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# PROCESS ENGINEERING (PETROCHEMICALS AND FERTILIZERS)

DP/IND/71/047

INDIA

TERMINAL REPORT

Prepared for the Government of India by the
United Nations Industrial Development Organization,
executing agency for the
United Nations Development Programme

United Nations Industrial Development Organization

United Nations Development Programme

# PROCESS ENGINEERING

# (PETROCHEMICALS AND FERTILIZERS)

DP/IND/71/047

INDIA

## Project findings and recommendations

Prepared for the Government of India
by the United Nations Industrial Development Organisation,
executing agency for the United Nations Development Programme

Based on the work of D. H. J. Freshlich, expert in process design

United Nations Industrial Development Organisation
Vienna, 1975

## Explanatory notes

A slash (/) between dates representing years indicates a crop year or financial year, e.g. 1971/72.

Reference to "tons" indicates metric tons, unless otherwise stated.

Reference to "dollars" ($) indicates United States dollars, unless otherwise stated.

The following abbreviations are used in this report:

| | |
|---|---|
| EIL | Engineers India Limited |
| R.H. | relative humidity |
| cP | centipoise |
| cSt | centistokes |

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CONTENTS

## SUMMARY

A short background of the project "Process Engineering (Petrochemicals and Fertilizers)" (DP/IND/71/047) given in the introduction explains the changes in the situation for the production of synthetic fibres owing to the oil crisis. The introduction also contains lists of the main producers of synthetics in India and the companies to which letters of intent have been issued.

The work of Engineers India Limited (EIL), the main engineering company in India, is described. The steps taken by EIL in the direction of basic engineering, especially for Nylon 6, during the last 12 months are reviewed and recommendations are made for continuing this work and for involving EIL in a pilot-plant project for SASMIRA in Bombay. The annexes indicate the scope of the engineering work to be done for a nylon plant.

## INTRODUCTION

The purpose of the project "Process Engineering (Petrochemicals and Fertilizers)" (DP/IND/71/047) was to strengthen the process-engineering manpower of India and to help in the designing of planned petrochemical, petroleum refining, synthetic fibre and fertilizer plants. The project was requested by the Government of India in July 1971 and approved by the United Nations Development Programme (UNDP) with the United Nations Industrial Development Organization (UNIDO) as executing agency. The project received a budget allocation of $80,000.

The project experts were to assist the Engineers India Limited (EIL), a Government of India undertaking under the Ministry of Petroleum and Chemicals, in training Indian engineers in process engineering. At the time the project was approved, EIL was expected to be involved in engineering work for more than 8 synthetic fibre plants of the planned 13 projects for which letters of intent had been issued. Most of the projects were intended for the production of polyamides (Nylon 6). However, there was a sharp and unanticipated increase in oil prices in 1973/74. As a result, the Government of India did not license any new synthetic fibre plants because of the tremendous shortage in both raw materials and foreign exchange. Accordingly, the project was revised and the total UNDP contribution was reduced to $33,500 in July 1975.

The situation varies for the three main areas of production of man-made fibres - polyamides, polyesters and acrylics. Polyamides are produced by seven established factories with a total licensed capacity of 25,000 tons/year for 1972, although the production in that year was only 11,000 tons. A production target for 1978/79 of 32,000 tons/year is set to meet the projected requirements.

The main producers and yearly production of nylon filament yarn are:

| Producer | Thousand tons |
|---|---|
| J. K. Synthetics Ltd, Kota | 3.84 |
| Garware Nylon Limited | 2 |
| Nirlon Synthetics, Fibres and Chemicals Ltd (Bombay) | 252 |
| Modipon Limited (Modinagar) | 2.2 |
| Century Enka Ltd (Poona) | 0.72 |
| Shree Synthetics Ltd (Ujjain) | 1.10 |
| Stretch Fibres Ltd (Nagpur) | 0.54 |

Letters of intent for a production of 2,100 tons/year each have been issued to:

