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Investigation of Fibre Diameter Distribution in Non-Woven Textiles for Medical Applications in Melt-Blown Polyester Technology

Abstract

Manufacturing non-wovens from fibre-grade polyesters by the melt-blown method from a polymer melt causes great technological problems. The structure of non-woven, its properties and characteristics are influenced by such parameters as the moisture of the polymer, the temperature of manufacturing at the separate zones of installation, the output and temperature of the air blowing out the melt, the take-up velocity of the non woven, the distance of the condenser from the spinning nozzle, and the thickness of the fibres received. As the non-wovens discussed are devoted to medical applications and filtration materials an appropriate spatial structure is an important parameter, and the smallest possible fibre thickness is required. The purpose of investigation was the optimisation of the process parameters and the obtaining of the thinnest possible fibres with optimum distribution of thickness, and optimum spatial structure. The manufacturing process allowed to obtain non-wovens which were characterised by the possibilities of shaping their structure in a wide range of parameters and with fibres of diameter from $2 \mu\text{m}$ to $14 \mu\text{m}$. For the production of non-wovens of surface mass 110 g/m^2 , the air flows that allow to receive optimum fibre thickness in the determined conditions were assessed.

Key words: melt-blown technology, non-woven, fibres, polyesters, diameter of fibres, air blow.

Introduction

Non-woven, which is manufactured from polymer by the melt-blown method, is characterised by comparatively small thickness of fibres, a particular spatial structure [1], and a lack of an irritating action, which allows its application for medical and filtration purposes. Nonwoven manufacturing technology from fibre-grade polypropylenes is well known, fully controlled, and used also at our institute. All over the world intensive research works have been carried out on the technology involved in nonwoven manufacturing using the melt-blown method. An example of such an investigation is the research program of the Reifenhauer Company [4 - 6]. Manufacturing non-wovens from polyester polymers by this method creates great technological problems which result from the properties of polyesters, such as the absorptiveness of moisture, the narrow range of processing temperatures and the level of drawing the manufactured fibres. On the other hand, polyester non-woven can be applied as an implant and medicine-carrier in medical applications, as filtration material at high temperatures and as an important component of composites.

Aim of the research

Research work on the development of manufacturing technology for non-woven

textiles using the melt blown method has been carried out at the Polmatex R&D Centre of Textile Machinery for many years. Positive results obtained by manufacturing polypropylene non-woven textiles inspired a team of researchers to further investigate manufacturing non-woven textiles made from fibre-grade polyesters. Such works were carried out as part of a research project entitled "Polyester non-woven textiles manufactured by melt-blown polymer method" (see "Acknowledgment").

The purpose of our investigations was the selection of technological process param-

eters for manufacturing poly(ethylene terephthalate) (PET) non-woven by the melt-blown method, optimisation of its spatial structure and obtaining the thinnest possible fibres.

Research apparatus

The investigations were carried out with the use of the test rig introduced in **Figure 1**, which was designed for manufacturing non-woven textiles by the melt-blown method.

The test rig was designed on the basis of experiments carried out with poly-

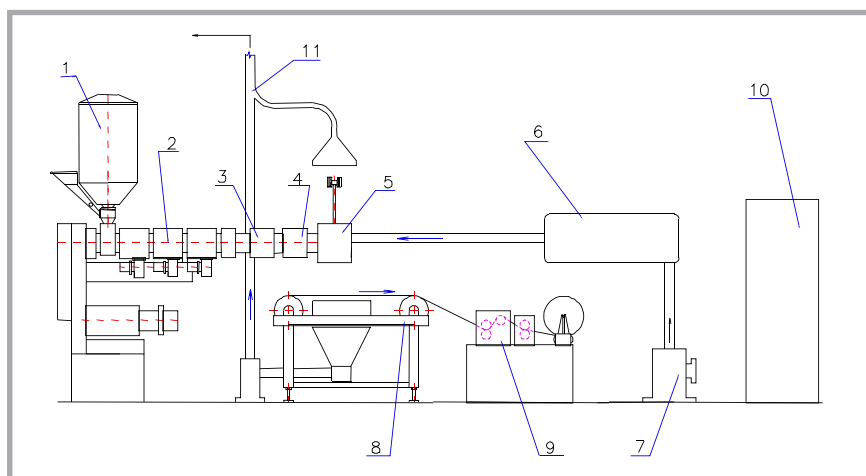


Figure 1. Test rig for manufacturing PET non-woven by the melt-blown method; 1 – dryer tanks, 2 – extruder, 3 – polymer filter, 4 – dosage pump, 5 – spinning beam; 6 – air heater, 7 – air supply installation, 8 – net band conveyor, 9 – nonwoven quilting assembly, 10 – control compartment, 11 – air-conducting installation.

propylene non-wovens [1] as well as the requirements related to drying fibres formed from polyesters in which the content of the moisture in the granulated product used for production cannot exceed 0.01%. As a result of these requirements, further development of the test rig was necessary [2, 3].

