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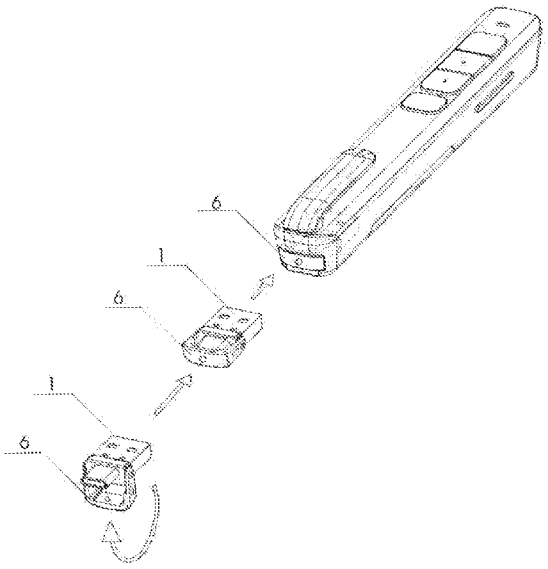


图 5

(57) Abstract: The present disclosure relates to a process of rapid drying and color fixation on a yarn or thread substrate. Specifically, it relates to fast drying of the yarn followed by rapid color fixation onto the yarn surface and inside the yarn body.

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[Continued on next page]

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YARN DRYING AND COLOR FIXATION

RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application Serial No. 62/845,889, filed May 10, 2019, which is incorporated by reference in its entirety.

FIELD

[0002] The present disclosure relates to a process of rapid drying and color fixation on a set of moving yarn or thread substrate comprising multiple individual yarns of different colors. It also relates to an integrated process for coloring and drying individual yarns or threads among a set provided in parallel, followed by color fixation into the yarn at a rate consistent with direct coupling to a dependent process of fabric formation, including tufting, weaving and the like.

BACKGROUND

[0003] Since the middle of the 20th century, commercial, residential and industrial applications of carpets have exponentially grown into a significant global market. Previously, carpets typically consisted of wool, but recent advancements in the synthetic fibers have led to the use of nylon, polyester and polyolefin [polypropylene, for example] fibers and yarns as less expensive, long-lasting and durable alternatives to wool.

[0004] The term "carpet" is often used interchangeably with the term "rug", although the term "carpet" can be applied to a wall-to-wall floor covering, whereas a "rug" is a partial floor covering and can be spread over any floor. Carpets and rugs can be made in any color by using differently dyed yarns. Solution dyed yarns are often used in carpet tufting. Alternatively, tufted white carpets can be dyed or printed in desired colors and patterns. Carpets made from colored or solution dyed yarns have superior aesthetics compared to printed and dyed carpets. Carpets can have many different types of patterns and motifs used to decorate the surface. To date, solid-colored and multi-color-patterned carpets and rugs are used in industrial and commercial establishments such as retail stores, hotels, restaurants, residential homes, etc.

[0005] As the consumer demand grows for uniquely designed and aesthetically superior multi-color-patterned carpets made of synthetic fibers, say, nylon or polyester, industrial processes are needed for making such flooring products cost-effectively while meeting or exceeding the end-use performance requirements. Most of the specialty carpet manufacturers today employ pre-colored yarns to create specialized designs. Pre-colored yarn can be created by inclusion of pigments in the polymer of a synthetic fiber spinning process. Alternatively, color may be provided by bulk package dying in a dye bath, or by spray dyeing griege yarn, winding, storing, and transferring it for later use. In any case, using pre-colored yarns in carpet tufting creates operational complexity with additional stock keeping units (SKUs) inventory investment, inventory storage costs, and additional labor for material handling and productivity losses due to extended transition times for product changeovers. In the case of modern carpet styling options for designer patterns today, yarns are produced in various colors, and a selection of yarns is then placed in a creel and strung up to the tufting machine. Removing and replacing yarn packages in order to change colors and patterns can take several people a number of hours, during which time the tufting machine is unproductive. In view of the above, it would be highly desirable to have a process to color individual carpet yarns to be fed directly to the tufting process without the requirement to inventory a wide range of colors, or to remove and replace yarn in the tufting creel with every design transition. Whether such capability is provided to every end feeding a fabric formation process or just a small subset, it can be well appreciated by one skilled in the art that successful commercial practice of such a coupled yarn coloring process would require the colored yarns to be accurately and deeply dyed, that the provided color would be permanent, color fast, and would not rub off in processing, handling or subsequent use, and that the speed of yarn through the coloring process would be fast enough to match the speed of the fabric-forming (or tufting) process being fed.

[0006] Known yarn coloring methods [including those taught in WO2017203524A1, WO2017200473A1, WO2017155451A1, US20160102430A1] generally focus on applying single colors rather than coloring, drying and color fixation on multiple yarns of different colors. Another technical problem to be overcome is yarn speed. It would be desirable to color the yarns and then directly transfer them to a tufting machine. The problem is that the inlet yarn speed for a tufting machine is typically greater than 10m/min. Known methods have not proven satisfactory for coloring yarns at this linear velocity, and this is especially true for heavy denier, bulked carpet yarns.

[0007] The process of the present disclosure provides a basis for high linear feed rates as required, by selection and unique combination of ink/colorant type, drying process and ink fixation process. The process of the present disclosure enables coloration, drying and fixation of multiple yarns of different colors without color transfer/contamination between adjacent yarns and color transfer/contamination from yarn to guide rolls and other parts of the machine. The process of the present disclosure also provides a way of maintaining almost zero tension in color fixation stage for bulked/crimped yarns to avoid loss of bulk/crimp at high temperature.

SUMMARY

[0008] Disclosed is a process for coloring a yarn, the process comprising:

a) applying a sublimation ink to the yarn;
b) exposing the yarn comprising the sublimation ink to drying conditions including raising the surface temperature of the yarn above ambient but below melting point of the yarn by applying radiant heat to the yarn for irradiation time sufficient to reduce the moisture content of the yarn to provide an at least partially dried yarn without touching other surfaces; and
c) exposing the at least partially dried yarn to curing/fixing conditions including conductive and convective heat transfer conditions above ambient temperature for a residence time sufficient to provide a fixed yarn;

[0009] wherein the sublimation ink applied in step (a) and at least partially dried in step (b) yarn diffuses more deeply into the center of individual fibers of the yarn in step (c) than would be observed in applying the sublimation ink and fixing the sublimination ink in the absence of intermediate drying step (b).

