EXECUTIVE SUMMARY

0.1 INTRODUCTION:

0.1.1 Nylon Filament Yarn (NFY) :

Nylon is a generic term for the long chain synthetic polyamides. Nylon 6 and Nylon 6,6 are two most important polyamides. Nylon 6 is manufactured by self-condensation of 6-amino caproic acid obtained from caprolactam. Like all other polyamides Nylon 6 is capable of being formed into a filament in which the polymer molecules are oriented, at large, in the direction of the axis. It can also be cut to small lengths to get staple fibres. NFY can be manufactured with varied degree of orientation such as low oriented yarn (conventional), partially oriented yarn (POY) and full oriented yarn (FOY). NFY is produced as multi-filament yarn or mono filaments in a wide range of deniers. It is also available in bright, semi-dull and dull lusters. The filament yarn is generally specified by denier/no. of filaments/ twist e.g. 76/36/2500 means that the yarn is of 76 denier having 36 number of filament and has been given 2500 twists per metre length. NFY is commonly manufactured in round cross sections but special cross sections such as triangular or multi-lobal are now being produced.

0.1.2 Properties of NFY :

NFY has excellent orientation and crystallinity characteristics which imparts it with good mechanical properties. NFY has good fatigue resistance and better resistance to the effect of prolonged heating for applications at a temperature lower than its melting point. It is highly resistant to chemical degradation and strains. It has excellent biological resistance.

NFY has a lower moisture regain and moisture transportability compared to natural fibres and hence apparel made from these yarns are not very comfortable particularly in tropical countries. It accumulates static charges and due to this also attracts dust particles carrying opposite charges. It is less resistant to fire. It has very poor affinity for basic and disperse dyes.

Nylon-6 and nylon-6,6 are two synthetic polyamides which are being manufactured on a commercial scale. The two polyamides have similar properties. Nylon-6,6 has higher melting point and fatigue resistance compared to nylon-6, and therefore may be preferred for applications such as tyre cord or carcass. However, process to manufacture nylon-6 is simpler than that for nylon-6.6 and it has superior resistance to light degradation. Also nylon-6 has advantage over nylon-6.6 in respect of dyeability, elastic recovery, and thermal stability and thus, for end uses like textile and carpet manufacture it may be preferred over nylon-6,6.

0.1.3 **End-uses of NFY :**

NFY's good bulk, handle and drape has helped in capturing a good share of textile market. Its high abrasion resistance, strength and refractive power makes it specially suitable for some uses like hosiery, swim-wear, upholstery, para-chute cloth, umbrella cloth, etc. It is also used for many industrial applications like tyre cords, fish-nets, ropes, seat belts etc. due to its high flexural strength and tenacity. Bulked continuous filament nylon yarn (BCF) is widely used in the manufacture of carpets due to its excellent bulk, wool like luster appearance and better resistance to stains, chemicals, insects, fungi and abrasion, as compared to wool.

0.1.4 **Manufacturing Process :**

The manufacturing process for NFY can be broadly divided into following production steps.

(a) Polymerisation of caprolactam to manufacture nylon chips

(b) Extraction and drying of chips

(c) Melt spinning of chips to manufacture spun yarn

(d) Processing of spun yarn

(e) Recycling of nylon 6 waste.

Caprolactam with a 3-5% of water and additives, like TiO_2 as delusterant is heated at temperature of 250°C to 270°C and pressure conditions to produce nylon-6 polymer. The polymerisation can be either a batch or a continuous process. Batch process is used for lower capacity plants for producing variety of polymers having different molecular weight. The continuous process has many advantages like consistency of quality, ease of operation and control and simplicity of design and operations and high capacity.

The polymer melt is generally converted into chips form which are washed to remove the monomeric and oligomeric impurities and then dried and remelted for spinning. It is possible to spin the polymer melt directly also. This process has limited commercial application for NFY manufacture as impurities which are not removed from the melt, can result into the variations in the property of the spun yarn.

In melt spinning process, polymer chips are melted to a desired viscosity and temperature in an extruder. The melt is then passed through sand or sintered metal filters, where filtering and shearing action produces a uniform polymer that can be extruded through spinnerette. The molten filaments enter the top of the tower or chimney where they are quenched or cooled by a laminar flow of air. The spin-finish is applied on cooled filament yarn. The yarn thus produced is collected on take-up winder. The flow of melt into the spinning mani-fold and speed of take-up unit may be varied to control the denier and degree of orientation of the spun filament yarn.

The undrawn spun yarn is then drawn to 3 to 4 times of its original length on draw twisting machines and are then subjected to secondary processes like crimping, twisting, etc., to make them useable for end applications.

Except for polymerisation process, the process for manufacturing NFY and PFY are similar in principle. The same spinning line may be used for spinning either nylon or polyester filament yarn or nylon tyre cord yarn, with minor modifications.

Waste generated at various processing stages amounts to 5 to 10% of the total production.

Depending on the quality of waste any of the following method may be used for recycling of nylon waste.

(a) Direct use of fibre waste

(b) Regranulation -

  (i) Without melting

  (ii) With melting

(c) Polymer Powder

  (i) Depolymerisation filteration

  (ii) Precipitation from solutions

(d) Recovery of caprolactam

(e) Recovery of amino caproic acid

The first three processes require relatively purer and undegraded form of waste. Between the last two, caprolactam recovery is mostly adopted because of easier purification of recovered caprolactam.