Industrial Development Corporation Orissa Ltd (Bhubaneshwar, Orissa)
Assam Industrial Development Corporation Limited (Gauhati, Assam)
M.P. Audigik Vikas Nigam Ltd (Bhopal, M.P.)
Haryana State Industrial Development Corporation Ltd (Chandigarh, Haryana)
Mysore State Industrial Investment and Development Corporation Ltd (Bangalore, Mysore)
Gujarat Industrial Investment Corporation Limited (Baroda, Gujarat)
Tamil Nadu Industrial Development Corporation Ltd (Tamil Nadu)
Andhra Pradesh Industrial Development Corporation Ltd (Hyderabad, A.P.)
Kerala State Industrial Development Corporation Ltd (Trivandrum, Kerala)
Bihar State Industrial Development Corporation Ltd (Patna, Bihar)
Punjab State Industrial Development Corporation Ltd (Chandigarh Punjab)
West Bengal State Industrial Development Corporation Ltd (Calcutta)
U. P. State Industrial Development Corporation Ltd (Kanpur)

The only producer of nylon staple fibre is J. K. Synthetics Limited (Kota, Rajasthan) with a capacity of four tons/day.

It is easy for a producing company to increase its capacity simply by copying the existing machinery, whereas a new company needs a licence either bought abroad for foreign currency or from an indigenous licensor and engineering company. To bridge this gap, EIL was selected by the Government of India to establish a synthetic-fibre engineering group. EIL, a design and consultancy organization, was established on 15 March 1965 as a joint venture of the Government of India and Bechtel Corporation of the United States of America to provide process design and detailed engineering services, procurement assistance, construction supervision, commissioning assistance and related services for setting up petroleum refineries, petrochemical and chemical plants and fertilizer plants. In 1967 the Government of India bought out the shares of Bechtel so that EIL is now fully government-owned.

EIL has a total of 1,900 employees of whom approximately 500 are engineers; about 12 engineers are currently working in the synthetic fibre section.

## I. FINDINGS

The main activities of the project were to strengthen process-engineering know-how in the design of synthetic fibre plants and to train counterpart personnel in process design of synthetic fibre plants. To achieve these objectives, work covered the typical tasks and fields of engineering, e.g. preparation of basic data book, process flow sheets for several types of plants, process description for the several sections, process diagrams, and calculation of the process such as material balances and heat balances.

In addition, consideration was given to other activities that arise during the planning period, such as preparation of a general bid inquiry check-list and factors related to the selection of licensors.

As the complete engineering work for a Nylon-6 plant contains many more items than could be included in the training course (see annex I), areas of particular importance were identified and treated more intensively. Roughly 80 to 90 per cent of the total engineering work can be done by EIL directly without any outside help; it has an especially strong capability for detailed engineering if it is supported by the basic engineering work of a well-established company.

## II. RECOMMENDATIONS

To meet the anticipated future demand in synthetic fibres, appropriate steps should be taken as early as possible to further strengthen EIL capability in this field. More man-hours should be devoted to some of the synthetic fibre projects which although not yet fixed may still be considered likely to be realized in future years.

Man-hours should be spent in preparing a pilot-plant project for polyester and nylon, including the preparation of test rows which could be run in the pilot plant and the process description of all the various conditions that might materialize in order to measure the influence of several parameters.

To strengthen process-engineering know-how in the design of synthetic fibre plants it would be useful to involve EIL's engineering capacity during the planning period for the UNDP/Federal Republic of Germany pilot plant for SASMIRA. Training courses abroad and in India in connexion with that project should be implemented, if possible within the resources available for the project.

