INSTALLATION AND METHOD FOR PRODUCING A FIBER FROM A POLYMER SOLUTION

The invention relates to a plant and to a process for producing hollow fibre membranes for fluid separation, in particular for gas separation.

The prior art discloses processes for production of membrane material for fluid separation, where such membrane materials based on polyimides, for example, are described in WO 2014/202324 A1 or WO 2011/009919. As integrally asymmetric membranes, called "integrally skinned asymmetric membranes" (ISA membranes), such membrane materials have a (separation-)active layer (separating layer) of 10 to 200 nm. It is well known that polyimides represent a class of polymer materials which make it possible to achieve gas separation of a fluid mixture at a high permeance of one of the fluids and/or at high selectivity. In this context, polyimides are characterized by very good mechanical, chemical and thermal durability in applications for gas separation.

It is known that polyimides and also other glass-like polymers which are used as membrane material for gas separation have a drop in initial separation performance, for example as a result of plasticization (softening) ("Quantification of sorption, diffusion, and plasticization properties of cellulose triacetate films under mixed-gas CO_2/CH_4 environment" Genduso et al.; J. of Membrane Science, Volume 610, 01.09.2020, article number 118269), as a result of physical ageing ("Physical aging of thin glassy polymer films monitored by gas permeability" Huang Y. et al.; Polymer, Vol. 45, Issue 25, pages 8377 – 8393, November 2004) and/or as a result of contact with impurities in the feed stream ("Properties of a polyimide gas separation membrane in natural gas streams"; White et al.; J. of Membrane Science, Volume 103, Issue 1-2, pages 73 – 82, 14.07.1995).

The aforementioned disadvantages can be partly or even completely avoided if the hollow fibre membrane is heated above 300°C, as described for example in WO 2011/009919 A1 and US 9,873,093 B2. It is further proposed therein, for establishment of defined, high permeances and selectivity, to provide a defined gradient during heating as part of the heat treatment, this gradient, for example according to WO 2011/009919 A1, comprising three stages in a recirculating drying cabinet (convection oven), namely at 70°C (0.5 h), 150°C (2 h) and 250°C (12 h).

For further improvement, WO 2014/202324 A1 proposes drying hollow fibre preferably at a temperature in the region of 50 and 100°C, followed by heat treatment. The drying is said to remove for example water, isopropanol or hexane, with the result that the total water and/or residual solvent content is in the range from 0% to 5% by weight. This is because an excessively high residual content of water and solvent in the heat treatment of whole membrane bundles leads to the membranes sticking to one another. Excess water can also lead to hydrolysis and thus to chain scission and a mechanically unstable membrane. According to WO 2014/202324 A1, it is

advantageous when the maximum content of water before commencement of heat treatment is below 5% by weight, even if any of the water were to evaporate during the heat treatment process. In this context, WO 2014/202324 A1 proposes providing a drying unit and a heat treatment unit, wherein the heat treatment has to be carried out at a temperature in the preferred range from 140°C to 180°C under vacuum in the range from 0.6 to 0.9 bar and under an inert gas atmosphere having an oxygen content of below 0.5% by volume, wherein a very long heat treatment time of preferably 10 to 16 hours is required.

Disadvantages of these previously known and fundamentally proven process regimes and plants are that a relatively elaborate plant construction has to be provided and that very long treatment times are required for the fibres.

It is thus an object of this invention to provide an improved plant and an improved process for a fluid separation membrane over known plants and processes while achieving unchanged or elevated product quality in terms of permeability and/or selectivity.

This object is achieved in accordance with the invention by a plant for producing a hollow fibre, wherein the hollow fibre is formed from at least one polymer solution. The plant here comprises a control and regulation unit, a media reserve and supply unit, a spinning unit for forming the fibre, wherein downstream of the spinning unit for the treatment of the fibre at least the following plant units are included, in the stated sequence:

a) an exchange unit for solvent exchange, which in particular comprises or may be essentially formed from a (first) fixing unit, in which the fibre directly after the spinning unit can be introduced or conducted through, and wherein advantageously a washing unit can be included downstream of the fixing unit,

b) at least one post-treatment unit, comprising
a thermal treatment unit with at least one thermal treatment station, wherein

at least one thermal treatment station of the thermal treatment unit is provided downstream of the exchange unit and is designed as a heat treatment station comprising at least one heat treatment oven, and wherein the at least one heat treatment oven comprises at least one heating element and/or an inlet for a heating medium, wherein the fibre can be conducted through and/or accommodated at least temporarily in the at least one heat treatment oven, wherein the heat treatment oven is designed to heat the at least temporarily accommodated and/or conductable fibre for a defined period of time (heat treatment time) up to a (limiting) temperature (heat treatment temperature) that is below the glass softening temperature (T_g), in particular and also

i) in the range up to 80°C below the glass softening temperature (T_G), and/or

ii) in the range of greater than 250°C and below the glass softening temperature (T_G).

What is meant here by "heat treatment time" is the duration or residence time of the conveyed or temporarily stationary fibre in the heat treatment oven and in the areas of the heat treatment temperature specified herein. In the present context, "limiting temperature", "heat treatment temperature" or "temperature in the heat treatment space" are used synonymously, unless stated otherwise. In this context, "interior of the heat treatment oven" means the space in which the fibre to be heat-treated is arranged or guided, also called "heat treatment space", and is exposed to the thermal influence of the heating element or heating medium for the purpose of heat treatment.

The system is preferably designed for continuous heat treatment of the fibre in the heat treatment oven, in particular for a dwell time of the fibre in the heat treatment oven of less than 30 minutes at standard pressure or slightly elevated pressure relative to standard pressure in the heat treatment oven. The system and in particular the heat treatment oven is advantageously designed such that the dwell time of the fibre in the heat treatment space or a heating section corresponding to the heat treatment space is in the range of 0.5 to 180 s, preferably 1.0 to 120 s, more preferably 1.0 to 60 s, more preferably 1.0 to 30 s, ideally 1.0 to 15 s.

In this case, the heat treatment oven and/or the heat treatment space may be designed so as to be free of guide elements that make contact with the fibre or may include the guide elements that make contact with the fibre, which deflect the fibre axis at least for some of the distance within the heat treatment oven and/or the heat treatment space and hence geometrically influence the dwell time of the fibre in the heat treatment space.

In one plant variant, it may be advantageous when the plant and in particular the heat treatment oven is designed such that the temperature in the heat treatment space or a heating section corresponding to the heat treatment space is in the range of 300 to 800°C, preferably in the range of 320 to 780°C, more preferably in the range from 350 to 750°C, more preferably in the range from 380°C to 700°C.

It has been found to be particularly advantageous when the plant, the heat treatment station and/or the heat treatment oven are designed such that a ratio V1 [s/T] of the dwell time [s] of the fibre to the temperature in the heat treatment space [K] is in the range from 0.0006 to 0.6 $s*K^{-1}$, preferably in the range from 0.0006 to 0.43 $s*K^{-1}$, more preferably in the range from 0.048 to 0.429 $s*K^{-1}$, more preferably in the range from 0.176 to 0.429 $s*K^{-1}$. The advantageous ratio V1 was found in particular for the temperature range in the heat treatment space of 300 to 800°C.

It has also been found to be particularly advantageous when the plant and/or the heat treatment oven are designed such that a ratio V2 [$s*m^{-1}*K^{-1}$] of dwell time [s] to internal diameter of the heat treatment space [m] and temperature in the heat treatment space [K] is in the range from 0.001 to 0.545 $s*m^{-1}*K^{-1}$, preferably in the range from 0.043 to 0.39 $s*m^{-1}*K^{-1}$, more preferably in the range

from 0.086 to 0.39 $s*m^{-1}*K^{-1}$. The advantageous ratio V2 was found in particular for the temperature range in the heat treatment space of 300 to 800°C.

The system advantageously comprises pulling devices, in particular downstream of the heat treatment oven. The pulling devices, also known as "pulleys", are designed in particular to exert a tension on the fibre in mN per individual fibre in the range of 10 to 500 mN in the heat treatment oven and in particular in the heat treatment space of the heat treatment oven, preferably in the range of 10 to 200 mN, more preferably from 10 to 100 mN, more preferably from 10 to 50 mN, more preferably from 10 to 30 mN.

In particular, it is advantageous when the fibres are conveyed through the heat treatment oven by the pulling device (pulley) with minimum pulling force. "Pulling devices" in the present context means any drive unit which directly exerts a tensile force on the fibre in axial direction thereof via a motor drive, for example a winding wheel, a roller, a clamp conveyor belt, etc. In the case of rollers, these are deflection rollers in particular, on the surface of which the fibre rests for an angular range and hence the direction of the fibre axis is altered, and in particular its direction is altered over a distance relative to the main conveying direction.

The heating element may be, for example, a resistance heater, a burner element, or a fluid-carrying heat exchanger, such that the heating element preferably heats the fibre contactlessly via a gas atmosphere in the heat treatment space. A distinction is made in the present context between "heating gas introduction" and a "burner element", in that the burner exhaust gases are not introduced into the heat treatment space in the case of a burner element, unless stated otherwise.

On the other hand, what is meant by "heating gas introduction" is that at least a partial volume flow of a heating gas is introduced into the heat treatment space and flows around the fibre. The source for a heating gas may be a burner and the burner exhaust gas generated therein, so that the heating gas is at least partly formed from burner exhaust gas, and in particular has a high percentage by volume of CO_2. In a preferred embodiment, "heating element" does not include an IR emitter, and "heating medium" does not include IR radiation. In this context, a heater that is not an "IR emitter" or does not emit "IR radiation" includes one such as a resistance heater, which emits a design-related IR radiation component, although this radiation component accounts for only a very small fraction, if any, of the total heating power, especially for the heating of the fibre.

In an advantageous embodiment, the heat treatment oven is designed and adjustable i) to heat the at least temporarily accommodated and/or conductable fibre for a defined time (heat treatment time) up to a limiting temperature which is not more than 1°C to 4°C below the glass softening temperature (T_g), in particular to a limiting temperature in the range of 70°C to 1°C below the glass softening temperature, preferably in the range of 65°C to 1°C, and/or ii) to heat the fibre to a temperature of greater than 250°C to 450°C, preferably 280°C to 450°C.

In particular, it is advantageous here if the plant is designed to maintain the difference of 1°C to 4°C from the glass softening temperature (T_G) with regard to the fibre that is at least temporarily accommodated and/or conductable, in order not to damage the structure, in particular the desired porosity, of the hollow fibre. In order to avoid damage to the fibre owing to fluctuations in the heating temperature, it may be preferred if the plant is designed such that instead of the aforementioned 1°C difference to the T_G, a difference of 1.5°C, 2°C, 2.5°C, 3°C or 3.5°C from the T_G can be provided.

By analogy, "not more than 1°C, in particular not more than 4°C" here means that it is particularly advantageous if the difference of at least 1°C, preferably 4°C, from the respective glass softening temperature (T_G) of the fibre material (polymer substrate) is maintained, in order not to damage the structure, in particular the desired porosity, of the hollow fibre.

In order to set defined material states of the fibre and to improve the regulatability of the heat treatment, according to an advantageous embodiment of the plant, it may be the case that at least one further thermal treatment unit is arranged, comprising a drying station upstream of the heat treatment station.

The heat treatment station and/or the heat treatment oven is thus designed to subject the fibre to heat treatment by means of a continuous process for a defined period of time (heat treatment time). In this case, the fibre for the actual heat treatment step can also be conveyed within the heat treatment oven in a step operation, such that the fibre or the fibre bundle are temporarily slowed down and/or temporarily stopped. Alternatively or additionally, the pulling device for conveying the fibre in the heat treatment station and/or the heat treatment oven, the continuous process and the control and regulation of the defined period of time (heat treatment time) is designed and/or controllable and regulatable accordingly.

Advantageously, the heat treatment station is connectable to or comprises a ventilation unit for operating the heat treatment oven and/or the heat treatment process, where the heat treatment oven is preferably connectable to the aeration unit or comprises a ventilation unit.

The ventilation unit comprises in particular at least one gas supply and at least one gas outlet, where the simplest case for the gas outlet is a separate opening in the heat treatment oven and/or the supply and/or exit opening for the fibres. Advantageously, the ventilation unit comprises a pressure sensor for detecting the pressure in one of the supply or discharge conduits of the (cooling) gas or for the interior of the heat treatment oven. A compressor may be integrated into the gas supply. The dimensions of the supply and/or exit opening for the fibres are advantageously such that, in addition to the fibres, there is a clear flow cross section for a gas or gas mixture, in particular a ring or frame-shaped flow cross section around the fibre. A particular advantage of the

circumferential flow cross section that was observable was that a very stable, largely laminar gas flow parallel to the fibre forms in the heat treatment space. As a result, very reproducible, stable process conditions were achieved in the heat treatment space of the heat treatment oven.

The fibre is thus directly or indirectly heat treated in the heat treatment station or heat treatment oven. In this context, "directly" means that the fibre is heated over a temperature gradient by means of a heating element and/or a hot surface, and also convectively by a gas flowing within the heat treatment space. In this context, "indirectly" means that the heat transfer, such as solid-state radiation etc., can also reach an individual fibre through adjacent individual fibres via reflectors and/or heated components, walls and/or wall sections.

