HVAC for the Man-made Fibre Industry

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Fabrics have been traditionally manufactured using fibres obtained from natural sources such as cotton, jute, linen, silk, wool, etc. The first man-made fibre was developed only in the late nineteenth century. It was made from cellulose which was a product of a chemical reaction on the inner fibrous bark of the mulberry tree. These fibres were called "artificial silk" or rayon and the first commercial scale plant was put up by a Frenchman, Count Chardonnet in 1891. In the USA large scale production was started by Samuel Courtaulds in 1910.

Rayon and viscose were man-made fibres, but they were not truly synthetic, since the raw material was a natural source like wood. Attempts were being made to make completely synthetic fibre, and finally in 1931 Wallace Carothers, a chemist in the DuPont company reported the invention of "giant" molecules called polymers. The fibre made out of this amide polymer was called Nylon-66. In 1938, Paul Schlack of I.G. Farben Co. in Germany polymerized caprolactam, which was called Nylon-6. It was also a polyamide like Nylon-66. The advent of nylon created a revolution in the fibre industry. Here was a fibre which was stronger but weighed less than any other commonly used fibre at that time. Its many useful properties found immediate applications during the Second World War. Immediately after the war a new synthetic fibre called "acrylic", which has wool-like properties, was introduced.

In 1941 Dickson and Whinfield of Great Britain produced a "polyester" fibre by condensation polymerization of ethylene glycol with terephthalic acid. Both the raw materials were known chemicals. The process was further modified to get better product quality using Pure Terephthalic Acid (PTA). DuPont obtained a license for this process for USA while ICI obtained the license for the rest of the world, and thus commercial production of polyester was started around 1953. Many other producers also joined in with some variants in the process, particularly using DMT (di methyl terephthalate) instead of PTA, to make polyster fibre. A recent innovation is microfibre which is a variety of polyester that has extremely thin filaments. It is found to be most suit-

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able when used in combination with nylon.

In India, the first polyester manufacturing plant was put up by CAFI (later called TFIL), an ICI subsidiary, around 1966. Later on manufacturing units were started by various business houses, but most were single units of small capacity. However, Reliance Industries was the first to realize the enormous growth potential in this industry, and put up a series of manufacturing units first at Patalganga in Maharashtra and later on at Hazira in Gujarat, in the late eighties and early nineties. In the recent past it has taken over other smaller units to emerge as the single largest producer of polyester fibre in the world. Indo Rama Synthetics is the other major manufacture of polyester in India.

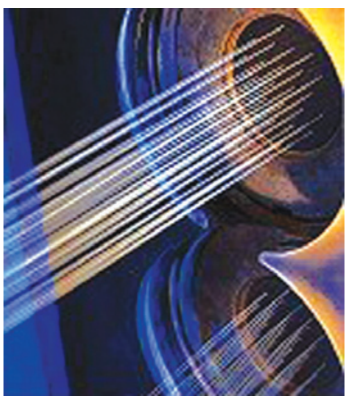
Types of Man-made Fibre

All synthetic fibres are formed by spinning the fibre filaments from the polymer which is in molten condition. There are three types of spinning processes; viz. melt-spinning, dry-spinning and wet-spinning. Melt-spun fibres are solidified by cooling the molten polymer; dry-spun fibres by evaporating a solvent, leaving behind the polymer in fibre form; and wet-spun fibres by hardening the extruded filaments in a liquid bath. Generally, nylons, polyesters, and glass fibres are melt-spun; acetates dry-spun; rayons and aramids wet-spun; and acrylics dry- or wet-spun. HVAC plays an important role in the manufacture of fibres which are melt-spun.

The Manufacturing Process

Melt-spun synthetic fibres are extruded from metallic spinnerets and solidified by a blast of cold air (appropriately called "quench air") to get continuous parallel filaments. This process is called "continuous spinning" and it differs from mechanical spinning of fibres (or tow) into yarn as in the case of cotton, which is generally referred to as "spinning". For melt-spun fibres, the filaments of each spinneret are drawn through a long vertical tube called a "quench chimney" within which the molten polymer is solidified by the quench air.

