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Air Conditioning for Synthetic Fibre Plants

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For most of history, the textiles people used, depended on the raw materials available locally, such as flax in Egypt, cotton in India and silk in China. Throughout the 20th century, the trend in textiles has been towards lighter weight materials. Synthetic materials produced from chemical compounds rather than plant fibres or animal hair have proved less-expensive substitutes for natural fabrics. Synthetic materials can also be superior to natural fibres in strength and durability.

Rayon was an early synthetic substitute for silk. Nylon, a synthetic fabric introduced in the 1930s was another early substitute for silk and quickly became the fibre of choice for women's stockings. Polyester, a form of plastic, was introduced in clothing in the early 1950s. Blended with rayon or cotton, polyester found its first use in so-called wash-andwear fabrics that needed little or no ironing.

Synthetic fibres such as Spandex have revolutionised clothing by making possible the production of extremely flexible, form-fitting garments. Other synthetic fibres created for special purposes, range from lightweight but extremely warm or water-resistant fabrics such as polypropylene and bullet-proof fabrics such as Kevlar that serve as a body armour.

Manufacturing Process

Manufacturing of synthetic fibres such as nylon or polyester filament requires 'controlled atmosphere' for the process. This article provides a brief overall design requirement and air-conditioning process to achieve the same. The late 60s and early 70s saw substantial investment in the man-made fibre sector in India. Many projects started coming up all over India for manufacturing nylon, polyester stable fibre (PSF) and partially oriented yarn (POY). The manufacturing process for nylon and polyester filament yarn is quite similar; but the raw material is different. Nylon uses caprolactam while polyester filament uses dimethyl- terephthaic acid (DMT) or pure terephthalic acid (PTA) as raw material.

The manufacturing process has three distinct sections :

- Polymerisation
- Spinning
- Stretching and heat set

Polymerisation

The polymerisation section needs no air conditioning. In polymerisation, the raw material in paste form is mixed with monoethylene glycol (MEG) in a reactor with additives and heated upto 260/270°C through high temperature heating medium for esterification and then polymerized through heating, agitating at high vacuum conditions (1.5 millibar). After polymerization, the product is injected through strands guide at 6 kg/cm^2 nitrogen pressure. The high temperature strands are cooled through demineralized (DM) water and cut into granules or chips by a cutter. These granules or chips form the raw material for further processing.

Spinning

The granules or chips manufactured from polymerization are the raw materials for spinning. The chips are dried through hot air circulation; the dried chips in predetermined quantities go through an extruder where they get heated up to 260/270°C and become a molten material. The molten material passes through a continuous polymer filter before it enters the metering pumps. The metering pump is fitted with a VFD drive and the rate of polymer flow is determined by the drive speed. The polymer then flows through the spin pack, where the molten high pressure polymer passes through a spin pack, fine filament gets formed and which comes down to quench boxes. The hot molten polymer drawn as fine yarn, gets quenched in the quench boxes by cold air and gets solidified as fine filament.

The polymer filament yarn which comes out of the quench box then goes down to the 'take-up' area. In the take-up machine, filament passes through a roller with finish application and is wound in bobbins. In case of PSF, multi position yarn is drawn from quench and collected at one point as a “tow, which is then fed to a tow collector, and collected in big tow cans. This tow is further processed in draw lines to stretch and heat set before it is cut and baled.

The general manufacturing arrangement of a spin section in a synthetic fibre plant, indicating the location of various machines is shown in **Figure 1.**