Annex I

SCOPE OF ENGINEERING WORK FOR A NYLON-6 PLANT

A. General engineering

1. Preliminary specifications of equipment and services for erection and operation of the plant.
2. Schedules, giving dates for customer's and supplier's deliveries of equipment and services.
3. Supervision of erection and start-up of the plant by supplier's personnel (after the conclusion of a separate contract for erection and start-up).
4. Erection programme, including details on erection personnel, tools and erection materials.
5. Plan for the start-up of the plant.
6. Details on personnel required for the operation of the plant.
7. Details on type and quantity of spare parts to be kept continuously on stock.
8. General instructions for installation of equipment and machinery, for piping and insulation of plant parts as well as for all tightness checks.
9. If required, recommendations for plant organization with hints for keeping an operation diary.

B. Process engineering

1. General description of the plant with explanation of the process, limits of capacity and subdivision into different plant stages.
2. Process flowsheet for production plant.
3. Diagram showing quantities of raw material input and product output, with by-products and losses.
4. Raw and auxiliary material requirements specifications for the operation of the plant.
5. Detailed process flowsheet with indication of all measuring and control points and schematic piping system for product utilities as well as raw and auxiliary materials.
6. Process schedules for plants or plant sections operated batchwise.
7. Detailed description of the process.
8. Insofar as required, detailed spin and twist tables as well as flowsheet giving quantities of intermediate and final products for the individual textile processing stages.
9. Details of transportation and transportation means within the plant, with transportation schedule.
10. Plant parts lists for the complete scope of delivery.
11. Instructions for start-up, shut-down, operation with reduced capacity, maintenance and periodical overhauls, as well as for steps to be taken in case of plant failure, including specification of operation data.

12. Methods and instructions for quality control of raw materials as well as intermediate and final products.

13. Requirement and specification of power and utilities required for the operation of the plant.

14. Peak values of power and utility supply system.

15. Recommendations for provision of emergency power supply.

16. Information on inlet and outlet of power and utilities in the different production stages.

17. Details and specification of effluents.

18. Recommendations for packaging and storage of final produot as well as for required auxiliary means.

19. Safety instructions based on local safety regulations.

C. Equipment layout

1. Preliminary sketches of items of equipment and/or data sheets with leading discussions, materials of construction, operating pressure and temperature, fare, weight, normal operating weight and overload weight.

2. Preliminary equipment layout within the preliminary building plans.

3. Final installation drawings, including all necessary ground plans and elevations.

4. Detail drawings for framing and supports for equipment items.

5. Details of openings required for the provision of flooring grids for the individual steel stagings.

6. Documentation drawings for the equipment of the suppliers delivery to facilitate spare parts identification and overhauls.

7. Individual operating instructions for equipment and maohinery to be delivered, including characteristic curves, descriptions of funotions, special instructions for assembly, operation, maintenanoe and lubrication, sectional views for spare parts lists.

## Annex II

## BASIC DESIGN DATA FOR NYLON-6 FILAMENT YARN PLANT

### A. Unit capacity

1. The plant capacity is considered as 6 tons of Nylon-6 filament yarn per day.

   Based on an onstream period of 8,000 hours per annum, the plant capacity would be 2,000 tons per annum.

2. The production programme would be according to the following product mix:

   Monofilament:

   300 tons per annum of 15 denier

   700 tons per annum of 20 denier

   Multifilament:

   600 tons per annum of 40 denier

   400 tons per annum of 76 denier

3. Monomer recovery is considered both from solid waste as well as extraction water. The capacity of monomer recovery section is based on 300 tons per annum of recovered caprolactam.

### B. Yields

1. Design of the plant is based on the production of semi-dull chips and yarn.

2. The polymerization reactor outlet stream shall have the following composition based on the conversion of monomer to polymer:

| | |
|---|---|
| Polymer | 87.5 % |
| Monomer | 12.0 % |
| Other components, e.g. $TiO_2$, $H_2O$, etc. | 0.5 % |

3. Production losses:

   (a) Solid waste:

| | |
|---|---|
| Solid waste from spinning | 2 % |
| Solid waste from take-up | 1 % |
| Solid waste from draw-twisting | 3 % |
| Monomer recovery from solid waste | 60 % |

