing bulky radicals leads to an increase in the storage time of the gas-containing drinks from 8–9 weeks to 10–11 weeks.

A container having an index of improvement in the barrier properties of at least 1.05 is being produced by blow moulding and stretching of a polyester composite containing a polyester (PET) and an additive enhancing the gas barrier, which comprises a dicarboxylic acid diester [25].

Moulded products, such as films, sheets, and thin-walled hollow containers, are being produced from a polymer composite containing 2–30 wt% polyamide resin, 69.5–97.99 wt% polyester resin, and 0.01–0.5 wt% polycarboxylic acid. The method for producing the polymer composite involves the production of a composite by mixing of two components in a melt. The article is produced by moulding of the polymer composite. The proposed composite is slightly coloured and has improved gas barrier properties, transparency, and mechanical properties [26].

The addition to PET of materials that are oxygen absorbers ensures “active” barrier properties, as the given additives enter into chemical reaction with oxygen found in the free space over the product in the container, and are also capable of absorbing oxygen penetrating through the walls of the bottle. Food and drinks (such as beer and fruit juices), cosmetics, medical compounds, and so on, are particularly sensitive to the action of oxygen and require high barrier properties in relation to oxygen in order to retain the freshness of the contents of the packaging and in order to avoid any change in taste, structure, or colour.

The oxygen absorbers most widely used commercially include iron oxide, salts of unsaturated fatty acids, and metal/polyamide compounds. One of the single-layer PET materials containing oxygen absorbers is MonOxbar. It is produced by Constar International, Inc. (Philadelphia, Pennsylvania). The material, which is a compound of company absorber and PET, is intended for the packaging of such oxygen-sensitive products as sauces, ketchup, beer, products enriched with vitamins, and other foodstuffs, especially in disposable packaging. MonOxbar polymers have been certificated and authorised for use in contact with foodstuffs in the United States and countries of the European Union [27].

In barrier layers of the walls of packaging that are made of mixtures of oxygen-absorbing materials with
base polymer resins such as PET, cloudiness may be the result of factors such as immiscibility of the oxygen-absorbing materials with the base polymer resins and the inability to create, by mechanical mixer, phase-disperse domains that are so small that they do not prevent the passage through them of light and the harmful effect of oxygen-absorbing material on the crystallisation behaviour of the PET base resin. One of the approaches for minimising such cloudiness is the careful selection of the base resin for improving the dispersibility of the oxygen-absorbing material, and thus reducing, but not essentially eliminating, cloudiness and minimising the harmful effect on crystallisation. The given approach may unexpectedly make the selection of the base polymer resin seriously more difficult. Another approach is to use composites that act as additives improving compatibility, to reduce cloudiness. This approach increases the stability of the layer, and the additive improving the compatibility introduces an additional material that must be assessed for suitability for contact with foodstuffs. In engineering there is a demand for barrier materials that ensure high oxygen-absorbing capacity and are essentially transparent without using the above agents.

Thus, an oxygen-absorbing composite has been proposed for creating packaging for the protection of sensitive materials against oxygen. The composite includes a polyester polymer, a compound of formula E in a quantity of roughly 0.10–10%, and one transition metal in the positive oxidised state in a quantity of 10–400 ppm. Compound E comprises a structure of the formula

![Chemical structure](image)

where Ar is an aryl or heteroaryl. A composite containing such an additive makes it possible to produce moulded articles with increased oxygen-absorbing properties and low cloudiness indices [28].

An ester polymer composite containing oxygen-absorbing polydienes and intended for the packaging of foodstuffs and drinks includes resin based on aromatic polyester and hydrogenated polydiene with terminal hydroxyl groups, for example vinyl polymers. The proposed composite possesses high oxygen-absorbing properties and rules out the emergence of colouring of polyester composites during reprocessing [29].