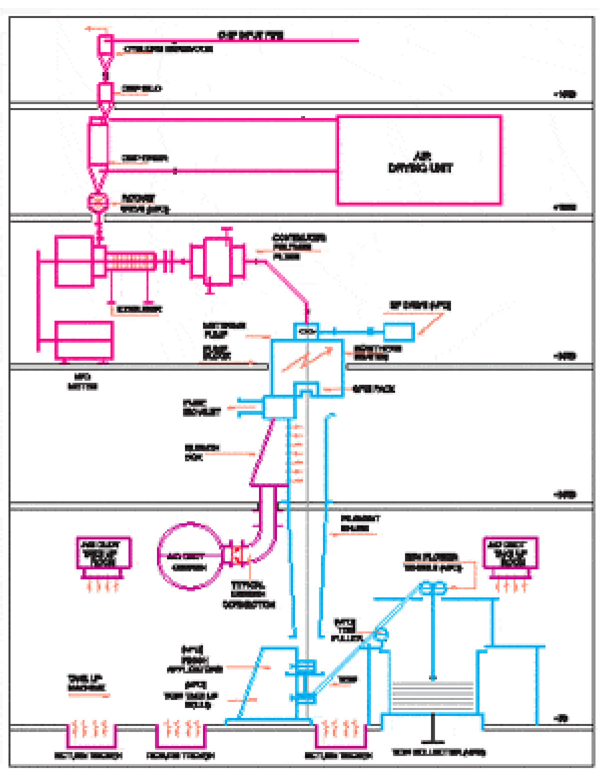

Figure 1 : General processing machinery arrangement in synthetic fibre plants.

In case of a nylon plant, the fine nylon filament is heat set, elongated and twisted and woven into bobbins. This process is called "draw twist". Separate machinery is employed for this process. In modern plants, to shorten the process, the draw twist process also gets combined in the take-up machinery called spin draw.

The draw twisted yarn gets further processed through ply twister, cable twister and sent as a finished product. In certain cases, draw twisted yarn after twisting to ply and cable is woven and the woven material is marketed as a finished product. This final finishing process is normally called a "textile process" and different machines are used for various applications.

The manufacturing process from "spinning to weaving" requires air conditioning with close tolerance, temperature and humidity. Manufacturing can be divided into various sections :

- Quench box
- Take-up area
- Draw twisting area
- Textile area

In addition to the above manufacturing areas, the other rooms requiring air conditioning are:

- Invertor Room
- Textile Lab
- Instrumentation Lab

We shall discuss air conditioning of each area separately.

Quench Box

The most critical air conditioning requirement in the manufacturing process of man-made fibre is the quench box. Molten polymer gets quenched and solidified as a fine filament yarn in the quench box. Hence the quality of air-cleanliness, quantity, velocity across the quench screens, temperature, humidity and static pressure inside the quench box are all critical for good quality of the finished product and productivity.

Normally each extruder line has four quench stations. Each quench station requires 650 to 1000 cmh (400 – 600 cfm) in case of polyester and 900 to 1400 cmh (600 – 850 cfm) in case of nylon, to maintain an air velocity of 0.4 to 0.6 m/sec. and 0.6 to 1.0 m/sec across the quench screen respectively. The air quantity and velocity are indicative numbers and vary according to the process design and contour of the quench screens.

Maintenance of constant pressure in the quench box for uniform velocity across the quench screen is very critical. Based on the manufacturer's design and pressure drop across the quench screen, each manufacturer specifies a static pressure requirement in the quench box, which varies from 8" to 24" water gauge (2000 – 6000 Pascals). Higher static pressure is required for high-speed machines. The temperature of quench air varies from 16 to 21°C and RH 65% +/ – 5%.

The quench air directly impinges on the hot molten polymer and hence should be absolutely clean for production of high quality yarn; hence pre-filters, fine filters and hepa filters are used in the supply air stream before the air enters the quench box.

A common quench air system is provided for 5 to 6 extruder lines totaling 20 to 24 quench stations, requiring total quench air of 20,000 to 25,000 cmh (12,000 to 15,000 cfm). Normally 100% fresh air is used in a quench air system. Recirculation in certain applications is considered if the ambient air temperature is high and no contamination of air is observed. A typical quench air system is shown in **Figure 2**. Outside air is first passed through a coarse filter and then through a normal-water air washer. Air surrounding the factory is expected to have high levels of "monomer" hence an air washer cleaning system is provided before conditioning the air as monomer gets dissolved in water. The air washer also helps to increase the humidity level particularly during the winter season. Air is then allowed to pass through a set of cooling coils, hot water coils and a humidifier section. In a quench system, the fan is kept before the cooling coil section, heating coil section etc. and the system is a blow-through design against the normal draw-through design used in standard air conditioning. The fan power requirement for quench air is quite high compared to a normal air conditioning system due to the high static pressure requirement; it is therefore advisable to have the fan motor heat picked up by the air stream before entering the cooling coil. The filtration arrangement comprising microvee (fine) EU-9 and hepa (superfine) EU-11/EU-12 filters is provided after the air conditioning sections.