   (b) Extraction water:

| | |
|---|---|
| Monomer concentration in extraction water | 6.5 % |
| Monomer recovery from extraction water | 80.0 % |

## Annex III

## SPECIFICATIONS OF RAW AND AUXILIARY MATERIALS AND PRODUCTS

### A. Raw and auxiliary materials

1. Caprolactam

| Specification | Unit | |
|---|---|---|
| Molecular formula | | $C_6H_{11}NO$ |
| Molecular weight | | 113.16 |
| Purity | % | 99.8 (Min.) |
| Bulk density | kg/litre | 0.6 to 0.7 |
| Melting point | °C | 68.8 (Min.) |
| Appearance | | Solid: white crystalline<br>Molten: clear liquid |
| Colour of aqueous solution[a] | APHA | 10 (Max.) |
| Permanganate number[b] | Second | 5000 (Min.) |
| Volatile bases | ppm | 8 (Max.) |
| Free bases | $cm^3/kg$ | 5 (Max.) |
| Water content | % | 0.1 (Max.) |
| Iron content | ppm | 1 (Max.) |
| Water insolubles | ppm | 10 (Max.) |
| Filtrate ignition residue | ppm | 20 (Max.) |

[a] Visual comparison of 40 % solution, calculated on a 100 % basis.
[b] 3 g of caprolactam in 100 ml water with 1 ml N/10 $KMnO_4$.

2. Glacial acetic acid

| Specification | Unit | |
|---|---|---|
| Molecular formula | | $CH_3COOH$ |
| Molecular weight | | 60 |
| Appearance | | Colourless, suspension free liquid |
| Purity | % | 99.5 (Min.) |
| Concentration | % | 99 |
| Specific gravity | | 1.055 to 1.058 |
| Melting point | °C | 16.7 (Min.) |
| Iron as Fe | ppm | 1 (Max.) |
| Sulphate as $SO_4$ | ppm | 2 (Max.) |
| Chloride as Cl | ppm | 1 (Max.) |

3. Titanium dioxide

| Specification | Unit | |
|---|---|---|
| Molecular formula | | $TiO_2$ |
| Molecular weight | | 80 |
| Type | | Anatase grade |
| $TiO_2$ content | % | 95 (Min.) |
| Specific gravity | | 3.8 |
| Refractive index | | 2.5 |
| Brightness | | good |

4. Diphyl

| Specification | Unit | |
|---|---|---|
| Content of diphenyl | % | 26.5 |
| Content of diphenyl oxide | % | 73.5 |
| Colour of the solid product | | Yellowish-white |
| Colour of the liquid | | Colourless to yellowish (clear) |
| Application in permanent operation | °C | Up to 400 |
| Boiling point at 1 atm | °C | 256-258 |
| Boiling range | °C | 1.0 |
| Solidification point | °C | 12.3 |
| Water content at 20°C | wt% | 0.02 |
| Density of the liquid at 20°C | $kg/m^3$ | 1062 |

## B. Products

### 1. Nylon-6 chips

| Specification | Unit | |
|---|---|---|
| Appearance | | Colourless |
| Dimension | | 3mm dia.x 3mm (cylindrical) |
| Solidification range | °C | 210 to 217 |
| Bulk density at 20°C | kg/m$^3$ | 680 |
| Water content | % | 0.05 (Max.) |
| Titanium dioxide content | wt% | 0 to 3 according to application |
| Dust content | % | 0.02 (Max.) |
| Hot water extractables | % | 0.50 (Max.) |
| Moisture pickup at 65 % R.H. | % | 4.5 |
| Number of black and/or coloured spots per 10g of chips | | 2 (Max.) |

### 2. Nylon-6 filament yarn

| Specification | Unit | Monofilament | Multifilament |
|---|---|---|---|
| Titre | denier | 15/1, 20/1 | 40/10, 76/20 |
| Denier variation | CV% | 3.0 | 2.5 |
| Uster Unevenness | U% | 1.5 | 1.5 |
| Tenacity at break | g/den | 5.0 | 4.5 |
| Elongation at break | % | 35 ± 5 | 35 ± 5 |
| Boiling shrinkage | % | 15 to 17 | 15 to 17 |
| Extract content | % | 2.0 | 2.0 |
| Full package weight | g | 1050 | 1050 |
| Full pirn yield | % | 80 | 80 |
| First quality yarn[1] | % | 85 | 85 |

[1] The first quality yarn is defined as full pirns without break, meeting the above specifications.