The test rig consists of the following parts:

1. A dryer tank with an additional filling up hopper.
2. An extruder equipped with a screw for processing polymers, as well as three heating zones with continuous temperature control, and the possibility of air-cooling.
3. An adjustable polymer filter which can be changed during the operation of the test rig.
4. A dosage pump with continuous control of the rotary speed.
5. A spinning beam of special design with nine heating zones of a continuous temperature control system. It is equipped with a grate, a multi-hole spinneret (nozzle) special polymer pressure and temperature sensors of small response time coupled with a continuous control system for the rotational speed of the extruder electric motor.
6. An air heater with continuous temperature control.
7. An air supply installation with a blower of special design.
8. A net band conveyor with the possibility of continuous control of the position in relation to the spinning beam.
9. A non-woven guiding assembly for cutting the edges and making strips of required length.
10. Two control compartments.
11. An installation to remove air from above the spinning beam and from below the condenser net conveyor.

The of 1000 mm length polymer melt is extruded by a single-row spinneret, in which 1000 bores of 1 mm were arranged. The streams of polymer melt are stretched and torn by two co-running streams of hot air flowing from the gaps placed along the line of the polymer spinning nozzle. The air stream puts the fibres generated this way onto the moving net of the condenser, on which continuous, consolidated non-woven of 1 m width is obtained. The thickness of the non-woven and its surface masses depend on the linear velocity of the net conveyor and the intensity of the polymer stream flow-

ing out of the spinning nozzles. The intensity of the polymer stream depends on the output of the dosage pump and is proportional to its rotational speed. For each value of rotation speed of the pump, appropriate temperatures are applied in the heating zones to maintain the assumed temperature of the melt at the inflow to the spinning nozzles, which is required for the forming process of fibres.

The following parameters have an impact on the textile structure of nonwoven produced by this technology with an established volume of flowing oil stream of polymer:

- output and temperature of blown air,
- velocity of non-woven received (linear velocity of the condenser net),
- distance of condenser from the spinning nozzles, [7].

The variation of each parameter affects the structure of non-wovens in a definite way. The quantity of air blowing up the polymer melt determines the drawing, which affects the diameter of fibres and their length. An increase in air quantity up to a certain level causes the thinning of fibres, which can be observed in **Figure 2**. Further increase in air quantity does not cause a decrease in its diameter. The air temperature for this spinning nozzle design should be practically equal or higher than the cooling of the spinning nozzle [7]. Too cold air causes disturbances in the process of polymer flow from the spinning nozzle or even makes the flow impossible. An increase in air temperature results in a decrease in the diameter of fibres produced. However, the effect of temperature change on fibre diameter is weaker than that of the volume of air quantity.

Any change in the distance of the condenser net from the spinning nozzles affects the spatial structure of non-

woven and its grade of consolidation. Non-woven textile produced at small distances is compact, flat, the fibres are more stuck together, the strength of non-woven is greater and the penetrability of air is smaller. An increase in the distance between the condenser net and spinneret gives more spacious (loose) non-woven textiles. As the air penetrability increases, the strength decreases as a result of weaker thermal bonding of the fibres building the non-woven.

The chosen method of obtaining non-woven enables non-woven of various area masses and different grade of consolidation to be made. The range of the parameter variations is very wide. The installation discussed here is within the range of 20 to 500 g/m². The wide choice in shaping the arrangement of fibre structure as well as its surface mass gives great possibilities of creating a wide assortment of non-woven textiles of different properties. For technical purposes non-woven textiles with a strong band and compact structure to be applied to the loaded foundation, as well as non-woven of loosely bound fibres made of thin fibres for filter inserts, are required. Similarly, thin non-wovens for dressing materials, or thick ones for absorption pads, can be used in medical applications. As the investigation carried out at the Industrial Medicine Institute showed, the polyester non-woven in question, produced by this technology and on this installation, does not show irritating or toxic properties, and it has obtained permission for medical applications.

The forming of fibres, and optimisation of thickness distribution

A very important parameter that characterises non-woven produced by the melt-blown method is the thickness of fibres and its statistic distributions. These prop-

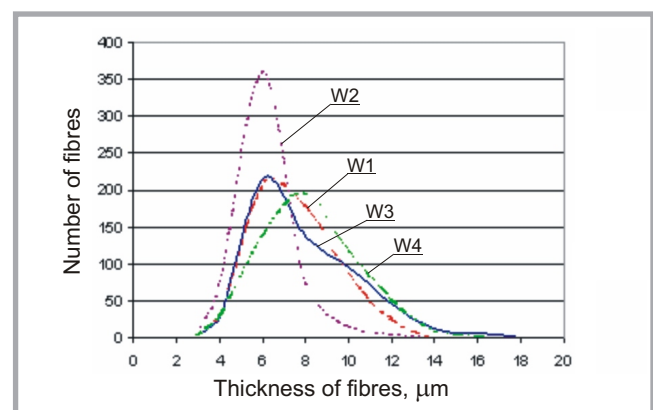


Figure 2. Distribution of fibre thickness; The sample denotations: W1, W2, W3, and W4.

erties are influenced by the air parameter used for polymer blow, particularly the output. Investigation into the effect of the air quantity required for the blow of polymer melt was made during the process of non-woven formation from polytereftelan ethylene of the commercial brand name 'PET mat' manufactured by the ELANA Plant in Toruń, Poland.