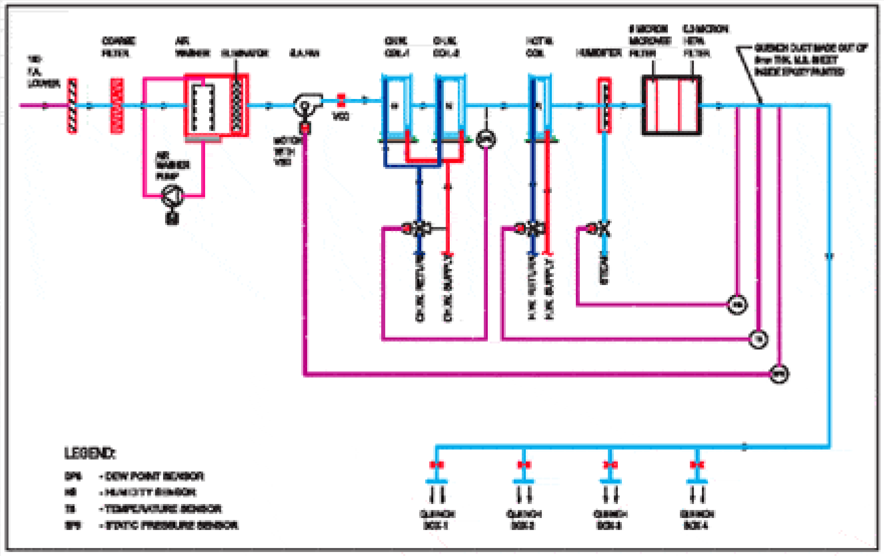

Figure 2 : Quench air equipment system.

The air is then taken through a special duct manufactured out of 6mm MS sheet of welded construction so as to withstand high pressure. To maintain high cleanliness level of the supply air, the MS duct is sand blasted inside and painted with epoxy paint before installation. The MS duct is insulated outside with 75 mm thick expanded polystyrene or equivalent material. The main quench supply air duct runs alongside the series of quench stations, normally below the quench boxes. Each quench box station is connected through a feeder duct with a damper for flow control. Typical quench air ducting with outlets is shown in **Figure 1**. The quench supply air fan motor is provided with a variable frequency drive (VFD). With varying fan speed, a quench system is maintained at constant pressure in the quench box irrespective of pressure losses across the filters or due to closing down of any particular quench station. During the 1970s when VFDs were expensive, static pressure control was effected through a variable inlet guide vane controlled by pneumatic actuators. These actuators were used to adjust the blower inlet guide vane based on the signal received from the static pressure sensor located in the common supply air duct. The instrumentation scheme for an air washer is shown in **Figure 2**. Even though many control methods are followed, the most common one is :

- chilled–water–coil leaving dewpoint temperature controlling chilled water flow, with a 3-way mixing valve
- supply air temperature controlling hot water flow with a 3-way valve
- supply air relative humidity controlling steam humidifier valve
- static pressure sensor located at the end of quench duct controlling VFD of supply air blower motor.

The high-pressure quench air system needs a service corridor around the air washer for pressure equalization to open the AHU doors for maintenance of the air handling system. See **Figure 3**.

