CHAPTER- 4

MATERIALS AND METHODS

4.1 MATERIALS

Following additional equipment/materials are required to modify existing FDY line:

a) Materials and equipment required to modify quenching system, spin finish application system and appropriate winding system.

Table.4.1 Materials required for modification of spinning line

SRNO.	ITEMS	QUANTITY(no.)
1	Four end winders with traverse cam	26(2 extra)
2	Groove guide	50
3	Groove guide fixing unit	50
4	Tension bar guide	50
5	Tension bar guides fixing unit	75
6	Traverse guide	1000
7	Oil roller	24
8	Spinneret	300
9	Modified paper tube	As per requirement
10	Modified spin finish oil	As per requirement
11	Modified quench chamber	24

b) Umbrella type splitting machines, warp splitters and warp knitting machines.

c) Additional testing and measuring equipment:

i) Dual type Anemometer

ii) Fabric testing instruments (tensile strength tester, bursting strength tester and instrument to measure air permeability).

4.2 METHODS

This study involves the production of 240/12 PET mother yarn by modifying existing spinning line. To achieve this aim subsequent set of activities are carried out:

4.2.1 Estimation of quench air quantity

Generally used terms **[50]**

- Screen size in mm –1200 x1170 (effective 1050 x 995)
- Spinneret size mm OD x ID x thickness = 77 x 72 x 20.
- Air velocity = 0.5 meter/sec.
- Effective width for cooling = Effective Spinneret diameter x no's of the ends.
- Air requirement per position = (1.05x0.955x0.5x3600=1880.55 m^3/ Hrs.
- 3 no's fan are running @ 70 of capacity each having 120000 CFM (Cubic feet per meter)

Per spinning position air consumption cubic meter/hr =

(0.7x3x120000x1.7/240)

Per spinning position air consumption cubic meter/hr = 1785

4.2.1.1 Calculation of filament yarn throughput per position

1. Spinning denier (d) = 126
2. Spinning Speed (N) = 3100 mpm
3. No. of ends per position (z) = 10
4. Nos. of filament per end = 36
5. Filament yarn throughput

(W) kg/hr=(0.06xdxNxz)/9000

W kg/hr = 26.04

4.2.1.2 Heat load on quench system per position (filament yarn)

Melt temp. of PET (T-melt) = 285 degree Celsius

Freezing temp.of PET (T-freeze) = 260 degree Celsius

Avg. Sp heat @ melt temp. (Cp-melt)= 0.48 kcal/kg /degree Celsius

Latent heat of fusion of PET (λ) = 11.5 kcal/kg /degree Celsius

Filaments cooled to temp (T-final) = 60 degree Celsius

Avg. Sp heat @ Solid fiber (Cp-solid) =0.40 kcal/kg /degree Celsius

q= (Wxcp-meltx(T-melt-T-freeze)) + (Wx λ) + (WxCp-solidx(T-freeze - T-final))

Q kcal/hr =2689

4.2.1.3 Theoretical amount of quench air per position (filament yarn)

1. Quench air supply temperature = 20 degree Celsius
2. Quench air exit temperature = 40 degree Celsius

3. Quench air pressure = 0.007kg/(cm^2)g
(Assuming70mmwc or 700 Pascal)
4. Sp heat of quench air = 0.25 kcal/kg degree Celsius
5. Mass flow of QA required = 537.82 kg/hr
6. Density of QA = 1.25 kg/m^3
7. Actual volume Flow = 430.26 m^3/hr
8. Volume flow at NTP (Q-theoretical) = 403.62 Nm^3/hr

4.2.1.4 Actual amount of quench air required per position (filament yarn)

This calculation is applicable for filament yarn only where cross flow QA system is followed. Table for row number factor for the quench air quantity

The actual amount of QA required = 4 x Minimum theoretical amount of air factor from table

Example: The term 4 has been taken as in cross flow only 25% air is used actual cooling

For f= 4, Q-act= Q-theoretical x1.113x4

Table.4.2 Inlet and outlet temperature of quench air

Polymer	T-melt, Degree Celsius	T-quench supply Degree Celsius	T-quench exit Degree Celsius	F factor for no of filament rows per spinneret		
PET	285	20	40	4	7	9
				1.113	1.188	1.735

4.2.1.5 Exit temperature of quench air based on actual quench air flow (Filament yarn)

1. Actual QA Vol.0 flow at NTP (Q-act) = 1796.9 Nm^3/hr
2. Density of QA at NTP = 1.31 kg/m^3

3. Actual mass flow of QA = 2353.96 kg/hr
4. Sp heat of quench air = 0.25 kcal/kg /degree Celsius
5. Quench Air supply temperature = 20 degree Celsius
6. Heat load for quench air = 2689 kcal/hr

   Exit Temperature = 24.57degree Celsius

4.2.1.6 Comparison of quench air as per quench air outlet temperature, screen size and actual plant data as frame size

Table.4.3 Quantity of quench air flow in Nm^3/hr [51]

Product: POY							
Denier	Spinning Speed, m/min	Polymer throughput, kg/hr	QA supply temp, degree Celsius	QA return temp, degree Celsius	No. of rows per spinneret (1 Position)	Row factor	QA flow Nm^3/hr
126	3100	26.04	20	24.6	4	1.113	1796.9
	As per screen size air consumption						1880.55
	Plant data as fan size						1785

This calculation is based on throughput for 126/36 FDY where dpf is only 3.5. In the case of 240/12 or 300/10 where dpf is 20 or 30 which is 6-8 times high. Therefore for optimized quenching. We have to increase the length of quenching and also adjust the quench air parameters accordingly.

4.2.2 Modeling of fiber formation and estimation of filament temperature in spinning line

To derive a relation of filament temperature for a given quench air temperature, melt temperature of polymer, Nusselt number, heat transfer coefficient from filament surface to surrounding air, quantity of melt per filament and specific heat of polymer, one has to calculate quantity of melt per filament, filament diameter and Nusselt number for the system.

4.2.2.1 Calculation of quantity of melt per filament

(I) for denier 126/36 PET

For this denier per filament comes out to be3.5 denier.