[0010] Sublimation ink (colorant) can be applied to the yarn using any suitable method known to those skilled in the art. One example of such a method is disclosed in commonly-assigned PCT Patent Application PCT/IB2019/060057. Applying sublimation ink via ink-jet printing is preferred, but not required. Ink-jet application is desirable because (among other reasons) it enables coloration of different yarns in different colors and provides better color control than an analog coloration method.

[0011] Yarn can be one yarn or multiple yarns in parallel. The skilled person will appreciate that the term "yarn" is used herein to refer to filaments, threads, fibers, yarns, and yarn bundles.

[0012] Step (b) can further comprise exposing the colored yarn to radiant energy at wavelength of from 0.7 μm and 4.0 μm.

[0013] Step (b) can further comprise controlling the radiant energy density at the surface of the yarn. For example, when the yarn comprises nylon-6,6, the radiant energy density at the surface of the fluid-treated elongated substrate is suitably controlled at from ≥ 10 Joules/cm2 to ≤ 2000

Joules/cm2; for example, from ≥ 20 Joules/cm2 to ≤ 1000 Joules/cm2; for example from ≥ 30 Joules/cm2 to ≤ 600 Joules/cm2.

[0014] The at least partially dried yarn of step (b) comprises < 5 % moisture, based on the weight of untreated yarn.

[0015] Step (c) can comprise curing the at least partially dried ink/colorant.

[0016] The combined residence time in the first step and the second step can, for example, be ≥ 100 milliseconds to ≤ 80 seconds. The combined residence time in the first step and the second step can be ≥ 5 seconds to ≤ 75 seconds.

[0017] The residence time in the first step can be from ≥1% to ≤25% of the combined residence time. For example, the residence time in the second step is from ≥75% to ≤99.9% of the combined residence time.

[0018] The yarn can have fibers of any suitable cross-sectional shape, with examples including round, trilobal, multi-lobal, square, rectangular, triangular, oval and star. The yarn can have fibers of a cross-section type chosen from the group consisting of solid, hollow, partially solid and partial hollow.

[0019] The disclosed process can be carried out as an individual unit operation. The disclosed process can also be operated with downstream tufting.

[0020] A device for drying and curing/fixing a colored yarn comprising sublimation ink(s) is also disclosed. The device can comprise:

a) a guide for transporting a yarn through a drying space without touching other surfaces;
b) at least one radiation energy source for transmitting thermal energy to the yarn in the drying space for residence time sufficient to provide an at least partially dried yarn;
c) guide for conveying the at least partially dried yarn of b) through a curing space; and
d) Conduction and convection energy sources for providing uniform thermal energy input to the yarn and maintaining the residence time in the curing space to obtain a cured yarn.

[0021] The drying space of the disclosed device can comprise at least one infrared [IR] radiation emitter. Suitable infrared radiation emitters emit infrared radiation in the wavelength range of between 0.7 and 4.0 μm. The device suitably provides residence time in the drying space to produce a yarn with < 5 % moisture. The device includes a curing space comprising at least one heated chamber and at least one conductively heated metallic conveyor inside the

heated chamber. The curing space of the device is suitably maintained in the temperature range of between 120 ºC and 250 ºC, for example, between 130 ºC and 240 ºC.

BRIEF DESCRIPTION OF THE FIGURES

[0022] FIGURE 1 is a schematic representation of an embodiment 101 according to the present disclosure.

[0023] FIGURE 2 is a schematic representation of an embodiment 201 according to the present disclosure.

[0024] FIGURE 3 is a cross-sectional analysis result of dye diffusion and fixation into the yarn according to Example 1 of the present disclosure.

[0025] FIGURE 4 is a cross-sectional analysis result of dye diffusion and fixation into the yarn according to Example 2 of the present disclosure.

[0026] FIGURE 5 is a cross-sectional analysis result of dye diffusion and fixation into the yarn according to Example 3 of the present disclosure.

[0027] FIGURE 6 is a cross-sectional analysis result of dye diffusion and fixation into the yarn according to Example 6 of the present disclosure.

[0028] FIGURE 7 is a cross-sectional analysis result of dye diffusion and fixation into the yarn according to Example 7 of the present disclosure.

[0029] FIGURE 8 is a cross-sectional analysis result of dye diffusion and fixation into the yarn according to Example 8 of the present disclosure.

[0030] FIGURE 9 is a cross-sectional analysis result of dye diffusion and fixation into the yarn according to Example 9 of the present disclosure.

DETAILED DESCRIPTION

[0031] The present disclosure relates to a combination of fast drying step followed by rapid colorant/dye fixation step for a color-applied yarn, thread or multiple yarns.

[0032] The present disclosure may be suitable for both, bulked as well as flat yarns.

[0033] Suitable colorants include sublimation inks. Sublimation inks can be cured without steaming and minimize wet processing which is common in processing of textiles and yarns. Sublimation inks are also uniquely suited to the present disclosure because sublimation inks don’t leave any deposits on heated metallic conveyors used in curing step, if the temperature of

heated metallic conveyors is above sublimation temperature of the dye. Depending on the base carrier, ink type could be water-based (aqueous), solvent-based, or oil-based. Ink may also contain surfactants, humectants, viscosity modifiers, binder resins, pH modifiers, and other functional chemicals as needed.