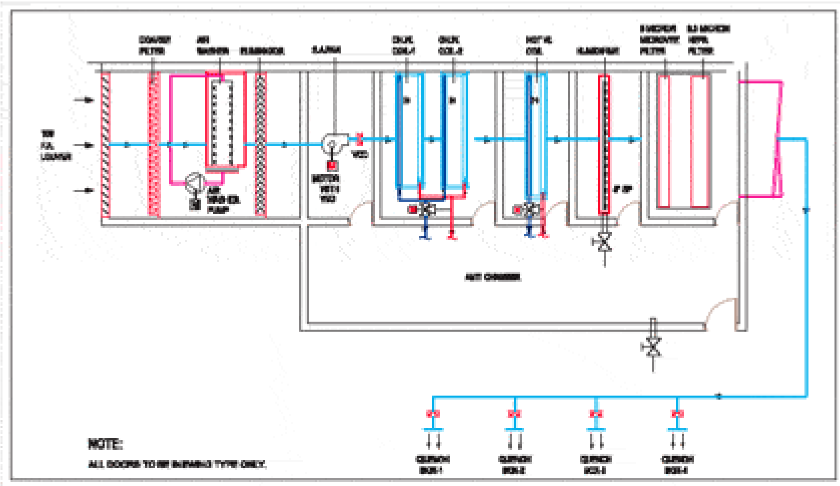

Figure 3 : Quench air system with auxillary corridor for high air pressure above 2000 Pa (8" WG).

Take-up Area

A take-up room comes below the quench room floor. Take-up room air conditioning is a re-circulated air conditioning system. Temperature and humidity in a take-up area is also quite critical. The table below shows various conditions for Polyester and Nylon 6.

	Polyester	**Nylon 6**
Temperature	21 - 23°C	18 - 21°C
Relative Humidity	55 - 65%	45 - 55%
Room Pressure	Positive	Positive
Cleanliness of air	Down to 5	Down to 5
	microns	microns
Fresh air	Normal	Normal

The take-up air distribution system is effected through special perforated registers at the ceiling level. Return air is collected at floor level through masonry floor trenches. These floor trenches are insulated from inside and treated outside by water proofing. The provision of special grilles for supply at the ceiling and floor return grilles enables close to unidirectional flow from top to bottom along the direction of filament movement. This is basically done to maintain the temperature and humidity conditions of air at the take-up point.

Aspirating type supply air diffusers are not used in the take-up area. Special heavy duty floor grilles are used for return air to take care of machinery movement over grilles. Masonry return air ducts are terminated in a corner of the takeup room from where sheet metal ducts are used to connect the return air back to the air handling system. Details of a typical air handling system are shown in **Figure 4**.

The pressure differential between a quench air system and take-up room is maintained in such a way that quench air is at a marginally higher pressure compared to take-up so that air flow from quench air to take-up along the flow direction of filament is maintained. A take-up air conditioning system is a recirculated system.

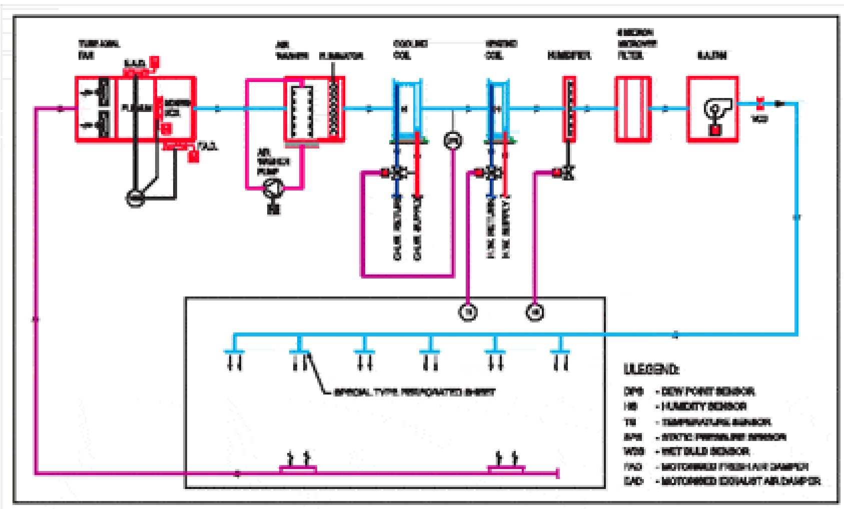

Figure 4 : Take-up air equipment system.