Mass of 1 meter of single filament of 3.5 denier = 3.5 / 9000gms

For take-up speed 3200 m/minute, quantity in Kg/sec/filament-

$= (3.5 \times 3200 \times 10^{3}) / (9000 \times 60)$

$= 0.0207 \times 10^{-3}$

(II) Similarly mass of one filament for 240/12 denier

At 3500m/minutes comes out = $(3500 \times 240 \times 10^{-3}) / (9000 \times 12 \times 60)$ kg/sec/hole

$= 0.129 \times 10^{-3}$ kg/sec/hole

4.2.2.2 Calculation of diameter of single filament [52]

We know, Diameter (D) in microns = 11.89 x $\sqrt{d/\rho}$, Where 11.89 is constant factor, d = denier per filament ρ= Average density of yarn in grams/cm^3

Therefore diameter of single filament for 126/36 PET yarn=11.89 x $\sqrt{3.5/1.38}$

=18.93 micron

$=18.93 \times 10^{-6}$ meters

(one micron = 10^{-6} meters)

Similarly diameter of single filament of 240/12 PET yarn =11.89 x $\sqrt{20/1.38}$

=45.42 micron

=45.42 x 10^{-6} meters

4.2.2.3 Calculation of Nusselt number of quench air at 20^0C

In heat transfer at a boundary (surface) within a fluid, the Nusselt number (Nu) is the ratio of convective to conductive heat transfer across (normal to) the boundary. In this context, convection includes both advection and diffusion. Named after Vilhem Nusselt , it is a dimensionless number. The conductive component is measured under the same conditions as the heat convection but with a (hypothetically) stagnant (or motionless) fluid. A similar non-dimensional parameter is Biot Number, with the difference that the thermal conductivity is of the solid body and not the fluid**.**

$$\mathrm{Nu}_L = \frac{\text{Convective heat transfer}}{\text{Conductive heat transfer}} = \frac{hL}{k}$$

Where, N_{uL} = Nusselt number **[53]**

h = coefficient of heat transfer from filament surface to surrounding air

L = characteristics length

K= thermal conductivity of air

The Reynolds number is defined as the ratio of momentum forces to viscous forces and consequently, quantifies the relative importance of these two types of forces for given flow conditions.

$$R_e = \frac{Inertial forc}{Viscous force} = \frac{\rho VL}{\mu} = \frac{VL}{v}$$

where:

V is the maximum velocity of the object relative to the fluid (SI units: m/s)

- L is a characteristic linear dimension, (travelled length of the fluid; hydraulic diameter when dealing with river systems) (m)
- μ is the dynamic viscosity of the fluid (Pa.s or N·s/m² or kg/(m.s))
- v is the kinematic viscosity ($v = \frac{\mu}{\rho}$) (m²/s)
- ρ is the density of the fluid (kg/m³).

The prandt number is defined as the ratio of momentum diffusivity to thermal diffusivity. That is, the Prandt number is given as[10]:

$$\mathrm{Pr} = \frac{\nu}{\alpha} = \frac{\text{viscous diffusion rate}}{\text{thermal diffusion rate}} = \frac{c_p \mu}{k}$$

Where:

μ momentum diffusivity (kinematic viscosity), $\nu = \mu/\rho$,(SI units: m^2/s)

α thermal diffusivity, $\alpha = k/(\rho c_p)$, (SI units: m^2/s)

μ dynamic viscosity, (SI units: Pa s = N s/m^2)

k: thermal conductivity, (SI units: W/m-K)

c_p: specific heat, (SI units: J/kg-K)

ρ Density, (SI units: kg/m^3).

We know Nusselt number is a function of Reynolds's numbers and Prandt number

$N_u = f(R_e, P_r)$

$R_e = D V/\nu$ where, D is diameter, V = velocity of fluid and ν is kinematic

viscosity of fluid

R_e of quench air 20^0C for 126/36 polyester yarn = D V/ν, (where, D (diameter of single filament of 3.5 denier) = 18.93 $x10^{-6}$ meter, V (velocity of air) =0.5 m/s and $\nu = 15.077x10^{-6}$ m^2/s)

$= 18.93\ x10^{-6}x0.5/15.077x10^{-6}$

$= 0.63$

$P_r = C_p\ \mu/K$ where, C_p= specific heat of air in K joule/kg.^{0}C, μ = dynamic viscosity of air kg /mt.s and K= Heat conductivity of air watt/meter.^{0}C

$P_r$number of air (at 20^0C) = $C_p\ \mu/K$

$=1005.6\ x\ 1.8116x10^{-5}/0.026$

$= 0.70$

Now, for this range of Reynolds's numbers and Prandt number we use the relation given by Hilpert

$N_u = hx\ d/k = CR_e^m P_r^{1/3}$

, where C= 0.99 and m=0.33are constant of this equation for circular cylinder in cross flow

N_u (of quench air at 20^0C) = $0.99\ x\ 0.63^{0.33}x0.70^{0.33}$

$=0.99x0.8585x0.89$

N_u (of quench air at 20^0C) =0.756 of quench air for 126/36 (single filament denier is 3.5) PET yarn

Similarly,

R_e of quench air 20^0C for 240/12 PET yarn= DV/ν, (Where, D (diameter of single filament of 20 denier) = 45.43 $x10^{-6}$ meter, V (velocity of air) =0.5 m/s and ν= $15.077x10^{-6}$ m^2/s)

$R_e = 45.43x10^{-6}x0.5/15.077x10^{-6}$

= 1.5065

$P_r$number of air (at 20^0C) = C_p μ/K

=1005.6 x $1.8116x10^{-5}/0.026$

= 0.70

Now, for this range of Reynolds's numbers and Prandt number we can use the relation given by Hilpert [**54**].

$N_u = h \times d/k = CR_e^{m1/3}P_r^{1/3}$

where C= 0.989 and m=0.33are constant of this equation for circular cylinder in cross flow

N_u (of quench air at 20^0C) = 0.99 x $1.5065^{0.33}x0.70^{0.33}$

=0.99x1.144x0.89

N_u (of quench air at 20^0C) = 1.008 of quench air for 240/12 (single filament denier is 20) PET yarn

4.2.2.4 Use of heat flow balance equation to derive filament temperature at x meter distance from the spinneret

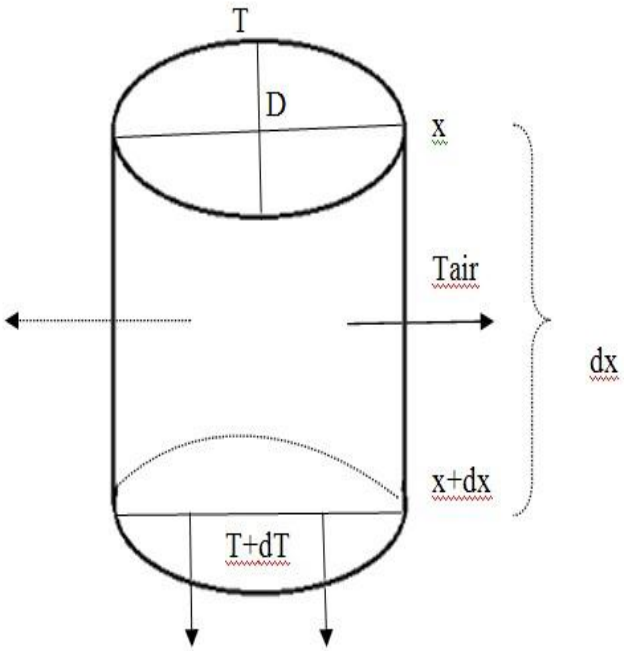

Fig.4.1: Heat flow balance of a filament volume element [55]

Simplified analysis

If it is assumed that mode of heat transfer between filament surface and quench air is only heat convection (i.e. no heat conduction and no heat sources within filaments, no heat radiation), then heat balance of any volume element between x and x+dx, is given by the following equation. The difference in heat flow into the unit volume that is the heat transfer from the surface of the unit volume into the surrounding air is given in Fig (4.1).