"Heat treatment" here means heating the fibre for a defined time (heat treatment time) up to a limiting temperature that is not more than 1°C to 4°C below the glass softening temperature (T_G), in particular in the limiting temperature range from 80°C to 1°C below the glass softening temperature, preferably in the range from 70°C to 1°C, particularly preferably in the range from 65°C to 4°C below the glass softening temperature. According to the invention, the fibre is subjected to heat treatment in the heat treatment oven, where the desired high separation properties of the hollow fibre membrane are formed. On employment of the present invention of a continuous heat treatment oven, heat treatment should be understood analogously to WO 2014/202324 A1, by heat treatment of hollow fibres at temperatures close to the glass softening point in order to obtain gas separation membranes which have a very high selectivity and additionally very good permeance.

The glass softening temperature T_g can be determined by various forms of differential scanning calorimetry (DSC), in particular according to the method of DIN 53765. The limiting temperature should also still be below the degeneration temperature (T_D), also called the "decomsing temperature".

Thus, in an analogous manner to T_G, the upper limiting temperature and the limiting temperature range can also be determined using the degeneration temperature (T_D) of a fibre and/or the fibre material (polymer substrate). This depends on whether the effects of degeneration or glass softening occur when the fibre and/or fibre material is heated in different or overlapping temperature ranges. Degeneration may consist, for example, in burning, ashing, cracking, embrittlement or other destructive effects.

In the case of a fibre material for which $T_D < T_G$ is a physical property, in which case the degeneration then consists in that increased material shrinkage already sets in at $T_D < T_G$, in particular $T_D << T_G$, the limiting temperature should analogously be less than T_D. Thus the plant should advantageously be designed, with regard to the at least temporarily accommodated and/or

conductable fibre, always to use the limiting temperature in an analogous manner to T_G so as to maintain the margin to T_D, in order in particular to not adversely affect the fibre dimensions (macrostructure) and/or the pore structure (microstructure) of the fibre.

Fibre materials with a pronounced degeneration at temperatures from and above T_D are, for example, PIM-1 polymers with high intrinsic microporosity. One example of a PIM is the polycondensation product of 5,5′,6,6′-tetrahydroxy-3,3,3′,3′-tetramethyl-1,1′-spirobisindane (CAS No 77-08-7) and 1,4-dicyanotetrafluorobenzene (CAS No 1835-49-0).

This degeneration temperature T_D can be determined by thermographic analysis in a nitrogen atmosphere (Konnertz, N. et al., Molecular mobility of the high performance membrane polymer PIM-1 as investigated by dielectric spectroscopy, ACS Macro Lett. 2016, 5, 528−532).

Thereby, in the case of the polymer materials in question, in particular, a fibre temperature of greater than 250°C, in particular greater than 280°C, is attained in the heat treatment oven, while complying with the aforementioned material-dependent margin from T_G and/or T_D.

The thermal treatment unit according to the invention can thus comprise a single thermal treatment station for implementing a single drying step, which is configured as a heat treatment station with a heat treatment oven and by means of which the fibre or the polymer material is heat-treated. In this embodiment with a single thermal treatment station, to be specific, a combined drying and heat treatment step takes place. However, it has been found that the high energy input in the heat treatment oven onto a wet or very damp fibre leads to adverse impairments of the fibre during heat treatment. Thus the thermal treatment unit can advantageously additionally comprise at least one further thermal treatment station for performance of at least one further drying step, in particular arranged upstream of the heat treatment station, in particular directly upstream of the heat treatment oven. Because of the high temperatures applied, the heat treatment in the heat treatment station always constitutes an independent drying operation or drying step.
This additional thermal treatment station may advantageously comprise, or be connected to, an alternative drying means and an alternative heating apparatus. In particular, a drying station may be provided for an independent drying step after the exchange station for discharging the solvent from the exchange station, in particular upstream of a coating station, for producing defined surface properties of the fibre when introduced into the coating station. Furthermore, advantageously downstream of a coating station, at least one further drying station for a further drying step can be provided, in particular for removing the solvent present in the coating station or in the coating material used therein. Even though "a thermal treatment unit" is being discussed here, this does not usually constitute a structural unit, but rather serves to refer collectively to all the thermal treatment stations and/or steps, i.e. different drying station and implementation of the respective drying steps. It is particularly advantageous if, directly upstream of the heat treatment station, a drying station is provided, which may be identical with one of the above, in order to establish a

state defined with regard to the moisture content of the fibre at the start of the heat treatment station and thus, in particular for the high-energy heat treatment, to enable as short a duration as possible.

The "heat treatment station" shall be understood in the present context to mean in particular the central heat treatment oven and all directly associated supply and removal apparatuses, such as, in particular, gas feed conduit, gas drain, sensors, optionally power controller/control unit, ventilation and/or cooling unit with the required connections, etc. The plant and in particular the heat treatment oven is designed to accommodate, in a continuous process, at least one individual fibre within, in order to heat it at least temporarily to a temperature below the glass softening temperature T_G or the degeneration temperature T_D by means of a heating element and/or a heating gas, as described herein. Although the heat treatment station is not identical to the heat treatment oven, in isolated cases below no distinction is made between heat treatment station and heat treatment oven, and what is meant is revealed by the textual context - for example, wording to the effect that "the heat treatment station comprises a heating element" means that the heating element is included by the heat treatment station as part of the heat treatment oven.

Even if the term "heating element" is primarily used hereinafter, this shall refer not only to a single heating element but also to a group of heating elements, for example a group of heating coils of an electrical resistance heater and/or a plurality of heating gas inlets into the heat treatment space.

A plant and an associated process have been found that make it possible to reduce the heat treatment times known from the prior art, by means for example of a convection oven in batchwise operation, through the development and continuous mode of operation of the heat treatment oven, by around a factor of 0.001 and more. Furthermore, protracted heating steps have been completely avoided. In particular, a plant and a process have been found which are designed to be operated continuously, in particular for continuous production of a hollow fibre as membrane for gas separation.

In addition to substances exemplified herein, "polymer solution" in the present context also refers to liquid and/or liquefied polymer melts. What is meant in particular by "polymer solution" is liquid and/or liquefied polymers present in a solvent or solvent mixture in particular. The polymer solutions include

- aromatic polyimides, aromatic polyetherimides, aromatic polyamides, polyarylene ethers, aromatic polybenzimidazoles and/or mixtures thereof;
- polysulfones and/or mixtures containing polysulfones;
- solutions of polymers having intrinsic microporosity (PIMs);
- generally, solutions of polymers suitable for the production of membranes for gas separation, in particular for the production of (spun) hollow fibre membranes;
- cellulose-based solutions

suitable for production of membranes for gas separation.

The polymer solution may further comprise 2D or 3D fillers that are suitable in terms of size and constitution for spinning using the spinning unit for hollow fibres. These fillers can advantageously be, for example, zeolites, MOF particles (Metal-Organic Framework materials), mexenes (MXenes) and/or graphenes. Furthermore, hollow fibre membranes are to be included in which the active separation layer is formed at least partially of a 2D or 3D filler, such as zeolites, MOF particles (Metal-Organic Framework materials), mexenes (MXenes) and/or graphenes.

Advantageously, the polymer solution is as described in EP 3083761 B1.

Particularly in the case that fillers are present in the polymer solution, it is advantageous when the number n of individual fibres in a fibre bundle to be subjected to heat treatment is less than 600 and bundles of individual fibres or smaller (partial) fibre bundles of up to a maximum of 180 individual fibres are subjected to heat treatment, preferably up to a maximum of 120 individual fibres, ideally up to a maximum of 100 individual fibres per part-bundle. Without being limited to one interpretation, fillers can cause greatly increased heat storage and/or reflection of the energy, so decreasing the homogeneity of the heat treatment of the individual fibres in the fibre bundle, and central fibres in particular disposed in the middle of the bundle are subjected to only incomplete heat treatment, if any.

In the plants, the fibres are preferably conveyed as a strand and uncut, with conveyor driving via conveyor rollers and/or at least one traction apparatus in the main conveying direction. The main conveying direction represents the main direction of movement in x direction. Advantageously, the fibres are diverted from the main conveying direction in x direction on partial sections many times, in particular in z direction, for example in the washing unit, the thermal treatment unit, etc., in order to enable the required dwell time in the respective unit.

The individual fibres, at least initially distanced from one another, are spaced apart, at least over part of the plant length, by comb-like or digit-like arraying elements of arraying units; typically, the individual fibres are arranged in an alignment next to each other, i.e. spaced apart from one another in y direction. In the heat treatment oven, the fibres can be conveyed individually, in part-bundles or as a total bundle. For formation of one or more (fibre) bundles, corresponding guiding means and/or grouping tools may be provided upstream of the heat treatment oven.

"Fibres" in the present context mean the group of individual fibres, regardless of plant location or treatment type, unit and/or station, with the plant location and treatment type, unit and/or location being apparent from the context. In particular, "fibre(s)" should primarily be understood to mean the

uncut individual fibre(s) or the fibre strand. The terms "fibre" and "individual fibre" are sometimes used synonymously.

The term "bundle", "part-bundle", "fibre bundle" or "fibre part-bundle" refers in the present context to an arrangement of a plurality of individual fibres in which the individual fibres are arranged such that they touch each other and, for example, are substantially parallel to each other or twisted relative to one another around a common longitudinal axis. A "bundle", "part-bundle", "fibre bundle" or "fibre part-bundle", referred to hereinafter as "bundle" for short, may be held and/or arrayed by at least one guiding and/or gripping tool, and may only be arrayed temporarily, unless something to the contrary is expressly described. Furthermore, a "bundle" may be mutually fixed and arrayed at least uni- or bilaterally through a fixing element, such as a band, a laced fastening or a clip, for example, at least temporarily.

The "main conveying direction" is determined by the sequence of the treatment units and stations of the plants, with the fibres themselves being diverted by means of guide elements as and when required. Thus the distance-dependent thread direction in the direction of the longitudinal fibre axis may be different from the (higher-level) main conveying direction. In the present context, the respective local "transport direction" within the plant is considered in particular parallel to the orientation of the "longitudinal fibre axis"; local, lateral displacements for changing the (transverse) distances of fibres to each other may be included here.

Advantageously, the plant comprises a multiplicity of guide and drive elements along the fibre filament conveying section, which, for example, may be guide digits, guide rollers, baffle plates or other suitable elements, where guide and drive elements may be located inside and outside of the treatment unit, including within liquids or within a volume of liquid.

The media included in the media reserve and supply unit may comprise
- fibre media, namely media and materials from which the fibre itself is formed at least temporarily, and
- process media, which are required for other treatment of the fibre and/or of plant elements. These may be, for example, the core fluid for forming the hollow fibre, fixing media for the raw fibre, washing liquids, such as water, alcohols, air, gases (N_2), etc., or other consumable media.

The spinning unit advantageously comprises a plurality of spinning heads, the spinning heads being configured in a manner known in principle and being connected to the corresponding feed conduits for media, in order to form hollow fibres and discharge them into a fixing unit or a fixing medium.

The control and regulation unit can be configured in one or more parts and is configured to operate the plant in at least partially automated fashion. Modification of operating parameters and/or the

display of plant-relevant information can be done via a central cockpit and/or decentralized input devices.

Even when treatment units, such as the "spinning unit", "fixing unit", "washing unit", etc., are mentioned only in the singular in the present context, they may also be constructed in several parts and/or occur several times along the main conveying section. Thus, for example, the generally known washing unit may be formed of two or more washing stations or washing tanks, which are filled with identical or different (washing) media and/or whose (washing) media have different physical properties, such as temperature, flow velocity, flow direction, etc. Advantageously, the washing liquids are water-based and/or organic washing liquids.

Aside from the heat treatment device and the heat treatment step, with regard to the plant details and the process details, reference is also expressly made to WO 2014/202324 A1, the content of which in this respect is expressly made the subject of this application, as an exemplary embodiment of the plant and the process, insofar as a hollow fibre is produced from a polymer solution. This applies, for example, to the media used and the treatment units and their identical or analogous structure, such as, for example, the spinning unit, fixing unit (called "precipitating bath" there), washing unit and/or thermal treatment unit. The fixing unit is referred to in WO 2014/202324 A1 as a "precipitating bath", in which a solvent exchange takes place. The exchange takes place, for example, from an aprotic dipolar solvent of the polymer solution, such as dimethylformamide (DMF) and/or N-methyl-2-pyrrolidone (NMP), to a non-solvent for the polymer material, such as water, for example. In at least one subsequent washing unit, an organic solvent or mixture thereof, such as isopropanol and/or hexane, for example, then removes the non-solvent.

This also affects, for example, the fibre medium as feed for the spinning step, which is called "casting solution" in WO 2014/202324 A1.

The aftertreatment unit comprises the thermal treatment unit and hence also the heat treatment station and may further also comprise a washing unit upstream of the thermal treatment unit. The aftertreatment unit may further comprise at least one coating station, in particular a coating station in which as coating material a polymer material, such as, for example, polydimethylsiloxane (PDMS) is applied to the fibre. Application may be carried out using a bath or a spraying apparatus.