The fibres are extruded in the form of light or heavy denier filaments for processing as continuous fibre or yarn. A synthetic oil, called spin finish oil, is applied to lubricate, give anti-static properties, and control fibre cohesion. The extruded filaments are usually drawn (stretched) both to align the molecules along the axis of fibre as well as to improve the crystalline structure of the molecules. This process of drawing increases the fibre's strength and resistance to stretching. If the drawing is accompanied by twist, it is called "draw-twist"; otherwise it is called "draw-wind". In modern plants high speed winders having speeds of the order of 3200 m/min or higher are used. When winding is associated with minimum of drawing, the yarn is called POY (partially oriented yarn). When the yarn undergoes heating while being drawn it is called FDY (fully drawn yarn). The area where the POY or FDY winders are installed is called the "take-up area". Thus the yarn is wound on bobbins in the "take-up" machines. In modern plants, the rate of production is so high that completely automated systems are used to carry out various functions such as loading empty bobbins, removing filled bobbins, handling filled bobbins to temporary storage and then to packing, etc.



For the manufacture of staple fibres the large number of filaments leaving the quench chimney are brought together to form what is called a "tow" which is drawn by a "draw-off " machine before collecting it in large cans. The cans are taken to a can creel area. Tow from different cans is taken together to form a big tow which undergoes a series of operations of heating and stretching in the "draw-line" area to improve its mechanical properties. The tow is then cut into short lengths called "staples" or somewhat longer lengths for tow-to-top conversion. When the tow is cut to make staples, the short fibres are allowed to assume random orientation. The polyester staple, alone or in a blend with other staples of cotton or wool, is then processed in a way similar to cotton yarn.

HVAC System Design Considerations

1. Close control of temperature (DBT), humidity (RH), flow (CMH), static pressure (Pa) and dust particulates is required for "quench air". These requirements dictate the selection of HVAC equipment and controls and are based on the Technology Licensor's recommendation. They may vary depending on the technology used.

2. Close control of DBT and RH is required for take-up (or draw-off) area also, although it is somewhat less critical than quench air.

3. The quench air (QA) duct should be sized and routed such that air turbulence is minimized. Air velocity in main duct is kept low, preferably below 5.0 mps. The main QA supply duct, often referred as QA plenum, is tapped to supply QA to the quench chimney of each spinning position. Flow measuring device and a modulating damper is provided in each branch to

continued on page 54

continued from page 52

monitor QA flow to each spinning position. Steady supply for QA at desired pressure and flow/velocity is important to obtain steady product (filament yarn) output. Blow velocity from quench chimney is of the order of 0.4 to 0.75 mps depending on product denier and is decided by the Process Licensor.

4. For the spinning area the main criterion is to remove the radiant heat from the hot surface of spinning equipment so as provide reasonable working conditions for the plant operators.

5. Exhaust of monomer vapours from the spinning area and spin finish oil mist from take-up area is required to avoid health hazard and choking of HVAC equipment. In case of PSF, the quench air AHU often operates on 100% fresh air. So, after the quench supply air has cooled the filaments in the quench chimney, the resultant warm air is then exhausted out after it is passed through a spray type wet scrubber.

6. A slight positive pressure is usually maintained in the spinning area with reference to draw-off area. This is important where fine denier filaments are used as in the case of polyester staple fibre (PSF). In case of polyester filament yarn (PFY) it is desirable but not essential.

7. The HVAC plant should be designed for continuous, non-stop operation for months together (24 hours a day, 7 days a week). So the equipment has to be heavy duty and reliable with provision of stand-by capacity wherever required. Depending on the production schedule, HVAC plants have to be operated at part load. So the equipment and controls should be selected to achieve part load operation for long durations.

8. For polyester or polyamide (nylon) plants the cooling loads for quench air, take-up, etc. are very high. So use of enthalpy-control system allowing optimum use of outdoor (fresh) air during temperate climate is common. Depending on outdoor air conditions the refrigeration load and correspondingly chiller and CHW pump power consumption can be significantly reduced.

9. Lately there is a trend for large capacity plants of PFY and PSF. The HVAC equipment sizes have also increased correspondingly. In spite of using compact sheet metal units the AHU sizes are quite large. Similarly sizes of supply air and return (or exhaust) air ducts and supply and return CHW piping are large. Large equipment requires large access and maintenance space. Considerable planning is therefore required while allotting space for HVAC equipment, ducting and piping.

10. In "draw-line" (fibre line) area of PSF plant, the tow undergoes a series of heating and stretching processes which generate substantial heat as well as release of steam/water vapour and spin finish oil fumes. A number of local exhaust systems are required to be provided as per draw-line equipment manufacturer's recommendation. Air conditioning the draw-line area is neither economical nor essential from the process point of view. However, to provide workable conditions (30-40°C DBT and 50-65% RH) for the operator, evaporative cooling system is often provided in the draw-line. The evaporative cooling system may use spray type humidifier or cellulose-pad type humidifier which has the advantage of a smaller size and lower water flow rate. In addition, spot cooling may be provided in the draw-line at specific locations for operator comfort.