0.1.5 Raw Materials, Catalysts, Additives, Spin Finish etc. :

For nylon-6, the only major raw material required is 99.5% pure caprolactam. Marginal quantities of demineralised water is also required as an initiator for ring opening during polymerisation. Nitrogen gas is required for blanketing, drying and conveying of polymer. Some additives in small quantities like TiO_2 to control luster of NFY are added. Spin finish is applied in predetermined quantities of 0.5 to 1% before being processed after melt spinning. Spin finish is a mixture of organic chemicals and its main functions are to provide surface lubrication plasticising and static protection to the yarn.

0.1.6 Historical Development of Technology Leading to Present State of the Art:

The developments in the technology of NFY can be classified into the following major areas :

(a) Product developments

(b) Developments in the polymerisation process

(c) Developments in spinning process

(d) Developments in waste recovery processes

The commercial production of nylon-6 was started in Germany in 1940 and during world war II. Poly-caproamide or nylon-6 fibres were manufactured and sold under the name of 'Perlon L'. Over period of time, the process has been developed to manufacture physically and chemically modified fibres suitable for special purposes. The illustrative list of such modified yarns is:

(a) Crimped and bulked yarn

(b) Modified cross-section yarn

(c) Mono-filaments

(d) High count yarn

(e) Hydrophilic and Antistatic Yarn

(f) Differentially dyeable yarn

(g) Abrasion resistant yarn

(h) POY and FDY.

The details of each of the above products are discussed in para 1.5.2

In polymerisation the batch autoclave process was replaced by continuous V K tube process in the early fifties. The initial V K tubes were single stage tubes with smaller capacities of about 1.5 tonnes per day.

The V K tube reactor has under gone numerous modifications in size, design features and number of stages to improve the residence time, conversion rate and quality of the product. They have grown in size upto 40 tonnes per day. At present, the V K tube reactor has two or three stages, with insertions or additions like baffles, agitators, strirrers, heat exchangers, etc. In India, continuous polymerisation using a prepolymeriser and a main reactor is being used, sometimes with an intermediate water recovery system.

With continuous polymerisation, the extraction and drying of chips was also made continuous. In place of batch tumbler dryer, continuous dryer using hot nitrogen is now the established means of removing moisture. Band and ribbon type chip cutter are now replaced by underwater granulator. Another development, which is still to find a significant commercial application, is direct spinning technology, where polymer melt from V K tube is directly transported to spinning manifold for spinning. Melting of chips, which was earlier done through grid melter and then by star spinning head is now done by means of an extruder. Extruder has also undergone many inprovements and modifications in material used, screw and barrel design, heating mode used and extruder zone lengths which has resulted in improved polymer melt.

In spinning, developments include increased spinning positions and number of ends per position. The design of quench duct has changed from closed duct with concurrent air flow type to open duct with either concurrent or cross air flow. Method of spin-finish application has changed from kiss-roll to closed finish application system with nozzle spray, which are essential at the prevalent high speeds of spinning and take-up of yarn. Non-volatile spin finishes have been developed to replace the volatile, fume producing finishes, which has improved the working conditions.

In the area of yarn take-up and processing, technology advancement has been significant. Take-up speeds have increased from earlier 1000 m/min to upto 6,000 m/min. Spinning and draw-twisting steps are now combined into one, by development of 'spin-draw' technology, which has resulted in economy of operation and production of fully drawn yarn (FDY) which is easier to handle and has longer shelf life, compared to the conventionally produced undrawn yarn. High speed spinning process, with commercialised speeds upto 6,000 m/min has resulted in significant increase in the throughput rate and better economy of operations and production of partially oriented yarn (POY).

The development of spin draw process, having the spinning and draw-twisting in one stage has resulted in considerable saving of manpower, operating space, initial investment and power consumption. The package size was also increased from 1.5-2 kg to about 9 kgs. Today, the largest bobbin of a high speed spinning could be about 25 kg. The spin-draw technology is however complicated because of the high take-up speed. Breakages are to be kept at a minimum in such a process. Package size also increases requiring suitable modification in further processes. The manufacturing process is not only becoming increasingly continuous, but is also being more and more automated. Microprocessor control system for recording and maintaining control over the process parameters have replaced manual recording and control. Waste recovery which was limited to washing of polymer strands and chips in demineralised water to remove water soluble impurities has now been improved upon to make operations more economical and environmental compatible. Catalytic cracking of oligomer into monomer at equilibrium state of polymerisation is most popularly used, at present.

0.2 STRUCTURE OF INDUSTRY AND STATE OF THE ART :

0.2.1 Structure of Industry (Macro-Level Picture) :

The total present licensed capacity to manufacture NFY is 72,700 TPA and installed capacity is about 43,000 TPA. The additional capacity of 40,000 TPA is covered under various letter of intent and industrial licences. The average output per plant for NFY has increased from 2200 TPA in 1978 to 3600 TPA in 1986. The production of NFY in 1977 was 16,342 tonnes which increased to 35,584 tonnes in 1984, with the average annual growth rate of 9.3%. for the last ten years.

Major units manufacturing NFY are Baroda Rayon, Century Enka, Garware Nylons, Jagatjit Cotton Textiles, J.K. Synthetics, Modipon, Nirlon, Shree Synthetics and two units of Lohia Machines Ltd. All these units are in private sector.

