REVIEW OF COMPACT SPINNING SYSTEMS

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THERMOPLASTIC WASTE RECLAMATION

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REVIEW OF COMPACT SPINNING SYSTEMS

FOR PRODUCING:

STAPLE FIBERS
MULTIFILAMENT YARNS
MONOFILAMENT YARNS
BICOMPONENT FIBERS
TAPE YARNS
SPUNBOND FABRICS
STRAPPING
EXPANDED PP FILM
MICRO FILAMENTS

By: Ken Hawn
Tex America, Inc.
STAPLE FIBER SPINNING

INTRODUCTION

The first commercial applications of short spinning systems were developed about 25 years ago and they were primarily used to produce polypropylene fibers in coarser deniers. Since this period, a wide range of machinery has been developed and short spinning systems have undergone a major evolution.

The great majority of staple fiber currently manufactured in the world is produced on two types of lines. These are traditional systems and compact systems. The primary differences are as follows:

A. Traditional spinning is characterized by:

1. Long cooling zone (up to 4 stories high)
2. High spinning speeds (up to thousands of m/min)
3. The process of stretching, crimping, cutting etc. cannot be carried out in a continuous manner because of the high speeds. There are usually two separate processes.

B. Short spinning processes differ from the traditional methods as follows:

1. The extruded filaments are cooled in a very short distance; often in less than an inch from the extrusion die.
2. The spinning speed is much lower (usually a maximum of 200 m/min)
3. The spinnerettes are larger and have a much higher number of holes.

Production of staple fiber using the short spinning concept is done on a continuous basis because the drawn tow speed is significantly lower than traditional spinning. Depending on the denier per filament (DPF), up to 500,000 filaments can be extruded, cooled by air, lubricated, drawn, heatset and cut in one process.

Short spinning systems are generally considered to have the following advantages over traditional systems.
1. They are essentially a single story plant layout without the need for a multi story spinning tower.

2. The process is simple and requires less floor space.

3. Since the process is continuous, less labor is required.

4. Maintenance costs are lower as a result of lower process speeds.

5. Air conditioning is not required.

6. Fiber quality is easier to control as a result of low spinning speeds.

This paper describes a new integrated short spinning line which utilizes circular heads and annular spinnerettes. We believe this system offers several major advantages over the traditional systems and earlier short spinning systems. This new technology allows a considerably higher production rate, higher fiber to fiber uniformity, and production of lower denier fiber; down to 1 denier per filament.

**ADVANTAGES OF THE NEW ANNULAR SYSTEM**

The essential difference between the new and previous short spinning technology lies in the shape of the spinnerettes, which are annular instead of rectangular. In other words, the spinnerette is in the shape of a ring. The reason this difference is beneficial is explained if one considers that in all spinning heads, the polymer enters through a channel and then flows under pressure towards the spinnerette holes.

As shown in the diagram "C" on the attached drawing, the annular spinnerettes improve polymer flow uniformity. As the drop in pressure from the entry to the spinnerette holes is equal for all the holes, a practical way of guaranteeing the same throughput per hole (and the same DPF) is to have the same distance (Shown as L) between the polymer entry (Shown as E) and all the spinnerette holes (Shown as H).

Once DPF uniformity has been obtained, cooling and stretching uniformity is also easier to obtain. In fact, DPF uniformity is probably the most important condition to guarantee all other filament uniformity and physical characteristics such as tenacity and elongation.

Also by using annular technology, the additional advantage of uniform fiber to fiber cooling is obtained since the air flows uniformly through the filaments outside the circle formed by the filaments themselves, a uniformity that cannot be achieved with rectangular and other types of spinnerettes. It is very difficult to blow air uniformly through the "wall" of filaments coming out of a rectangular spinnerette.
The air flow to quench the fiber is shown in a cross section of the spinnerette in diagram B. A schematic drawing of the annular head is shown in diagram A. With the "Annular System", the cooling air is still pushed through the individual filaments as with other cooling systems, but because of the annular design of the spinnerette, the pressure drop across each row of filaments is uniform.

The quantity of air flowing through the filaments, due to pressure difference, is so high that filament density (Filaments/square inch) can easily be doubled (as compared to rectangular and other spinnerettes) when fine denier filaments are produced.

A double goal is thus reached: (1) It is easy to produce filaments even as fine as 1.0 DPF or less, and (2) Productivity rates can be kept high when fine DPF products are produced.