11. The polymerization building which houses all equipment required to produce the molten polymer does not require air conditioning (except the control room) and is usually provided with natural ventilation only.

Typical Air Conditioning System and Controls

• A typical system can be studied to get an idea of the system components. *Figure 1* shows the schematic of a HVAC system for quench air of a large POY polyester plant. This system works with minimum 10% fresh air with rest of the air re-circulated. If the plant is located in a geographically temperate region, winter conditions are quite favourable for 100% fresh air operation. *Figure 2* shows the air conditioning process plotted on the psychrometric chart. The design condition for quench air at the user point is 20° +/–1°C DBT and 80%+/–3% RH at a static pressure of 1000 Pa + / – 20Pa.

• The system components include air handling unit, supply air ductwork, and return air ductwork. The AHU consists of return air plenum and filter, return air fan, modulating type exhaust damper, modulating type balancing damper, modulating type fresh air damper, pre-filters, spray type air washer, chilled water cooling coil split into two banks, water droplet eliminator, supply air fan, fine filters and supply air plenum. The supply air flow rate is approximately 110,000 CMH and cooling capacity approximately 200 TR for a spinning capacity of approximately 50 TPD of fine denier POY.

• The fresh air/balancing/exhaust air dampers are sized to handle 100% supply air flow when fully open. During normal operation the exhaust damper will be set to remain in an almost closed position while the fresh (outdoor) air damper is set at minimum opening to allow 10% flow, and the balancing damper fully open to allow 90% of return air. Temperature and humidity sensors in the RA and FA stream provide signals to controller which compares the respective enthalpy continuously. The controller also compares the enthalpy of design supply air condition with that of fresh air.