## Annex IV

### UTILITY SPECIFICATIONS

1. **Steam**

M.P. steam (saturated), $kg/cm^2g$ 12.5 ± 10 %

2. **Water**

(a) Cooling water

Type of system: Recirculating with raw water makeup

Battery limit pressure at grade-level:

| | |
|---|---|
| Supply, $kg/cm^2g$ | 5.0 |
| Return, $kg/cm^2g$ | 2.5 |

Temperature:

| | |
|---|---|
| Supply, °C | 32 |
| Return, °C | 42 |

| | |
|---|---|
| Total alkalinity, ppm as $CaCO_3$ | 100 to 120 |
| Calcium hardness, ppm as $CaCO_3$ | 300 (Max.) |
| Total hardness, ppm as $CaCO_3$ | 700 (Max.) |
| Chloride content, ppm as NaCl | 750 (Max.) |
| Silica content, ppm as $SiO_2$ | 125 (Max.) |
| Total dissolved solids, ppm | 1500 (Max.) |
| Suspended solids, ppm | 60 to 90 |
| pH value | 7.0 to 7.5 |

(b) Demineralized water

| | |
|---|---|
| Battery limit pressure at grade-level, $kg/cm^2g$ | 4.0 |
| Temperature | Ambient |
| Total hardness, ppm as $CaCO_3$ | 0.25 (Max.) |
| Total dissolved solids, ppm | 3 (Max.) |
| Silica content, ppm as $SiO_2$ | 0.20 (Max.) |
| Chloride content, ppm as Cl | 3 (Max.) |
| Iron content, ppm | 0.05 (Max.) |
| pH | 7.0 to 7.5 |
| Specific resistance at 25°C, ohm-cm | 500,000 |

(c) Chilled water

Type of system: recirculating

Battery limit pressure at grade-level:

| | |
|---|---|
| Supply, $kg/cm^2g$ | 4.0 |
| Return, $kg/cm^2g$ | 2.0 |

Temperature:

| | |
|---|---|
| Supply, °C | 10 |
| Return, °C | 16 |

| | |
|---|---|
| Total dissolved solids, ppm | 10 (Max.) |
| Total hardness, ppm as $CaCO_3$ | 0.25 (Max.) |
| Chloride content, ppm as Cl | 3 |
| Silica content, ppm as $SiO_2$ | 0.6 |
| Turbidity | 0 |
| pH | 7 to 7.5 |

(d) Service water

| | |
|---|---|
| Battery limit pressure at grade-level, $kg/cm^2g$ | 4.0 |
| Temperature | Ambient |
| Calcium hardness, ppm as $CaCO_3$ | 120 |
| Magnesium hardness, ppm as $CaCO_3$ | 160 |
| Total hardness, ppm as $CaCO_3$ | 280 |
| Alkalinity, ppm as $CaCO_3$ | 400 |
| Total dissolved solids, ppm | 750 |
| Silica content, ppm as $SiO_2$ | 50 |
| Chloride content, ppm as NaCl | 300 |
| pH value | 7 to 8 |

(e) Plant air and instrument air

| | |
|---|---|
| Battery limit pressure, $kg/cm^2g$ | 7 |
| Dew point, °C | -20 (Max.) |
| Oil content | Oil free |
| Suspended particles | None; dust free |

(f) Inert gas (Nitrogen)

| | |
|---|---|
| Pressure, $kg/cm^2g$ | 10 |
| Oxygen content: | |
| for polymerisation section, ppm | 10 (Max.) |
| for spinning section, ppm | 3 (Max.) |
| Hydrogen content | Traces |
| Dew point, °C | -20 (Max.) |