Nearly all the companies manufacturing NFY also manufacture polyester filament yarn and nylon tyre cord. Garware Nylons are also marketing nylon chips. Lohia Machines manufactures only NFY and Shree Synthetics manufactures only NFY and PFY. There are some companies, viz. Baroda Rayon, J.K. Synthetics, which also manufacture rayon yarn. Century Enka is the only NFY manufacturer which also produces engineering plastics and polymer resins and JCT which is basically a cotton textile manufacturing company, manufactures only NFY and is planning to manufacture PFY also.

Five of the existing manufacturers are located in the western region. Out of the balance, four units are in the northern region and one unit is in the central region. The southern and eastern regions are not having any manufacturing unit at present. However letters of intent have been taken by state industries development corporations in southern and eastern regions.

Almost all the present NFY manufacturing companies are multi-product companies and though all of them have done well in the past in terms of sales turnover, net profit addition to net worth and net assets etc. the credit cannot go to NFY alone. At present, NFY production is best with stiff competition from PFY, lack of newer avenues for NFY application, higher cost of caprolactam which is still imported substantially and small capacity plants.

The three pioneering companies in this field, namely, Nirlon, J.K. Synthetics and Garware Nylons started manufacturing NFY with small capacity plants of 0.5 to 2 tpd without entering into any foreign collaboration agreement but with imported plant and machinery as well as the raw materials. They had made a package deal with the plant and machinery and/or raw material supplier, to help them in the initial start-up phase. All the companies which followed the three pioneering companies preferred to start with technical collaboration with foreign suppliers. All these earlier collaborations were for conventional spinning.

0.2.2 **Plant and Equipment :**

The plant and equipment owned by a NFY unit depend on its manufacturing process. Companies like Baroda Rayon, have batch process and hence have autoclave, tumble dryer and discontinuous washing/extraction system. The spinning system consists of extruder, spinning manifold, an open quench duct, traditional take up units operating at about 1,000 mt/min. and draw twisting machines.

The second class of units have continuous V K tube polymeriser, continuous chip production, extraction and drying, pneumatic conveying system for transportation of chips to spinning, extruder, spinning manifold, open quench duct and take up unit operating at conventional speed of 1,000 m/min. and followed by draw twisting machines and few take up winders having a speed upto 4500 m/min. for POY manufacturing. In this category the few units viz., Jagatjit, Nirlon, Modipon, and J.K. Synthetics have a prepolymeriser and a V K tube and the rest have just one V K tube.

Indian NFY manufacturing companies seem to have absorbed the technology supplied to them by their early collaborators and have improved/modified it to suit local market conditions. The modernisation and expansion efforts of NFY industry were directed to marginal modification of plant and equipment and addition of equipment for line balancing to increase the through-put. However now number of them have collaborations with leading world know-how suppliers to incorporate latest technology in their plants.

0.3 **DETAILS OF UNITS VISITED :**

Following manufacturers were visited during the study :

1. Baroda Rayon Corporation Ltd.
2. Century Enka Limited

3. Garware Nylons Limited

4. Jagatjit Cotton Textile Mills Ltd.

5. J.K. Synthetics Ltd.

6. Modipon Ltd.

7. Nirlon Synthetic Fibres and Chemicals Ltd.

8. Shree Synthetics Ltd.

9.* Gujarat Nylons Ltd.

10.* Petrofils Co-operative Ltd.

* New Units

The details of the technological status, R & D efforts and technology updation efforts made by each of the above manufacturers are discussed in detail in this report and summarised hereunder.

3.1 **Baroda Rayon Corporation Ltd. :**

The Baroda Rayon Corporation Ltd., acquired facility to manufacture NFY and a collaboration with Snia, Italy in 1973. It started with an installed capacity of 6 TPD and has now grown to 14 TPD capacity. The company still operates on batch autoclave polymerisation and chips extraction/drying process. Even for its recent expansion plans, the company has decided to use batch autoclave polymerisation process only. The company intends to modernise its spinning plant by incorporating spin-draw and high speed spinning technology.

3.2 **Century Enka Ltd. :**

The company commissioned its NFY plant in 1969 in collaboration with Glaztstoff A.G., West Germany. The company also manufactures polyester filament yarn, nylon tyre cord, engineering plastics and polymer resins. The present licensed and installed capacity of NFY plant are 6000 TPA and 5000 TPA respectively.

3.3 **Garware Nylons Ltd. :**

The company started manufacturing NFY in 1962 starting from imported nylon chips. The polymerisation unit was added in 1965. They also manufacture nylon mono-filaments, polyester filament yarn, nylon chips for plastics industry etc. Their licensed and installed capacity is 6,000 TPA.

0.3.4 **Jagatjit Cotton Textile Mills Ltd. (JCT) :**

JCT originally a cotton textile company, entered into the field of NFY production in 1979, with a technical collaboration agreement with M/s. Zimmer A.G. Its present licensed capacity is 6,000 TPA and installed capacity is 4,500 TPA. JCT started with a continuous single stage polymerisation process and conventional spinning plant. The company added a prepolymeriser and some other equipments to increase plant capacity in a phased manner. The company has a conventional and a high speed spinning plant, having 4 positions and 8 ends per position. It has also developed 'spun-dye' process technology through inhouse R & D efforts.

0.3.5 **J.K. Synthetics Ltd. :**

J.K. Synthetics Ltd., is a pioneering NFY manufacturer in India. It started with a plant capacity of 800 kgs/day in 1962 and has now grown to 6,000 TPA or about 20 tpd size. For the present plant J.K. has no foreign collaboration. However for its expansion plans for NFY it has entered into collaboration with M/s. NOY, Italy for supply of basic engineering and know-how. The company has an active R & D centre, which has helped it in absorbing the conventional technology and developing certain patented product/process modification for better results.