The heat balance equation can be written as

$$Q \times C_p x\,(T) - Q \times C_p x\,(T+dT) = h \times (T-T_{ai} x\, \pi \times D \times dx$$

and N_u (Nusselt no.) $= h \times D/k_{air}$

Where Q = Polymer throughput

C_p = A specific heat of polymer

k_{air}= Heat conductivity of air

h = Heat transfer co-efficient from the filament surface to surrounding air from equation (III) and (IV)

$Q \times C_p \times (T - T - dT) = N_u \times (T - T_{air}) \times k_{air} \times \pi \times dx$.(V)

$dT/dx = - (T - T_{air}) \times N_u \times k_{air} \times \pi / Q \times C_p$..... (VI)

in equation (VI), T_{air} is the temperature of surrounding air.

The Nusselt no. (or h) is an essential parameter for calculating filament temperature profile $T_{x.}$ It can be written

$N_u \times \pi \times k_{air} / Q \times C_p = 1/L_c$

Now the equation (VI) can be written as $dT/dx = -(T - T_{air}) \times 1/L_c$.....(VII)

Where, L_c = cooling length

Now integrating the above differential equation (VII),

$$\int dT = -(T - T_{air}) \; x \; 1/L_c \; x \int dx + C$$

or

$$\int \frac{dT}{(T - T_{air})} = \; -(1/L_c) \int dx + C$$

or

$\log(T - T_{air}) = \; -x \; x \; 1/L_c + C$..... (VIII)

but at x=0, $T=T_{melt}$

or

$$\log(T_m - T_{air}) = \; -0 \; x \; 1/L_c + C$$

now putting the value of C in equation (VIII), it becomes

$$\log(T_x - T_{air}) = -x\ x\ 1/L_c + \log(T_m - T_{air}) \quad \text{..... (IX)}$$

or

$$\log\left[\frac{(T_x - T_{air})}{(T_m - T_{air})}\right] = -\ x\ \text{x}\ 1/L_c$$

or

$$\frac{(T_x - T_{air})}{(T_m - T_{air})} = e\text{^}(-x\ x\ 1/L_c)$$

or

$$(T_x - T_{air}) = (T_m - T_{air})\ x\ e\text{^}(-x\ x\ 1/L_c)$$

or

$$T_x = T_{air} + (T_m - T_{air})\ x\ e\text{^}(-x\ x\ 1/L_c) \quad \text{.....(X)}$$

Where, L_c = Qx C_p /N_ux π x k_{air}

4.2.2.5 Calculation of filament temperature at different distance

Now calculating filament temperature T_x for denier 126/36 at take-up speed 3200 mpm for a distance of 1meter from spinneret.

Q for 126/36 PET yarn

=126 x3200/9000 =44.8gms/ min

=44.8/36/60 x 10^{-3} Kg/s/hole

=0.02 x 10^{-3} Kg/s/hole

Now, calculating L_c for given throughput for 126/36 denier. L_c= Qx C_p /N_ux π x k_{air}

Here, Nusselt number= 0.716 for 126/36 denier

L_c=0.02x10^{-3}x1005.7/0.756x3.14x0.026

= 0.020114/30x10^{-3}

=0.323 meter

By substituting the values of x, T_{air}, T_{melt}, N_u, $k_{air,}$ Q and C_p in equation (VIII), and get, T_x (x=1 meter for 126/36 PET yarn) =20^0 C + $(285-20)^0$ C x$e^{-1/0.323}$ temperature of quench air and melt temperature of polymer are taken in ^{0} C instead of in ^{0} kelvin

=20^0 C + $(285-20)^0$ C x$e^{-1/0.323}$

=20^0 C + $(285-20)^0$ C x$e^{-3.0968}$

=20+265x$e^{3.0968}$

=20+265/$2.7^{3.0968}$

=20+11.975

=31.975^0 C

Similarly calculating temperature of yarn at (x= 1meter) for 240/12 PET multifilament

Q for 240/12

=240 x3500/9000 =93.33gms/ min

=93.33/12/60 x10^{-3} Kg/s/hole

=0.129 x10^{-3} Kg/s/hole

Now, calculating L_c for single filament of 240/12 PET yarn (denier of single filament is 20) L_c= Qx C_p /N_ux π x k_{air}

Here, Nusselt number for 240/12 denier = 1.009

L_c =0.129 x10^{-3} x 1005.7 /3.14 x 1.008 x 0.026

=1.5765 meter

By substituting the values of x, T_{air}, T_{melt}, N_u, $k_{air,}$ Q and C_p in equation (X), and get, T_x (x=1 meter for 240/12 PET yarn) =20^0 C + $(285-20)^0$ C x$e^{-1/1.5765}$

temperature of quench air and melt temperature of polymer are taken in ^{0} C instead of in ^{0} kelvin

$=20+265x e^{-1/1.5765}$

$=20+265/2.7^{0.6343}$

$=20+265/1.877$

$=20+141.18$

$=161.18^0$ C

Similarly x= 1.5meter for 240/12

We substitute the values of x, T_{air}, T_{melt}, N_u, $k_{air,}$ Q and C_p in equation (X), and get, T_x (x=1.5 meter for 240/12 PET yarn) $=20^0$ C + $(285-20)^0$ C $x e^{-1.5/1.5765}$ temperature of quench air and melt temperature of polymer are taken in ^{0} C instead of in ^{0} kelvin

$=20+265x e^{-(1.5/1.5765)}$

$=20+265/2.7^{0.9515}$

$=20+265/2.5730$

$=20+102.99$

$=122.99^0$ C

Similarly x= 2meter for 240/12

We substitute the values of x, T_{air}, T_{melt}, N_u, $k_{air,}$ Q and C_p in equation (X), and get, T_x (x=2 meter for 240/12 PET yarn) $=20^0$ C + $(285-20)^0$ C $x e^{-2/1.5765}$ temperature of quench air and melt temperature of polymer are taken in ^{0} C instead of in ^{0} kelvin

$=20+265x e^{-(2/1.5765)}$

$=20+265/2.7^{1.2686}$

$=20+265/3.5255$

$=20+75.166$

$=95.166^0$ C

Similarly x= 2.5meter for 240/12

We substitute the values of x, T_{air}, T_{melt}, N_u, $k_{air,}$ Q and C_p in equation (X), and get, T_x (x=2.5 meter for 240/12 PET yarn) $=20^0$ C + $(285\text{-}20)^0$ C x$e^{-2.5/1.5765}$ temperature of quench air and melt temperature of polymer are taken in ^{0} C instead of in ^{0}kelvin