Other Advantages of the "Annular System" are:

1. Circular spinnerettes have no dead spots where polymer contamination can build-up as with rectangular ones. This is why color change time is shorter and spinnerette "Life" is longer.

2. The circular form allows the spinnerette pack to be heated more simply and uniformly using only electrical heaters. Heaters are oversized to assure very long life. Dowtherm systems have also been supplied.

As can be seen in the table, producing a tow with single filaments of one denier, the production is 130 lbs/spinnerette and the tow speed is 155 yds/min. On the other hand, producing a tow with single filaments of four denier, it is possible to attain a production rate of 400 lbs/spinnerette at a production speed of 116 yds/min. Recent developments, not listed, allow production rates of over 500 lbs/hour.
### TYPICAL PRODUCTION ATTAINABLE WITH POLYPROPYLENE

<table>
<thead>
<tr>
<th>Denier</th>
<th>Number of Holes in Spinnerette</th>
<th>Threadline Speed (Yds/Min)</th>
<th>Output per Spinnerette (Lb/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>64,000</td>
<td>155</td>
<td>130</td>
</tr>
<tr>
<td>1.5</td>
<td>64,000</td>
<td>155</td>
<td>200</td>
</tr>
<tr>
<td>2.5</td>
<td>64,000</td>
<td>155</td>
<td>330</td>
</tr>
<tr>
<td>3.0</td>
<td>64,000</td>
<td>145</td>
<td>370</td>
</tr>
<tr>
<td>4.0</td>
<td>64,000</td>
<td>116</td>
<td>400</td>
</tr>
<tr>
<td>6.0</td>
<td>45,000</td>
<td>111</td>
<td>400</td>
</tr>
<tr>
<td>9.0</td>
<td>45,000</td>
<td>111</td>
<td>400</td>
</tr>
<tr>
<td>15.0</td>
<td>18,000</td>
<td>111</td>
<td>400</td>
</tr>
<tr>
<td>*2.0</td>
<td>64,000</td>
<td>135</td>
<td>225</td>
</tr>
</tbody>
</table>

### TYPICAL PRODUCTION WITH POLYESTER

<table>
<thead>
<tr>
<th>Denier</th>
<th>Number/Holes in Spinnerettes</th>
<th>Threadline Speed (Yds/Min)</th>
<th>Output Per Spinnerette Lbs/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>45,000</td>
<td>120</td>
<td>145</td>
</tr>
<tr>
<td>3.0</td>
<td>45,000</td>
<td>110</td>
<td>200</td>
</tr>
<tr>
<td>6.0</td>
<td>45,000</td>
<td>110</td>
<td>400</td>
</tr>
<tr>
<td>15.0</td>
<td>18,000</td>
<td>100</td>
<td>400</td>
</tr>
</tbody>
</table>

These production rates are possible due to annular spinnerette design, which allows more holes per spinnerette than with spinnerettes of rectangular design.

Consequently, this technology allows the manufacture of more lbs/hr with fewer spinnerettes.
COMPOSITION OF THE LINE

The polymer usually arrives at the manufacturing site in rail cars, or trucks and it is usually transferred by vacuum to a silo. The polymer is removed by vacuum to the metering system. The polymer can also be delivered in boxes and fed directly to the metering system. However, the polymer is generally less expensive in larger quantities.

Compact Spinning lines are generally composed of the following equipment:

1. Metering System for feeding polymer, color, and additives

This system is utilized to mix virgin granule with a color master batch or pigment and additives so as to obtain the desired color fiber or fiber with the correct properties. The system can be volumetric or gravimetric and up to 7 components can be metered into the extruder. The system is often controlled by a microprocessor.

2. Extruder

The polymer and additives are fed through the hopper into the extruder and they are pushed by the screw along the heated cylinder towards the filter. The extruder includes a special dynamic mixing section. The barrel is electrically heated with ceramic heaters divided into the required zones. The power is provided through a thyrister system which is activated by microprocessor type temperature controllers.

As the polymer moves along the cylinder, it is melted by the simultaneous action of both the heating elements in the cylinder and by the push exerted by the screw. The screw also exerts a strong mixing action on the melt.

Therefore, the main functions of the extruder are to melt the polymer and push it through the filter. Extruders are offered in a complete range of sizes from 90 - 200 MM with a length to diameter ratios up to 33 to 1. The barrel and screw are specially hardened to resist wear.