In one advantageous embodiment of the plant, it may be the case that the thermal treatment unit as a thermal treatment station comprises a drying station through which the individual fibres are conducted, wherein the drying station comprises

- at least one drying element and/or
- a feed conduit and a drain conduit for a drying medium, such as in particular a heated gas, and

whereby the interior of the drying station is at least at a temperature of over 30°C, advantageously of over 40°C, and ideally of over 50°C, where substance-dependent limits for explosion protection must be observed. In this case, it is also advantageous if the interior can be heated to at maximum 200°C.

The fibres are preferably dried at a temperature in the range between 50 and 100°C, with the washing medium, in particular ethanol, isopropanol, butanol, heptane and hexane, being drawn off.

The drying station is ideally designed so that the total moisture content after drying is between 0% and 5% by weight, preferably < 3% by weight and especially preferably 0.1% to 3% by weight. The moisture content is formed essentially or exclusively from the fractions of water and the respective solvent.

Advantageously, the fibres are conducted as a strand, i.e. uncut, through this treatment station and supplied downstream, in particular directly downstream of the heat treatment station.

In a further advantageous embodiment of the plant, it may be the case that the thermal treatment unit as a thermal treatment station, in particular as a further treatment station, comprises a dehumidification station (flushing station) in which the individual fibres are conducted through at a distance from one another transversely to axial direction (longitudinal fibre axis (A_F)), in particular as a strand and uncut, and which comprises at least one nozzle element which is directed onto the path of at least one individual fibre or fibres, and by means of which a gas jet can be guided onto at least one individual fibre, in particular a group of individual fibres. Advantageously, all the individual fibres are dehumidified by means of such nozzle elements. The dehumidification in this station essentially consists in removing the respectively adhering external liquid from the respective fibre fluid-dynamically by a gas pulse. In one execution variant, the nozzle element may be a gas nozzle and/or a group of gas nozzles, which are formed as a slit nozzle.

In a further advantageous embodiment of the plant, it may be the case that

i) a grouping station with a grouping unit is arranged upstream of the heat treatment station,

ii) the heat treatment station is arranged within a grouping unit, and/or

iii) the heat treatment station is arranged between two grouping stations of a grouping unit,

wherein

in the grouping station and/or in the grouping unit there is at least one grouping means by means of which at least one group of n individual fibres can be combined in mutual contact as bundles. In this case, n is fundamentally not limited and values up to n = 600 individual fibres are possible,

where n is advantageously an integer value of from 2 to 180, preferably from 20 to 150, ideally from 30 to 120.

In an advantageous embodiment, it may be the case that the (end) bundle is formed in at least two steps, for example by forming, in a first step, in a grouping station, two or more part-bundles from the total number of the conveyed individual fibres by means of grouping means and forming the (end) bundle, with the total number of the individual fibres, downstream in a grouping station. Advantageously, the heat treatment station with the heat treatment oven is arranged between the first grouping station and the (last) grouping station for forming the (end) bundle. In the case of very large bundles, this can have the advantage that a more uniform and, in particular, faster heat treatment of all of the individual fibres can take place. Owing to parallel treatment of the two or more part-bundles in the heat treatment station or the heat treatment oven, the latter can be made structurally smaller.

In a further advantageous embodiment of the plant, it may be the case that the heat treatment station and/or the heat treatment oven comprises a ventilation unit and/or is connected to a ventilation unit and/or the heat treatment oven has at least one gas inlet opening, in particular a gas inlet opening for atmospheric air (ambient air).

In this way, a gas supply and/or gas discharge can take place. Furthermore, escaping vapours can be selectively discharged, and supplied gases, such as air and/or inert gases, e.g. N_2, CO_2, can be pretreated and conditioned in an appropriate manner. Thus, a ventilation unit may comprise or be connected to a gas conditioning unit.
The gas conditioning unit advantageously comprises any treatment elements for setting an advantageous gas quality, such as (HEPA) filters, dehumidifiers and/or temperature adjustment units, for example. A "ventilation unit" refers to any driven gas flow that is not caused solely by thermal conditions or occurs passively. What is meant by "occurs passively" is that the gas is entrained at least partly by the conveyed fibre. The ventilation unit is advantageously connected to the heat treatment station and/or the thermal treatment unit via a feed conduit and/or a drain conduit, where the drain conduit can be connected to a gas cleaning unit, such as, for example, a gas scrubber and/or a filter, in particular an activated carbon filter, to separate off harmful gas components and/or to prepare them for disposal.

Surprisingly, the gas atmosphere in the heat treatment oven, i.e. the gas composition and in particular O_2 concentrations that are not high, has almost no influence on the quality of the fibre, especially not on selectivity and/or permeance. Without wishing to be tied to one interpretation here, it is assumed that due to the very short heat treatment times, the oxidative influence of oxygen is very limited, and so the heat treatment oven can be open to the atmosphere.

Advantageously, in one embodiment of the plant, it may be the case that the ventilation unit comprises and/or is connected to at least one gas conditioning unit for the supplied cooling gas.

Even though the term "cooling gas" is generally used for the supplied gas and an essential function or purpose of the gas supplied to the interior of the heat treatment oven is indicated, this should not be understood in a limiting manner. Cooling gas also refers to the gas or the gas component that flows at least partially, in particular completely, through the interior of the heat treatment oven, in particular at least partly through the space between the wall elements, (lateral) reflectors, interstices in a heating element, etc., in that the fibres to be subjected to heat treatment in intended operation are also arranged such that at least partial flow of the cooling gas around these fibres is possible. In the case of the use of a heat exchanger in the heat treatment oven, this may preferably be arranged in the form of a jacket, wall element or self-supporting heat exchanger in the interior of the heat treatment oven, in order to prevent a constant temperature and/or exceedance of a limit temperature, i.e. overheating, of individual components of the heat treatment oven. In particular, it is possible by means of cooling gas to create a defined, constant gas atmosphere at the inlet of the heat treatment space and hence also within the heat treatment space, even in the case of ambient conditions subject to significant diurnal and/or seasonal fluctuation.

The gas conditioning unit may form a structural unit or consist of multiple elements, such as, in particular, a drying unit for setting a defined humidity (H_2O) in the cooling gas, a filter unit, in particular an HEPA filter, for establishing a defined particle content or substantial freedom from particles in the cooling gas. Additionally or alternatively, the gas conditioning unit may comprise or be formed from a gas separation unit or module, by means of which an O_2 depletion, in particular from ambient air, can be initiated. The gas separation unit may comprise, in particular, at least one hollow fibre filter/module which corresponds identically or in an analogous manner to the filter modules and/or filter materials described herein.

The ventilation unit, the cooling unit and/or the gas conditioning unit may comprise at least one flow control unit, in particular a flow control unit which can be controlled and/or regulated by means of the control and regulation unit. Alternatively or additionally, the ventilation unit, the cooling unit and/or the gas conditioning unit may be connectable or connected to such a flow control unit.

Gas feed via a ventilation station into the heat treatment oven and the heat treatment space, particularly in addition to a heating element such as a resistance heater, has an advantageous effect on the controllability and regulatability of the atmosphere in the heat treatment space. The gas feed conduit here may include one or more inlet openings and/or channels into the heat treatment oven. Furthermore, the heat treatment oven may comprise a gas outlet, in particular from the at least one heat treatment space, for controlled and/or regulated discharge of the hot gas mixture. This gas outlet may include one or more outlet openings from the heat treatment oven.

Direct introduction of gas into the heat treatment oven provides an advantageous degree of freedom for controlling and regulating the oven, and the fibre can be protected directly, for example in the event of temporary overheating of the components of the heat treatment oven, without interruption of production. All aforementioned apparatuses, elements and components include all sensors and control and regulation units required for this purpose, or are connectable or connected thereto.

In an advantageous embodiment it may thus be the case that

i) the heat treatment space of the heat treatment oven is open to the atmosphere during operation as intended, and/or

ii) has least one gas inlet opening for regulated (active) introduction of gas into the heat treatment space, especially for regulated introduction of an O_2-containing gas mixture.

In particular, heating gas from an external heating gas source can be conducted via the at least one gas inlet opening in the heat treatment space.

In this case, "open to atmosphere" means that, even in a heat treatment oven that is mechanically closed or can be closed, in closed operation as intended, there is at least one passage opening through which a fibre can be conveyed during operation of the heat treatment oven. Advantageously, a heat treatment oven has two passage openings: an inlet and an outlet opening for the fibre.

What is meant here by "in operation as intended" is the state of the heat treatment oven, in particular a largely mechanically closed state of the heat treatment oven, in which the heat treatment of a fibre inserted in the heat treatment space takes place. Furthermore, "open to the atmosphere" means that a wall opening and/or a supply channel is provided through which the fibre or the fibre bundle can be introduced into the heat treatment space, and in parallel a gas or gas mixture, in particular air, is able to flow into the heat treatment space.

In this case, the fibre inlet and/or the fibre outlet may be formed as an inlet or outlet opening, such as a cutout in the material, in a heat treatment oven provided for a batchwise or continuous operation. In an improvement of this embodiment, a lock chamber may be provided, in particular a heatable lock chamber, which is preferably heated with a heating gas to limit the entry of cold and/or unconditioned ambient air. The heating gas may be air, an O_2-containing gas mixture or an inert gas, such as nitrogen (N_2) or carbon dioxide (CO_2). Surprisingly, however, it has been shown that the passive entry of ambient air has no adverse effect on the fibre quality, especially not on selectivity and/or permeance.

In a further advantageous embodiment, the ventilation station is alternatively or additionally configured to introduce or conduct an inert gas into or through the heat treatment oven, in particular

nitrogen (N_2). Advantageously, the ventilation station is designed to produce a low-oxygen atmosphere in the heat treatment oven; in particular, the O_2 content therein may be lowered, but is not less than 5.0 mol%, in particular not less than 10 mol%, preferably not less than 15 mol%. However, it has been found to be particularly preferable when the cooling gas used is ambient air, in particular ambient air conditioned by means of a gas conditioning unit, which in particular has not been depleted of O_2 and/or altered, i.e. enriched or depleted, with regard to the N_2, O_2,CO_2 or noble gas components.

The gas flow within the heat treatment oven and in particular in the heat treatment space is not limited and can follow directly along or transversely to the fibre and/or take place indirectly through internal spaces of the heat treatment oven which are delimited by components, such as reflectors or partition walls, from the interior space surrounding the fibre. Particularly advantageous is gas flow or flow attack parallel or largely parallel to the fibre, whereby less mechanical stress and fewer vibrations are generated in the fibre or the fibre bundle.

In order to shorten reaction times with the required lowering of the temperature in the heat treatment space, the heat treatment oven in one advantageous embodiment has a cooling unit, in particular a cooling unit which is operated with a fluid, such as water for example.

In a further advantageous embodiment of the plant, the heating element of the heat treatment oven, such as a resistance heater, may have a power based on the length (m) of the heat treatment oven or resistance heater in metres of at least 7.5 kW/m, advantageously of at least 10.0 kW/m and ideally of at least 15 kW/m. Advantageously, the power of the resistance heater is not more than 100 kW/m, preferably not more than 50 kW/m, and ideally of not more than 35 kW/m. Heating elements in particular that can be operated at a power of 8 to 17.5 kW/m are capable of heat treatment of a polymeric hollow fibre or a bundle of up to 100 individual fibres within a period of time of less than 15 s, ideally less than 10 s, and of achievement of specification-compliant permeances and selectivities.

In addition to at least one heating element, the heat treatment oven may have one or more reflectors in its interior, where a reflector may be mounted on a wall or may form at least part of an inner wall or an inner wall section of the heat treatment oven.

In a further, advantageous embodiment, it may be the case that the heat treatment oven is formed of two or more parts and for this purpose has at least two mutually shielded interior spaces (heat treatment spaces) or sections. Such a heat treatment oven is designed to heat the fibre in at least one heating step in a first interior or portion for a first treatment period with a first power and to heat treat the fibre in at least one power step in a further interior or portion downstream for a further treatment period with a further power, different from the first. What is meant here by "shielded" is that at least one separation element and/or deflecting element, especially a separating element having a suitable low passage opening, is provided. This ensures that, in particular, the energy

from the further interior or section does not get into the downstream interior or sections. The separating element may also be a lock element or interspace without a heater, heating element and/or heating gas input, in particular with no IR radiation emitter.

In a further, advantageous embodiment, at least one fibre accumulator may be provided upstream and/or downstream of the heat treatment station, especially upstream of the heat treatment station, so that the fibre or the bundle can be conveyed within the heat treatment station with a reduced conveying speed or can be stopped at least temporarily, i.e. can have a conveying speed of 0 m/s for a defined partial duration of the heat treatment. Ideally, the fibre accumulator is motor driven and/or motor controllable; particularly advantageously, the fibre accumulator is integrated in an adjacent treatment unit.