$=20+265xe^{-(2.5/1.5765)}$

$=20+265/2.7^{1.5858}$

$=20+265/4.8312$

$=20+54.85$

$=74.85^0$ C

4.2.2.6 Calculation of filament temperature at quenching air of 17^0C and quench air velocity 0.8 m/s

We know Nusselt number is a function of Reynolds's numbers and Prandt number

$N_u = f(R_e, P_r)$

R_e = D V/ν where, D is diameter, V = velocity of fluid and ν is kinematic viscosity of fluid

R_e of quench air 17^0C for 240/12 polyester yarn = D V/ν , (where, D (diameter of single filament of 20 denier) = 45.43 x10^{-6} meter, V(velocity of air) =0.8 m/s and ν = 14.84 x10^{-6} m^2/s)

= 45.43 x10^{-6}x 0.8/14.84 x10^{-6}

= 2.45

P_r= C_p μ/K where, C_p= specific heat of air in k joule/kg.^{0}C, μ = dynamic viscosity of air kg/m.s and K= Heat conductivity of air watt/meter.^{0}C

$P_r$number of air (at 17^0C) = C_p μ/K

=1006.0 x 1.8061 x10^{-5}/0.0253

= 0.71618

Now, for this range of Reynolds's numbers and Prandt number we can use the relation given by Hilpert

$N_u = h \times d/k = CRe^m P^{1/3}$

where , C= 0.99 and m=0.33 are constant of this equation for circular cylinder in cross flow

N_u (of quench air at 17^0C) = 0.99 x $2.45^{0.33}$x $0.71618^{0.33}$

=0.99 x 1.34 x 0.895

N_u (of quench air at 17^0C) = 1.188 of quench air for 240/12 (single filament denier is 20) PET yarn

As per equation X

$T_x = T_{air} + (T_m - T_{air})$ x e^(-x x $1/L_c$)

Where , L_c = Q x C_p/N_u x π x k_{air}

Now, calculating $L_c$forthesingle filament of 240/12 PET yarn

(denier of single filament is 20) Lc= Q x C_p/N_u x π x k_{air}

Here, Nusselt number for 240/12 denier = 1.188

L_c =0.129x10^{-3}x 1006.0 /3.14x 1.188 x0.026

= 1.34 meter

Now calculating the filament temperature at x = 1.5m.

$T_{x\ (1.5\ m)}$ = 17 + (285-17) x e^(-1.5/1.34)

= 17 + (268/e^1.12)

= 17 + (268/2.7^1.12)

= 17 + 268/3.04

= 17 + 88.15

= 105.15^{0}C

$T_{x\ (2.0\ m)}$ = 17 + (285-17) x e^(-2.0/1.34)

= 17 + (268/e^1.49)

= 17 + (268/2.7^1.49)

= 17 + 268/4.39

= 17 + 61.04

= 78.04^{0}C

$T_{x\ (2.5\ m)}$ = 17 + (285-17) x e^(-2.5/1.34)

= 17 + (268/e^1.86)

= 17 + (268/2.7^1.86)

= 17 + 268/6.38

= 17 + 42.01

= 59.01^{0}

4.2.3 Details of the modifications and optimization of quench system:

Major modification carried out are first increasing area of quench screen, optimization of quench air parameters, relocation of spin finish application system, changing mode of spin finish application from jet spray to kiss-roll application system, four ends winding with traverse cam system from eight ends bi-rotor winding system

4.2.3.1Modification of quench system

Following modifications are carried out in quenching system keeping in view 5-6 time heavy dpf yarn in case of 240/12 from existing 126/36 PET FDY yarn.

Quench screen length before modification

(Length = 120 cm)

(a)

Modified quench screen

(Length = 200 cm)

(b)

Fig.4.2: Quench screen length before and after modification

4.2.3.2 Increasing area of quench screens

To meet required quantity of air length and breadth of quench screens are increased. Length from 120 cm to 200 cm and width of the screen from 84cm to 89cm (by taking leverage of gap between two adjacent spinning positions) thus the increased area becomes 17800cm^2 from existing 10080 cm^2 (percentage increase in quench are 76.59%)

Quench screen before modification (Width = 84 cm)

(a)

Modified quench screen (Width = 89 cm)

(b)

Fig.4.3: Quench screen width before and after modification

Fig.4.4:

Quench chambers of two adjacent positions before increasing width of quench screen

Fig.4.5:

Quench chambers of two adjacent positions after increasing width of quench screen

Presently machine manufacturers are supplying new spinning lines for PET mother yarn which is further split into PET Mono-Filaments. The major modifications of these new spinning lines are mainly based on the fact that in the case of mother yarn denier per filament is about 5-6 times more as compared to normal 130/36 multifilament PET yarn. In the following figure screen size of new mother yarn line is of 2500 mm length and 1000 mm width supplied by TMT, JAPAN, and BARMAG, GERMANY.

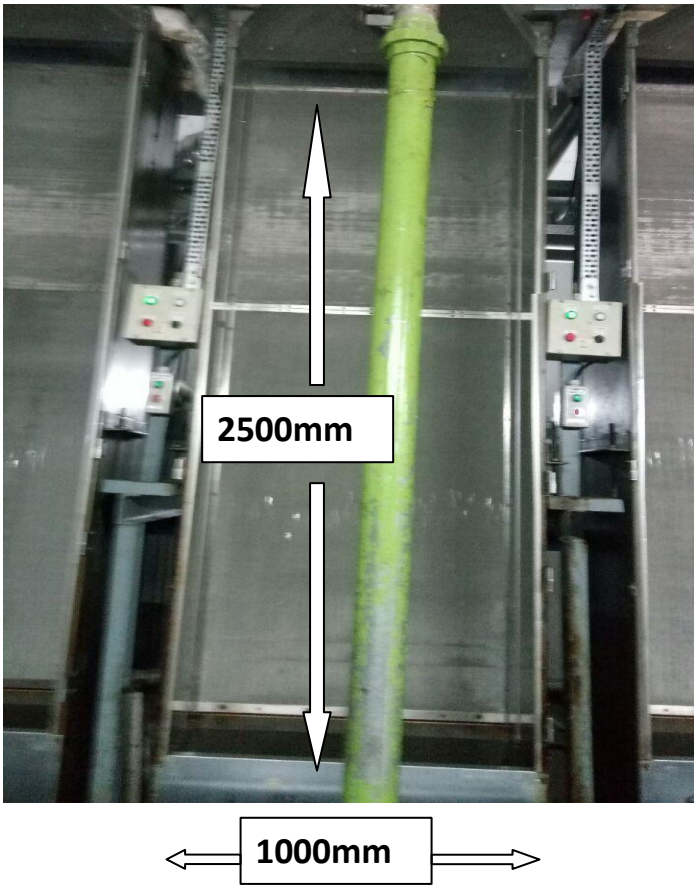

Fig.4.6

New screen size of 2500mm length and width1000mm supplied by TMT, Japan

4.2.3.3 Optimizing quench air parameters

Quench air temperature is reduced from existing 21^0C to 18^0C by putting one extra cooling coil in quench system and velocity of air is increased from 0.5 m/s to 0.8 m/s and humidity of quench air is increased from 75% to

80% on the basis of the back calculation of heat balance equation. All these quench air parameters are optimized to ensure even and timely quenching of the heavy dpf20/1 PET mono single filament.

