Fiber In-House Recycling – Experiences and Challenges of Industrial Practice

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There is always a challenge making things perfect like nature.
Content

1. Textile polyester in-house recycling – driving forces

2. Fiber and filament production waste management
   ✤ sources of waste generation (example POY direct spinning)
   ✤ waste handling and logistics

3. Different possibilities of in-house waste recovery
   ✤ closed material circuit or total material recycling
   ✤ stand alone side stream recovery spinning lines
   ✤ partial or total glycolysis
   ✤ waste sales and downgrading

4. Main problems and hurdles of textile waste in-house recycling
   ✤ waste collection
   ✤ waste handling and storage
   ✤ waste recovery process steps
   ✤ Chain destruction of the polymer - IV loss
   ✤ fiber origin impurities – spin finish

5. Effective waste recovery - process suggestions

6. Summary
1. Textile polyester in-house recycling – driving forces

The majority of modern textile polyester production plants is running high capacity output lines between 400 and 800 t/d of direct conversion melt to filament or melt to staple fiber. Especially in China operating companies with several of such lines at one production site.

Besides high degree of automation, modern spinning equipment and well optimized polymerization processes the generation of certain amounts of production waste is unavoidable.

Apart from some completely destructed polymer material caused by sudden shut downs like power cut or equipment failures all generated waste exists of high value and high quality polymer.
1. **Textile polyester in-house recycling – driving forces**

Following the general target of the plant owner to maximize the profit all measures to increase the A-grade filament or fiber production yield are of high priority and besides waste avoidance the recycling of unavoidable production waste is mandatory.

Provided a yield of POY of 98% A-grade product is achieved a 500 t/d POY-line is producing for instance 7,5 t/d waste which is a loss correlated to an estimated POY-price of 12 000 RMB/t of 31 Mio RMB or about 3,6 Mio Euro per annum. Adding the waste generation during conversion from POY to DTY an optimistic estimation is ending up with losses in a similar level.

As consequence one could say: Successful total recycling of production waste during spinning and texturing - a 500 t/d filament plant has a potential of about 60 Mio RMB turnover exposure increase per annum.
2. Fiber and filament production waste management

Sources of waste generation (example POY direct spinning)

Following the product-flow-direction the following wastes appear:

~ polymer solid lumps occurring during frequent central melt filter candle change
~ polymer solid lumps occurring during spin pump change
~ polymer solid lumps occurring after spin pack change
~ polymer solid lumps occurring after die wiping and re-start of spinneret
~ fiber waste non-stretched, without spin finish, spinneret re-start, spin breaks
~ fiber waste stretched, containing spin finish, re-start spinning position
~ fiber waste stretched, containing spin finish, all kinds of damaged bobbins or yarn
~ fiber waste stretched, containing spin finish, all kinds of yarn off-cut from bobbin cores

In the same way staple fiber lines or texturing mills have clearly defined kinds of waste sources.
Waste handling and logistics

During inspection of many different polyester and polyamide spinning mills during the last 25 years it was clearly to observe, that waste handling and waste logistic was in majority of companies not part of original plant design, most of the time professional designed and executed waste collection, waste storage and transport tools are missed, waste handling and logistic is often recognized as a bothersome duty and burden.

With the target of total waste recycling all kind of production scrap is becoming a side-product of high value requiring for

~ clear definition of all waste sources
~ supply of waste handling instructions
~ supply of waste collection equipment
~ supply of waste transport equipment
~ supply of waste storage equipment
~ release of clear waste processing instructions

As design suggestion:

Such equipment should be designed to handle up to 5% of the plant production capacity to cover periods of unexpected losses of production and facility malfunction.
3. Different possibilities of in-house waste recovery

- Closed material circuit or total recycling

Like total recycling within the melt polycondensation line where nowadays all occurring side streams are direct recycled, the same target is on agenda of a modern spinning mill.

As archetype of total recycling one should have a look at latest continuous production of biaxial oriented PET film. In the former time the unavoidable scrap from edge trimming was transported to a waste-film mill and the so produced fluff was fed to an intermediate storage silo. At the same time all other scrap coming from film breaks, off-grade mill rolls and off grade film rolls was also fed to this film cutter. As next step the film fluff was fed to re-granulation unit. The so produced amorphous re-PET resin was dosed to the virgin film PET – see sketch of slide 8.

Latest technology of internal film recycling applying decentralized film cutters, the majority of about 20% fluff from edge trimming is fed without intermediate storage or pelletizing to a degassing extrusion device from where the melt is going directly back to the main extruder. Mill roll and floor scrap is converted to fluff which is fed in parallel in a certain feeding ratio to the edge trim fluff – see sketch of slide 9.