It is advantageously the case that, in the plant, the heat treatment oven has a channel- or alley-like configuration, and has at least two walls or wall sections parallel to the local transport direction of the fibre, especially in the direction of the longitudinal fibre axis (A_F) as in intended operation of the plant. In this case, the walls or wall sections may be covered with or at least partly formed from aforementioned reflectors, heating element(s), heat exchangers. Thus, a fibre is conducted uncut as a strand through the heat treatment station and subjected to heat treatment during conveying in the direction of the fibre axis. The heat treatment oven, in this embodiment, may thus have an inlet opening and an outlet opening in which the fibres are continuously introduced and discharged. In order to improve the controllability and regulatability of the heat treatment step and the heat treatment oven, at least one guide and diverter may be included, in particular a movable diverter, by means of which the fibre is diverted at least once in the region and/or within the heat treatment oven. It is particularly advantageous when the guide and diverter is implemented adjustably, in particular motor-adjustably, so that the dwell time of a fibre or a fibre section in the heat treatment oven and in particular in the region of the heating element and/or heating gas inlet/passage can be controlled as required. Dwell time in the heat treatment oven and heat treatment time are also used synonymously in the present context.

In a very economical embodiment of the heat treatment station, this is formed as an alley or channel with walls parallel to transport direction, in particular to the longitudinal fibre axis. In principle, the position and number of heating element and/or heating gases relative to the conveyed fibre are not limited if the skilled person pays attention to the quality-relevant parameters, such as power of the heating elements, duration of fibre exposure and uniformity of energy input to the fibre.

According to a very advantageous embodiment of the plant or else, in an analogous manner, of the process, it may be the case that the plant and the process are configured to transport the fibre or the fibre bundle continuously from the spinning unit to at least the outlet of the heat treatment station. In particular, it is advantageous to continuously convey the individual fibres uncut each as a

strand or at least one fibre bundle uncut as a strand from the spinning unit to and through the heat treatment station.

In this case, "continuous" conveying or transport of the fibre is also understood to mean at least temporary intermediate storage and/or stacking in a fibre accumulator.

The at least one heat treatment station with the at least one heat treatment oven may advantageously be arranged at one of the following plant locations:

- downstream of the washing unit, wherein no (further) thermal treatment station of the thermal treatment unit is arranged upstream of the heat treatment station,
- downstream of at least one dehumidification station of the thermal treatment unit,
- downstream of at least one drying station, in particular downstream of a drying station which is arranged downstream of a coating station or application station.

Overall, the heat treatment station is used in particular for concluding heat treatment of the (externally) wet (raw) fibre or the (raw) fibre contaminated with (internal) residual moisture composed, for example, of detergent, solvent and/or exchange medium, so that the skilled person can provide a suitable installation location where the fibre arrives wet, i.e. undried or with a defined residual moisture content after passing through a drying station.

What is meant here by a "wet fibre" is that the fibre has not yet passed through a thermal treatment station after the washing unit or that only adhering (external) fluid has been stripped, drained and/or roughly removed with a gas jet under pressure or vacuum. The heat treatment station is regularly downstream of and outside the washing unit.

In a particularly advantageous embodiment of the plant, an end-processing unit is arranged downstream of the heat treatment station. In particular, the end-processing unit may comprise at least one winding wheel or a bundling tool and/or an applicator. Overall, the term "end-processing unit" is intended not to be construed in a restrictive manner and to describe a unit in which any kind of temporary or permanent connection of individual fibres takes place. In particular, individual fibres or a fibre bundle, uncut, can be continuously wound up with the winding wheel until the winding wheel is fully loaded and can then be cut and subsequently cut to a defined length and/or otherwise processed. By means of a bundling tool, a temporary or permanent bundling of a (partial) group of fibres can be carried out in addition or alternatively. Here, for example, all or a subset of the uncut fibres are wrapped inline and, optionally, tensioned with respect to one another. For tensioning, a tape, a band or other entwining means can be looped around the fibre group and suitably fixed. The end-processing unit may be completely or partially embraced by the post-treatment unit or connected to the post-treatment station. The bundled groups of individual fibres (fibre bundles) can advantageously be cut in the region of the wrapping; this is not to be understood restrictively and

the cut in the transport direction of the fibre bundle may take place ahead of, behind or through the tape, the band or the entwining means.

Alternatively, the end-processing unit is arranged upstream of the heat treatment station, where the heat treatment station comprises at least one heat treatment oven.

Another advantageous embodiment of the plant provides that a fibre accumulator (unit) is provided, also called "band store". The latter may be arranged in particular upstream of the heat treatment station. This fibre accumulator is advantageously equipped with movable diversion elements, which are motor drivable and/or controllable and regulatable. In this way it can be made possible that fibres are produced continuously upstream of the heat treatment station and downstream of the fibre accumulator the fibres or the (fibre) bundle can be taken off discontinuously and/or at different speeds. In particular, the fibre accumulator can be used to stop the fibre and/or the fibre bundle in the heat treatment station.

In a further advantageous embodiment, the end-processing unit comprises a cutting apparatus for the fibres or the fibre group. In particular, a cutting apparatus by means of which the conveyed fibres or fibre group can be cut inline. For this purpose, it is particularly advantageous if the bundling tool and/or the cutting apparatus can be moved and/or swivelled in the fibre conveying direction in order to avoid interrupting fibre production. The end-processing unit may further be designed to form an (end) bundle of y x n fibres or the y part-bundles from a plurality of y part-bundles each of n fibres and to fix them at least temporarily.

"Temporarily fixing" here means that the fibres of such a group are fixed against each other in such a way, e.g. braced, that they can be transported and/or further treated as a group and that the falling-out of an individual fibre is reliably prevented. The formation of such (partial) or (end) bundles from a plurality of fibres is typically followed by adhesive bonding (potting) and finishing, i.e. formation of the filter cartridge, or by manufacture of the filter module with insertion of the filter cartridge.

In another advantageous embodiment, the post-treatment unit of the plant comprises a discharging station. This is used in particular at the entrance of a drying unit or at the entrance of an end-processing unit, to diminish disruptive electrical charges; for this purpose, for example, a spray medium containing an electrolyte and/or an iron-containing substance is applied to the fibres. In an alternative embodiment, the electrical discharging is effected by contacting, in particular by means of a looping contact, with a grounded electrical conductor.

In a further advantageous embodiment, the post-treatment unit of the plant comprises a coating station, the coating station being for applying at least one coating to the separatory layer of, for example, a polymer material to the base fibre, wherein the separatory layer with the coating and

the entire fibre or the at least one fibre bundle must subsequently be subjected to heat treatment in the heat treatment oven in order to set the desired separation properties of the hollow fibre membrane.

In one very advantageous embodiment, polydimethylsiloxane (PDMS) can be applied as coating material in the coating station (coating step), e.g. by means of a spraying apparatus or by means of a dip bath. In the case of an ISA membrane, the PDMS coating is used, for example, to close surface defects in the separatory layer, on whose separation properties it may also have a minor effect. A fibre thus coated is then advantageously dried in a drying station and subsequently subjected to downstream heat treatment, where in the heat treatment step by means of energy input up to the limiting or heat treatment temperature in total the desired separation properties of the hollow fibre are developed. Ideally, each coating station is followed by a drying station.

The present hollow fibres for gas separation may especially be of two basic types:

i) ISA membrane
These comprise a support structure and a thin outer layer as the separatory layer, wherein the support structure and the outer separatory layer are produced monolithically from the same material in the spinning process and specific high separation properties are formed in the heat treatment step. A first separatory layer is formed during exchange (displacement) of the solvent in the fixing station of the exchange unit since displacement of the solvent results in formation of a compressed layer like a skin on the outside of the membrane. The thickness of this separatory layer is adjustable for example via the distance of the spinning nozzle from the fixing bath. In a further, advantageous embodiment it may be provided that the separatory layer or the fibre comprising the stated separatory layer is coated (coating step) with at least one polymer material distinct from the base fibre, especially with the polymer material polydimethylsiloxane (PDMS).

ii) Asymmetric composite membranes (AC membranes) comprising a base fibre as a basic or support structure and an applied outer separatory layer, wherein at least one further coating layer may be included.
To this end a porous base fibre which, in contrast to the ISA membrane, does not yet comprise an outer separatory layer is spun in a spinning apparatus and the subsequent exchange steps. This base fibre is then coated in an application station (coating application step) with at least one material distinct from the base fibre, as the outer separatory layer. This separatory layer may

i) comprise or substantially consist of a polymer material corresponding to one of the polymer solutions described herein, such as, for example, aromatic polyimides, aromatic polyetherimides, aromatic polypolyamides, polyarylene ethers, aromatic

polybenzimidazoles and/or mixtures thereof, wherein optionally one or more 2D or 3D fillers may be included, for example zeolites, MOF particles (metal-organic framework materials), mexenes (MXenes) and/or graphenes, or

ii) be substantially formed from an inorganic or metal-organic material, for example zeolites, MOF particles (metal-organic framework materials), mexenes (MXenes) and/or graphenes, where suitable binders may be provided.

The base fibre and/or the separatory layer of an AC membrane according to i) or ii) may be provided with a coating, in particular polydimethylsiloxane (PDMS), analogously to the ISA membrane.

In one variant embodiment of the plant and the process, at least one application station or coating application step for applying a separatory layer to a base fibre may therefore be provided, to produce an AC membrane. In addition, at least one coating station may be provided, as set out above.

According to the invention, the two aforementioned basic types of a hollow fibre membrane are finally heat treated in the heat treatment oven, where the desired high separation properties are developed.

Advantageously, a drying station is located directly downstream of the at least one application station and/or the at least one coating station; in particular, a drying station is provided directly downstream of each application station and/or coating station.

The invention further comprises a process for producing a fibre which is spun from a polymer substrate, wherein the fibre, in particular, is a hollow fibre for gas separation, and wherein the process comprises the following steps:
- the step of spinning the fibre from the polymer solution,
- the step of exchange for exchange of a solvent, in particular an aqueous solvent, wherein the exchange step may comprise at least one fixing step with a liquid fixing medium and/or at least one washing step in/with a washing medium, in particular in a tank with a washing medium, where the washing step in particular may follow on from the fixing step,
- at least one drying step comprising a heat treatment step in which the fibre is heated to a temperature below the glass softening temperature (T_G) of the polymer substrate, wherein the fibre is heated, i.e. heat-treated, in the heat treatment step by means of at least one continuously operated heat treatment oven by a heating element and/or a heating gas.

In this case, the fibre is continuously heated in the heat treatment step by means of at least one heating element (252) and/or a heating medium in a heat treatment oven to a temperature

i) in the range up to 80°C below the glass softening temperature (T_G), and/or
ii) in the range of greater than 250°C and below the glass softening temperature (T_G).

The temperature here in the heat treatment oven may be greater than T_G, and must be determined in particular depending on the geometry of the heat treatment oven, especially the interior space, and the dwell time of the fibre in the heat treatment oven.

In this case, the fibre is heated continuously in the heat treatment oven by means of the heating element and/or a heating medium in an ambient gas atmosphere. In addition, a cooling gas can be introduced passively or actively supplied, which at least partly generates the gas atmosphere in the heat treatment step.

The production process is preferably a process for continuous heat treatment of the fibre in the heat treatment oven, in particular for a dwell time of the fibre in the heat treatment oven of less than 30 minutes at standard pressure or slightly elevated pressure relative to standard pressure in the heat treatment oven. In an advantageous process variant, the dwell time of the fibre in the heat treatment space or a heating section corresponding to the heat treatment space is 0.5 to 180 s, preferably 1.0 to 120 s, more preferably 1.0 to 60 s, more preferably 1.0 to 30 s, ideally 1.0 to 15 s. It is advantageously possible here for the fibre to be transported contactlessly in the heat treatment space or for the fibre to be deflected by contacting guide elements in the fibre axis at least for some of the distance within the heat treatment oven and/or the heat treatment space, so that the dwell time of the fibre in the heat treatment space is influenced geometrically by deflection.

In one process variant, it may be advantageous when the temperature in the heat treatment space or a heating section corresponding to the heat treatment space is in the range from 300 to 800°C, preferably in the range from 320 to 780°C, more preferably in the range from 350 to 750°C, more preferably in the range from 380°C to 700°C.

It has been found to be particularly advantageous when, in one process variant, the ratio V1 [s/T] of dwell time [s] of the fibre in the heat treatement space to the temperature in the heat treatment space [K] is in the range from 0.0006 to 0.6 s/K, preferably in the range from 0.0006 to 0.43 s/K, more preferably in the range from 0.048 to 0.429 s/K, more preferably in the range from 0.176 to 0.429 s/K. The advantageous ratio V1 was found in particular for the temperature range in the heat treatment space of 300 to 800°C.

It has also been found to be particularly advantageous when, according to one process variant, a ratio V2 [s/m*K] of dwell time [s] of the fibre in the heat treatment space to the internal diameter of the heat treatment space [m] and the temperature in the heat treatment space [K] is in the range from 0.001 to 0.545 sm*/K, preferably in the range from 0.043 to 0.39 sm*/K, more preferably in the

range from 0.086 to 0.39 sm*/K. The advantageous ratio V2 was found in particular for the temperature range in the heat treatment space of 300 to 800°C.