(g) Fuel oil

| | |
|---|---|
| Calorific value, kcal/kg | 10,000 |
| Kinematic viscosity at 50°C, cSt | 80 (Max.) |
| Flash point (Pensky-Martin closed), °C | 66 (Min.) |
| Sulphur content, wt.% | 3.5 (Max.) |
| Water content, wt.% | 1.0 (Max.) |
| Ash, wt.% | 0.1 (Max.) |

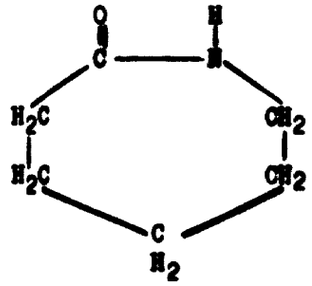
(h) Power

| | |
|---|---|
| Voltage | 420/220± 10 % |
| Frequency, Hz | 50 ± 3 % |

## Annex V

## PHYSICAL PROPERTIES OF RAW AND AUXILIARY MATERIALS AND PRODUCTS

### A. Caprolactam

| Physical property | Unit | At | | Reference |
|---|---|---|---|---|
| Molecular formula<br><br>$C_6H_{11}NO$<br>$(C_5H_{10}CONH)$ | | |  | |
| Molecular weight | | | 113.16 | |
| Appearance (salt) | | | Solid: white crystalline | 1 |
| | | | Molten: clear liquid (≤10 APHA) | 1 |
| Density of solid lactam | $g/cm^3$ | 20°C | 1.124 | 2 |
| Bulk density | $g/cm^3$ | 20°C | 0.5 to 0.7 | 2 |
| Density of molten lactam, $\rho_L$ | $g/cm^3$ | | $\rho_L = 1.075 - 7.7 \times 10^{-4}\theta$, (where $\theta$ is temperature in °C) | 2 |
| | | 80°C | 1.013 | 2 |
| | | 77°C | 1.03 | |
| Melting point, $\theta_m$ | °C | | 69.2 for pure lactam | 2 |
| | | | $\theta_m = 69.2 - 2.94$ cw (where cw is water content in %) | 2 |
| Solidification point, $\theta_s$ | °C | | $\theta_s = 69.2 - 3.57$ cw (where cw is water content in %) | 2 |
| Boiling point | °C | 1 atm | 268.5 | 2 |
| | | 100 mm | 200.0 | 3 |
| Flash point | °C | | 125 | 1 |

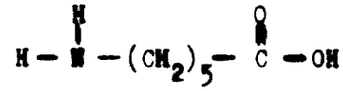
| Physical property | Unit | At | | Reference |
|---|---|---|---|---|
| Ignition point | °C | | 139 | 2 |
| Vapour pressure, P | mmHg (abs) | | $\log P = 8.90 - \frac{3,200}{T}$ (where T is temperature in °K) | 2 |
| | mmHg (abs) | 20°C | <0.1 | |
| Heat of vaporization, $\Delta H_v$ | cal/g | | $\Delta H_v = 172.6 - 0.215\ \theta$ (where $\theta$ is temperature in °C) | 2 |
| | | 268.5°C | 115 | 2 |
| Heat of solidification | cal/g | | 30 to 35 | 2 |
| Heat of fusion | cal/g | | 29 | 1 |
| Heat of combustion | cal/g | | 7,616 ± 20 | 2 |
| Heat of polymerisation | cal/g | | 33.6 | 2 |
| Heat capacity | cal/g°C | 25°C | 0.3299 | 1 |
| | | 35°C | 0.3394 | 1 |
| | | 70°C | 0.5060 | 1 |
| Viscosity of molten laotam, $\eta_L$ | cP | | $\log \eta_L = \frac{1,282}{T} - 2.70$ (where T is temperature in °K) | 2 |
| | | 160°C | 1.8 | 2 |
| | | 80°C | 8.7 | 2 |
| | | 78°C | 9.0 | 1 |
| Refractive index, $n_D$ | | 40°C | $n_D^{40} = 1.4935$ | 1 |
| | | 30°C | $n_D^{30} = 1.4965$ | 1 |
| Solubility in water | g/100 g solution | 0°C | 72 | 2 |
| | | 20°C | 82 | 2 |
| | | 25°C | 84 | 3 |
| | | 40°C | 90 | 2 |
| | | 60°C | 96.8 | 2 |