3. Screen Changer

The melt is forced through a certain number of appropriate screens in order to prevent impurities and other substances from reaching and damaging the metering pumps. This system is a continuous screen changer which is hydraulically operated. Special systems can be used for reclaimed fiber.
4. Distribution manifold to feed polymer to the spinnerettes

A pressure transducer is fitted to the entry of the distribution manifold in order to provide feedback control of the screw revolutions and maintain the constant pressure of melt from the exit of the extruder.

The manifold is heated by means of heating elements and has the purpose of distributing the melt to all the metering pumps. The system is equipped with static mixers. The line can be provided with systems supplying 1, 2, 4, 6, 8, 10, or 12 extrusion heads.

5. Extrusion Die

The extrusion die includes metering pump, screenpack, breaker plate and spinnerette. The screenpack can be easily removed from the bottom with the aid of special equipment which is provided with the line. The die and manifold are electrically heated. Very even heat is provided through thyristor and micro processed controlled systems and special insulation.

6. Quenching System

Each extrusion head is equipped with a patented system to quench the melted fiber as it is extruded. A fan for each die forces air through the circle of extruded filaments from the inside at a very high volume and velocity to insure even and very fast cooling of each filament. The velocity, volume, and temperature of the air can be varied as necessary to meet fiber requirements. The system uses a central heat exchanger for consistent cooling.

7. Pulling and Spin Finish Applicator

The pulling system is driven by DC motors which provide a constant speed to obtain filaments with very consistent denier. The filaments are uniformly spread over the finish roll and wet with a even quantity of antistatic and lubricating fluid. The speed of the finish roll can be adjusted to change the amount of finish applied to the filaments. The pulling units are staggered to produce a tow which is even and not thick. This insures even heat transfer and drawing in subsequent processes.

8. Slow Drawing Unit

The drawing of the filaments is attained by increasing the speed between the slow and the fast unit. Draw stand are provided with 7 rolls which are heated or cooled depending on requirements of the fiber being processed. The rolls are driven with helical gears lubricated in an oil bath. The gears are supported from both sides. All wear surfaces are specially treated for long wear. Draw stands are equipped with nip rolls and scrapers to avoid wraps.
9. **Hot Air Steam Saturator**

Drawing is essential to attain the required mechanical properties of the fiber. The system heats the filaments to allow the orientation of the molecules. This is a recirculation system which includes steam injection into electrically heated air. The system is hydraulically opened for easy threading of the tow. Systems vary depending on the fiber type and required specifications.

10. **Fast Drawing Unit**

The fast stretching godet is provided to mechanically orient the fiber. The mechanical features of the fast drawing unit are the same as the slow draw unit.

11. **Finish Application Unit**

The kiss roll finish application unit with a variable drive is provided to apply necessary lubricants, anti-static and/or cohesive additives to the filaments to make the fiber more processable in customer applications. This finish is normally applied just before the tow enters the crimper.

12. **Tow Collector**

The tow collector reduces the width of the tow in order to insure the width of the tow is the same width as the crimping chamber and to insure uniform thickness of the tow.

13. **Dancer Roll Unit**

The dancer roll unit controls the speed of the crimping machine thus maintaining a constant tension on the tow. This is a 3 roll system with pneumatic tension control.

14. **Crimping Machine**

A steam chamber preheats the tow to facilitate the crimping process. The tow is fed through rollers which are heated or cooled into a stuffer box where the crimp is formed. The pressure on the feed rolls and plates in the stuffer box is pneumatic. Discs seal the edge of the feed rollers and they are continually rotated to reduce wear. A pneumatic system also opens the head for easy cleaning. Steam injection into the crimping chamber is also available.
15. Thermosetting Oven & Dryer

A thermosetting oven is provided to dry the fiber after the crimping process and to relieve the internal stresses created during drawing. Fiber is heat stabilized when it exits this oven. This is not necessary on all applications and several different systems are offered depending on desired fiber characteristics.

16. Tow Tensioning Device

This is a tensioning device which allows the tow to be straightened prior to the staple cutting operation. This allows the manufacturer to assure that a uniform quality cut is obtained by insuring the same length of fiber enters the tow cutter.

17. Staple Cutter

A tow cutter is provided to cut the fiber to the desired staple length. Two independent units are provided so that one is always available in the continuous operation when it is necessary to change blades, etc. This is a rotary system with large reels to facilitate clean and consistent cuts. The blade spacing is available in increments of 10 or 15 MM to cover the complete range of staple lengths.