It is advantageously the case in the process that a tensile force in mN per individual fibre is exerted on the fibre, which is in the range of 10 to 500 mN, preferably in the range of 10 to 200 mN, more preferably from 10 to 100 mN, more preferably from 10 to 50 mN, more preferably from 10 to 30 mN.

It is advantageously the case in the process that, in the heat treatment step, n individual fibres are subjected to parallel heat treatment, where n =< 600, preferably n =< 180, especially preferably n =< 120, ideally n <= 100. It is also advantageous when, in the heat treatment step, n individual fibres are subjected to parallel heat treatment, where n >= 2, preferably n >= 10, especially preferably n >= 20, ideally n >= 40. This results in an advantageous range of 2 to 600 individual fibres that are subjected to parallel heat treatment in the heat treatment step, for example as a single fibre bundle, or correspondingly smaller fibre bundles.

In one variant of the process, it may be advantageous that the heat treatment time is in the range of 0.5 to 60 s, preferably 1 to 30 s, ideally 1 to 20 s. If there is a multistage heat treatment, or a heat treatment in which a preceding warming step is carried out, followed by at least one power step in which the fibre is subjected to heat treatment at maximum power, the aforementioned heat treatment times refer to the power step or the sum of the power steps.

In a further improvement, which in particular results in better controllability and regulatability of the continuous process, it may be the case that a cooling gas is supplied, which cools at least part of the heat treatment oven and/or the fibre in the heat treatment step, where the cooling gas flows through the heat treatment oven (251) with a gas exchange frequency (AF) of 0.15 per minute (0,0025 pro sec; untere AF) up to 30 per minute (0,25 pro sec; obere AF) , cooling gas and where the heating energy introduced in the heat treatment oven (251) is =< 50 kJ/m.

Advantageously, the cooling gas at the inlet has an inlet temperature 5 to 50°C below the outlet temperature of the heat treatment oven, preferably 5 to 30°C, ideally 5 to 15°C.

The "exchange frequency" or, synonymously, "gas exchange frequency" refers here to the volume of the interior space of the heat treatment oven, in particular the proportion of the interior space, in which the fibre is accommodated and the heating element or heating gas acts thermally on the fibre, and in particular directly thermally acts on the fibre, where the cooling gas flows through this interior space and/or part of the interior space of the heat treatment oven.

Overall, it was observed that controlled (cooling) gas flow and guiding is for the uniformity of the quality of the fibre, especially for the shaded fibres, and the energy distribution in the heat

treatment oven. It has also been found that, surprisingly, there is a relationship between the exchange frequency and the energy supplied with regard to selectivity and permeability of the fibre. It was found that permeability is improved at higher exchange frequencies with constant or essentially constant selectivity. Furthermore, improved selectivities coupled with slightly reduced permeabilities were observed at low exchange frequencies. It is thus possible here to provide a teaching that a plant operator can control and regulate exchange frequencies and/or energy input depending on the specification of the fibre to be produced.

In a further advantageous embodiment of the process, it may be provided, in the heat treatment step, for the fibre to be heat-treated or heated in such a way that the fibre for a defined time (heat treatment time)

i) is heated to a limiting temperature which is not more than 1°C, in particular not more than 4°C below the glass softening temperature (T_G), in particular to a limiting temperature in the range of 70°C to 1°C below the glass softening temperature (T_G), preferably in the range of 65°C to 1°C, and/or

ii) to heat the fibre to a temperature of greater than 280°C to 450°C and below the glass softening temperature (T_G).

It is particularly advantageous here when the difference of not more than 1°C to 4°C from the glass softening temperature (T_G) is observed in order not to damage the structure, in particular the desired porosity, of the hollow fibre. In order to avoid damage to the fibre owing to fluctuations in the heating temperature, it may be preferred if instead of the aforementioned not more than 1°C difference from T_G, a difference of not more than 1.5°C, 2°C, 2.5°C, 3°C or 3.5°C to T_G is provided. The respective maximum temperature difference from T_G can be provided depending on the respective fibre material and on the plant and/or the process.

By analogy, "not more than 1°C, in particular not more than 4°C" here means that it is particularly advantageous if the difference of at least 1°C, 1.5°C to for example 4°C, from the respective glass softening temperature (T_G) of the fibre material (polymer substrate) is observed, in order not to damage the structure, in particular the desired porosity, of the hollow fibre. This applies in the same way to the degeneration or decomposition temperature (T_D).

It is particularly advantageous when the process for producing a heat-treated fibre is carried out by means of a plant designed according to at least one of the embodiments and variants described herein. It has been found to be particularly advantageous when the heat treatment space of the heat treatment oven is of channel- or alley-like design and the fibre is guided contactlessly in the region of the heat treatment space. This means that the fibre has no contact on one or more sides with deflection elements in the heat treatment step. In this way, membrane properties can be established particularly uniformly.

It may be an advantage in one variant of the process that a group of m individual fibres is formed before the heat treatment step in a grouping step to form at least one bundle of n = 5 to 600 individual fibres and subsequently subjected to heat treatment as the bundle, wherein either
- n is less than m, such that two or more part-bundles are formed, or
- n is equal to m, such that only one bundle is formed.

In a very large total number m of individual fibres, it may be advantageous when part-bundles of n individual fibres are formed in order to reduce mutual shading and insulation of the fibres in the heat treatment space. The part-bundles can be subjected to heat treatment in a common heat treatment space in the heat treatment oven. Alternatively or additionally, part-bundles can be subjected to heat treatment in a second heat treatment oven and/or separate heat treatment space.

One advantage in a variant of the process may be that the fibre is transported continuously from the spinning unit to at least the exit from the heat treatment station, and in particular is transported uncut.

In a further preferred embodiment of the process, it may be the case that the heat treatment step is effected at a pressure in the range from not more than +2 bar to atmospheric pressure, preferably +1 bar, preferably +0.5 bar or equal to atmospheric pressure. This ensures, in particular, that there is always a defined flow/direction within the heat treatment space in the heat treatment oven and in particular no outside air is drawn in. The flow direction of the cooling gas within the heat treatment space is not limited, and it has been found to be advantageous to subject the fibres to an opposing flow at least for part of the length or part of a distance. This has the advantage that the heat (energy) is transported from the fibre sections that have been exposed to the heating element for the longest time to the fibre sections that have been exposed for a shorter time and are hence cooler.

Even when a single fibre is mentioned in the present case, a group of individual fibres or a fibre bundle can also be treated in an analogous manner. In particular, in one process variant, a heat treatment oven and the heating element therein are used to treat a fibre bundle of n individual fibres of 2 up to n = 600, as set out above. It may be advantageous here when the individual fibres in a fibre bundle are wound, turned or twisted relative to one other with respect to a common (theoretical) central longitudinal axis. This has the advantage that the individual fibres come into closer contact and are thus more densely packed and that the risk of fibre breaks at individual fibres is reduced during shrinkage processes.

In a preferred process variant, in the heat treatment step, the fibre can be treated by means of the heating element based on the length of the heating element in metres (m) of at least 5.0 kW/m, preferably at least 7.5 kW/m and ideally at least 10 kW/m. In this case, it may also be

advantageous when the heating output is not more than 100 kW/m, advantageously not more than 50 kW/m and ideally not more than 35 kW/m.

All aspects and advantages described herein in respect of the plant shall also apply identically or analogously to the process and vice versa, provided they are not technically precluded/impossible.

Advantageously, the heat treatment step may take place in an inert or largely inert atmosphere in which the O_2 content in the heat treatment oven is below 1000 ppm. Surprisingly, however, it has been found to be technically feasible and economically very advantageous to set the atmosphere in the heat treatment oven at a gas mixture of not less than 5.0 mol%, in particular not less than 10 mol%, preferably not less than 15 mol%. It has been found in a particularly preferable and surprising manner to perform the heat treatment step in ambient air, especially conditioned ambient air. The remaining gas constituents of the cooling gas are advantageously N_2; in particular, the remaining gas constituents are greater than 95 mol% of N_2. It is thus possible to supply ambient air with ~21 mol% of O_2.

In this case, "conditioned ambient air" means that ambient air or another O_2-containing gas mixture is filtered in a suitable manner prior to introduction into the heat treatment oven and/or the heat treatment step, in particular with regard to the particle concentration, and/or with regard to moisture content and/or temperature.

The energy for heat treatment is advantageously supplied by a heating element, for example a resistance heater, a burner, a heat exchanger, etc. at least single-sidedly in the direction of the fibre or fibre bundle in the heat treatment oven and advantageously distributed by convection and/or reflection by at least one inner wall and/or at at least one reflector within the heat treatment oven. Alternatively or additionally, the energy can be introduced directly into the interior via a heating medium, such as a heating gas. In this case, the heating gas can be produced indirectly via a heat exchanger or in a burner as combustion offgas. The combustion offgas may in particular originate from the combustion of a carbonaceous substance, in particular a carbonaceous gas or gas mixture. The carbonaceous gas or gas mixture may advantageously be or comprise methane, ethane, propane or butane.

As an outstanding effect, it was surprisingly found that the entire heat treatment time using a continuous volume flow rate of a heating gas and/or a continuous heating element, for example a resistance heater, for a bundle of up to 80 individual fibres requires only, for example, 0.1% of the heat treatment time compared to a standard batchwise heat treatment oven, such as an electrical air circulation or convection oven. According to an advantageous embodiment of the process, it may thus be the case that the heat treatment time is in the range of 0.1 to 60 s, preferably 0.5 to 30 s, ideally 1 to 20 s.

In order to limit diffusion processes in the fibre comprising residues of dissolution or exchange medium, it may be advantageous not to implement the energy input in a single step during heat treatment. Thus, in a further process execution, the heat treatment step may consist of at least two component steps, namely

1) at least one heating step in which the line is in the range from 5% to 25% of the maximum power, advantageously 7.5% to 15%, ideally 10%, and
2) at least one power step in which the defined maximum power for heat treatment in the heat treatment oven is introduced.

In the case of such a multistage heat treatment step, the heat treatment time is calculated essentially according to the power step or the sum total of the power steps.

The duration of the heating step is advantageously 1/6 to 1/3 of the power step, where the power step is advantageously in the range from about 0.1 to 60 s, preferably 0.5 to 30 s, ideally 1 to 20 s.

Even though a distinction is made in the present context between "heat treatment step" and "power step", "heat treatment step" is also used in some cases synonymously for the "power step" in which the maximum power is introduced into the heat treatment oven by the heating element and/or the heating medium. There is an advantage in respect of a simple and efficient process regime when the heating step is effected by cooling by means of cooling gas over at least some of the distance within the heat treatment oven, and is generated in particular by cooling by means of an incoming gas stream.

In a further process execution, an advantage may be that the fibre is conveyed at least over part of the duration of the heating and/or power/heat treatment step. Advantageously, the fibre is conveyed throughout the heat treatment step.

According to a further-improved process variant, it may be the case that the heat treatment oven

i) is open to the atmosphere, in particular has an inlet or outlet opening for the fibre and a passive gas or air entry with the conveyed fibre takes place in the heat treatment oven, and/or
ii) comprises or is connectable to a ventilation station, via which a gas or a gas mixture, in particular air, N_2 and/or CO_2, is introduced into the interior (heat treatment space) of the heat treatment oven.

In alternative embodiments of the process, as described above for the heat treatment oven, gas is guided via at least one lock.

Thus, in a further advantageous embodiment of the process, it may be the case that the heat treatment oven is open to the atmosphere. In this case, atmospheric gas (air) in a for a continuous

process can be conducted via the fibre inlet and/or the fibre outlet as an inlet or outlet opening, which are hot passively and discharged.

It is advantageous here when the gas or gas mixture passively or actively introduced with the fibre, especially air, flows parallel to conveying direction of the fibre, especially in the same direction as the fibre. This avoids vibrations and hence mechanical stresses on the fibre, where the flow direction of the gas or the gas mixture is possible in principle. However, it has been found to be particularly advantageous when the cooler incoming gas flows into the heat treatment oven in the same direction since, as a result, the thermal transition for the cold incoming fibre is less rapid, analogously to multistage heat treatment.

In a simple but very economically viable process variant, no lock chamber is provided. In an improvement of this embodiment, a lock chamber may be provided, in particular a heatable lock chamber, by means of which the fibre is first heated and the interior of the heat treatment oven is shielded. Preferably, a heating gas is introduced into the lock chamber in order to limit the entry of cold ambient air, or of ambient air with significant temperature fluctuation, and/or to reduce the thermal load on the fibre at the outlet. The heating gas here may be a gas mixture, such as air, an O_2-containing gas mixture. Alternatively or additionally, the gas (mixture) may comprise at least one inert gas, such as nitrogen (N_2) or carbon dioxide (CO_2). Alternatively, the lock chamber may include a heating element to achieve the same effect.

In order to improve the controllability and regulatability of the production process, a gas can be supplied in a further advantageous embodiment, in particular into the at least one interior (temperature control space) in addition to any heating element disposed and/or active therein, wherein, by means of a connected or connectable ventilation station into the heat treatment oven, a gas mixture, in particular air, is introduced into the interior by means of, for example, a compressor (actively). The gas can be supplied to the heat treatment oven via one or more inlet openings, with provision of a gas outlet.