The transferability of this direct recycling concept to textile polyester production is stepwise and partially possible today. All required hard ware together with the belonging know how is available.
Example sketch of process recycling during BO-PET production – old technology

Solid waste from filter exchange and line re-start
MDO-waste during film break or re-start
TDO waste during film break or re-start
Off-grade mill rolls
All kind of floor scrap

About 5% of throughput

Waste from edge trimming about 20% of throughput

Virgin PET resin

R-PET resin

R-PET silo

Film fluff silo

Cutter Filter Extruder

About 5% of throughput

Central Film cutter
Virgin PET resin

Example sketch of process recycling during BO-PET production – latest technology

- Vakuum Extrusion
- MDO
- TDO
- Edge trimming
- Winding

Virgin PET resin

Solid waste from filter exchange and line re-start
- MDO-waste during film break or re-start
- TDO waste during film break or re-start
- Off-grade mill rolls
- All kind of floor scrap

About 5% of throughput

Waste from edge trimming about 20% of throughput

Direct conveying of film fluff

Edge trim cutter

Winding

Film fluff silo
Stand alone side stream recovery spinning lines

Another recycling approach is to process all collected waste on especially recycling dedicated spinning lines. In this case all collected waste is converted to pellets which are after sufficient blending converted via extrusion spinning to heavy titer / coarse POY filaments or to standard staple fiber. Another outlet for such R-PET pellets could be spunbond / nonwoven.

Disadvantage of such solution is a certain kind of downgrading. Advantage is higher tolerance limits for impurity level.

Waste glycolysis

Different to the mechanical recycling during waste glycolysis the collected polyester waste is downgraded by melting the waste in presence of MEG, filtering this melt and feeding this melt prior the finisher back to the polycondensation line.

Disadvantage of this technique is the high risk introducing non-controlled high levels of impurities to main product stream with the result of quality losses within the main production line.

Waste sales

Especially smaller textile PET plants are collecting the waste and sell it to a specialized waste recycling company.

Disadvantage is the high economical loss.
4. Main problems and hurdles of textile waste in-house recycling

+ **Waste collection**

Difficulties of waste collection are based on the psychological effect, that waste is an unwanted / not-liked material. As an unavoidable evil the plant worker sometimes missing attention regarding clean treatment and handling. The antagonism to produce as less as possible waste but of high as possible purity is sometimes difficult to resolve.

Therefore it needs efficient equipment, tools and instruction to treat waste like a “high quality product”.

Main target is to avoid floor touch or open floor storage of waste. All waste needs at its source the collection in covered or sealed waste bins, boxes or bags. In case floor scrap is unavoidable frequent floor cleaning is mandatory.

The production records which are published in the production rooms on display boards should contain all information about waste generation and especially about the rate amount of clean and direct recycled polymer.
**Waste handling and storage**

Difficulty of waste handling and storage is at first and foremost its broad range of physical nature like small lumps, large lumps, loose and low density bulky filaments and dense packed filaments. Especially waste of textured yarn is of high bulk.

To increase bulk density of high bulk wastes different methods are useful like bale pressing or thermal pressing in presence of superheated steam. Another way to increase bulk density is the direct agglomeration by applying for instance PALLMAN or CONDUX agglomeration devices.

Handling problem of all wastes of endless filaments and fibers is the danger of un-controlled wrapping on all kind of rotating machine parts. One way out is converting all endless filament / fiber waste directly to long staple waste by guillotine cutters or short fiber fluff by milling.

It is recommended to collect and store all types of waste separated by material types.
Waste recovery process steps

Grinding/ Cutting
To further processing all kinds of solid melt lumps heavy solids crusher or shredder are used. Available is such equipment for instance from Herbold (www.herbold.com), Pulian (www.granulator.com.tw/) or Weima (www.weimaamerica.com).

For fiber and filament communication several principles are useful which are milling (Herbold), or QSPXMEC Ltd. (www.chinaqdj.com), culliotine cutting by Pierett (www.pierret.com) or universal shredding by Vecoplan (www.vecoplan.com)

Compacting
Especially the bulky fiber and filament waste needs to be reduced in volume. After cutting the fibers to fiber fluff a compactor is treating the fibermaterial under high friction to reach a certain platization and size reduction. Equipment for compacting is coming from Pallmann (www.pallmann.eu) or Herbold

Re-pelletizing
To feed the collected polymer waste back to melt spinning it is necessary to melt it by extrusion. Most of the time there is an intermediate pelletizing used to clean the melt by filtration and to assure quality grade separation and blending.
Main problems during re-pelletizing are chain destruction of the polymer, intensive intermingling and distribution of foreign impurities and discoloration by thermal degradation.