[0034] Once the ink is applied to a textile yarn or substrate, it is necessary for the colorant to infuse into and dye the fiber, thus becoming part of the substrate itself. This process is known as ink curing or dye fixation. Industrial drying and fixation techniques such as convection oven, infrared oven and steaming are most commonly used for colored yarns. In some cases, microwave, RF and acoustic technologies are used. The total residence times in all these processes are typically several minutes long. These traditional drying and curing processes use one type of heat transfer technology common to both drying and curing. Though such technologies may be available, these traditional drying and color fixation processes tend to be slow, and may not be particularly suitable for bulked yarns because bulked yarns are very sensitive to heat and tension during drying and fixation process. Prolonged heat and tension conditions can lead to loss of crimp/bulk in yarn/fibers. In some cases, yarn is laid in coiled form to avoid loss of crimp/bulk. Such processes are not suitable for closely-spaced multiple yarns of different colors.

[0035] The present disclosure solves the problem of exposing color-applied yarn or thread to heat and tension for minutes in the traditional drying and color fixation processes. The present solution relates to a combination of fast drying step followed by rapid colorant/dye fixation step applied to a color-applied yarn, thread or multiple yarns, such that the yarn or thread does not experience prolonged heat and tension conditions.

[0036] In one embodiment, the present disclosure relates to separating the drying and curing steps where each step is designed to maximize the performance. In addition, this solution facilitates handling of bulked yarns without stretching out the crimp/bulk.

[0037] FIG. 1 is a schematic representation of an embodiment 101 according to the present disclosure. In FIG. 1 guide rolls labeled 3a, 3b and 3c guide a continuous color-applied yarn or thread through the various processing units. Not shown in FIG.1 are other possible variations of the guide rolls, such as, size, number, location, orientation, directional movement, etc. A skilled person in the field of fiber/yarn processing will appreciate that the yarn tension may be controlled separately in each location depending on the individual processing steps.

Commercial means for moving the thread(s) or yarn(s) may be employed for the desired processing speed and consistency. Yarn tension in both drying step and fixation step are kept very low so that there is no significant loss of fiber crimp in bulked yarns. Heated metallic conveyors enable transport of yarn inside fixation unit with almost no tension. Temperature inside the fixation unit is high to enable sublimation of ink and, therefore, maintaining low tension is very important in fixation step. For example, the yarn tension in the fixation step can suitably be from ≥ 0 to <=0.02 g/denier based on yarn denier.

[0038] Referring to FIG. 1, a color-applied wet yarn 11 is guided in a drying unit 21, wherein the yarn spends adequate time at the condition that decreases the moisture content present in the yarn as it passes through. The colored yarn 31 exiting the drying unit has a lower moisture content than that in the yarn 11 at the entrance of unit 21.

[0039] The dry yarn 31 is further guided into a dye fixation unit 41. In unit 41 dye diffusion and fixation in the yarn substrate may be accomplished by exposing the yarn to elevated temperatures for some suitable time. The fixation unit 41 may be designed such that the yarn spends adequate time at the pre-determined elevated temperature and the dye is fixated in the yarn. The dye fixation is complete for the yarn 51 which is guided out by guide rolls 3c at the fixation unit 41 exit.

[0040] Though not shown in the figures, it is possible to process more than one yarn or thread in parallel through the processing units capable of handling parallel lines [or a sheet of equally spaced yarn or thread] through their processing regions. A reasonable spacing can be maintained between the two neighboring yarns, strands or threads by way of guide rolls/spacers.

[0041] In one embodiment, the present disclosure provides a unique design and combination of Infra-red [IR] technology and rotary heat press that enable fast drying and rapid dye fixation during the color-applied yarn process. The rotary heat press includes moving heated metal conveyors that are enclosed in a heated chamber to provide uniform heating.

[0042] FIG. 2 is a schematic representation of an embodiment 201 according to the present disclosure. In FIG. 2, a drying unit 22 represents an IR technology setup equipped with two emitters. The color-applied wet yarn 12 undergoes drying in the drying unit 22 that uses an IR technology consisting of two emitters of sufficient energy output (say, wattage). The two emitters may be arranged to face each other with the colored yarn 12 passing in between the two emitters. The IR emitters are designed to be of adequate length as desired for the drying

performance. The color-applied yarn 12 speed may also be controlled for optimum drying. The moisture content in the yarn 13 exiting the drying unit 22 is lower than that at the drying unit inlet, i.e., yarn 12 at roller 5a location.

[0043] The dried yarn is then passed through a dye fixation step, which consists of slow-moving heated metal conveyors 32 housed inside the heated chamber 42. The temperature of both, heated chamber 42 and heated metal conveyors 32 may be maintained and controlled to a suitable temperature.

[0044] In one embodiment, the heated chamber 42 houses an assembly of one or multiple metal conveyors 32. The metal conveyors 32 are guided by multiple sets of end rollers 72 turning around their center axes such that horizontal serpentine flow arrangement is obtained for the material being carried by the conveyors. Other non-limiting arrangements may include one or multiple assemblies of moving surfaces having the continuity to carry the material from inlet to the outlet of the unit. Such arrangements may be vertically mounted, horizontally mounted, inclined or combinations thereof. Units 5a, 5b and 5c schematically represent the guide rollers for a previously colored yarn 12 to stay on track as it passes through the units. Other mechanical details, not shown in FIG. 2, are known and understood to a skilled person in the field of fiber/yarn processing.

[0045] The uniformly heated chamber 42 may also prevent accumulation of the possible condensable materials evolving from the yarn inside the dye fixation unit. Such condensable materials may include glycols, solvents, residual moisture and dye constituents present in the vapor phase. The stream 62 represents an exhaust stream that would remove such condensable materials out of the heated chamber 42. The drying and dye fixation of the moving yarn 52 at the exit of the heated chamber 42 may be complete and uniform across the fiber cross-section in the yarn.

[0046] The residence time for the moving yarn inside the drying unit 22 may be in the range of about 0.1 seconds to about 15 seconds. The residence time for the moving yarn in contact with the heated metal conveyors 32 may be in the range of about 5 seconds to about 60 seconds. For example, the yarn length of about six meters may provide adequate residence time of about 18 seconds from start to end once inside the heated chamber 42 and onto the metal conveyors 32. The combined residence time of the moving yarn through drying unit 22 and fixation unit 42

time may be about 75 seconds, about 50 seconds, about 30 seconds, about 20 seconds or about 5 seconds.