During the investigation into the forming process of non-woven as a constant parameter, the following were established: the temperature of melt and air, a surface mass of 110 g/m² (based on the requirements of the Institute of Industrial Medicine), the polymer output, the polymer and air temperature, the linear velocity of the condenser net, as well as the position of the condenser versus the spinning nozzles.

These values are reserved by the "know-how" of the technology developed and are in the disposition of Polmatex-Cenaro. Only one parameter, i.e. the air flow volume of the blow of the polymer melt, varied. The range of variations was from 0.049 m³/s to 0.075 m³/s, which guaranteed the obtaining of fibres of adequate thickness (diameter). Non-woven manufactured at an air stream volume output of 0.049 m³/s is characterised by a loose structure and larger quantity of fibres sticking-out on the surface. Thanks to this, the non-woven textile feels softer. Opposite to this type of material are the non-wovens that were obtained at an air stream volume output of 0.066 m³/s and 0.075 m³/s. These non-wovens have a compact structure which resembles paper in its feel, but without fibres sticking-out on the surface.

The samples of non-woven for the investigation of fibre thickness were denoted as follows:

W1 – non-woven obtained at the following intensities of air stream blowing the polymer melt: 0.049 m³/s,
W2 – 0.061 m³/s,
W3 – 0.066 m³/s,
W4 – 0.075 m³/s, (see **Figure 1**).

Investigation into fibre thickness was carried out at the Laboratory of Raw Materials and Textile Products of the Textile Research Institute in Łódź according to the standard PN-86/P-04761.08 "Methods of Investigation of Raw Textile Materials. Chemical Fibres. Diameter Determination".

It can be concluded from the analysis of the results that with an increase in air quantity from 0.049 m³/s to 0.061 m³/s, the mean diameter of fibres decreases on average by 6.52 µm to 5.19 µm. The number of fibres in the range of diameters from 2 µm to 8 µm also increases. The fibres in this range represents about 96% of all fibres of sample W2, and the fibres of diameter 4 ÷ 6 µm represent about 68% of all fibres in the sample. The minimum diameter of the fibres was obtained with such a quantity of air. Further increase in the air quantity used to blow polymer melt (from 0.061 m³/s to 0.066 m³/s) causes an increase in the mean diameter of fibres in the sample. In sample W3 the mean diameter of fibres increased to 7 µm, and the number of fibres ranging from 2 µm to 8 µm in diameter fell to 70%. With a further increase in the air blowing the polymer, the number of thin fibres decreases within the range of 2 µm to 8 µm, which represents about 66% of all fibres of sample W4.

From the analysis of investigation results pertaining to the thickness of fibres under different conditions of non-woven formation, it is clear that there is an optimum air quantity for blowing polymer melt to achieve the largest number of non-woven thin fibres of diameter 6 µm. Below and above this optimum the number of thin fibres of non-woven decreases. The distribution of fibre thickness in the non-wovens under investigation is presented in **Figure 2** for samples W1, W2, W3, and W4.

To facilitate the transformation of investigation results to be applied to a spinning beam of another design, another hole diameter in the spinneret and a different pitch of their distribution as well as the quantity of air stream volume for a 1 cm length of the beam in normal conditions were analytically recalculated, and the ratio of air mass to the mass of polymer was determined. It can be concluded from this analysis that for the non-woven with the largest amount of thin fibres of 6 µm diameter, the air stream output blown towards the stream of polymer melt is 6 × 10⁻⁴ m³/s (2.16 m³/h) for a beam of 1 cm width, and the ratio of air stream mass to polymer stream mass is about 50. These values were confirmed experimentally.

The technology discussed makes it possible to manufacture polyester non-woven of large structural diversity and with a wide range of surface mass. The applica-

tion of polyester non-woven textiles with regard to specific properties and qualities will widen with the improvement of technology and manufacturing installations. Research works in this domain are in progress.

Conclusions

The results of investigations carried-out led to the following conclusions:

1. The technology of manufacturing non-woven textiles by the melt-blown method from polymer melt allows to obtain PET fibres of diameter in the range of 2 µm – 14 µm.
2. There are optimum conditions of air flow and polymer that allow to attain 74% of fibres of thickness within the range of 2 µm - 8 µm and 65% of fibres of thickness within the range of 4 µm – 6 µm.
3. The conditions for manufacturing the fibres given in p. 2 are:
 - an air stream output blown towards the stream of polymer melt of 6 × 10⁻⁴ m³/s (2.16 m³/h) for a beam of 1 cm width
 - a ratio of air stream mass to polymer stream mass of approximately 50.



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