• When enthalpy of fresh air is lower than pre-set value

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continued from page 54

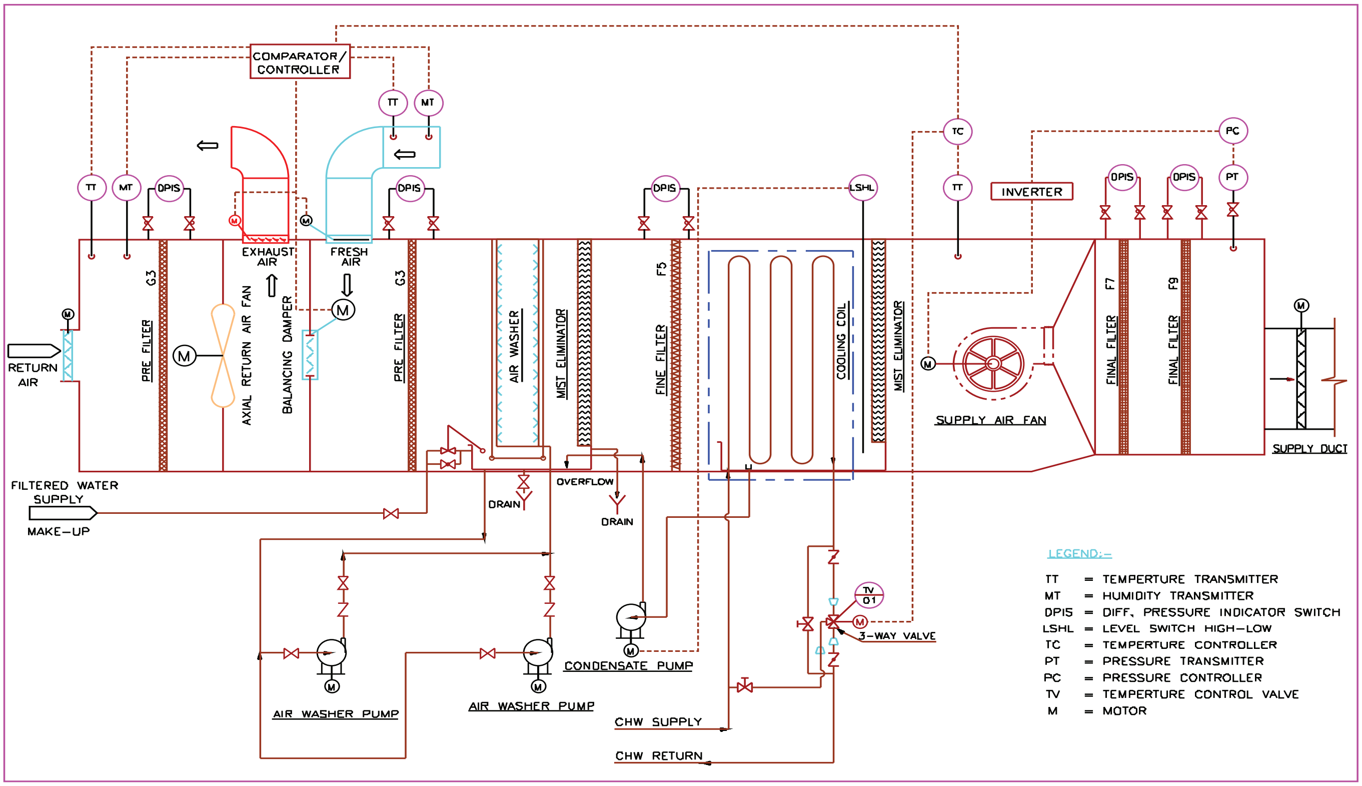

Figure 1: HVAC system schematic - POY quench air AHU

of RA but is higher than design SA condition, the exhaust damper and fresh air dampers are fully open and balancing damper fully closed. Thus the unit works on 100% fresh air providing substantial reduction in refrigeration requirement. However, when the enthalpy of FA is lower than the design SA condition itself, then the FA and EA dampers are modulated such that the mixture condition results in design SA condition after the mixture passes through an air washer. At this condition, refrigeration requirement is reduced virtually to zero.

• The supply quench air temperature is sensed at the outlet of cooling coil and is maintained at the set point by the 3-way mixing type control valve on chilled water return line. The quench air supply pressure in supply air plenum is sensed and is maintained at the set point by varying the fan speed using a variable frequency drive. While deciding the set points it is necessary to provide allowance for the temperature rise due to supply air fan power, and pressure drop in supply ducting and damper, such that the user point requirements are satisfied as required by the process.

HVAC Equipment

1. The high side HVAC equipment comprises of water chillers, chilled water pumps, cooling tower and cooling water pumps. Requirement of 3000 to 6000 TR capacity chilling plants are not uncommon - e.g. for a 800 TPD polyester plant (having 50-50 capacity split between PFY and PSF) chilled water refrigeration requirement is estimated at approximately 5500 TR. To meet such a large capacity, one has to select either centrifugal chillers, or vapour absorption chillers each having a capacity of 1000 TR or more. Theoretically, for large capacity plants vapour absorption chillers are ideal where large quantity of low pressure process steam is available. However, absorption units have been unable to develop a high level of confidence due to various operational problems. So, in spite of large electric power requirement, centrifugal chillers still remain the first choice for this application. As centrifugal chillers offer a high degree of reliability, a stand-by unit is rarely considered. Usually the unit capacity and quantity is decided such that all units are required to take care of peak requirement only and during normal operation at least one unit will remain idle, and is thus available as stand-by. For smaller plants, screw chillers could be considered but their main limitation is maximum capacity per unit which is only around 400 TR.

2. The cooling towers are usually designed to achieve an approach of 3-4°C with temperature range of 5-6°C. For large capacity plants induced draft, cross flow cooling towers with wooden or FRP fill were commonly used. Now induced draft, counter flow cooling towers with PVC fill are also being used. Both cross flow and counter

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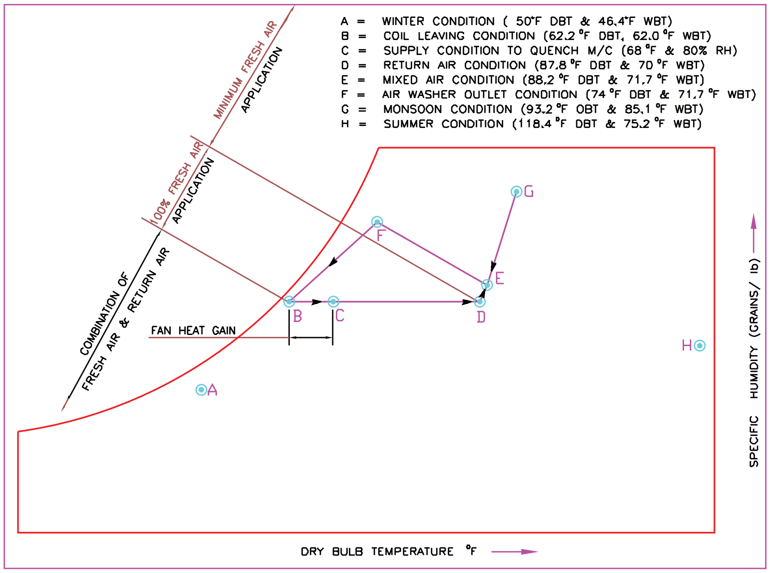

Figure 2: POY quench air system: psychrometric process

flow towers are available in timber construction as well as in RCC construction. The timber has to be chemically treated Himalayan pine (or equivalent) wood. A stand-by cell is often considered to take care of the maintenance requirement.