0.3.6 **Modipon Ltd. :**

Modipon Ltd., was established in 1965 in collaboration with Rohm & Haas Co., U.S.A., a leading manufacturer of NFY in USA with an initial licensed capacity of 1,800 TPA. The company has a continuous process and its present installed capacity is 4760 TPA. Their modernisation plan for which approval for collaboration with 'Snia', Italy, was obtained in Feb. 1986, includes incorporation of two latest technologies viz., 'Spin-draw and Spin-dye' processes. The company also has a government recognised R & D centre, which has carried out many fruitful projects.

0.3.7 **Nirlon Synthetic Fibres and Chemicals Ltd. :**

Nirlon, another pioneer in field of NFY manufacture, started in 1962, with an installed capacity of 720 TPA. The initial plant was only a spinning unit. A nylon-6 polymeriser was imported only in 1968. Company's existing installed capacity is 4,000 TPA, and has a two stage continuous polymeriser plant. Company has a R & D centre, duly recognised by government.

0.3.8 **Shree Synthetics Ltd. :**

Shree Synthetics started in 1970 with a collaboration with Chemtex Inc., U.S.A. Its present installed capacity is 3,452 TPA. The company's major production of NFY is for sarees. It has a continuous polymerisation plant. Its R & D division has many achievements to its credit, in developmental work.

0.3.9 **Gujarat Nylons Ltd. and Petrofils Co-operative Ltd. :**

The two new units under implementation are M/s. Petrofils and M/s. Gujarat Nylons, coming up in Gujarat State, in collaboration with M/s. Lurgi. The proposed plants, of 6,000 TPA capacity each, are to have continuous polymerisation and 'spin-draw' and 'single step high speed spinning' process. The product mix is planned to include speciality products like fine denier yarns, monofilaments, etc.

0.4 **DEMAND FOR NFY - PRESENT AND PROJECTED :**

In India NFY finds major application in the manufacture of sarees which accounts for the 70% of the total NFY consumption of the country. The balance consumption is divided between dress materials (12.5% approx), hosiery (12.5% approx.) and T shirts and twines (5% approx.). The geographical consumption pattern for NFY is 82% to 85% in the western region of Bombay and Surat, 8 to 12% in the state of Punjab and the balance spread in the country. Production of NFY in the year 1986 is reported to be 35,585 MT and its import into the country for the same year is estimated at 115 MT. Thus, the total availability of NFY can be estimated at approx. 35,700 MT during 1986. The share of NFY in terms of its % in total synthetics has reduced from 50% in 1970 to 22% in 1985 in India. The PFY is preferred in mens wear due to its much higher crease recovery and wrinkle resistance, better shape, longer retention of prints and colours, better abrasion and pilling resistance compared to both NFY and PSF.

PFY has provided a very strong competition to NFY for textile end use. Surat, the citadel of NFY user industry is now showing signs of preference for polyester POY over NFY. However there are specific traditional applications like cheaper sarees, hosiery, readymade garments etc. where NFY is maintaining its share. The use of PFY in sarees is picking up at a faster pace in the recent past since the development of crimping, twisting, texturising and wet processing technology has increased the air permeability of PFY which overcomes the inherent defect of low moisture absorption. It has also rendered a lot of manoeuvreability in design, patterns, fashion etc.

The output of NFY manufacturing unit may either be in form of draw-twisted conventional yarn, Partially Oriented Yarn (POY), fully drawn yarn (FDY), or Fully Processed Yarn (FPY). Nylon POY or FDY is still not produced in substantial quantity in India and its ancillary units are yet to establish. Ancillary units for draw-twisted conventional yarn are those which carry out the operations of either crimping, twisting or weaving. There is a major concentration of these units in and around Surat city and the ancillary units are by and large in the small scale sector. Due to its modest resources, ancillary industry has not been able to modernise its facilities, and this is one of the constraints in market development and new product introduction for NFY.

India imports special quality NFY, but the imports are now on decline, as the Indian manufacturers have modernised and modified their plants to satisfy this demand too. India does not export NFY, though it has been exporting nylon fabrics worth Rs. 16 millions. The export of nylon fabrics is also on the decline, due to the uneconomic operation of Indian nylon industry and growing mass production efforts of certain South Asian and Pacific countries.

0.5 STATE OF THE ART SCENE (INTERNATIONAL) :

Polyamide are fast losing their share of world synthetic fibre production to polyester. In 1970 nylon accounted for 40 percent of total synthetic fibre production and polyester accounted for 34%. In 1985, these figures were 26% and 49% respectively, with share of polyacrylics and other synthetic fibres remaining near constant. In the world, nearly 70% of NFY/NSF is used for carpet and industrial application and it is the only market of NFY which is growing in the world at present.

The six major nylon producing countries are Japan, U.S.S.R., U.S.A., Taiwan, South Korea, and West Germany, which have total production capacities of over hundred thousand tonnes per annum each. The West European countries and United States, which together used to account for 64% of world NFY production in 1970, now have about 50% share of world market. Japan's share has also declined from 16% in 1970 to 9% in 1985. The countries which have increased their world market share of NFY production are Asian countries like China, Taiwan and South Korea. These countries have also major expansion plans on card.