Thus, the introduction of oxygen-absorbing agents into polyethylene terephthalate leads to protection of the packaged product against oxygen. However, not all oxygen absorbers can be used in contact with foodstuffs. The occurring oxidation reactions with the participation of absorbed oxygen may lead to the formation of undesirable and even toxic substances, which limits the area of applicability of the given method of controlling the barrier properties.

The main alternative material for the manufacture of plastic beer bottles remains polyethylene naphthalate (PEN). PEN has high barrier and heat resistance properties (an order of magnitude higher than the properties of PET), which prolongs the fitness of the beer and enables it to be pasteurised. At the same time, the cost of this polymer remains fairly high (in relation to polyethylene terephthalate), which limits its wide application. The exceptions are countries in which the government is encouraging the use by breweries of reusable plastic containers. In Europe, about 40% of the entire quantity of containers used for the bottling of beer is made up of reusable PEN bottles. They differ from disposable bottles primarily in their greater weight – about 100 g. Such bottles can be used up to 40 times. At each bottling, a special label is applied to the bottle, in order to keep a record of the number of times the container has been used. After application of the final label, the bottle is sent for general recycling. In the European region, Carlsberg and Tuborg brands are sold in reusable PEN bottles.

The polymeric materials widely used at present can be placed in the following decreasing order of barrier properties in relation to oxygen: polyvinyl dichloride (PVDC), ethylene–vinyl alcohol (EVOH), polyamide (PA), and polyethylene terephthalate (PET, Lavsan).

The barrier properties of polymeric materials are influenced considerably by the following:

1. The degree of orientation of the polymeric material. This characteristic shows the degree of stretching of the long molecular polymer chains within the material and is determined by the elongation factor of the polymer melt in the process of production (extrusion). According to data of ZAO Uralplastik, oriented polyamide film has an oxygen permeability that is half that of non-oriented polyamide film.

2. The temperature of the surrounding medium.

3. The thickness of the polymeric material.

As is known, reduction in the temperature of the surrounding medium and increase in the thickness of the polymeric material increase the barrier properties of the film material. Table 1 gives values of the coefficients of oxygen and steam permeability for different polymeric materials according to Exxon-Mobil data.

From Table 1 it can be seen that the highest barrier properties in relation to oxygen are possessed by ethylene vinyl alcohol (EVOH) material. However, because of its high cost, it is encountered in practice very rarely. The undoubted leader, in terms of both barrier property indices, is polyvinyl dichloride (PVDC), but it is a material that does not lend itself to reprocessing, is not recycled
in any way in practice, and when incinerated gives off poisonous gases [31]. Thus, polyethylene terephthalate remains the most optimum material for the creation of containers – it is only a matter of improving its barrier properties.

ACKNOWLEDGEMENTS

This study was conducted within the framework of a complex project for the setting up of high-tech production, carried out with the participation of VUZ Dogovor OOO Tanneta with a grant from the Russian Ministry of Education and Science from 12 February 2013, No. 02.G25.31.0008 (Russia government resolution No. 218).

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<table>
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<tr>
<th>Type of material</th>
<th>Coefficient of steam permeability (g/m²) within 24 h at 90% relative humidity and temperature of 38°C</th>
<th>Oxygen transmission factor (cm³/m²) within 24 h at 23°C</th>
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<tr>
<td>LDPE</td>
<td>15–20</td>
<td>3000–13 000</td>
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<tr>
<td>HDPE</td>
<td>3–12</td>
<td>500–3000</td>
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<tr>
<td>Non-oriented PP</td>
<td>8–10</td>
<td>1000–6000</td>
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<tr>
<td>Oriented PP</td>
<td>5</td>
<td>2400</td>
</tr>
<tr>
<td>PVDC</td>
<td>1–5</td>
<td>1–3</td>
</tr>
<tr>
<td>EVOH</td>
<td>15–50</td>
<td>0.2–2.5</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>120</td>
<td>2500–7700</td>
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<tr>
<td>PA</td>
<td>&gt;150</td>
<td>30–100</td>
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<tr>
<td>PET</td>
<td>15–30</td>
<td>50–150</td>
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