4.2.4 Modification and Relocation of spin finish application system

In the case of normal running PET multi filaments like 126/36, 150/36, 50/48 etc. jet spray spin finish application system is placed about 100cms away from spinneret in the quench chamber as temperature of single filament in all these deniers cool down (solidify) in about 60cm distance from the surface of the spinneret, but in case of 240/12 PET mother yarn it requires about 200cm length to cool down temperature of single filament of 20 denier up to 70^0C.

Therefore finish application system has to bring down from quench chamber to take-up area before final winding of the yarn on bobbins. And also to apply even spin finish throughout

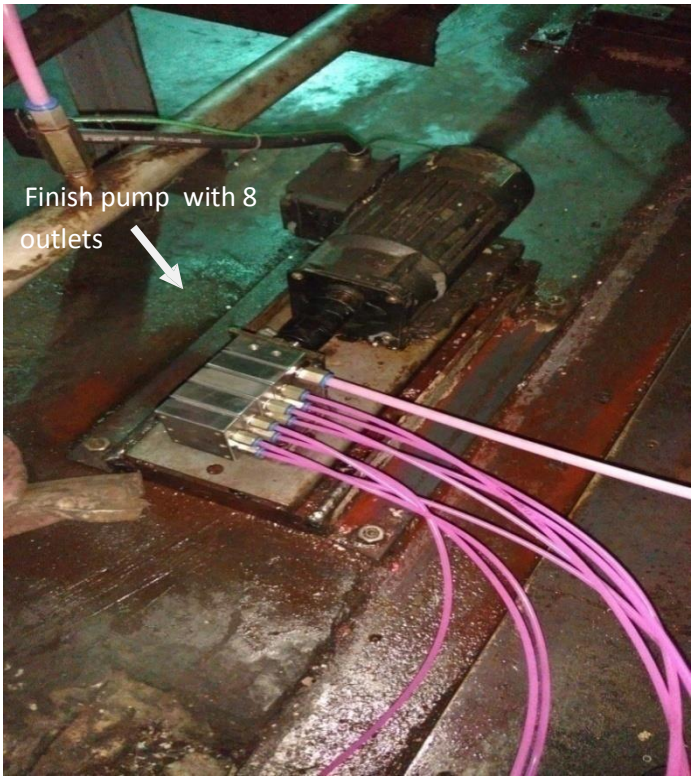

Fig.4.7: Jet spray finish application system

the surface of each single filament to ensure better performance at splitting stage, kiss- roll spin finish application system at take-up is installed at take-up above winding assembly. One can control percentage finish application at the surface of the filament by adjusting concentration of spin finish solution and adjusting the contact length of the filament at kiss roll. Estimation of percentage finish on the yarn surface is given in detail in Annexure 1.

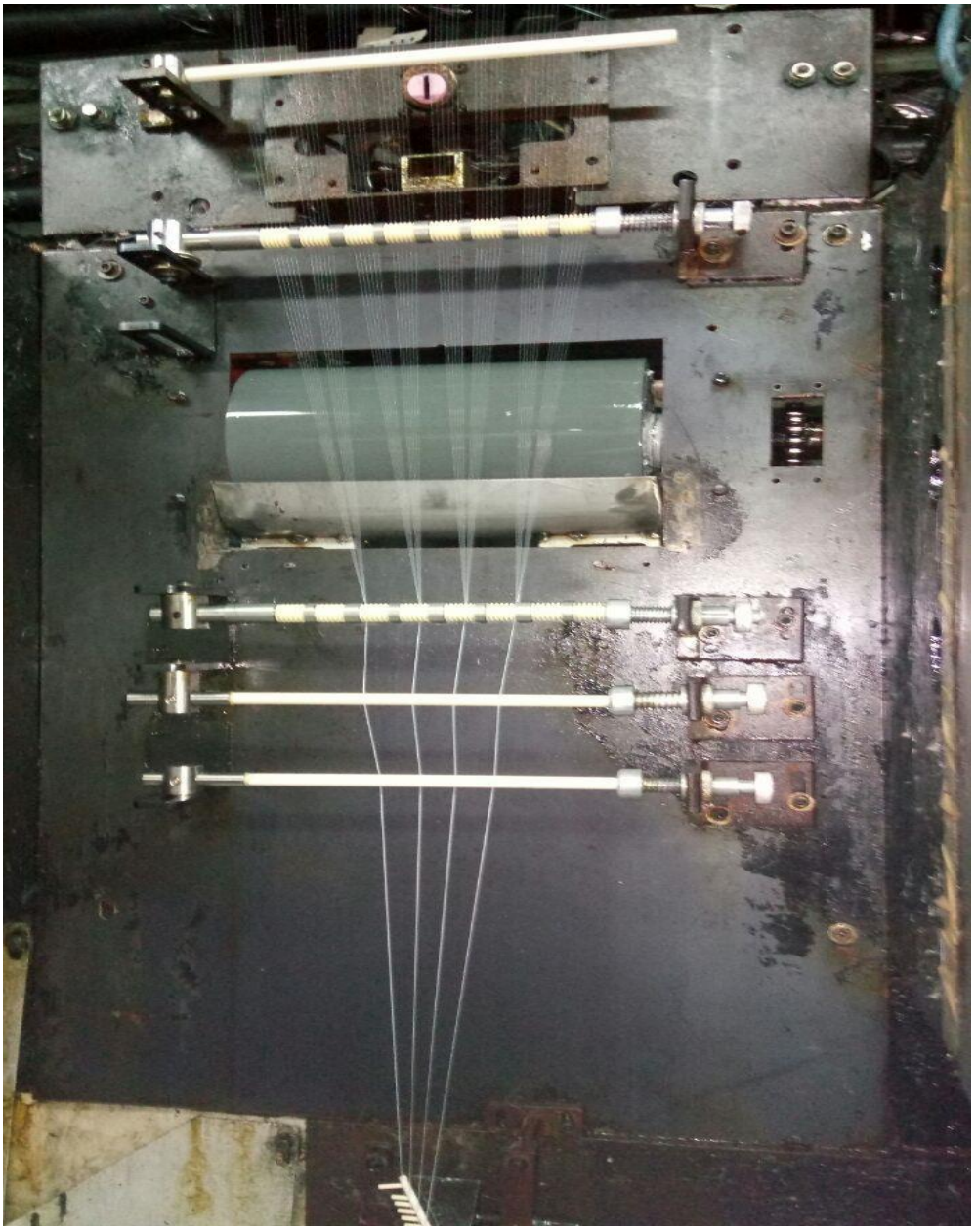

Fig.4.8: 240/12 Four end PET mother yarn with kiss roll finish application system