At present continuous multi-stage polymerisation, followed by continuous extraction, washing and drying of chips is the standard nylon-6 polymerisation process. Spinning of NFY is increasingly done by spin-draw process or high speed spinning process, though conventional process is still in use. The process know-how and technology offered by various suppliers are identical in principle.

The major suppliers of NFY technology are :

- EMS Inventa AG
  Switzerland

- Didier Engineering GmbH
  West Germany

- Zimmer A.G.
  West Germany

- Snia BPD
  Italy

- Lurgi GmbH
  West Germany

- Unitika
  Japan

- E.I. du Pont de Nemours & Co
  U.S.A.

The salient features of contemporary technologies of each of above technology suppliers are summarised hereunder :

0.5.1 **EMS Inventa** is a Swiss Company, which has supplied manufacturing plants to maximum number of countries, as compared to any other know-how supplier. For NFY manufacture it has developed a compact spinning unit which reduces the height of plant from traditional 14 to 16 m. to 6 to 7 m. height. It has also developed a special type of high speed spinning process, known as H4S process, which combines high speed spinning of NFY with open-wrap cold drawing of filaments and subsequent steam treatment for heat setting.

0.5.2 **Didier Engineering** has been in the field of man-made fibres since 1960's, and has developed its own technology for NFY production. Didier provides the most compact plants. As per a design patented by Didier the whole spinning unit height is reduced to 3 to 3.5 m., instead of 14 to 16 m., by proper arrangement of guide roller and winding machine, which are arranged laterally with respect to quench duct, instead of a level below it, in traditional designs.

0.5.3 **Zimmer A.G.** was founded in 1950, as an engineering and contracting company. Out of its basic and detailed engineering and plant erection experience, it developed know how for NFY manufacture, which has now been supplied to more than 50 units, all over the world. Zimmer has a specific design of extractor, which results in a high extract content in washing water, thus saving energy in the caprolactam recovery plant. In spinning manifold it offers melt freeze valves, instead of shut-off valves used commonly to avoid leakage problems.

0.5.4 **Snia BPD** developed know-how for nylon in 1952. It now offers its patented caprolactam recovery process, a high speed spinning process known as 'HSP', 'Spun-dye' process to give predyed yarn, and a process to texturise NFY so as to impart yarn with increased elasticity, improved handle, softness, and feel.

0.5.5 **Lurgi** is basically an engineering company, which now offers plant and know-how for nylon-6 and nylon-6,6, both continuous and batch process. Lurgi offers knowhow for 'spin draw' and 'high speed spinning' process and for caprolactam recovery unit, which is designed to give excellent conversion ratios.

0.5.6 **Unitika** is a Japanese know-how supplier, which has its own production back-up. Its technology is being commercialised by Mitsubishi, Japan. It has patented certain additive matrix to obtain antistatic NFY and NFY with hexalobal cross-section. It offers a separate system for both recovery and extraction of water, upto final stage, which is usually combined into one's in other plant designs.

0.57 **DuPont,** U.S.A. is the pioneer in production of polyamide fibres. It offers the latest technology for nylon-6.6 of textile, as well as, industrial grade filament yarn, and is considered a world leader in NFY manufacture.

A project profile for a new NFY plant of capacity 12,000 TPA is placed at **Annexure-I.**

0.5.8 **Details of Technology of Various Licences**

The technology or know-how suppliers for NFY production in India, have predominantly been the engineering companies, like Zimmer, Lurgi or Snia. The reason for this are, low fees, experience of detailed engineering and erection of plant, availability of latest equipments and willingness to collaborate with the Indian manufacturers. The world leading nylon manufacturers have not shown much interest in Indian industry development; by way of foreign collaborations.

Technology for NFY Plant is more or less standardised. Polymerisation process is of continuous multistage having prepolymeriser, V K Tube reactor and stabiliser/aging stage. Spinning process could be either a conventional spinning or a spin-draw process. Latest trend is towards spin-draw process.

Research and development efforts in the field of synthetic fibres, worldover, are presently concentrated on :

(i) modification of product properties to make it suitable for increasing number of end uses.

(ii) modifying process to achieve either more efficient operation or to make it suitable for new products being developed.

(iii) modifying plant design to either modify product properties or to achieve more economic operations.

The efforts in product modification has resulted in development of following new products details of which are discussed in para 2.3.

(i) Hydrophilic NFY

(ii) Antistatic NFY

(iii) Flame retardant NFY

(iv) Hollow NFY

(v) Bi Component fibre

(vi) Heterofil fibres

(vii) Graft polymerised fibres

(viii) Cross-linked NFY

(ix) Biologically active NFY

The process modifications can be summarised as follows :

(i) Non-aqueous polymerisation

(ii) Anionic polymerisation

(iii) Solid-state polymerisation

(iv) Direct spinning of polymer melt

(v) Spin-draw process

(vi) High speed spinning process

(vii) High speed spin-draw process

(viii) Draw warping process

(ix) Incremental draw processing

(x) Spin-dyeing

(xi) High speed spinning streching steaming process (H4S process)

The detailed description of modifications made in polymerisation as well as in spinning equipment is also given in para 2.13.