Direct gas introduction provides a degree of freedom for controlling and regulating the oven for the process and effectively protects the fibre in the event of, for example, temporary overheating of the components of the heat treatment oven, without interrupting the process. This is particularly advantageous when the heating element, such as a resistance heater and/or an internal fluid-carrying interior, is separated from the heat treatment space and the fibre guided therein by a solid wall element, and hence there is high system inertia and/or longer dead times before regulatory changes toward lower temperatures (cooling effects) become effective for the conveyed fibre.

Although the plant and the process are primarily described for continuous heat treatment in the present context, the present invention is not limited to this. The heat treatment oven may also be a

batch unit, so that the fibres, a fibre bundle or a group of fibre bundles are heat treated in batch operation by means of at least one heating element and/or the heating gas.

Alternatively, the fibres are advantageously cut to a desired length before heat treatment and/or advantageously fixed at least temporarily as (partial) bundles, analogously to the plant treatment units described herein. In this stepwise or batchwise heat treatment, it is advantageous overall to heat treat the individual fibres or the fibre bundles hanging or held vertically in axial direction, so that the individual fibres remain aligned largely parallel to each other.

The solution according to the invention will now be described in detail with reference to working examples. The figures show:

- Fig. 1 the plant in a first execution variant,
- Fig. 2 the plant in a second execution variant,
- Fig. 3 the plant in a third execution variant,
- Fig. 4 the plant in a fourth execution variant,
- Fig. 5 the plant in a fifth execution variant,
- Fig. 6 two execution variants for the transport of the fibre in the heat treatment station,
- Fig. 7 the test setup as a schematic diagram and
- Fig. 8 a further graph as a comparison of the dwell times in the heat treatment oven.

The plant 100 as shown in Figure 1 has a main conveying direction A which is shown from left to right and in a Cartesian system represents x direction. The plant 100 comprises a control and regulation unit 130, a reserve and supply unit 140, a spinning unit 106, a fixing unit 150, a washing unit 160 and a post-treatment unit 170. The post-treatment unit 170 comprises a thermal treatment unit 200, with a drying station 210 of the heat treatment station 250 according to the invention, and an end-processing unit 180. The fibre 110 is transported through the plant 100 in the main conveying direction A and deflected and diverted repeatedly in y direction or z direction over parts of the distance. The control and regulation unit 130 is connected to the plant 100 or parts thereof via data wires 132, as shown by way of example by a dashed-and-dotted line. Other elements for energy and data transmission and automation of the plant are basically known to those skilled in the art and not further illustrated here. The reserve and supply unit 140 is likewise shown only roughly and comprises tanks 142 or a tank farm for media, in particular for the polymer solution 102 from which the fibre 110 is formed, and process media 104, a pump (unit) 146 and an (inert) gas reserve. These are connected to the spinning unit 106 in a media-conducting manner.

The fibre 110 is formed in the spinning unit 106 in an otherwise unspecified manner, as described, for example, for a hollow fibre from a polymer solution in WO 2014/202324 A1. Alternatively, the fibre can also be obtained from a polymer melt, in particular as hollow fibre. The process media

104 here are in particular the process media required in the spinning process, such as the core fluid for forming the inner cavity of the respective individual fibre 110.

The freshly formed fibre 110 is introduced into the fixing medium, a non-solvent, of the fixing unit 150 and is discharged via guide rollers 108 from the tank of the fixing unit 150, where alley guides 109 which have a comb-like or multidigital configuration orient the individual fibres 110 in y direction at a defined distance from one another. The washing unit 160 comprises a plurality of guide rollers 108 which are arranged below the fluid level of the washing liquid and by means of which the fibres 110 are held in the washing liquid, in particular in an organic washing liquid, for a defined cycle time to remove the non-solvent from the fibre 110. In a manner which is not shown, the washing unit 160 may comprise a plurality of tanks connected in series.

The drying station 210 is connected downstream to the washing unit 160, wherein, in a grouping station 260, the fibres 110 are combined into a bundle 112 at the entrance to the drying station 210 and are conducted through the drying stations as a strand via diverting rollers 108. The drying station 210 is connected to a gas feed conduit 212 and a gas drain conduit 214, where in the gas feed conduit 212 there is a heat exchanger 216 for heating the feed conduit C. The feed conduit C is in particular dehumidified air. In the drying station 210, the bundle 112 in the form of a strand is repeatedly deflected by deflection rollers 108 while being dried by a surrounding flow of the heated gas. The deflection rollers 108 are typically static bodies over which the conveyed fibre 110 or the bundle 112 is drawn, where in certain embodiment variants (not shown) it may be advantageous to drive at least individual deflection rollers 108 such that they rotate about their own longitudinal axis and in the direction of the longitudinal fibre axis A_F and hence reduce stress within the fibre 110 or bundle 110.

The heat treatment station 250 connected in main conveying direction A comprises a heat treatment oven 251 as a central element with a heating element 252, where the heating element 252 takes the form of an electrical resistance heater and is disposed in the housing 256 of the heat treatment oven 251. The heat treatment oven 251 takes the form of a channel and continuously receives, on the input side, the predried bundle 112 for a heat treatment time (dwell time) of about 2 to 20 s, where the heat treatment time can be divided into two or more component steps, such as a heating step and a power step.

The heat treatment station 250 or heat treatment oven 251 is connected to a ventilation unit 290 comprising a gas feed unit 270 and a gas drain unit 272, where a compressor 226 and a gas filter unit 274 are parts of the gas drain unit 272. The gas feed and drain 270, 272 in the example shown are part of the ventilation unit 290, where the gas feed unit 270 comprises a gas source and/or is connected to supply and/or suction elements for external atmospheric air. In addition, the gas feed unit 270 is connected to a flow control unit 136, which in the example shown is a controllable gas valve and/or throttle. The flow control unit 136 is connected to the central control and regulation

unit 130 via the data wire 132 and can be controlled centrally. In an alternative embodiment which is not shown, the flow control unit 136 is an (only) locally controllable and/or regulatable gas valve or gas throttle. The ventilation unit 290 further comprises a gas conditioning unit 298, by means of which ambient run is sucked in, and the cooling gas stream is dehumidified and filtered by means of HEPA filter.

By means of the compressor 226, especially in the case of relatively high flow resistances through a downstream filter 274, full flow through the filter 274 can be ensured because the feed and drain of the fibre bundle 112 may not be sealed with respect to the heat treatment space. This is intended to prevent excess heating and/or adverse discharge of gases from the heat treatment space. In a simplified embodiment (not shown), no compressor and/or filter is provided in the gas drain unit 272.

At the discharge end of the heat treatment station 250, opposite to the input side, is disposed a conveying means 280 configured as an arraying and conveying unit and which transmits the (fibre) bundle 112 in compact formation to the end-processing unit 180. Within the drying station 210, the bundle 112 can be guided vertically (z direction) in portions (several times) by corresponding deflections 108 or, as in e.g. Fig. 3, can be guided horizontally (x direction) (several times). In this case, "vertical" or "horizontal" means the main orientation for the purpose of linguistic illustration and also includes (slightly) inclined orientations.

The end-processing unit 180 comprises a fixing station 182, a cutting station 184, a lifting unit 186 and a transport element 188. Via the conveying means 280, the bundle 112 is transported to the end-processing unit 180 and there, at the free end and/or in the separation or cutting area of the bundle, is fixed with at least one otherwise unillustrated fixing means, such as a band, a tape, a cord, etc., as a group (fibre bundle), in particular being multiply wrapped and thus fixed as a group. Parallel or subsequently, the bundle 112 is captured by the lifting unit 186, which in the exemplary embodiment illustrated is configured as an x-y-z lifting and gripping unit. In the cutting station 184 and a separating means symbolically represented as a knife blade, a bundle 112 is cut off at a set length from the (bundle) strand, and may optionally be temporarily stored or stacked as an end-processed bundle 112.

Subsequently, by means of the transport means 188, the end-processed bundles 112 are passed in transmission direction B out of the end-processing unit 180.

The plant 100 shown in Figure 2 differs from the plant of Fig. 1 in particular in that no drying station 210 is provided, but the fibres 110 after the washing unit 150 are directly introduced into the heat treatment station 250 or the heat treatment oven 251, which can be formed in principle analogously to the aforementioned heat treatment station 250 from Fig. 1. In the example as shown in Figure 2, the heat treatment oven 251 as heating element 252 has a resistance heater 253, opposite which a

reflector 254 is disposed in the interior of the heat treatment oven 251. Connected downstream of the washing unit 160 is the heat treatment station 250, where, in a grouping station 260 at the entrance to the heat treatment station 250, the fibres 110 are combined into a bundle 112 and conducted as a strand in a linear manner, i.e. without further diversion, through the heat treatment station 250. In the discharging conveying zone and above the washing unit 160 is disposed a dehumidification station 220 which drives liquid adhering to the fibre 110 back into the tank of the washing unit 160 by means of the nozzle units 222 in the region of the deflection roller 108 in said station.

The lower detail illustration framed by dashed lines shows the guiding of the fibres 110 at the transition from the washing unit 160 to the heat treatment station 250 and the grouping station 260 in plan view. Two further, analogous plan views are shown in Figure 6. As shown in the detail view of Figure 2, at the exit of the washing unit 160, the fibres are spaced apart from one another in y direction by means of the alley guide 109 and compressed downstream by means of the lateral guide rails 262 of the grouping station 260 to form a bundle 112 of the individual fibres 110 that are then in mutual contact.

The compaction takes place in y direction and in z direction, where height guides (not shown) analogous to the lateral guide rails 262 can additionally be provided in order to carry out compaction in z direction in a mechanically defined way and to avoid deformation of the hollow fibre geometry. For this purpose, at least two groups of the fibres to be bundled for a defined conveying zone at different heights (z direction) are guided through such height guides before being laid one on top of another in z direction and formed into a common bundle 112. This plant setup without a drying station 210 and the associated process regime has been made possible by the use of a heat treatment station 250 with a resistance heater 256 because it has surprisingly been found that it is possible with continuous heat treatment to prevent adhesion even of initially relatively wet individual fibres 110 in the bundle 112. In other words, even relatively moist fibre bundles 112 can be heat-treated without or after only a small amount of drying by resistance heating for example.

Elimination of the drying station 210 and the associated conduits and assemblies is associated with considerable energy savings and considerable reductions in the required footprint of the plants.

Figure 3 shows, in a very schematic manner, the plants 100 and the fibre 110, and also the bundle 112 on its way through the plant 100. In addition to or in contrast to the working examples of Figures 1 and 2, the plant 100 comprises a coating station 120 and a discharge station 190, which are known in principle. The aforementioned grouping stations are not shown in Figure 3 and can be provided as required. Analogously to the plant 100 shown in Figure 1, at least temporary winding, stacking and/or cutting of the fibre bundles 112 takes place in the end-processing unit 180. In this plant design, differently to the above, the end-processed and cut fibre bundles 112, in particular a

plurality of at least temporarily end-processed fibre bundles 112, are heat treated downstream of the end-processing unit 180 batchwise in a heat treatment oven 251 of the heat treatment station 250 by means of resistance heaters (not shown).

In the working example of Figure 4, unlike the plant variant of Figure 3, the heat treatment oven 251 of the heat treatment station 250 is arranged upstream of the end-processing unit 180. The mutually spaced-apart individual fibres 110 or the at least one fibre bundle 112 is continuously transported through the heat treatment oven 251 and subjected to heat treatment. In particular, the transport speed and/or the length of the heat treatment oven 251 are dimensioned and/or matched to one another in such a way that the required dwell time (heat treatment time) of the individual fibres 110 or the at least one fibre bundle 112 in the effective zone of the resistance heater (not shown) can be maintained.

In the working example of Figure 5, in contrast to the previous embodiment variants of Figure 1 to Figure 4, the invention also comprises a fibre accumulator 230, which is arranged ahead of the heat treatment station 250 as part of the thermal treatment unit 200. Thus, an accumulation step for the fibres 110 or bundle 112 may precede the heat treatment step.

The fibre accumulator 230 has two opposing groups of diversion elements 232, which, driven dynamically as a group or individually, can change their position relative to each other. In this way, a defined fibre length or bundle length can be accumulated, while e.g. downstream of the fibre accumulator 230 the fibres 110 or the (fibre) bundle 120 are transported at a slower rate, or temporarily stopped, compared to the case upstream of the fibre accumulator 230.

In other words, the plant comprises

- a first conveying section F1, in which the fibres can be conveyed at a first conveying speed v1, in particular can be conveyed continuously, and
- a second conveying section F2, in which the fibres can be conveyed at a second conveying speed v2, in particular can be conveyed discontinuously and/or with varying speed, wherein

a (dynamic) fibre accumulator 230 is arranged between and/or in the transition from the conveying section F1 and the conveying section F2.

The conveying section F1 here comprises the spinning unit 106, the fixing unit 150 and the washing unit 160, and conveying section F2 comprises the heat treatment station 250 with the heat treatment oven 251. In the region of the conveying section F1 and/or F2, a (respective) strand drive can be provided to pull the fibres 110 or the bundle 122. In particular, in the conveying section F2, the strand drive is used for the complete or partial emptying of the fibre accumulator 230 and/or for

accelerating the fibres 110 or the bundle(s) 112, as an accelerating means, out of the heat treatment station 250.