Return air gets sucked through an axial flow return air fan and pumped to a return air plenum which has provision for 100% exhaust of return air or recirculation, based on ambient air conditions. Return air goes through an air washer, cooling coil, heating coil and humidifier before the supply air fan discharges it into a supply air plenum for filtration. Clean conditioned supply air is then allowed through GSS air ducting for distribution to the take-up room. The operating pressure of a take-up fan will be around 50 mm. A detailed control scheme for take-up is shown in **Figure 4**.

The most common control scheme followed is :

- chilled–water–coil leaving dewpoint temperature controlling chilled water flow with a 3-way mixing valve
- room air temperature controlling hot water flow with a 3-way valve
- room relative humidity controlling steam humidifier valve

- ambient air wet-bulb controlling energy enthalpy scheme, closing / opening of exhaust dampers and fresh air dampers.

The control element mentioned under 'd' is for an energy enthalpy cycle. Whenever ambient air total enthalpy is lower than return air enthalpy, 100% outside air is used for air conditioning in order to save energy. For this purpose, ambient wet-bulb temperature is measured and whenever the ambient wet-bulb falls below the desired setting, an electric actuator opens the exhaust damper and allows all the return air to exhaust out. Simultaneously, the fresh air damper gets opened, and the damper connecting the return air to the mixing chamber is closed thereby allowing 100% outside air circulation.

Draw Twist Area

Draw twist air conditioning load is quite high due to the heaters fitted in the machine. Draw twist air conditioning does not fall under the critical category. A simple air conditioning system without any sophisticated controls is normally provided. Here also the energysaving enthalpy scheme taking 100% fresh air is used whenever ambient conditions are favourable. In draw twist, the yarn is heat set, elongated and twisted to give further strength to the yarn. The conditions required for draw twisting are 25 to 27°C and RH upto 65% with cleanliness down to 5 microns.

Textile Area

The textile area is where the yarn gets twisted through a ply twister, cable twister and sent as a finished product to tyre cord industries. Sometimes, weaving also takes place through textile machinery. Air conditioning is not very critical for the textile area machinery or process. A few major manufacturers initially installed an evaporative cooling air washer for the textile area but subsequently converted this to air conditioning, basically to enhance human comfort. The sensible load in the textile area is quite high due to high equipment load. Manufacturers who converted to an air conditioning system from an air washer ventilation system observed substantial quality improvement in the final product and also good productivity improvement after air conditioning. The floor area for textile machinery is quite large and with very high equipment load, the air conditioning load is also quite high, which made these manufacturers to go in for ventilation in the initial start up stages.

The temperature requirement for textile area ranges from 22 to 25°C and RH of 55% to 70%. Air distribution is effected from the ceiling and return air gets collected through masonry floor ducts and floor grilles.

Other Areas

Invertor Room Air Conditioning

A large number of process machines in the man-made fibre industry require variable speed drive and a large number of invertor drives are used for motors driving rotary valves, extruder metering pumps, quench fans, finish applicators and tow collectors. These invertors are generally located in a common panel at two to three locations. Invertors dissipate a lot of heat during operation and need good ventilation or air conditioning for very reliable performance. Hence invertor rooms are normally air conditioned, maintaining a temperature of around 23 to 25°C and RH not exceeding 60%. A standard air conditioning system with air handling unit fitted with chilled water coil is used for invertor room air conditioning. Being a high sensible-load application, the system requires a higher dehumidified cfm compared to normal applications. No sophisticated controls are required for the invertor room air conditioning system.

Textile & Instrumentation Labs

Textile and instrumentation lab temperature requirement is 22 to 25°C and RH of around 55%. While the temperature and humidity tolerance bandwidth is large for the instrumentation lab, the textile lab tolerance is very minimal. Even though both air conditioning systems use standard air handling units, the control scheme for a textile lab is quite elaborate with a 3-way mixing valve for chilled water coil, 2-way valve for hot water coil, dehumidifier etc. An instrumentation lab normally has a cooling coil controlled by a 3-way mixing valve. Both the systems are re-circulated type and the AHUs are located in a separate AHU room adjacent to the lab area.