| Physical property | Unit | At | | Reference |
|---|---|---|---|---|
| Solubility in benzene | g/100 g solution | 0°C | 25 | 2 |
| | | 20°C | 43 | 2 |
| | | 40°C | 60.5 | 2 |
| | | 60°C | 78 | 2 |
| Density of solution in water, $\rho_w$ | g/cm$^3$ | 20°C | $\rho_w = 0.99 + 8.8 \times 10^{-4} C$ (where C is concentration of lactam) | 2 |
| Refractive index of solution in water, $n_D$ | | 25°C | $n_D^{25} = 1.333 + 1.66 \times 10^{-3} C$ (where C is concentration of lactam) | 2 |
| Viscosity of water | cP | 20°C | 1.43 (10%) | 2 |
| | | | 2.87 (30%) | 2 |
| | | | 4.16 (40%) | 2 |

Sources:

1. Earl D. Oliver, "Nylon-6", Report No. 41 (Palo Alto, Process Economics Program, Stanford Research Institute), p. 158, 159, 160 and 163.
2. Kunststoff-Handbuch, Band VI (Polyamide), p. 677.
3. Chemicals and Plastics Physical Properties, CMC Edition, Catalogue No. U-70 of Union Carbide.

## B. Nylon-6 chips

| Physical property | Unit | At | | Reference |
|---|---|---|---|---|
| Molecular formula | | |  | |
| Molecular weight | | | 10,000 to 20,000 | |
| Density | kg/m$^3$ | 20°C | 1,130 | |
| Bulk density | kg/m$^3$ | 20°C | 680 | |
| Melting point | °C | | 215 | |

| Physical property | Unit | At | | Reference |
|---|---|---|---|---|
| Softening point | °C | | 170 | |
| Melt viscosity | P | 250°C | 2,200 | |
| Relative solution viscosity a/, $\eta_{rel}$ | | | 2.2 - 2.6 | 1 |
| Heat capacity | cal/g °C | | 0.485 + 3.36 x $10^{-4}$T (where T is temperature in °C) | 1 |
| | | 0°C | 0.33 | |
| | | 100°C | 0.472 | |
| | | 150°C | 0.510 | |
| | | 250°C | 0.580 | |
| Heat of fusion | cal/g | 215°C | 34.5 | 1 |
| Heat of vaporisation | cal/g | | 116 | |

Source: Earl D. Oliver, "Nylon-6", Report No. 41 (Palo Alto, Process Economics Program, Stanford Research Institute), p. 157 and 161.

a/ The relative solution viscosity is determined as solution in sulphuric acid and is related to the average molecular weight by the equation:

$$Mw = 11,300\ (\eta_{rel}-1)$$

## C. Diphyl

Diphyl is an eutectic mixture of 73.5% by weight of diphenyloxide and 26.5% by weight of diphenyl. It has virtually one single boiling point and one single solidification point. Other properties of diphyl are listed below.