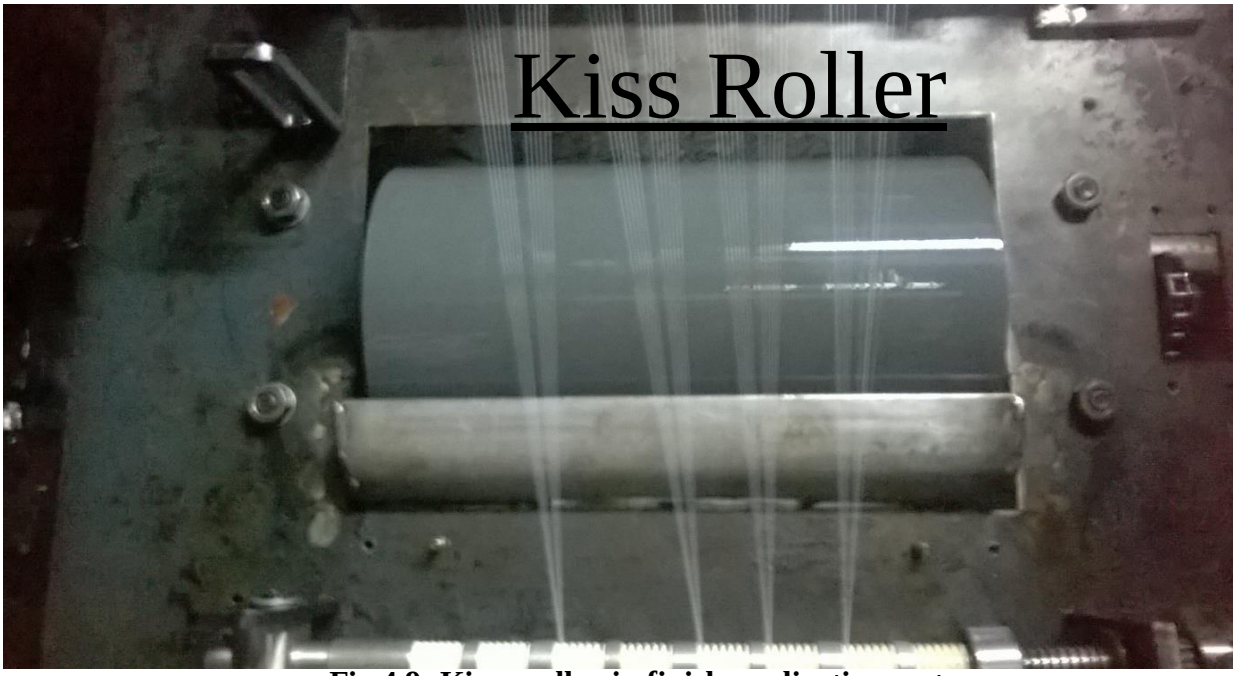

Fig.4.9: Kiss - roll spin finish application system

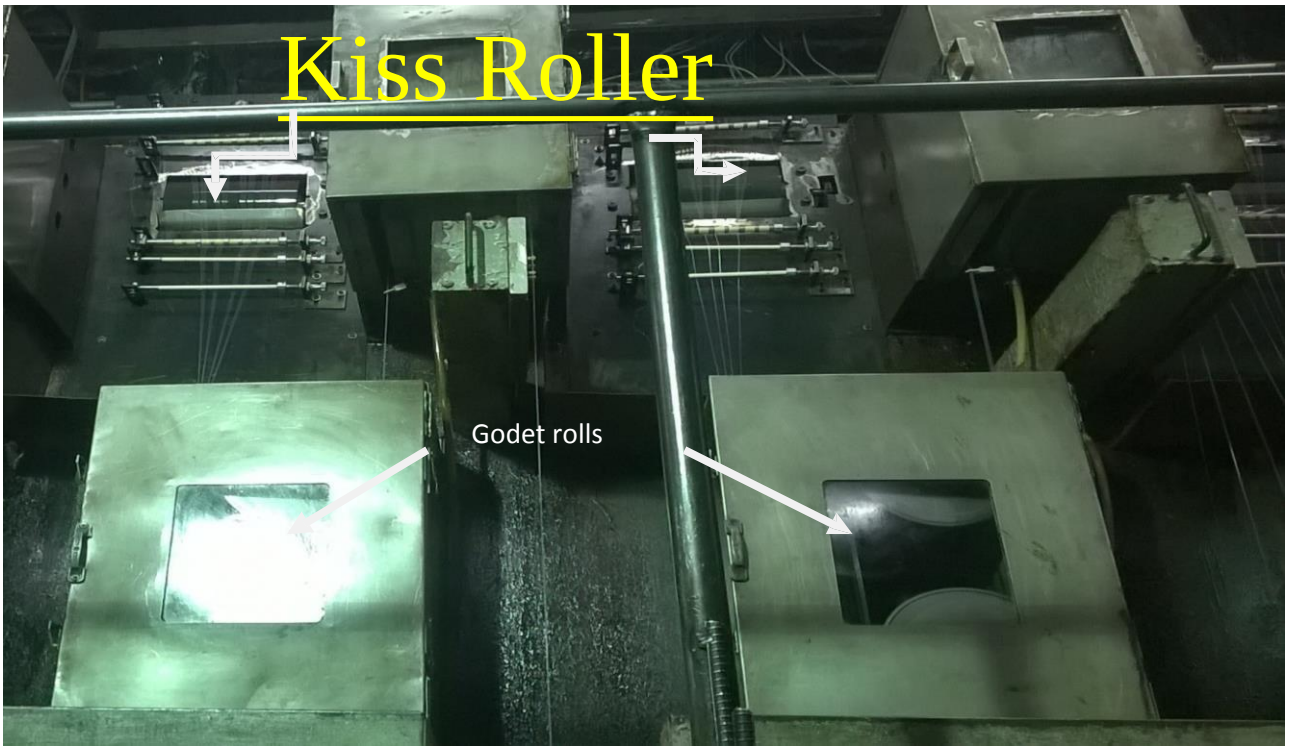

Fig.- 4.10 : Kiss-roll spin finish application system at two adjacent spinning positions