3. The cooling water pumps and chilled water pumps are usually selected to work as one pump per chiller unit. In addition at least one pump is taken as stand-by. For low capacity duty, radial split horizontal centrifugal pumps can be used. However when pump capacity is higher than 300-400 CMH, axial split centrifugal pumps are selected for their better efficiency. For cooling water service vertical multi-stage turbine type pumps have also been used. They offer a more compact layout but have additional constraints of maintenance.

4. The low side equipment includes a number of large capacity air handling units to cater to various main process areas, and some smaller units to cater to auxiliary and service areas. The smaller AHUs are standard sheet metal units with inclusion of humidifier, heating coil, fine filters, etc. as accessories depending upon the particular application. The larger AHUs can be either site built-up units of fully masonry construction, or sheet metal units using pre-fabricated panels and sections. Masonry AHUs require considerable interaction and co-ordination between HVAC equipment designer/supplier and civil building designer/contractor.

5. In India until the early nineties, AHUs of masonry construction were more common, as sheet metal AHUs of large capacity had to be imported. However, now sheet metal AHUs of large capacity, such as mentioned in the example above, are readily available locally. The AHU casing is made of double skin sheet metal panels having 40-50 mm PUF or fiberglass insulation sandwiched in between. Main framework of the AHU is made of extruded aluminium sections. Doors of standard size of 600mmW (or 450mmW) x 1800mm H are provided for maintenance access to each section. Air lock with provision for pressure balancing is provided for access to fan and fine filter sections. AHUs are mounted on discrete concrete blocks laid along the full width or full length of AHU. In some designs the AHU is installed on a flat, full size concrete pad and the floor panel is eliminated. It is claimed that this is done to avoid bulging out of floor panels which can happen due to frequent visits of maintenance staff for filter cleaning, coil cleaning, air washer spray system cleaning, fan maintenance, etc. However, it should be noted that this design increases equipment load considered for civil design and results in higher construction cost. The top surface of the concrete pad has to be water-proofed and coated with epoxy in the fine filter section. Care should be taken to avoid condensation on the lower surface of floor slab, by providing under-deck insulation, if required.

6. As quench air comes in direct contact with molten polymer leaving the spinnerets, its filtration requirements are high and usually three levels of filtration are required. Filters of class G3/G4 as pre-filter and class F6 and F8/F9 as fine and final filters are widely used. For take-up and spinning areas, two-level filtration (class G3/G4 and F6) is usually adequate. Cleaning frequency and life of filters is dictated by effective exhaust of monomer and spin finish oil vapours and good house-keeping of plant area. While pre-filters have to be regularly cleaned, the fine filters are selected to provide large dust holding capacity as they are non-cleanable type and have to be replaced. Double-spray type air washers also help in washing/cleaning the recirculated air. Deck-type air washer (which requires lower L/G ratio and thereby a smaller pump) has been tried but without any satisfactory results.

7. The cooling coil poses a major selection problem in case of quench air AHU working on 100% fresh air basis at all times; e.g. PSF quench air. While increasing the fin density higher than 10 fpi (fins per inch) results in clogging the coil in a short period, restricting it to 8 fpi leads to coils needing 8 rows or more. Therefore to provide flexibility of operation and continuous availability of equipment, the cooling coil is often split into two coil banks. Each coil can have 4 or 6 rows using

continued on page 60

continued from page 58

a fin density of 10 fpi or 8 fpi. Each coil may be selected to give around 70% of total cooling capacity, if used individually. Thus even when one coil is removed for maintenance or replacement, the working coil can keep the plant running, although at somewhat lower capacity.