18. Bale Press

The fiber is normally pneumatically conveyed to the baler. The baling system is designed to meet customer requirements.

19. Main Control Panel

The system is completely operated by a Siemens or similar computer and all temperatures, speeds, pressures, etc., for the entire system are changed from the control panel.

ADVANTAGES OF THE ANNULAR SYSTEM OVER EARLIER SHORT SPIN SYSTEMS ARE AS FOLLOWS:

1. Minimum labor required - a fully optimized plant will only require one operator per shift plus a baler operator and utility personnel.

2. Minimum labor skills are required due to computerized controls

3. Process flexibility: Staple ranging from 1 - 135 DPF can be produced in both natural and color.
4. Extremely high production as related to the capital investment.

5. It is possible to start with as low as 2 spinning heads and expand a system.

6. Physical properties of the fiber produced on the line are excellent because of the uniformity of polymer distribution and flow and because of the patented system for quenching.

SPINNING POLYESTER AND NYLON ON SHORT SPINNING SYSTEMS

The availability of raw material for polyester in the form of bottle resin, reclaimed waste, and virgin granulate appears to be increasing and it is possible to use the short spinning systems for this purpose.

The following changes in the system are necessary:

1. With polyester, a dryer consisting of a hot dehumidified air generator and a hopper, must be placed to feed the extruder. The dryer is used to reduce the humidity of the granulate to avoid hydrolysis. Depending on the raw material, it may also be necessary to add a crystallizer in the polymer feeding system.

2. The tow must be heated before the first godet and other modification must also be made in the drawing line.

3. Dimensions of the capillaries in the spinnerettes must be changed to a size suitable for polyester or nylon.

4. It is beneficial to modify the polymer distribution system when spinning polyester or nylon.

5. When processing reclaim, an oversize or double filter system is used.
BICOMPONENT FIBERS

Short spinning systems can be modified to use specially designed spinning heads to produce conjugate fibers as well as sheath core fibers.

Although the density of holes is 50 holes/square inch, there can be a very narrow distribution of the ratio between the two components of conjugate fibers.

EQUIPMENT AVAILABLE FOR SPINNING FIBER TRIALS

A full size single head unit with an annular spinnerette is available at Meccaniche Moderne for spinning trials on Polyester, Nylon, and Polypropylene. A bicomponent laboratory unit is also available for trials and demonstrations.

MULTIFILAMENT EXTRUSION LINE

Compact spinning lines have now been designed to produce yarns for the following applications from polypropylene, polyester or nylon.

<table>
<thead>
<tr>
<th>Application</th>
<th>Denier Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geotextiles</td>
<td>1000 denier</td>
</tr>
<tr>
<td>Filters</td>
<td>1000 denier</td>
</tr>
<tr>
<td>Ropes</td>
<td>1000 - 2000 denier</td>
</tr>
<tr>
<td>Sewing Yarns</td>
<td>220 - 450 denier</td>
</tr>
<tr>
<td>Industrial Fabrics</td>
<td>300 - 200 denier</td>
</tr>
<tr>
<td>Upholstery</td>
<td>200 - 1500 denier</td>
</tr>
<tr>
<td>Carpet Backing</td>
<td>1200 - 1500 denier</td>
</tr>
<tr>
<td>Belts &amp; Straps</td>
<td>1000 - 2000 denier</td>
</tr>
</tbody>
</table>
THE SYSTEMS ARE GENERALLY BUILT IN THE FOLLOWING CONFIGURATIONS:

1. High tenacity yarns in the range of 600 - 1500 denier.

The systems are continuous and generally consist of the following components:

1. A system for metering the polymer and additives.
2. Extruder with filter (Usually 60 - 90 MM).
3. Polymer distribution system to the spinnerettes. This system includes metering pump and static mixers. Usually 5 to 10 spinnerettes are used with up to 16 yarns per spinnerette. The denier per filament is as low as 1.5.
4. Quenching System.
5. Drawing Sections:
   (a) For high tenacity yarns, up to 2 drawing sections are needed to obtain maximum tenacity. Yarns with tenacities of 7 have been produced.
   (b) The systems for medium tenacity yarns are generally equipped with a hot roll annealing godet.
6. Electronically controlled take up winders.
7. The systems can be equipped with microprocessors to control speeds temperatures, and operation of the winders.
TYPICAL PRODUCTION PER SPINNERETTE FOR POLYPROPYLENE

<table>
<thead>
<tr>
<th>Denier</th>
<th>Tenacity</th>
<th># of Yarns</th>
<th>Speed</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>7.5</td>
<td>8</td>
<td>150 MPM</td>
<td>22 lbs/hr</td>
</tr>
<tr>
<td>600</td>
<td>5.2</td>
<td>16</td>
<td>350 MPM</td>
<td>49.6 lbs/hr</td>
</tr>
<tr>
<td>200</td>
<td>5.2</td>
<td>16</td>
<td>350 MPM</td>
<td>16.3 lbs/hr</td>
</tr>
</tbody>
</table>

Total production of the line will depend on the size of the extruder and number of spinnerettes. Typical productions are 200 - 400 lbs/hr. per line.