Latest development is in construction of NFY plant sizes of more than 50 TPD for achieving economy of scale, and also having flexibility of production of speciality yarns. For better control and monitoring, microprocessor based centralised control systems are now being used. The spinning unit efficiency has increased from 95 to 97% due to availability of better quality of filtered polymer melt, reduced variation in melt viscosity, temperature, and pressure and reduced yarn breakage and rejection due to improved quenching process, and vibration free take-up machines. The design of spinning plants have become more compact with the increase in number of spinning positions. Work is continuing for increasing the spinning efficiency upto 99% or more.

0.6 TECHNOLOGY ABSORPTION :

0.6.1 Technology Absorption Efforts :

Research and Development efforts are being carried out in the national research institutions and in the R & D cells of individual manufacturing units, for technology absorption and process optimisation.

Although NFY is not a product which gets as much attention from researchers as related textile synthetic fibres, it has been subject of study in institutions like National Chemical Laboratory (NCL), Pune; Indian Institute of Technology (IIT)Delhi; Silk and Art Silk Manufacturing Industries Research Association (SASMIRA); Man Made Textile Research Association (MANTRA), Surat; private research Institutions like Sir Padampat Research Centre set up by J. K. synthetics Ltd; Shriram Institute of Industrial Research, etc. and in-house R & D centre of the manufacturing industry. However, till date, none of these research institutes have developed the latest technology of manufacturing NFY which can be commercialised for horizontal transfer of technology to Indian industries. These institutes are only engaged in minor research projects for optimisation of production parameters or improvement of product characteristics.

A, **National Chemical Laboratory (NCL)**, Pune : The studies at NCL in the field of polymer involves developing mathematical models for different polymeric phenomena, testing hypothesis which have been either reported in literature or have been observed in their own laboratory.

B, **Indian Institute of Technology**, Delhi: The notable studies carried out at the Institute are, twist contraction of NFY, dyeing of chemically modified nylon-6, crystallization of fractionated nylon-6, effect of heat setting on structure of NFY, texturisation of nylon and modified nylon, etc.

C, **SASMIRA**: SASMIRA is a full fledged research institution set up for carrying out basic and applied research in the field of man-made fibres and silk industry. It has a pilot plant for NFY, PFY, NTC etc. The pilot plant is used to carry out various trial productions to test the findings of laboratory studies and also for testing production parameters for industrial clients.

D. **Man Made Textile Research Association (MANTRA) :** MANTRA has been established to carry out research and development and testing/technical services activites in the areas of man-made fibres. It has facilities such as laboratories, workshop for pilot plant machineries, mini dye house, computer colour matching etc. Among the siginificant works carried out by MANTRA is the modification of nylon-6 by chemical treatment. They are also involved in development efforts in the field of yarn processing covering crimping, twisting and dyeing of yarn.

E, **Bureau of Indian Standards :** The Bureau of Indian Standards has formulated standards on methods of test and product specification in the field of NFY. Table 1 contains list of such standards.

TABLE-1

STANDARDS FORMULATED BY BUREAU OF INDIAN STANDARDS IN THE FIELD OF NFY

A. **Methods of Test :**

IS : 7703	Methods of test for continuous filament polyester and polyamide flat yarn
Part I-1975	Linear density
Part II-1975	Tenacity and elongation at break
Part III-1975	Commercial mass
Part IV-1981	Sampling
Part V-1987	Unevenness percentage
IS : 667-1981	Methods for identification of textile fibres
IS : 832-1985	Methods for determination of twist in yarns
DOC : TDC 10 (2202)	
DOC : TDC 10 (2348)	Under preparation
DOC : TDC 10 (2492)	
DOC : TDC 10 (2504)	

B. **Product Specifications :**

(i) **Textile Applications**

IS : 7867-1975	Continuous filament textile polyamide (nylon) yarn

(ii) **Industrial Applications :**

IS : 4399-1967	Nylon fabrics for industrial and special purposes
IS : 8430-1977	Nylon fabrics for inflatable equipment
IS : 8991-1978	Nylon fabrics for sleeping bag
IS : 9536-1980	Specification for Nylon Tyre Cord
IS : 11326-1985	Nylon fabrics for coating with natural or synthetic elastomers
IS : 11574-1986	Polyamide filter cloth
IS : 11573-1986	Polyamide yarn for cycle and rickshaw tyres
IS : 11673-1986	Nylon umbrella cloth
IS : 11915-1986	Nylon fabrics for making mountaineering equipment
Under Print	Polyamide duck-back for industrial use

(iii) **Aerospace Applications :**

IS : 4227-1981	Cord, nylon, braided for aerospace applications
IS : 4228-1978	Nylon tapes
IS : 4229-1978	Nylon sewing threads
IS : 4437-1973	Braided nylon cords
IS : 4726-1986	Light weight nylon fabric
IS : 4727-1968	Nylon webbing
IS : 5010-1969	Nylon fabric for heavy supply dropping parachutes
IS : 5304-1969	Nylon fabric for seamine dropping parachutes
IS : 6349-1969	Tapes, nylon, tubular
IS : 6900-1978	Proofed nylon leno fabric
IS : 8947-1978	Nylon webbing for aircraft safety belts
IS : 9267-1979	Tubular nylon webbing.

(iv) **Ropes and Cordages :**

IS : 4572	Polyamide multifilament ropes
Part I-1982	General requirements
Part II-1983	Hawser laid ropes for specific applications
Part III-1983	Hawser laid ropes for general purposes
Part IV-1982	8 strand plated ropes
IS : 6590-1972	Braided nylon ropes for mountaineering purposes.