❌ **Chain destruction of the polymer - IV loss**

General problem of all thermal recycling processes is the polyester destruction by hydrolysis. Especially all fiber containing spin finish have moisture content. The spin finish pick up is in a range of 0.5%.

To reduce the impact of moisture content a sufficient way is extrusion under vacuum. There are meanwhile several multi screw extruder provider which are offering fiber waste extrusion under vacuum like for instance Coperion ([www.coperion.com](http://www.coperion.com)) or Gneuss ([www.gneuss.com](http://www.gneuss.com)).

**Fiber origin impurities – spin finish**

Process origin impurities of fiber waste caused by spin finish are chemicals like mineral oil, glycerol, white oil, phosphorous containing esters, waxes and detergents. Problem is that spin finish composition is most of the time secret to the spin finish producer. A close cooperation to spin finish producer is to gain information about spin finish composition.
To facilitate successful fiber recycling the spin finish producers should communicate the chemical composition of spin finish to the fiber manufacturer. It would be also requested to adjust spin finish composition to the requirements and conditions of fiber recycling.

Main requests for the chemical composition of a recycling friendly finish are

- Boiling temperature at 20 mbar << 150°C
- High thermal stability at 280°C
- No discoloration during melt treatment (10 min at 280 – 290°C)
- Chemically inert to polyester

Spin finish composition of the above described chemical properties is easy removable by vacuum during extrusion without causing polymer destruction and discoloration
5. Effective waste recovery - process suggestions

Designing an overall waste management concept for polyester filament and fiber production, the first and most important decision is where to feed the recycled polyester back to the product stream. The answer is very much dependent on the production situation at the dedicated site like:

- extrusion spinning POY plant
- stand alone single continuous POY direct spinning plant
- stand alone single continuous SF spinning plant
- complex production plant existing of several continuous direct spinning POY-lines
- complex production plant existing of several POY and SF line

As an example, a difficult production situation which is the stand alone single direct spinning plant is selected.
Main Waste Sources Direct Spinning

Polycondensation

Direct Spinning Plant

melt lumps from filter change

( .......... )

melt lumps from filter start up and die head change

melt lumps from spinneret change and purge

Filament fluff dry from spinneret purging restart spinneret

filament fluff spin finish from spinning restart

POY bobbin waste

Single POY Spinning Unit
Waste Processing Center and Re-Pelletizing

- Melt lumps from filter change
- Melt lumps from filter start up and die head change
- Melt lumps from spinneret change and purge
- Filament fluff dry from spinneret purging restart spinneret
- Filament fluff spin finish from spinning restart

Waste Processing Center

Slow Motion Compact Shredder

Vacuum Degassing Extrusion e.g. MRS Gneuss,

R-PET pellet silo / blender
R-PET pellets IV 0,61 dl/g
Feeding of Recycling Pellets

Polycondensation

Direct Spinning Plant

Single POY Spinning Unit

Metering Pump

Static Mixer

Fine Filtration

Vacuum Degassing

MRS Vacuum Extrusion Unit

R-PET Pellets
Waste Direct Feeding

Polycondensation

Direct Spinning Plant

Single Spinning Unit

Metering Pump

Static Mixer

Fine Filtration

Vacuum Degassing

MRS Vacuum Extrusion Unit

Fiber / Filament / Lumps Direct Feeding

Slow Motion Compact Shredder

CCFEi
New developed fiber direct-recycling unit

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6. **Summary**

- Spinning waste in-house recycling provides in a closed loop the potential of profit optimization.
- Recognizing all kinds of appearing waste as high value raw material.
- Most important prerequisites of successful in-house recycling are dedicated facilities, tools and instructions for collection, transport, storage and processing.
- Planning and execution of successful in-house recycling depends on plant design and product assortment structure. There is no general technical solution. Each plant needs a tailored in-house recycling project.
- A broad variety of spinning waste processing machinery and methods are available in the market. To keep the waste polyester as clean as possible the manual handling and the processing steps should be reduced to minimum.
- Spin finish producer should be involved in the recycling project to assure low impact if spin finish during waste melting and melt processing.
- For waste extrusion and re-pellet production vacuum extrusion processes without pre-drying are recommended.
- As archetype for high efficient in-house recycling the total loop technology of BOPET-film production is useful.
Thanks for your kind attention!