[0047] Examples of colored yarn drying setup may include Infra-red [IR] wavelength technology. Infrared [IR] heating or drying involves heat transfer by radiation between a hot element and a material at lower temperature that needs to be heated or dried. The hot elements consist of gas emitters or electrical lamps which are aligned in order to create a heating region(s) or zone(s). The peak wavelength of the radiation is dependent of the temperature of the heated element. Thermal radiation is described as infrared in the electromagnetic spectrum between the end of the visible, i.e., between 0.78 μm and 1000 μm. In general, infrared radiation is split into three main categories, in function of the wavelength peak of the radiation: Short-wave IR (SwIR): from 0.78 μm to 2 μm, Medium-wave IR (MwIR): from 2 μm to 4 μm, and Long-wave IR (LwIR): from 4 μm to 1000 μm.

[0048] In one embodiment, the preferred IR wavelength may be in the range of 0.7 μm to 3.0 μm. For example, the near-IR or NIR wavelength range of 0.7 μm to 1.2 μm; short-wave IR [SwIR] wavelength range of 1.2 μm to 2.0 μm; part of medium-wave IR [MwIR] wavelength range of 2.0 μm to 3.0 μm.

[0049] The drying unit may be designed to operate in horizontal, vertical or inclined orientation.

[0050] The IR emitter wattage may depend on the number of yarns (or threads) being processed, and also on the moisture content of the colored yarn at the entrance of the IR drying setup. The IR emitter length may depend on the yarn movement speed through the device, which may be designed to provide adequate residence time in the unit.

[0051] In some embodiments, more than one IR module may be used in series, in parallel or combinations thereof. Such modules may have different IR wattage outputs, different emitter lengths to give different residence times, and combinations thereof.

[0052] Examples of ink fixation step may include an arrangement where the colored (dried) yarn may pass through and spend some time in a heated environment. In one embodiment, the fixation step may include a heated chamber where the yarn is moved over a series of metal conveyors for adequate exposure time at the design temperature. The temperature inside the heated chamber may be maintained up to 250 °C, and preferably in the 150 °C to 220 °C range. The surface temperature of the heated metal conveyors may be maintained up to 250 °C, and

preferably in the 150 ºC to 220 ºC range. The temperature may vary from one metal conveyor to the next in order to provide an optimal temperature gradient for optimal dye diffusion and fixation in the fibers.

[0053] The number of repeating heated metal conveyors, conveyor lengths and the spacing between the conveyor stacks may vary depending on the yarn thickness and desired residence time.

[0054] It may be possible for the drying unit and fixation unit to be operating in-line, out-of-line, and in any orientation, i.e., vertical, horizontal or inclined with respect to each other.

[0055] The following Table provides exemplary conditions for both drying and fixation steps for different substrates

Table – Exemplary Substrates, Fluid Treatments and Conditions

Yarn	Denier (or other suitable description	Fluid Treatment and Dosage	Step (b) IR Wavelength (µm)	Step (b) – Drying Energy Density (Joules/cm2)	Step (b) – Residence time (sec)	Step (c) – Fixation Surface Temperature(°C)	Step (c) – Air Temperature (°C)	Step (c) – Residence Time (sec)
Nylon-6,6	2490 denier	10% ink	0.8	560	2	210	210	18
Nylon-6,6	2490 denier	10% ink	1.5	95	4.5	210	210	27
Nylon-6	1100 denier	10% ink	0.8	504	2	195	195	18
PET	2340 denier	10% ink	0.8	504	2	200	200	18
Nylon-6	2490 denier	10% ink	1.5	95	4	185	185	30
PBT	2490 denier	10% ink	1.5	95	4	195	195	30

EXAMPLES

EXAMPLE 1

[0056] A two-ply nylon 66 yarn, denier 2490, 128 filaments, 4.5 twists per inch [tpi], is printed/colored using sublimation inks. The ink usage rate is 10% on weight of the yarn.

[0057] FIG. 2 is a schematic representation of an embodiment 201 according to the present disclosure. In FIG. 2, a drying unit 22 represents an IR technology setup equipped with two emitters. A heated chamber 42 houses an assembly of metal conveyors 32. The stream 62 represents an exhaust to remove evolved condensables in the vapor-phase out of the heated chamber. The metal conveyors 32 are guided by multiple sets of end rollers 72 turning around their center axes such that horizontal serpentine flow arrangement is obtained for the material being carried by the conveyors. Units 5a, 5b and 5c schematically represent the guide rollers for a yarn 12 to stay on track as it passes through the units. Other mechanical details are not shown in FIG. 2.

[0058] The above color-applied wet yarn 12 is dried using an IR technology setup 22 consisting of two emitters of about 2.1 KW each facing each other with the colored yarn 12 passing in between the two emitters. The IR emitters are 10 inch in length. The colored yarn 12 speed is maintained to about 20 m/min. The moisture content in the yarn 13 exiting the drying unit is measured to be 3.6 % by weight. The dried yarn is then passed through a dye fixation step, which consists of slow-moving heated metal conveyors 32 inside the heated chamber 42. The temperature of both, heated chamber 42 and heated metal conveyors 32 is maintained at 210 °C. The yarn length that is in contact with the heated metal conveyors 32 is about six meters and provides adequate residence time of about 18 seconds from start to end once inside the heated chamber 42 and onto the metal conveyors 32. The combined drying unit 22 and fixation unit 42 time for the moving yarn is about 20 seconds, which is much shorter than the traditional methods available.

[0059] The dye fixation quality is confirmed using a cross-sectional analysis of dye diffusion into the individual fiber, as shown in FIG. 3. Dye is not only present close to the surface of individual fiber but also diffuses into the center of each colored fiber. The individual four-hole

cross-section fibers show complete dye penetration and fixation on the fiber surface and inside the fiber.

EXAMPLE 2 - Comparative

[0060] A two-ply nylon 66 yarn, denier 2490, 128 filaments, 4.5 twists per inch [tpi], is printed/colored using sublimation inks. The ink usage rate is 10% on weight of the yarn.