SPUNBONDED SYSTEM

The following is a brief description of a spunbonded system offered by Meccaniche Moderne of Italy.

The spunbonded system is fed by two extruders which are arranged on a second story platform and they are parallel. Each extruder has a hopper and the granulate is fed by a pneumatic system from the silos and additives are added through a special metering system.

There are four spin beams located on the platform at the same level between the two extruders. For a 3.4 meter system, each extruder feeds two spin beams at 3 equal positions and each spin beam contains 6 spinnerettes fed by 6 double spin pumps for a total of 24 spinnerettes. Each spinnerette would commonly contain 504 holes. Therefore, a system would contain 504 x 24 or 12,096 individual filaments.

The filaments are extruded and pass through chutes where they are cooled by chilled air which can be varied in temperature.

After the filaments are cooled, they enter into venturi type tubes where their downward flow is accelerated with a compressed and blown air system of relatively low pressure. The filaments from each spinnerette are equally divided into six venturi tubes. Therefore, each system has 24 x 6 or 144 tubes to draw the filaments. The filaments are usually drawn between 200 - 300% of the unstretched yarn length.
As the cooled and drawn filaments pass through the venturi tubes they are randomly laid on a conveyor belt which is constructed of an open mesh stainless steel material. The filaments are controlled with a special distribution system which is attached to the venturi tube. The filaments are held in place by a vacuum which is drawn from beneath the conveyor.

The filaments laid on the conveyor pass directly to the calender unit where they are thermobonded. The fabric can also be embossed at this point. The finished fabric is then wound on large rolls where it is trimmed and cut to the proper size and automatically doffed. The edge trim is usually returned to the extruder.

If a needle punched fabric is produced, the direction of the conveyor can be reversed and the filaments fed to the needle punch line.

**TYPICAL PRODUCTION RATES ON PP ARE:**

<table>
<thead>
<tr>
<th>Grams/Square Meter</th>
<th>Denier</th>
<th>90mm Extruders</th>
<th>120mm Extruders</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>1.5 - 2.5</td>
<td>660 lbs/hour</td>
<td>880 lbs/hour</td>
</tr>
<tr>
<td>50</td>
<td>1.5 - 2.5</td>
<td>880 lbs/hour</td>
<td>880 lbs/hour</td>
</tr>
<tr>
<td>350</td>
<td>6</td>
<td>880 lbs/hour</td>
<td>1500 lbs/hour</td>
</tr>
<tr>
<td>500</td>
<td>10</td>
<td>880 lbs/hour</td>
<td>1500 lbs/hour</td>
</tr>
</tbody>
</table>

We believe this system offers the following advantages:

1. Fabric evenness and strength in the width direction is improved by using 4 spin beams to spread and layer the filaments.

2. Total energy consumption is very low as a result of a special venturi system.

3. The system is designed for Polypropylene, Polyester, or Nylon 6. Two extruders also allow the possibility of using different polymers or colors as well as improving evenness.

4. Bicomponent or melt blown systems can be incorporated.

5. The system is very flexible. It is easy to make modifications in denier size, lay down characteristics, vacuum, etc.
EXPANDED PP FILM

Systems with the general configuration of a tape line can be modified to produce expanded polypropylene film. This product is generally used for decorative ribbon or insulating materials for the cable or other industries.

MICROFIBER FILAMENT LINES

Filaments as fine as .4 DPF are now being produced on systems which could be classified as compact systems. The extruder is located at a level which is 20 feet from the floor. Polymer drying and feeding equipment would normally add about another 10 feet to this level in a typical installation.

Systems are available to produce microfiber yarns which are partially or fully oriented from polyester, nylon, and polypropylene. Common yarns are 40, 70, and 180 denier.

The system is heated with dowtherm and speed range from 2,500 - 4,000 MPM.