0.6.2 **Indigenisation of Capital Equipment, Spares, etc. :**

Technology absorption efforts have resulted into indigenous production of certain process equipments and many spares and sub-assemblies are now being developed in the country. However, many specialised items like spinning manifold, spinnerette, etc., are still being imported. The hindrances in development of indigenous capabilities in this regard are lack of consistent demand, performance guarantee clause, terms of foreign collaborations, etc.

0.6.3 **Indigenisation of Raw Materials :**

The major raw material for manufacture for NFY is caprolactam. There is only one manufacturer, Gujarat State Fertiliser Corporation Ltd, of caprolactam in India at present. It is only recently that the Government has given license to two other units to manufacture caprolactam. Till these units go into production by 1990, there is going to be a constraint in indigeneous availability of caprolactam.

Besides the availability, quality of indigenous caprolactam is not up to the mark. Permanganate number of indigenous caprolactam is 15000 where as it is 18000 in imported caprolactam which is better for polymerisation process. Moreover, batch to batch variations of caprolactam by local manufacturers is also quite substantial and requires adjustment in polymerisation parameters to take care of such variations. Therefore, effective steps should be taken to improve the quality besides increasing the production capacity. Another major material required in NFY is fibre grade TiO_2. Fibre grade TiO_2 is not being manufactured in India. Most of the other additives are available indigenously.

0.6.4 **Modifications and Improvements in Process Plant and Equipment :**

Due to increasing competition both from within the industry and from other synthetic fibres like polyester, Indian NFY industry has now realised the need for 'know-why' exercise. As a result of their efforts in this direction, need for better technology was felt and the industry has started acquiring better technology for expansion or modernisation. Modifications and improvements in technology were till recently limited to expansion of production capacity through better line balancing and addition of equipments. However, now the industry is planning to incorporate the latest technology and effectively modernise its manufacturing facilities. In product features there is trend to go in for production of very low and high denier range filament yarn, with other than circular cross-section and manufacture of POY, flat fully drawn yarn, spun-dye yarn, etc.

The good financial performance of NFY manufacturers cannot be credited to their technological advancement or absorption efforts. It is more due to the prevailing market conditions, closed Indian economy, and to the flexibility of changing over from NFY to PFY or NFY production.

Technology absorption efforts are retarded due to smaller plant capacity, lack of indigenous manufacturing capacity to produce capital equipments, parts and spares, and lack of skilled manpower and lack of will on part of managements of NFY units to take up absorptive R&D on a significant scale.

The Indian NFY industry has not been able to contribute significantly in the export market due to :

(i) High production cost.

(ii) Declining demand of NFY of textile grades produced in India in world market.

(iii) NFY suitable for growing market like carpet, parachutes etc. not manufactured in India.

5 Modernisation Needs :

(a) The maximum licensed plant capacity at present is 6,000 TPS which is much below the now defined minimum economic capacity of 12,000 TPA. To make operation more economic, the expansion of capacities should be in first front of modernisation efforts. The plants with totally outdated technology should be either allowed to be scrapped out or marginally modified for speciality yarns. No investment should be made in renovation of such units.

(b) The existing Indian plants need to be made more continuous and automatic, to achieve better control and lower cost of production. The waste recovery system employed in existing manufacturing units are required to be made more efficient to minimise the net waste.

(c) In the area of spinning many new technologies viz. 'Spin-draw', 'High-speed-spinning' and 'Mass-colouration' or 'spun-dye' process have been commercialised which result in higher productivity at lower cost of production. The first two processes result in a package weight at take-off of 8 to 9 kg, for which the NFY user industry is not equipped. Therefore the need to modify spinning process, is combined with need to modify the user industry, as well. The 'spun-dye' process is ideally suited for Indian conditions, as it results in mass production of fast coloured yarn, with virtually no pollutants due to dyeing process.

(d) Much better results can be achieved by carrying out small design modifications in the existing plant and machinery. Small variations in the design of V K tube reactor can result in reduced residence time, improved polymer quality and narrower molecular weight distribution. Addition of a pre-polymeriser can increase the capacity of polymerisation unit by about 50 per cent, and there are a significant number of Indian companies which do not have a pre-polymeriser. In case of spinning line, spinnerette design needs to be modified for speciality yarn production, and the present practice of not incorporating a filter unit between extruder and spin-pack needs to be changed. A filter is very essential to obtain a homogenous polymer melt, required for manufacturing superior quality yarn, with modified characteristics and at higher speeds. There is a need to modernise quenching system also being used in NFY plants.

The NFY manufacturers can be classified into two groups, those catering primarily to hosiery, readymade garment and knitting market and those catering primarily to textile market. Except for two units, Lohia and Jagatjit, all the other existing units fall in second category. On the basis of technology and plant and equipment, the industry can again be divided into two major classes, one having batch polymerisation process and therefore autoclave, tumbler dryer and discontinuous extraction system, and second having continuous polymerisation process and hence V K tube, continuous nitrogen dryer, and continuous extraction system. Majority of existing units belong to class two and can however be again divided into units having single stage or multi (two) stage continuous polymerisation process. The latter type will have a prepolymeriser and V K tube reactor in polymerisation plant, whereas the other will have only one V K tube reactor.

7 TECHNOLOGY GAP :

Indian NFY Industry is trying to keep pace with the technological changes at International level but there is always a time lag in technology absorption and upgradation. Till recently, due to various constraints, technology upgradation efforts were limited in India. Only during recent years, a strong need is felt and these efforts are being intensified.