[0061] The above colored yarn is dried and dye fixation is performed using a conventional convection oven maintained at 210 °C for about 30 seconds.

[0062] The dye fixation quality is confirmed using a cross-sectional analysis of dye diffusion into the fiber, as shown in FIG. 4. The individual four-hole cross-section fibers show non-uniform and incomplete dye penetration and fixation. Most of the ink remains on the surface of the fibers with no ink fixation inside the fibers.

EXAMPLE 3 - Comparative

[0063] In this example, the setup and procedure described in Example 2 are used, except the colored yarn is dried and dye fixation is performed by increasing the exposure time in the 210 °C convection oven to about 4 minutes instead of 30 seconds as in Example 2.

[0064] The dye fixation quality is confirmed using a cross-sectional analysis of dye diffusion into the fiber, as shown in FIG. 5. In this example, a longer exposure time results in complete dye coloration and fixation on the fiber surface and inside. However, the drying and fixation times for colored yarns with such conventional methods are typically of the order of minutes versus in seconds according to the present disclosure, and therefore, too long from a processability perspective. The longer the drying and fixation times, the slower will be yarn movement rate through the equipment, and correspondingly, there will be lower downstream processing throughput. Such process cannot be coupled to a conventional tufting machine due to the difference in the yarn speeds between color fixation process and tufting process.

EXAMPLE 4

[0065] In this example, the setup and procedure described in Example 1 are used, except that dye drying and fixation steps are designed to process up to 50 yarns or threads in parallel. These 50 threads run as a parallel sheet at the same speed of 20 m/min and through the IR emitters and metal conveyors inside the heater chamber.

[0066] The dye fixation quality is confirmed using a cross-sectional analysis of dye diffusion into the fiber. It shows complete dye penetration and fixation on the fiber surfaces and inside the fibers, according to the present disclosure. The overall drying and dye fixation times are of the order of 20 seconds for all 50 yarns processed in parallel.

[0067] This example illustrates drying and dye fixation for a multi-yarn coloration system and scalability aspects.

EXAMPLE 5

[0068] In this example, the setup and procedure described in Example 4 are used, except that dye drying and fixation steps are designed to process up to 2000 yarns or threads in parallel. These 2000 threads run as a parallel sheet at the same speed of 20 m/min and through the IR emitters and metal conveyors inside the heater chamber.

[0069] The dye fixation quality is confirmed using a cross-sectional analysis of dye diffusion into the fiber. It shows a uniform and complete dye penetration and fixation on the fiber surfaces and inside the fibers, according to the present disclosure. The overall drying and dye fixation times are of the order of 20 seconds for all 2000 yarns processed in parallel.

[0070] This example further illustrates the scalability aspect of the present disclosure and its practicability for performing a multi-yarn process.

EXAMPLE 6

[0071] In this example, the basic setup and procedure described in Example 1 are used, except that drying and fixation steps are designed to process up to 25 yarns or threads in parallel. These 25 yarns run as a parallel sheet at the same speed of 12 m/min and through the IR emitters and metal conveyors inside the heater chamber. Yarn type is two-ply nylon 6 yarn, denier 2490, 128 filaments, 4.5 twists per inch [tpi], is printed/colored using sublimation inks. Sublimation ink is Elvajet Cyan SR340 from Sensient Colors LLC. The ink usage rate is 10% on weight of the yarn. Drying unit consists of three IR emitters placed on one side of the yarns. Each IR emitter is about 5.4 KW and about 1.5-micron wavelength. Heated length of each emitter is about 24 inches. The temperature of both heated chamber and heated metal conveyors is maintained at 185°C. The yarn length that is in contact with the heated metal conveyors is about six meters and provides adequate residence time of about 30 seconds from start to end once inside the heated chamber

and onto the metal conveyors. The combined drying unit and fixation unit time for the moving yarn is about 34 seconds, which is much shorter than the traditional methods available.

[0072] The dye fixation quality is confirmed using a cross-sectional analysis of dye diffusion into the fiber, as shown in FIG.6. It shows complete dye penetration and fixation on the fiber surfaces and inside the fibers, according to the present disclosure.

EXAMPLE 7 - Comparative

[0073] The same yarn as Example 6, two-ply nylon 6 yarn, denier 2490, 128 filaments, 4.5 twists per inch [tpi], is printed/colored with the same ink and usage rate. The colored yarn is dried and dye fixation is performed using a conventional convection oven maintained at 185°C for 34 seconds, the same temperature and residence time as Example 6. The dye fixation quality is confirmed using a cross-sectional analysis of dye diffusion into the fiber, as shown in FIG. 7. The individual four-hole cross-section fibers show non-uniform and incomplete dye penetration and fixation. Most of the ink remains on the surface of the fibers with no ink fixation inside the fibers.

EXAMPLE 8

[0074] In this example, the setup and procedure described in Example 6 are used, except that yarn type is polybutylene terephthalate. The temperature of both heated chamber and heated metal conveyors is maintained at 195°C. The dye fixation quality is confirmed using a cross-sectional analysis of dye diffusion into the fiber, as shown in FIG.8. It shows and complete dye penetration and fixation on the fiber surfaces and inside the fibers, according to the present disclosure.

EXAMPLE 9

[0075] In this example, the setup and procedure described in Example 1 are used, except yarn type of polyethylene terephthalate, two-ply, 2340 denier, 260 filaments and trilobal cross-section is used. The temperature of both heated chamber and heated metal conveyors is maintained at 200°C. The dye fixation quality is confirmed using cross-sectional analysis of dye diffusion into the fiber and found to be satisfactory, as shown in FIG.9.