4.2.5 Modification of winders

To avoid deflection of filament before final winding 8 end winders are modified to 4 end winders and also to avoid twisting of yarn traverse cam system is put instead of existing bi-rotor system of winding

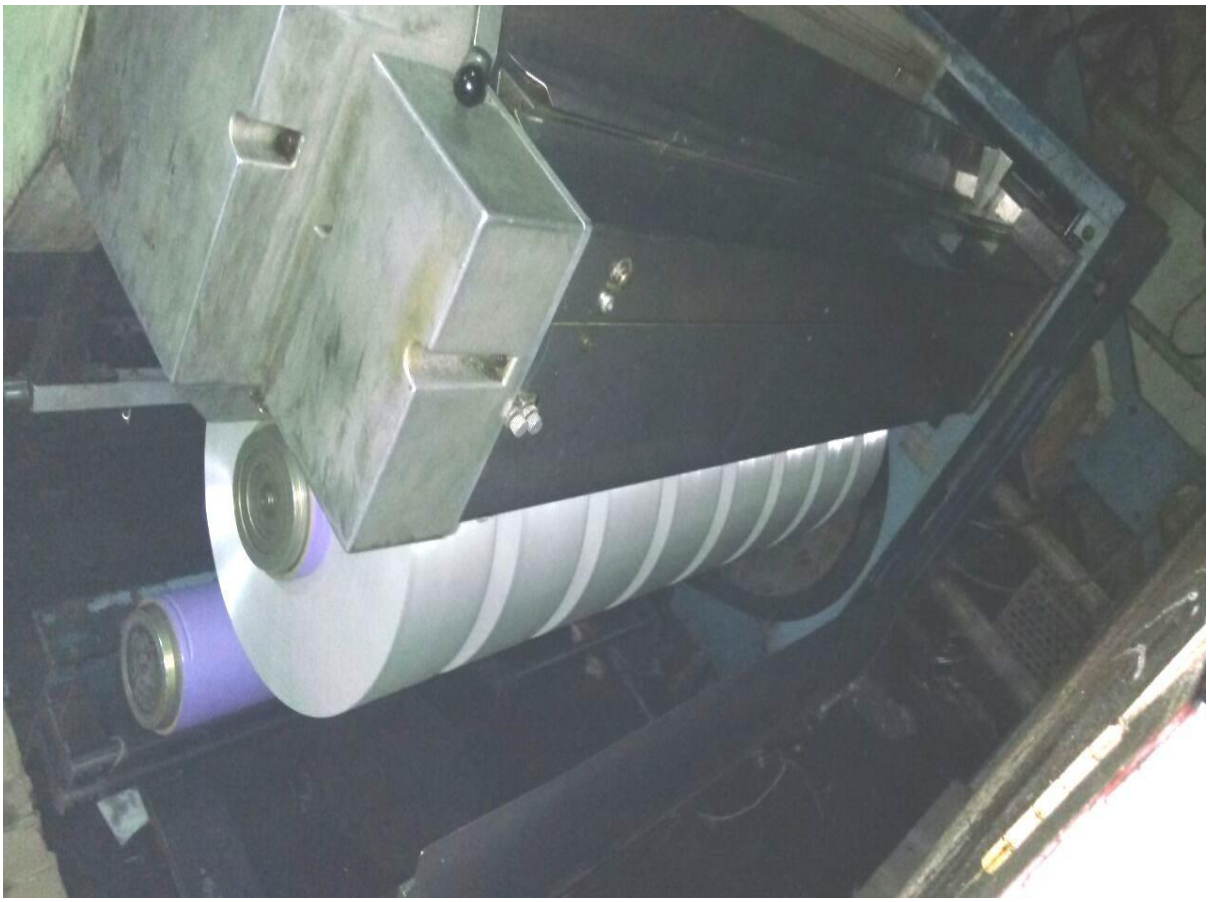

Fig.4.11: Take - up with 8 ends winder

Fig.4.12: Modified take-up with 4 ends winder

4.2.6 Process of splitting

It is the final step to produce the monofilament yarns from mother yarn. Earlier umbrella type splitters were in use and monofilament after splitting was wound on cops. Now a days warp splitters of high speed 600 to 800 mpm are already installed at Surat. In these machines directly warpers beams are prepared.These warper beams are directly loaded on warp knitting machines to produce knitted fabric of required width.

Fig 4.13 Umbrella type splitting machine top view

Fig 4.14 Umbrella type splitting machine full view

Fig 4.15: High-speed Warp splitting Machine, China made

Fig 4.16 Creel of warp splitting machine

Fig 4.17 Monofilament formation process at warp splitter

Fig 4.18 High-speed warp knitting machine

4.3 TESTINGS

4.3.1 Testing of PET mother yarn (240/12)

All required chemical and physical properties of yarn are checked at the facilities available in the labs of leading spinner at Kadodara ,Surat and same are compared with the industry standards.

4.3.1.1 Testing's of yarn at chemical laboratory:

I. Intrinsic viscosity of polymer chips,
II. End groups of polymer,
III. % Ash in the polymer chips,
IV. % Spin finish in mother yarn (240/12, 300/10) and respective PET Monofilaments 20/1and30/1

4.3.1.1.1 Testing of Intrinsic Viscosity (IV)

As per Annexure-1(testing of IV), polymer samples solution was prepared .Titration values are as under

Blank efflux time in sec—61.10 (Only solvent)

Solution efflux time in sec.—83 (solution)

RV= 83/61.1 =1.35888

$$\text{I.V.} = \frac{[\sqrt{\{(RV-1)X1.48+1\}}-1]}{0.37} \text{ dl/gram}$$

IV value calculated comes as 0.639 dl/gram

4.3.1.2 Polymer Ends Group Analysis

Molecular characterization of polymers, particularly linear polymers, by end group count assumes importance, particularly for Polyester/polyamide polymer, and the relevant analytical data may be used for the determination of polymer molecular weight, which would invariably be M_n.

Use of chemical methods, mostly titration, for selected, suitable linear polymer systems (e.g. polyesters or polyamides bearing – *COOH* and – *OH* or – *COOH* and – NH_2 end group respectively) requires that the polymer is free from traces of impurities and that the structure of the polymer based on prior considerations be such as to bear a known number of chemically determinable specified functional groups per molecule. For a precisely linear polymer, quantitative determination of all end groups present (each polymer molecule having two end groups, one at each end) would give a direct measure of the number of polymer molecules in a given mass of the polymer, and hence, a measure of the average molecular weight (M_n) then obviously follows. Chemical methods of end group determination are generally reliable for molecular weight $\leq$ 25,000, and they are therefore more suited to characterize thermoplastic condensation (step – growth) polymers, where M_n is seldom >25,000.