In this embodiment, in particular, the storage capacity of the motor-driven fibre accumulator 230, the possible acceleration and transport speed of the fibre accumulator 230 in the accelerated removal of the stored fibres 110, 112 and the length of the heat treatment oven 251 are dimensioned and/or matched to each other in such a way that the required dwell time (heat treatment time) of the individual fibres 110 or the at least one fibre bundle 112 in the effective zone of the resistance heater (not shown) can be maintained.

Figure 6 shows two further embodiments of grouping stations 260 in a plan view and the resulting orientations and positions of individual fibres 110 in the heat treatment station 250. The partial view I. shows grouping station 260, which consists essentially of two comblike or multidigital alley guides 109, where the two opposing alley guides 109 have different distances between the individual digits or individual guides. Both alley guides have the same number of individual digits, or the number of individual digits depends on the number of parallel-guided individual fibres 110. In this case, an individual fibre 110 may be present on each side of individual digits, depending on the cross-sectional area and geometry of the individual digits.

The alley guide 109 arranged at the entrance of the heat treatment station 250 and the heat treatment oven 251 reduces the spacing of the individual fibres 110 to a few millimetres, e.g. down to 2 mm to 3 mm. There is no compression until the parallel individual fibres 110 make contact with one another and the individual fibres 110 with their longitudinal fibre axes essentially span a common plane. Although this embodiment is the most structurally complex, it allows the shortest heat treatment times for the fibres 110 and hence requires the shortest extension of the heat treatment station 250 in the main conveying direction (x direction). Optionally, a second grouping station 260 can be arranged downstream, by means of which the (end) bundle is shaped.

The partial view II. shows the grouping station 260 (here 260.1), which also consists essentially of two comb-like or multidigital alley guides 109, wherein the two opposing alley guides 109 also have different distances between the individual digits or individual guides. The alley guide 109 disposed at the entrance of the heat treatment station 250 has a significantly smaller number of individual digits or individual guides than the alley guide 109 at the outlet to the washing unit 160 or the drying station 210. This is because grouping station 260 and the introductory alley guide 109 shape multiple part-bundles 112 from the total number of individual fibres 110 and subsequently conduct them as part-bundles 112 through the heat treatment station 250. In the example shown, three part-bundles 112.1, 112.2 and 112.3 are shaped, which are heat treated in parallel at a distance from one another in the heat treatment station 250 and transported through this heat treatment station 250. Part-bundles 112.1, 112.2 and 112.3 can subsequently be combined in a second grouping station 260.2 to form an (end) bundle 112.

Even though the heat treatment oven 251 in the present context is always shown in a horizontal (recumbent) alignment in which the transport direction of the fibre 110 or the fibre bundle 112 is aligned in the direction of the x axis or the main transport direction A, this is not to be understood in a restrictive manner. It will be apparent to the skilled person that the heat treatment oven 251 can assume any orientation and/or inclination in space, especially vertical or slanted. The alignment and/or transport direction of the fibres and/or the fibre bundle then follows this orientation of the heat treatment oven in an analogous manner and may in particular also be from the bottom upward or from the top downward.

The laboratory and test setup shown in Figure 7 and the graphs shown in Figure 8 are described and discussed hereinafter together with the discussion of the test results.

Test setup

The tests were conducted with a heat treatment station 250 as shown in Figure 7, which is of analogous design to Figure 3 and is essentially a detailed representation of Figure 3. The heat treatment station 250 comprised, as a central element, a heat treatment oven 251 having a closed housing 256 comprising two half-shells which, in the illustrated closed state, form the heat treatment space 254 within as the interior. A passage opening 258 is arranged formed at each of the end faces. Resistance heaters 252 are integrated in the housing 256 in both half-shells, indicated by a grid-like pattern. In the interior of the heat treatment oven 251, a channel-like interior is formed as heat treatment space 254, through which the fibre bundle 112 is conveyed, coming from the drying station 180, in the heat treatment step. The elements for bundling the individual fibres 110 to a fibre bundle 112 are not shown.

The temperature is measured by means of a temperature sensor 294. The temperature sensor 294, the resistance heater 252 and the fibre drive (not shown) are connected via data wires to the control and regulation unit 130. The tests were conducted in continuous operation. Heat treatment oven 251 was thermally insulated on the outer shell, but not actively cooled.

Downstream of heat treatment oven 251, bundle 112 was cut to length and examined with regard to selectivity and permeance.

The suitability of the fibre for gas separation is evaluated with particular regard to permeance and selectivity. Permeance is the ratio of permeability to thickness of the fibre wall or membrane wall and represents a measure of the gas flow through the fibre wall or membrane and is thus an indicator of the structure and permeability of the hollow fibre or fibre bundle.

<u>Permeability and permeance</u>

Gas permeabilities are expressed in barrers (10^{-10}·cm^3·cm^{-2}·cm s^{-1}·$cmHg^{-1}$). The permeances of the hollow fibre membranes for gases are reported in GPU (gas permeation units, 10^{-6} cm^3·cm^{-2}.s^{-1}.$cmHg^{-1}$) or derived units. Permeance is the ratio of permeability to substrate thickness (membrane thickness) for corresponding units, for example the unit l m^{-2} h^{-1} bar^{-1}.

Permeability

Permeabilities for gases are measured by the pressure rise method. This involves applying a gas or gas mixture to one side of a flat film of between 10 and 70 µm in thickness. On the other side, the permeate side, there is a vacuum (of about 10 - 2 mbar) on commencement of the experiment. The rise in pressure on the permeate side over time is then recorded.

The permeability of the polymer (substrate) can be calculated by the following formula:

$$P = \frac{V_{dead}.MW_{gas}.l}{\rho.R.T.A.\Delta p}.\frac{dp}{dt}.10^{10}$$

P		permeability in barrers (10^{-10} cm^3(STP) cm) / (cm^2 s cmHg)
		[barrer] = 1.333*1017 * [m^3 (STP)*m/(m^2*s*Pa)]
		with STP (standard temperature and pressure): 0°C, 101 325 Pa
V_{dead}		volume of the permeate side in cm^3
MW_{GAS}		molar mass of the gas in g mol^{-1}
l		thickness of the film in cm
ρ		density of the gas in g cm^{-3}
R		gas constant in cm^3 cmHg K^{-1} mol^{-1}
T		temperature in kelvin
A		area of the film in cm^2
Δ p		pressure differential between feed and permeate side in cmHg
dp/dt		pressure rise per unit time on permeate side in cmHg s^{-1}

If the permeance of hollow fibres is being measured, a volume increase method is used. Permeance P/l is calculated (because the thickness of the separatory layer is unknown) by the following formula:

$$P/l = \frac{Q(STP)}{R.T.A.\Delta p}.10^{6}$$

P/l		permeance in GPU (gas permeation units, 10^{-6} cm^3·cm^{-2} s^{-1} $cmHg^{-1}$)
Q		gas flow on the permeate side in cm^3 (STP)/s

R	gas constant in cm^3 cmHg K^{-1} mol^{-1}
T	temperature in kelvin
A	external area of the hollow fibres in cm^2
Δ p	pressure differential between feed and permeate side in cmHg
dp/dt	pressure rise per unit time on permeate side in cmHg s^{-1}

The selectivities of different gas pairs are pure gas selectivities. Selectivity between two gases is calculated from the ratio of permeabilities:

$$S = P_1 / P_2$$

S	ideal gas selectivity
P_1	permeability or permeance of gas 1
P_2	permeability or permeance of gas 2

Experiments

Experiments 1 and 2 were conducted in the above-described test setup according to Figure 7. In this case, reference fibres from a batch process and a non-heat-treated fibre were compared with fibres that had been subjected to continuous heat treatment in accordance with the invention. The reference fibres were heat-treated in an electric convection oven under reduced pressure for 6 hours, in the form of fibre bundles of 80 individual fibres (V0a), a fibre bundle of non-heat-treated 80 individual fibres, and continuously conveyed and heat-treated fibre bundles of the same number of individual fibres with different dwell times in the continuously operated heat treatment oven. The different conveying rates of the fibre were used to derive the dwell times of the fibre or of a discrete fibre section in the heat treatment oven.

Experiments

Experiments V1 and V2 examined the effect of dwell time of the conveyed polyimide fibre at a higher constant temperature compared to experiment 1 in the heat treatment oven. This involved comparing two bundles of polyimide fibres at different temperatures.

Table 1 shows the measurements from the two experiments V1 and V2. The fibres were spun from polyimide polymer material, and in all tests the core temperature of the heat treatment oven was constant at about 450°C. The core temperature was measured in the centre of the oven, and the temperature gradient in the direction of the longitudinal axis in the interior (heat treatment space) remained negligible because of the entry of ambient air.

The heat treatment oven (251) used was a continuous tube oven from Nabertherm® RSRC 120-1000/13. It has a continuous working tube that had been heated in a heating section by an external resistance heater. The working tube used was a metal pipe. The metal working tube was not heated on the input and output side of the heating section and was atmospherically cooled. The

continuous oven was operated in a non-inclined horizontal alignment. The working tube constitutes the heat treatment space in the heating section.

The fibre bundles of at least 30 individual fibres were fed in at one end of the working tube (input side) and conducted through the heated area (heating section), and were led out at the other end (output side) under tensile stress.

The technical data of the continuous tube oven included the following:

- maximum temperature of 1300°C in the interior (heat treatment space)
- nominal power not more than 13.7 kW - 14.4 kW
- stainless steel working tube, open at both ends
- type S thermocouple, freely radiating heating elements onto the working tube
- outer oven housing made of structured stainless steel sheets, perforated
- hinged, hood-like oven housing; in particular, inner oven hood with integrated resistance heater
- integrated control and switching unit

There was an option for three-zone regulation of the resistance heater, with the establishment always of the same temperature in all three zones.

Because of its design, the continuous tube oven had an adjustable speed for the mounted working tube of between 0.28 and 6 revolutions/minute, but this was not utilized in the experiments.

The heating section is of three-zone design, where, in the three zones, the heating coils embedded in an inner oven hood of the resistance heater are disposed opposite and act directly on the working tube. In addition, the continuous oven had thermally insulated inlet and outlet nozzles on the outside of this inner oven hood, on the outside of which there are no heating coils of the resistance heater, such that these are not heated directly, but were not cooled either.

In order to determine the dwell time of the fibre in the heat treatment space (heating section), inlet and outlet nozzles were also considered to belong to the heating section because of the conduction of heat in the metallic working tube. The length of the heating section thus comprised the insulated inlet and outlet nozzles and corresponds to the length of the heat treatment space of the heat treatment oven.

The inner oven hood was thermally insulated from the environment on the jacket side and pointed, on the flat end faces on the inlet side and the outlet side, a round opening corresponded essentially to the internal diameter of the working tube and was 110 mm, through which the respective fibre bundle of n individual fibres was conducted.

The individual fibres were continuously dried before the heat treatment step upstream of the heat treatment oven at a temperature of about 80°C. Cooling gas was introduced into the heat treatment oven as unregulated (passive) ambient air together with the conveyed fibre bundle and exited on the outlet side in an unregulated manner and exited in heated form from the passage opening thereof. The fibre bundle comprised 30 individual fibres (n = 30). In the downstream direction, the fibre bundle was cut and measured for O_2 permeance and O_2/N_2 selectivity as described herein. The hot exhaust air coming out of the outlet-side passage opening was extracted and discharged with a fume hood in the hall interior of the experimental plant. The temperature in the heat treatment space of the continuous oven was about 450°C.

Table 1: Results of Experiment 01

Test no.	Heat treatment	T [°C]	Duration [sec]	Normalized O_2 permeance	Normalized O_2/N_2 selectivity
V1_a	non-heat-treated	--	irrelevant	2.09	0.80
V1_b	Reference; batch	--	irrelevant	1.00	1.00
V1_1	continuous	450	1.8	**1.26**	0.93
V1_2	continuous	450	2.2	**1.04**	**0.94**
V1_3	continuous	450	2.4	0.74	**1.06**
V1_4	continuous	450	2.8	0.73	**1.04**
V1_5	continuous	450	3.3	0.42	**1.24**
V2_a	non-heat-treated	--	irrelevant	2.27	0.80
V2_b	Reference; batch	--	irrelevant	1.00	1.00
V2_1	continuous	450	2.2	**1.14**	0.95
V2_2	continuous	450	2.4	**0.88**	**1.01**
V2_3	continuous	450	3.0	0.32	**1.22**
V2_4	continuous	450	2.8	0.46	**1.12**
V2_5	continuous	450	3.3	0.29	**1.24**

The corresponding graph is shown in Figure 8. The y axis shows here normalized O_2/N_2 selectivity and the x axis normalized O_2 permeance, with normalization based on the reference fibre (V2_0b). The continuous trend line serves primarily for optical orientation and in the narrower sense does not constitute a mathematical dependence. The different symbols have the meaning as displayed in the graph legend. No measuring point for the non-heat-treated fibre is displayed in the graph of Figure 8.