Refrigeration Plant

We have so far discussed about the individual air conditioning requirements for various manufacturing processes. However the refrigeration requirement for all these processes are combined and a "centralized refrigeration plant" is installed to take care of all the individual requirements. Normally a separate utility building adjacent to the manufacturing area houses the refrigeration plant along with other utilities like air compressors, boilers, generators, UPS etc.

The refrigeration requirement for a Nylon plant is comparatively high compared to a PSY plant. The approximate indicative figures are:

- 125 to 170 refrigeration ton / metric ton per day of PSF
- 600 to 650 refrigeration ton / metric ton per day of Nylon.

The above refrigeration load estimates will vary depending on :

- location of the plant (city weather conditions)
- design of quench chamber
- 100% fresh air or recirculated air for quench or other areas
- take-up room size machinery and volume
- whether textile facility is included in the overall facility or not.

During the early 70s when centrifugal chillers were not manufactured in India, a battery of water-cooled recips used to serve the refrigeration requirement. Since the process and inside room temperature requirement between quench, takeup and other areas are different, refrigeration plants are grouped to operate at two levels of chilled water leaving condition viz., 5°C and 7.5°C to make the system energy efficient.

During the 80s when Indian manufacturers came up with centrifugal chillers, old recip chillers were replaced with centrifugals. When high energy-efficient centrifugals came into the market during the late 80s and early 90s, gradually most of the plants replaced both reciprocating and low energy centrifugal chillers with energyefficient centrifugals of 0.65 kW/TR. The scene changed from a battery of recip chillers of 100/120 TR capacity, to a few energy efficient centrifugal chillers of 600/800 TR. This change gave a substantial energy benefit to the man-made fibre industry. During the same period, a few organizations went in for captive power plants with diesel generating sets or a gas turbine. These organizations installed absorption chillers and produced refrigeration through the cogeneration route.

The chilled water produced in the refrigeration plant is pumped to various air conditioning systems through constant speed centrifugal pumps. Since the plant room is located away from the manufacturing area, where air washers are located, extensive chilled water piping is common for this industry. All utility piping used to get clubbed and laid on pipe racks from the utility area to the manufacturing area.

The air conditioning scheme described in the earlier pages is a system with a normal-water air washer and a closed circuit chilled water coil. In the initial period of evolution of this industry, a chilledwater air washer was extensively used, for cooling and dehumidifying instead of a chilled water coil plus air washer to save cost. The piping system used to be slightly different for chilled water air washer application. Chilled water pumps located in the plant room would supply chilled water to the make-up of the air washer through a 2-way control valve. The amount of chilled water allowed into the air washer is based on the process load requirement of the specific air washer. The overflow water from the air washer would then be collected into a common piping header by a gravity flow arrangement upto the plant room. The return piping from the air washer being gravity return, proper care (over-sizing) had to be done. The chilled water being exposed to the air stream normally picks up impurities like dust particles, monomers etc. and these used to settle down in the chiller. For better maintenance, chillers for such applications usually had a drain provision between baffle plates.

The open gravity return system had a lot of operating problems such as overflow of hot well during shutdown, collection of impurities in the circulation water, clogging of piping etc. Hence, new plants which came up during the late 70s avoided chilled-water air washers and had a closed-circuit cooling coil with a separate normal-water air washer.

Conclusions

Synthetic fibre plants have not seen large expansions in the last decade due to a glut in the market. Recently, business is looking up in this industry. The new plants will see some advancement in the design of the air conditioning system. Prefabricated panel type air washers will replace masonry air washer systems. High efficiency axial flow fans will replace centrifugal blowers for all areas except for quench. Much more sophisticated building management systems will replace conventional, electrical and pneumatic instruments used in earlier plants.