Selected/suitable chemical methods may be applicable for molecular characterization and end group estimation of vinyl polymers, if formed in the presence of a calculated dose of a strong chain transfer agent, such as a mercaptan , carbon tetrachloride or hydrogen sulfide, etc. If the polymer chain length is overwhelmingly determined by chain transfer, the number of polymer molecules may be related to the fragments of the chain transfer agent incorporated in the polymer chain end as determined, taking recourse to chemical analysis. Often, such incidence of a chain transfer reaction would create two chain ends (one consequent to the interception of the

propagation process by the chain transfer reaction and the other consequent to reinitiating that follow).

Alternatively, the molecular weight of a vinyl polymer may at times be calculated from a count of the initiator fragments occurring in the polymer, provided the initiation and termination mechanisms are known with a good degree of certainty and that chain transfer is unimportant.

Chemical methods as tools of molecular weight determination are only selectively applicable in systems where end groups are easily characterized by chemically, and they become insufficiently sensitive when the molecular weight is large. Spurious sources of end groups admitted into the system inadvertently and not taken into account in the assumed reaction mechanism become more and more consequential as the molecular weight increases; with increase in molecular weight the number of actual end groups ultimately comes down to a point where their quantitative determination turns very difficult if not impractical and uncertain.

Some worthy and relevant physical methods of end group detection and estimation are: tracer technique, infrared absorption spectroscopy, and ultraviolet absorption

Numbers of Carboxylic (COOH) groups show the length of polymer chains present in PET polymer. A number of end groups indicate that the polymer is inferior. For a standard PET polymer end, groups should be more than 32.

As per Annexure-1(testing of COOH group), polymer samples solution was prepared. Titration values are as under.

Polymer weight—1gram Normality- 0.025, V2-1.4, V1-0.2

CALCULATION:

-COOH GR. Milli. Eq./kg. = N x (V_2 - V_1) /W x 1000

Where, V2 = Volume of 0.05 N KOH required for the sample.

V1 = Volume of 0.05 N KOH required for blank.

N = Normality of KOH solution.

W = Sample wt. in gms.

Calculated value of COOH group comes as 30 meq. /kg

4.3.1.3 % Ash in the polymer chips

When we burn PET polymer, the main polymer got converted to CO_2. And only TiO_2 remains as ash in the crucible.

As per Annexure-1(testing of % ash), polymer samples solution was prepared .Titration values are as under.

W1- 41 gram ,W2-41.4 gram and W3 -41.00112

$$\%ASH = \frac{(W3-W1) \times 100}{(W2-W1)}$$

% ash comes as 0.28

4.3.1.4 % Spin finish

In a chemical lab, it is to find out the amount of spin finish present in the yarn by extracting the yarn in a solvent. And then by weighing solvent, we can find out % spin finish in the yarn. Nowadays for quick testing industries are using NMR method .The details of NMR testing are given below.

In the production of artificial fibers such as polyamide and polyester, the fibers are sprayed with an oil-based coating to reduce static electricity and friction as well as enhance other physical characteristics. This coating is known in different countries as spin finish, oil pick-up (OPU) and finish on yarn (FOY). Measurement of the applied spin finish by low-resolution Nuclear Magnetic Resonance (NMR) is fast, simple and solvent free and allows

tighter control of the manufacturing process. This translates, in real terms, to fewer out of specification products and lower production costs due to less finish material being used.

Method

The traditional method of testing is to dissolve the coating in an organic solvent and then determine the amount of dissolved oil in the solvent either gravimetrically (following distillation) or by use of infrared spectroscopy. All these methods are time-consuming, use hazardous solvents and require skilled operators. Some variations also require the use of mercury-containing catalysts. Low-resolution pulsed NMR provides an alternative method which is quick and easy to perform, simple to calibrate and is capable of determining finish levels below those accurately measurable by solvent extraction. For instance, the measurement of mineral oil on staple polyester is particularly difficult because of the low levels of finish and therefore is an ideal application for NMR.

Calibration and Results

After setting the relevant method parameters, a calibration must be generated before unknown samples can be measured. This is done by measuring a set of standards of known coating weight using the easy calibration software.

Samples are weighed and pushed into a sample tube, then inserted into the instrument. Measurement time is approximately one minute per sample. Weights can be entered manually or automatically from an electronic balance, into the application software.

It is recommended that at least six, preferably 12, calibration standards should be used, with coating weights evenly spread over the range of interest. When all the standards have been measured, the calibration can be edited on-screen using the RI Calibration software. Calibrations can be stored

on disk and recalled later for editing or to add extra measurement points. If reference values are not known at the time of measurement, they can be added later if the file has been saved to disk.

Fig 4.19: ALPHA MNR spin finish tester

4.3.1.5 Testing of physical properties of yarn (240/12):

I. Denier Testing,

II. Yarn strength g/d (in grams per denier) and % elongation,

III. % Uster value (a measure of unevenness).

Denier

Denier is a measure of linear density or finesse of the yarn. Basically, it is a measure of mass/unit length of the yarn. There are two systems to measure mass/unit length.

1 Direct System

In this system, length is fixed and we measure the weight of that fixed length i.e. weight in grams/unit length.

2 Indirect System

In this system, weight is fixed and no. of leas out of that fixed weight are counted .Denier is a measure of the fineness of the yarn by the direct system. The weight of the yarn in grams of 9000 meter of length is called Denier of that yarn, i.e. if the 9000-meter length of any continues filament weighs 20 grams then it means that Denier of that yarn is 20.

Lea of 90 meters was made on wrap reel and same was put on Metelar balance giving accuracy up to 3 decimal points in grams.

The resulting values of weights were multiplied with 100 for calculating the denier

Table 4.4 Denier of parent/mother yarn

SR NO.	Weight in grams of 90 meter of yarn	Denier
1	2.412	241.2
2	2.413	241.3
3	2.421	242.1
4	2.415	241.5
5	2.395	239.5
6	2.399	239.9
7	2.422	242.2
8	2.418	241.8

4.3.2 Yarn strength in grams per denier (g/d) and % elongation

The strength of the yarn is measured on Instron Machine in terms of grams/denier and corresponding % elongation is measured when the yarn breaks during testing.

Table.4.5 Elongation, shrinkage , tenacity and % OPU of Mother Yarn

S.N.	% Elongation	% Shrinkage	Tenacity(g/d)	% OPU	%Uster
Target	25	6.5	4.5	0.80	Less than 1.3
1	25.1	6.8	4.98	0.77	1.1
2	24.93	6.5	4.95	0.79	1.1
3	24.8	6.4	4.88	0.79	0.95
4	24.9	6.9	5.01	0.81	0.99
5	25.2	6.5	4.92	0.82	0.99
6	24.85	6.5	4.95	079	0.95
7	25.3	6.4	4.99	0.79	0.97
8	24.98	6.4	4.92	0.80	1.0

4.3.3 % Uster value (measure of unevenness)

Uster value is a measure of unevenness of mass along the length of the filament,more % Uster value means yarn is more uneven along the length.