On the one hand, it has been found that, surprisingly, in spite of the very short heat treatment times of less than 10 s, it was possible to achieve selectivities and permeances in the region of the conventionally produced reference fibre. The heat treatment time of the reference fibre was a dwell time of about 6 hours in the electric convection oven, and so it was possible to shorten the dwell time by a matter of hours. In terms of selectivities, it was even possible to achieve improvements of up to 26% with only small losses in permeance. It was particularly surprising that dependence of selectivity and/or permeance on dwell time is apparent, and so selectivity and permeance are describable as a function of dwell time in the heat treatment oven.

It was particularly surprising that dependence of selectivity and/or permeance on dwell time and/or temperature in the heat treatment space is apparent, and so selectivity and permeance are describable as a function of dwell time in the heat treatment oven. It has thus been shown that, depending on the desired specification, a desired optimum in terms of permeance and selectivity can be established via adjustment of the process parameters of dwell time and/or temperature.

A continuous flow of gas in conveying direction through the heat treatment oven was observed, which was detectable owing to the hot gases exiting at the fibre outlet. In the heat treatment space of the heat treatment oven, in this mode of operation of the heat treatment oven with exclusively passively introduced gas, which is ambient air here, a largely laminar flow in conveying direction through the heat treatment space of the heat treatment oven is assumed.

The hollow fibres produced in accordance with the invention are particularly suitable for the gas separation of CO_2, O_2, CH_4 and N_2, in particular for gas separation of air or biogases.

This result is particularly surprising since the prior art, for example WO 2014/202324 A1 or WO 2011/009919 A1, always requires an inert atmosphere in the heat treatment step, and it has now been shown that, in the case of continuous, very brief heat treatment with high energy inputs, no pure N_2 atmosphere or significantly O_2-depleted atmosphere is required for production of highly permeable and highly selective gas separation membranes. It has also been found that the slow heating of the fibres in the heat treatment step of 0.1 to 10°C/min which is recommended in WO 2014/202324 A1 (page 10, end) can be significantly undershot without disadvantages regarding the selectivity and permeance of the fibre.

Reference numerals

100 plant
102 polymer solution
104 process medium
106 spinning unit
108 guide roller
109 alley guide (y direction)

110 fibre
112 fibre bundle, fibre part-bundle

120 coating station (PDMS)

130 control and regulation unit
132 data wire
134 controller (power)
136 flow control (unit)

140 reserve and supply unit, also supplying unit
142 tank
144 inert gas reservoir
146 pump (unit)

150 fixing unit
160 washing unit
170 post-treatment unit
180 end-processing unit
182 fixing station, banding station
184 cutting station
186 lifting unit (x-y-z unit)
188 transport element, conveyor belt

190 discharge station
200 thermal treatment unit
210 drying station
212 gas feed conduit
214 gas drain conduit
216 heat exchanger

220 dehumidification station
222 nozzle unit
224 gas feed conduit
226 compressor

230 fibre accumulator
232 deflection elements (dynamic, movable)

240 exchange unit

250 heat treatment station
(thermal treatment station 3)
251 heat treatment oven
252 heating element, e.g.
254 heat treatment space (interior)
256 housing
258 passage opening
260 grouping station

270 gas feed unit
272 gas drain (unit)
274 gas filter unit

280 conveying means

290 ventilation unit
292 heat exchanger
294 measuring unit (temperature)
296 measuring unit (flow rate)
298 gas conditioning unit

300 heating step
302 ramp-up
304 power step
306 cooling step

A main direction of delivery
B onward transport direction
C feed conduit
F1, F2 conveying section

Claims

1. Plant (100) for producing a hollow fibre, in particular a spun hollow fibre, from at least one polymer solution (102), comprising a control and regulation unit (130), a media reserve and supply unit (140), a spinning unit (106) for forming the fibre (110), wherein downstream of the spinning unit (106) for the treatment of the fibre (110) at least the following plant units are included, in the stated sequence:
   a. an exchange unit for solvent exchange (240), in particular comprising a (first) fixing unit (150), in which the fibre directly after the spinning unit (106) can be introduced or conducted through, and advantageously comprising at least one washing unit (160) downstream of the fixing unit (150),
   b. at least one post-treatment unit (170) comprising
   a thermal treatment unit (200) with at least one thermal treatment station,
   characterized in that
   at least one thermal treatment station of the thermal treatment unit (200) is provided downstream of the exchange unit (240) and is designed as a heat treatment station (250) comprising at least one heat treatment oven (251), and wherein the at least one heat treatment oven (251) comprises at least one heating element (252) and/or an inlet for a heating medium, wherein the fibre (110) can be conducted through and/or accommodated at least temporarily in the at least one heat treatment oven (251), and wherein the heat treatment oven (251) is designed to heat the at least temporarily accommodated and/or conductable fibre (110) for a defined period of time up to a (limiting) temperature that is below the glass softening temperature (T_G), in the range of:
   i) up to 80°C below the glass softening temperature (T_G), and/or
   ii) greater than 250°C, and wherein the heat treatment station (250) and/or the heat treatment oven (251) is designed in particular to subject the fibre (110) to continuous heat treatment.

2. Plant according to Claim 1, characterized in that
i) the heat treatment space of the heat treatment oven (251) is open to the atmosphere during operation as intended, and/or
ii) there is at least one gas inlet opening for regulated (active) introduction of gas into the heat treatment space.

3. Plant according to either of the preceding claims, characterized in that the heat treatment oven (251) is designed, for the at least temporarily accommodated and/or conductable fibre (110), i) to heat it for a defined time up to a limiting temperature of not more than 1°C to 4°C below the glass softening temperature (T_G).

4. Plant according to any of the preceding claims, characterized in that the thermal treatment unit (200) as a further thermal treatment station comprises a drying station (210) upstream of the heat treatment station (250), through which the individual fibres (110) can be conducted as a strand, wherein the drying station (210) comprises

a. - at least one drying element and/or

b. - a feed conduit and a drain conduit for a drying medium, such as in particular a heated gas, and

whereby the interior of the drying station (210) can be heated at least to a temperature of over 30°C, advantageously of over 40°C and ideally of over 50°C, wherein the interior is heatable at maximum to 200°C.

5. Plant according to any of the preceding apparatus claims, characterized in that the thermal treatment unit (200) as a further thermal treatment station comprises a dehumidification station (220) upstream of the heat treatment station (250) in which the individual fibres (110) are conducted through at a distance from one another transversely to axial direction (longitudinal fibre axis (A_F)), and which comprises at least one nozzle element (222) which is directed onto the path of at least one individual fibre (110), and by means of which a gas jet can be guided onto at least one individual fibre (110), in particular a group of individual fibres (110).

6. Plant according to any of the preceding apparatus claims, characterized in that
i) a grouping station (260) of the grouping unit is arranged upstream of the heat treatment station (250),
ii) the heat treatment station (250) is arranged within a grouping unit, and/or
iii) is arranged between two grouping stations (260) of a grouping unit, wherein
in the grouping station (260) there is at least one grouping means by means of which at least one group of n individual fibres (110) can be arranged in mutual contact as bundles (112), wherein n is an integer value of from 2 to 180, preferably from 20 to 150, ideally from 30 to 120, optionally up to n = 600.

7. Plant according to any of the preceding apparatus claims, characterized in that the heat treatment station (250) comprises a ventilation unit (290) or is connected to a ventilation unit (290) and/or the heat treatment oven (251) has at least one gas inlet opening, in particular a gas inlet opening for air.

8. Plant according to any of the preceding apparatus claims, characterized in that the heating element (252) and/or the heating gas, in particular the resistance heater, has a power of
- at least 7.5 kW/m, advantageously at least 10 kW/m and ideally at least 15 kW/m, and

- of not more than 100 kW/m, advantageously of not more than 50 kW/m, ideally of not more than 35 kW/m.

9. Plant according to any of the preceding apparatus claims, characterized in that the heat treatment oven (251) has a tube-, channel- or alley-like configuration, comprising at least two walls or wall portions, in particular parallel to the longitudinal fibre axis (A_F).

10. Plant according to any of the preceding apparatus claims, characterized in that the at least one heat treatment station (250) comprising the heat treatment oven (251) is positioned at one of the following plant sites:
    a. downstream of the washing unit (160), wherein no (further) thermal treatment station of the thermal treatment unit (200) is arranged ahead of the heat treatment station (250),
    b. downstream of at least one dehumidification station (220) of a thermal treatment unit (200),
    c. downstream of at least one drying station, in particular downstream of a drying station which is arranged downstream of a coating station or application unit.

11. Plant according to any of the preceding apparatus claims, characterized in that an end-processing unit (180) is positioned downstream of the heat treatment station (250).

12. Plant according to any of the preceding apparatus claims, characterized in that a fibre accumulator (230) is positioned upstream of the heat treatment station (250).

13. Plant according to any of the preceding apparatus claims, characterized in that it is designed to transport the fibre (110) continuously from the spinning unit (106) to at least the outlet of the heat treatment station (250).

14. Plant according to any of the preceding apparatus claims, characterized in that the post-treatment unit (170) comprises a coating station (120) and/or a discharging station (190).

15. Process for producing a fibre (110) which is spun from a polymer solution (102), in particular for the parallel production of m (individual) fibres (110), comprising the following steps:
- the step of spinning the fibre (110) from the polymer solution (102),
- exchange step for exchange of a solvent, wherein the exchange step may comprise at least one fixing step with a liquid fixing medium and/or at least one washing step in/with a washing medium, in particular in a tank with a washing medium,

- drying step comprising a heat treatment step in which the fibre (110) is heated to a temperature below the glass softening temperature (T_G), **characterized in that** the fibre (110) is continuously heated in the heat treatment step by means of at least one heating element (252) and/or a heating medium in a heat treatment oven (251) to a temperature
i) in the range up to 80°C below the glass softening temperature (T_G), and/or
ii) in the range of greater than 250°C and below the glass softening temperature (T_G).

16. Process according to Claim 15, characterized in that, in the heat treatment step, n individual fibres are subjected to parallel heat treatment, where n =< 600, preferably n =< 180, especially preferably n =< 120, ideally n <= 100.

17. Process according to Claim 16, characterized in that, in the heat treatment step, n individual fibres are subjected to parallel heat treatment, where n >= 2, preferably n >= 10, especially preferably n >= 20, ideally n >= 40.

18. Process according to any of the preceding process claims, characterized in that the heat treatment time is in the range of 0.5 to 60 s, preferably 1 to 30 s, ideally 1 to 20 s.

19. Process according to any of the preceding process claims, characterized in that a cooling gas is supplied, which cools at least part of the heat treatment oven (251) in the heat treatment step, where the cooling gas flows through the heat treatment oven (251) with a gas exchange frequency (AF) of 0.15 per minute (0,0025 pro sec; untere AF) up to 30 per minute (0,25 pro sec; obere AF) , cooling gas and where the heating energy introduced in the heat treatment oven (251) is =< 50 kJ/m.

20. Process according to any of the preceding process claims, characterized in that, in the heat treatment step, the fibre (110), for a defined period of time,
i) is heated up to a limiting temperature of not more than 1°C, in particular 4°C, below the glass softening temperature (T_G) and/or
ii) is heated to a limiting temperature in the range of 70°C to 1°C below the glass softening temperature (T_G) and/or
iii) is heated to a temperature in the range from greater than 280°C to 450°C and below the glass softening temperature (T_G).

21. Process according to any of the preceding process claims, characterized in that the heat treatment step is effected at a pressure in the range from not more than +2 bar to atmospheric pressure, preferably not more than +1 bar, preferably not more than +0.5 bar, and ideally equal to or essentially equal to atmospheric pressure.

22. Process according to any of the preceding process claims, characterized in that the cooling gas supplied to the heat treatment oven (250) in the heat treatment step is oxygen (O_2) in a concentration of not less than 5.0 mol%, especially not less than 10 mol%, preferably not less than 15 mol%, and is particularly ambient air with ~21 mol%.

23. any of the preceding process claims, characterized in that, in the heat treatment step, the fibre (110) is treated by means of the heating element (253) and/or the heating medium, based on the length of the heating element, with a power of
- at least 5.0 kW/m, preferably at least 7.5 kW/m and ideally at least 10 kW/m, and where
- the line is not more than 100 kW/m, advantageously not more than 50 kW/m and ideally not more than 35 kW/m.

24. Process according to any of the preceding process claims, characterized in that the fibre (110) is produced in a plant (100) designed according to at least one of the preceding apparatus claims 1 to 14.

25. Process according to any of the preceding process claims, characterized in that at least one group of m individual fibres (110) is formed (aligned) before the heat treatment step in a grouping step to form at least one bundle (112) of n = 5 to 600 individual fibres (110) and subsequently subjected to heat treatment as the bundle (112), wherein either
- n is less than m, such that two or more part-bundles (112) are formed, or
- n is equal to m, such that only one bundle (112) is formed.

26. Process according to any of the preceding process claims, characterized in that the fibre (110) is transported continuously from the spinning unit (106) to at least the outlet of the heat treatment station (250), in particular transported uncut.