8. Fans for return air handle large volumes but require low static pressure. So for RA duty tube-axial or vane-axial fans are quite suitable. However, for supply air duty, high air flow at somewhat higher static pressure, which varies depending on level of filter clogging, is the requirement. So for SA duty, centrifugal fans with backward curved blades, which has non-overloading characteristic, should be used. In case of quench air supply fans, since a minimum static pressure at user point (quench chimney) is required at all times, a variable frequency drive is a must to take care of varying system pressure drop due to filter clogging. For other areas, fixed speed drive is provided. V-belt drive is preferred since it allows some speed adjustment if required during commissioning, or to meet higher flow/pressure requirement at a later date. All fans should be of heavy duty construction suitable for continuous operation. The impeller and casing is made of carbon steel with surface finish in the form of galvanizing, epoxy painting or powder coating. As the fans handle air having high RH, corrosion resistant surface finish is necessary to enhance life of the equipment, and to maintain cleanliness of supply air.

9. Most of the modern plants use electronic instruments and controls. Even if the main manufacturing plant is provided with Distributed Digital Control System (DDCS), the air conditioning plants are usually controlled by an independent system with only minimum traffic of data with the main plant DCS. This philosophy is followed for other utility packages as well. The control system uses micro processor based controllers which are operated by a software developed for this specific purpose. Controller performance is enhanced by using PID functions to give an accurate and smooth control of desired parameters. The sensing elements are located in the HVAC equipment or in the air conditioned space. The controllers and recorders are mounted in a cabinet which can be installed along with printer and monitor in a convenient separate room. Control and power cables connect the control cabinet to the sensors and electric actuators. For monitoring purpose use of PC (micro-computer) with video monitor is common. The PC saves selected data in its hard disk so that tables/charts showing status of different A/C plants, set points, actual conditions, alarm status, etc. can be seen on screen and prints can be obtained when desired. All set points can be changed through a monitor with security password as required.

Points to Remember

- From the foregoing it can be noted that HVAC design and equipment play an important role in the planning and execution of man-made fibre plants, particularly polyester and polyamide plants. They require a high capital investment, have high operating cost, occupy considerable space and are critical to get rated output of quality product. Every effort is needed to optimize their cost and space without affecting product quality and output.
- At the planning stage it is important to know about the fibre quenching process as well as the yarn processing done on take-up machines. Air conditioning requirements can be substantially different for different processes. For example, in case of FDY (fully drawn yarn) the take-up machine load is substantially high as compared to POY (partially oriented yarn) take-up machine. This results in increasing the cooling load as well as supply and return air flow. If adequate space is not provided for the AHUs and the ductwork the situation can become really serious. Even for take-up area having POY machines, AHU sizes of 18-20m long × 7-8m wide × 4-5m high are common. Similarly supply and return ducting routing from AHU to and from the process area requires considerable planning with reference to other equipment and services. So a thorough study of space requirement is a must. It is all the more important when the spinning machines and take-up machines are purchased directly by the end user and not supplied by the polymerization process licensor (know-how supplier). It is often seen that, in such case the process licensor does not give due importance to the space requirement of HVAC equipment and ductwork in their planning.
- Selection of proper instruments and control system can have a far reaching effect. Wherever feasible, enthalpy control system should be incorporated to optimize on refrigeration requirement. It should be noted that RA fan and motorized dampers for exhaust and fresh air become essential while adopting enthalpy control system. Use of 2-way control valve in place of 3-way control valve is increasing due to low cost, less clumsy piping and possibility of power saving. Use of variable speed drive for the secondary chilled water pumps while using 2-way valves gives a good saving in operating cost.
- The condensate collected from cooling coil surface is at low temperature and is often of large quantity. As a measure of energy saving it is possible to transfer the condensate, by gravity or by using a pump, from cooling coil condensate pan to the air washer sump. This will

continued on page 62

continued from page 60

minimize the make-up water requirement as well provide some saving in refrigeration load.

• Over the years, the polyester yarn manufacturer's philosophy for handling HVAC systems has undergone a major change.

a) Earlier, the entire low-side work including supply of AHUs, controls, piping and ducting was awarded to a single HVAC contractor. However, nowadays low-side activities are split and the AHUs, ducting, piping and controls are procured separately.

b) Ducting is now machine made as against totally site fabricated ducts which required massive space requirement and involved a lot of site activity. Now, L-shaped pieces of ducts are made on machines in duct fabricator's shop and transported to site for assembly and erection. Duct design and fabrication according to SMACNA standards has become more common.

c) This change in execution strategy has resulted in the need to provide more details at the preliminary design stage itself. Secondly, the interface compatibility between supplies from different sources is now the responsibility of the detail-engineering agency and the end-user rather than individual equipment suppliers. ❖