Technology gap exist between the technology at international and Indian level. The following areas have been identified.

- Product Development
- Plant Capacity
- Melt-Spinning Process
- Yarn Processing
- Manufacture of Plant and Equipments
- Availability of raw materials, additives and spin-finish etc.
- Present technologies for downstream processes.

0.7.1 **Product Development :**

(i) The following newly developed products are yet not used in India.

(a) Extra-fine filaments to match the silk like feel

(b) Cationic dyable, NFY

(c) Bi-component yarns

(d) NFY suitable for carpet, parachute and umbrella cloth

(e) High denier yarns for soft luggage, sports outerwear and recreational equipments

(f) Nylon POY

(ii) In the area of product modification, both chemical and physical modifications are being tried to improve the product characteristics and product features. Products with better moisture regain, lower static charge collection, differential dyeability, improved fire retardancy, easy crimpability, different cross-section, improved resistance to abrasion, ultraviolet rays, chemicals, etc. are being developed.

0.7.2 **Plant Size :**

Plant size in India is maximum 20 tonnes per day, whereas at international level plants are having capacity of 50 TPD.

0.7.3 **Polymerisation Process :** Addition of prepolymeriser or pretreaters and multistage polymerisation in V K tubes is not yet carried out in all the plants in India. Direct spinning line eliminating clip formation is also not yet adopted in India.

0.7.4 **Melt Spinning Process :** Advanced processes like spin-draw, high speed spinning, spun-dye and mass colouration processes and other superior processes like incremental draw processes and draw wraping process are yet not commercialised in India. Latest micro-processor and computerised controls, sophisticated yarn-sensors and monitors, semi-automatic and automatic yarn doffing systems are also yet not used in Indian NFY plants.

0.8 SUGGESTED MEASURES TO BRIDGE THE GAP :

To bridge the existing technological gap, some measures are enlisted here below :

(i) All the new plants going for expansion, should import latest technology alongwith the know how for **Product Development.**

(ii) Emphasis should be put more on research and development efforts for optimisation of production parameters to manufacture new type of products and speciality yarns.

(iii) The research and development work at the national level research institutions should be better organised for development of new products suitable to Indian markets, for optimisation of process parameters for better economy, and for upgradation of available technology.

0.8.1 Thrust Areas of Indigenous Technology Development, Targets, Methodology and Suggestions :

Considering the time lag of development of technology at international level and in India, the thrust areas for immediate indigenisation efforts are identified as follows :

(i) To import the latest technology and know-how available at international level to absorb and upgrade this technology by constant interaction with collaborators. In general, the latest technologies would mean continuous polymerisation in multi-stage V K tube reactors, continuous extraction and drying of chips, spin-draw technology or high speed spinning processes for fully oriented yarn.

As number of variables are involved, like product modifications for newer applications, process modification and plant designing to suit for newer applications, there is not a single technology which can be termed as **LATEST.**

(ii) To develop process parameters for the manufacture of new products suitable to local conditions as well as to improve the quality of the existing products.

(iii) To develop indigenous manufacture of equipments as far as possible and wherever it is economically viable to do so.

(iv) To interact constantly with the internationally reputed manufacturers of NFY.

(v) To develop indigenous consultancy for basic and detailed engineering services.

The targets should be :

(i) To import the latest technology and to avoid repetitive imports of technologies.

(ii) Increased percentage of indigenous equipment used in plant.

(iii) Reduction in cost of production to a level comparable to international level, and

(iv) To encourage development of indigenous consultancy organisation as a single source of knowhow in India for horizontal transfer.

0.8.2 **Suggested Methodology to achieve targets in Thrust Areas of Indigenous Technology :**

To achieve the targets in thrust areas of indigenous technology, methodology suggested is as under :

(a) To encourage the development of a central organisation preferably a company having expertise in basic and detailed engineering, plant and equipments procurement and inspection both at indigenous and international level. This sort of central organisation may be common for more than one related products and not necessarily for NFY.

(b) Approval of foreign collaboration and import of capital equipments should ensure import of latest technology and plant and equipments as well as to provide necessary incentive to indigenous development of manufacture of plant and equipment. Overall efforts should be made to boost the modernisation.

(c) Research and development work at national level research institute such as SASMIRA, National Chemical Laboratory and others, to be comprised of research projects to solve the problems of NFY industry. The research institute together with a Central Company should be organised to take up the projects of technology research aiming at absorption and upgradation of latest imported technology at international level. The research institute should have association with industry so that the projects carried out by them, are tested at the industry level. For the development of indigenous engineering know how, and plant and equipment suppliers, research institutes should have a close association with engineering organisation like EIL or PDIL, who have vast experience in basic and detailed engineering and plant procurement and inspection.

0.8.3 Resources Needed for Development of Indigenous Technology :

For development of indigenous technology, financial resources will be required to a considerable amount. As the NFY industry has reached a maturity state and also considering country's economic situation, a detailed appraisal of cost-benefits should be carried out before earmarking funds for this purpose. Part of the funds should be made available from the industry in some form of levy for this specific purpose.

Resources, in terms of trained manpower, will also be required and a systematic approach for development of technical skill and constant interaction with foreign experts is required. The scheme of training of Indian technicians abroad and visit of foreign technicians in India should be further encouraged and liberalised. Institutes like I.I.T.'s, SASMIRA, etc. should conduct specific courses to train technical people in particular areas of technology of synthetic fibres.