CLAIMS

1) A process for coloring yarn, the process comprising:
   a) applying a sublimation ink to the yarn;
   b) exposing the yarn to drying conditions including raising the surface temperature of the yarn above ambient by applying radiant heat to the yarn for irradiation time sufficient to reduce the moisture content of the yarn to provide an at least partially dried yarn without touching other surfaces; and
   c) exposing the at least partially dried yarn to curing/fixing conditions including conductive and convective heat transfer conditions above ambient temperature for residence time sufficient to provide a fixed yarn;

      wherein the ink applied in step (a) and at least partially dried in step (b) yarn diffuses more deeply into the center of individual fibers of the fixed yarn in step (c) than a like colored yarn treated with the same sublimation ink but not irradiated as in step (b).
2) The process of claim 1, wherein step (b) further comprises exposing the sublimation ink-treated yarn to radiant energy at wavelength of from ≥ 0.7 μm and ≤4.0 μm.
3) The process of claim 1 wherein the at least partially dried yarn of step (b) comprises < 5 % moisture, based on the weight of untreated yarn.
4) The process of claim 1, wherein step (c) comprises curing the at least partially dried sublimation ink.
5) The process of claim 4, wherein the sublimation ink comprises a colorant.
6) The process of claim 1, wherein the combined residence time in the first step and the second step is ≥ 100 milliseconds to ≤ 80 seconds.
7) The process of claim 6, wherein the combined residence time in the first step and the second step is ≥ 5 seconds to ≤ 75 seconds.
8) The process of claim 6, wherein the residence time in the first step is from ≥1% to ≤25% of the combined residence time.
9) The process of Claim 6, wherein the residence time in the second step is from ≥75% to ≤99.9% of the combined residence time.
10) The process of Claim 1, wherein the yarn substrate is chosen from the group consisting of:
   a) filaments;

b) threads;
c) fibers;
d) yarns;
e) yarn bundles; and
f) parallel sheets of yarns of different colors.

11) The process of claim 10 wherein the yarn substrate comprises carpet yarn.

12) The process of Claim 10 or 11, wherein the yarn has fibers of a cross-sectional shape chosen from the group consisting of round, trilobal, multi-lobal, square, rectangular, triangular, oval and star.

13) The process of Claim 12, wherein the yarn has fibers of a cross-section type chosen from the group consisting of solid, hollow, partially solid and partial hollow.

14) The process of any one of claims 1-13, further comprising carrying out the process steps in at least one selected from batch, semi-batch, semi-continuous and continuous mode.

15) The process of any one preceding claim wherein the yarn tension in the fixation step (c) is from ≥ 0 to <=0.02 g/denier based on yarn denier.

16) An agent-cured yarn having < 5% moisture of the total weight produced by the process of any of claims 1 through 15.

17) A device for yarn drying and fixing a colored yarn comprising sublimation ink(s), the device comprising:
a) a guide for transporting a yarn through a drying space without touching other surfaces;
b) at least one radiation energy source for transmitting thermal energy to the yarn in the drying space for residence time sufficient to provide an at least partially dried yarn;
c) guide for conveying the at least partially dried yarn of b) through a curing space; and
d) conduction and convection energy sources for providing uniform thermal energy input to the yarn and maintaining the residence time in the curing space to obtain a cured yarn.

18) The device of claim 17, wherein the drying space comprises an at least one infrared [IR] radiation emitter.

19) The device of claim 18, wherein the at least one infrared radiation emitter emits infrared radiation in the wavelength range of between 0.7 and 4.0 μm.

20) The device of claim 17, wherein the drying space produces said yarn with < 5 % moisture of the total weight.

21) The device of claim 17, wherein the curing space comprises an at least one heated chamber and an at least one conductively heated metallic conveyor inside the heated chamber.

22) The system of claim 17, wherein the curing space is maintained in the temperature range of between 120 ºC and 250 ºC.

23) The device of claim 17, wherein the curing space is maintained in the temperature range of between 130 ºC and 240 ºC.

FIGURE 1

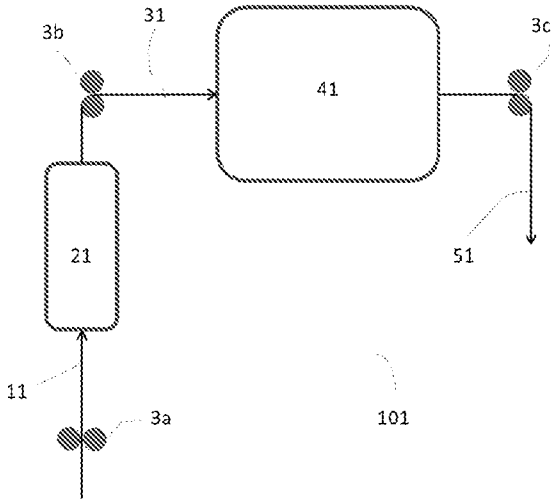


FIGURE 2

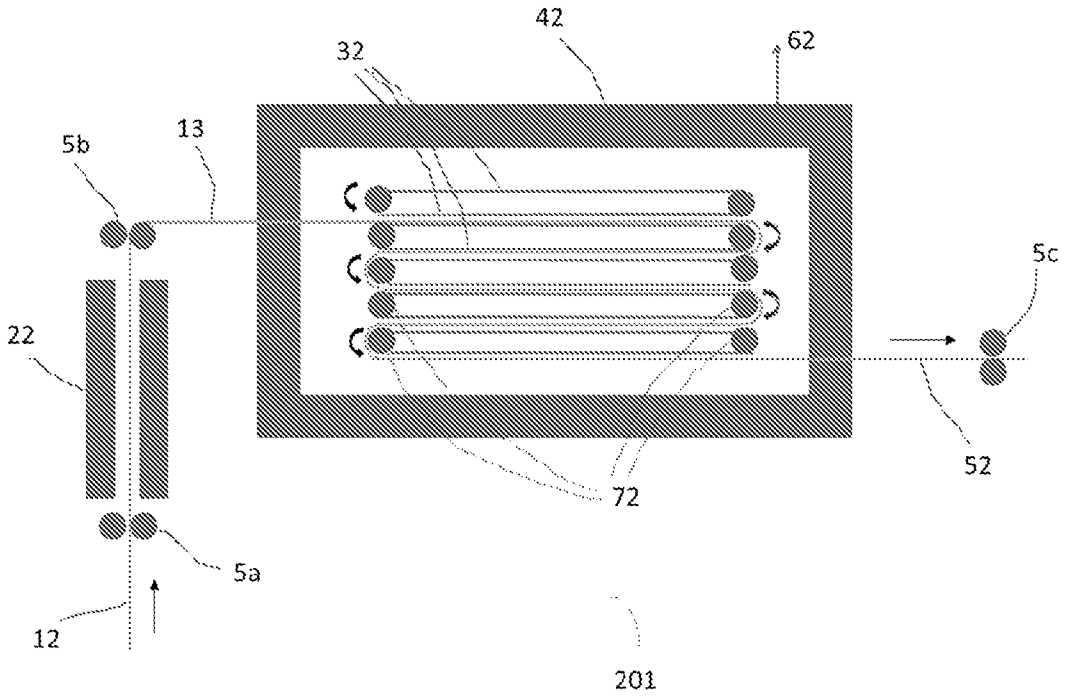


FIGURE 3

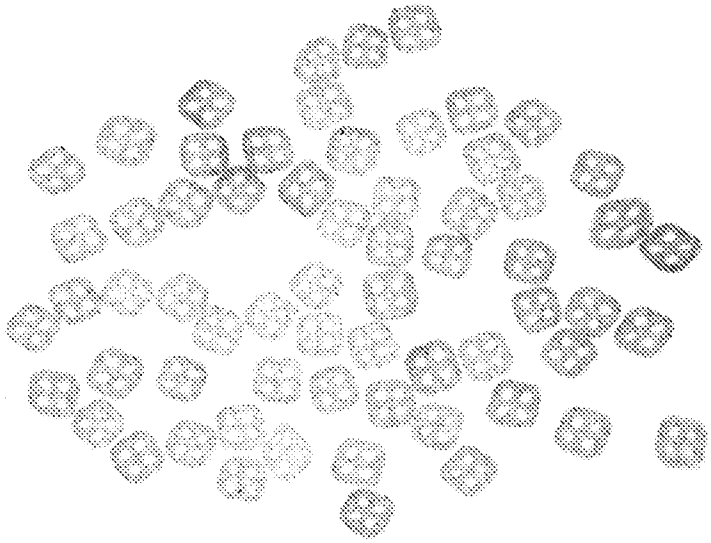


FIGURE 4

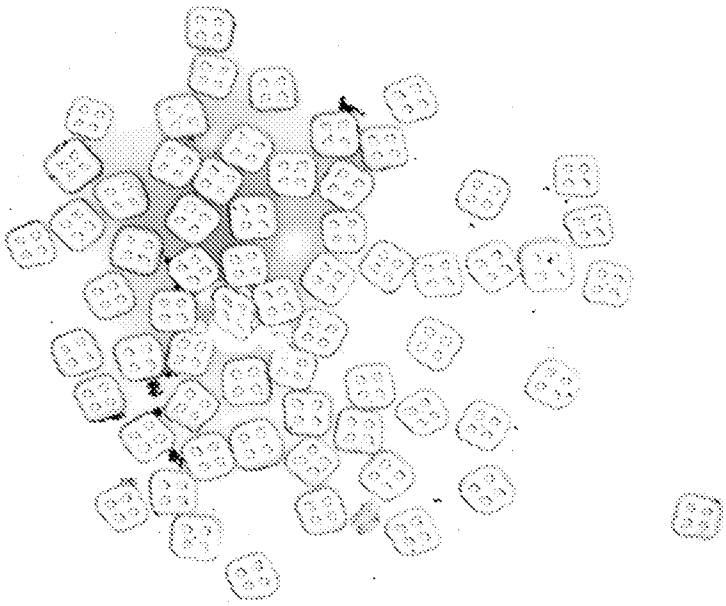


FIGURE 5

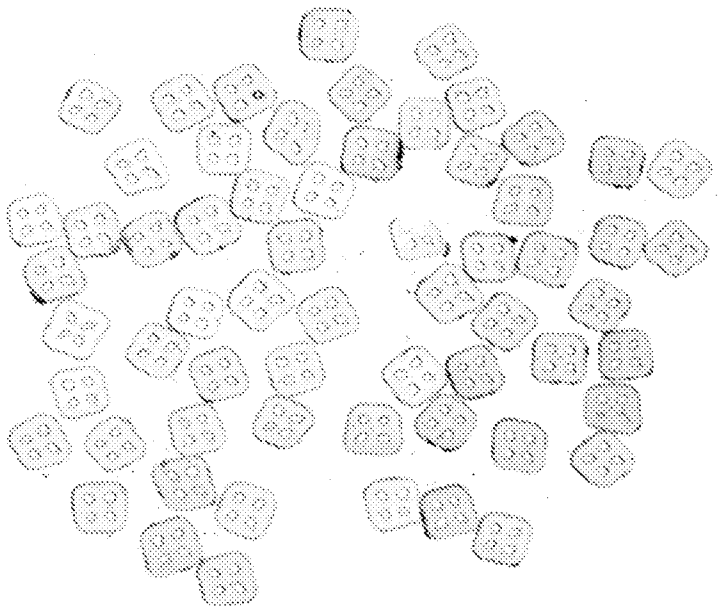


FIGURE 6

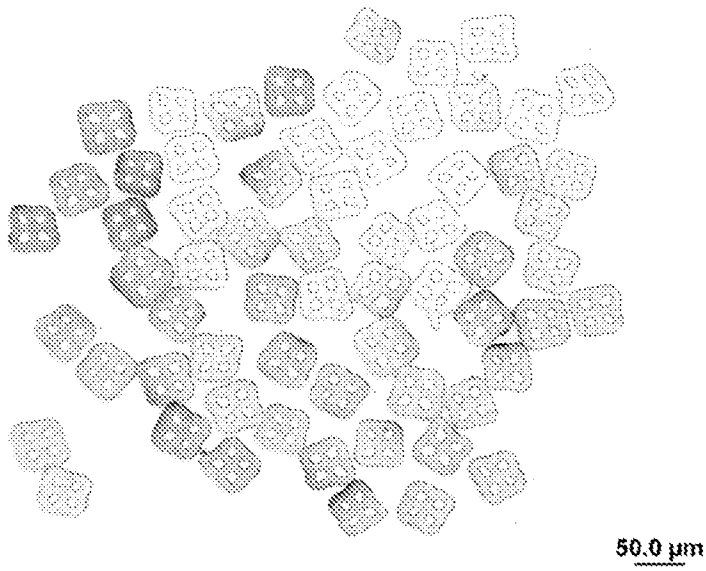


FIGURE 7

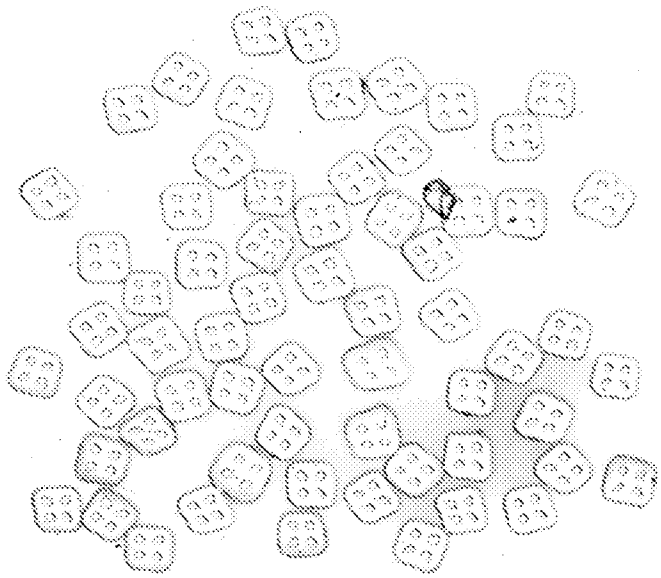


FIGURE 8

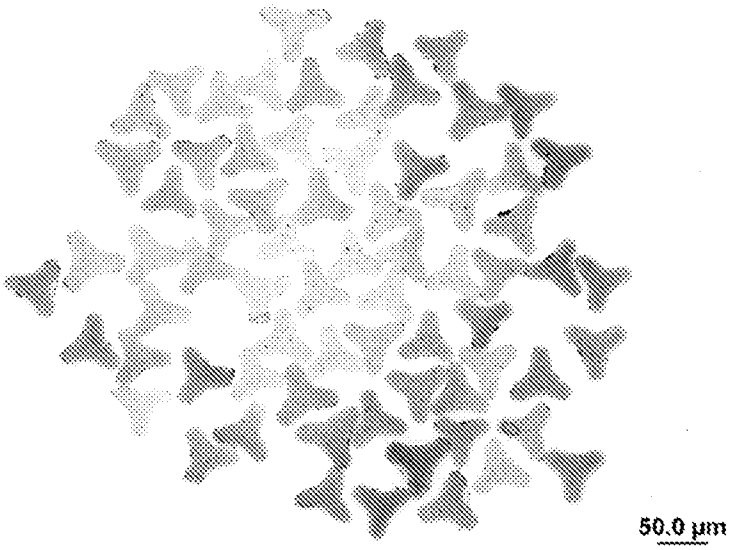
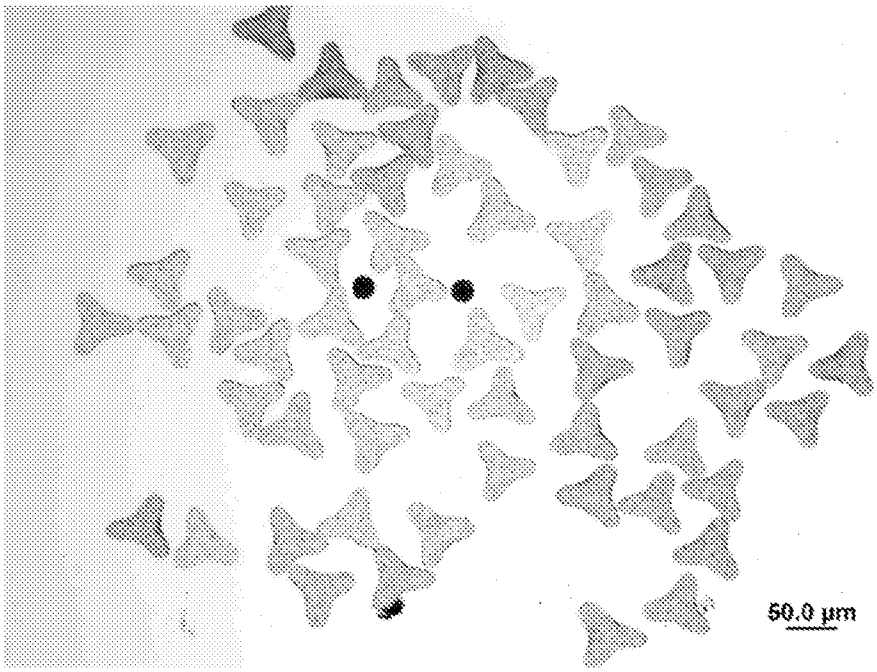


FIGURE 9



INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2020/054237

A. CLASSIFICATION OF SUBJECT MATTER
INV. D06P1/00 D06P5/28 D06P5/20 D06B21/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
D06P D06B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/172772 A1 (SANTIAGO WILLIAM [US]) 9 September 2004 (2004-09-09) paragraphs [0022] - [0026], [0037], [0044] - [0056]; claims; figures	1-10,14, 16-23
X Y	EP 1 520 924 A1 (VINCENZO ZUCCHI S P A [IT]) 6 April 2005 (2005-04-06) paragraphs [0012], [0029], [0034], [0035], [0036], [0037]; claims; figures	1-10, 14-23 11-13
Y	US 2014/082859 A1 (MORTON BRYAN [US] ET AL) 27 March 2014 (2014-03-27) paragraph [0027]	11-13
A	US 2016/102430 A1 (GRIER WILLIAM DOUGLAS [US]) 14 April 2016 (2016-04-14) cited in the application claims	1-23

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
14 July 2020	22/07/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Blas, Valérie

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 2016061287 A1	21-04-2016