| Physical property | Unit | At | |
|---|---|---|---|
| Chemical formula of diphenyl | | | $C_6H_5-C_6H_5$ |
| Chemical formula of diphenyl oxide | | | $C_6H_5-O-C_6H_5$ |
| Molecular weight of diphenyl | | | 154 |

| Physical property | Unit | At | |
|---|---|---|---|
| Molecular weight of diphenyl oxide | | | 170 |
| Mean molecular weight of diphyl | | | 165.76 |
| Colour of solid product | | | Yellowish-white |
| Colour of liquid | | | Colourless to yellowish (clear) |
| Odour | | | Geranium |
| Miscibility with water | | | Practically nil |
| Application in permanent operation | | °C | Up to 400 |
| Boiling point | °C | 1 atm | 256 to 258 |
| Boiling range | °C | | 1.0 |
| Solidification point | °C | | 12.3 |
| Water content | wt% | 20°C | 0.02 |
| Flash point | °C | | 115 |
| Fire point | °C | | 138 |
| Ignition temperature in air | °C | | 615 |
| Ignition temperature in oxygen | °C | | 550 |
| Ignition group | | | $G_1$ |
| Lower explosion limit of vapour in air | vol% | | 101 |
| Upper explosion limit of vapour in air | vol% | | 3.47 |
| Density of liquid | $kg/m^3$ | 20°C | 1,062 |
| Density of vapour | $kg/m^3$ | 1 atm | 3.8 |
| Vapour pressure | $kg/cm^2$ | 400°C | 11.3 |
| Heat of vaporisation | kcal/kg | 1 atm | 69 |
| Specific heat of liquid | kcal/kg °C | 20°C | 0.38 |
| Thermal conductivity of liquid | kcal/m h °C | 20°C | 0.12 |
| Dynamic viscosity of liquid | cP | 20°C | 4.34 |
| Kinematic viscosity of liquid | cSt | 20°C | 4.04 |
| Dielectric resistance | | 20°C | 3.30 |
| Electric resistance | ohm-cm | 20°C | $1.35 \times 10^{11}$ |
| Gross calorific value | kcal/kg | | 8,970 |
| Net calorific value | kcal/kg | | 8,650 |

## Annex VI

## PROCESS DESCRIPTION

### A. Monomer melting

Flaked lactam is charged into a melting tank through the feeding device fitted with a built-in lump crusher to break any lumps of lactam if formed during storage. A fan in the feeding device removes any dust formed. The melting tank is jacketed for hot water heating and provided with an inner steam heating coil. Lactam is melted in an inert atmosphere of nitrogen to prevent oxidation.

Molten lactam is pumped into the mixing tank through a basked type filter to remove any foreign matter. Catalyst and stabilizer are charged to the mixing tank where the agitator provides for intimate mixing. The stabilized caprolactam is discharged to the rundown tank through a filter. As the lactam has to be kept under a nitrogen blanket, the lactam melter, mixing tank and rundown tank are all connected to a compensation vessel, maintained under a specified nitrogen pressure to compensate for level changes in the tanks. The run down tank serves as a surge vessel for subsequent continuous feed to the V.K. tube reactor.

All the tanks and lines handling molten lactam are jacketed for hot water heating. The hot water circulation system consists of an expansion vessel, circulation pumps and heat exchanger for steam heating of the hot water. Return water from jackets of tanks and lines is pumped through the heat exchanger to control temperature of the circulating water which goes to the jackets of the tanks and lines.

### B. Delustrant preparation

Titanium dioxide, used to control lustre in the yarn is prepared in a separate system. It consists of a $TiO_2$ preparation tank and a colloid mill for microgrinding of $TiO_2$. $TiO_2$ suspension is prepared with distilled water and some quantity of lactam and chemicals to impart stability to the emulsion. After suspension has achieved the desired particle size of $TiO_2$, it is transferred to $TiO_2$ surge tank through mixing and settling tank which removes oversized $TiO_2$ particles. The surge tank is kept under agitation.

Predetermined quantities of the stabilized lactam and the $TiO_2$ suspension are pumped to the mixing chamber of the V.K. tube reactor by two component metering pumps from where it is continuously fed to the V.K. tube polymerization reactor.

## C. Polymerization

The process for polymerization is a continuous one. The polymerization takes place under atmospheric pressure. The V.K. tube is a jacketed stainless steel column divided into four parts and connected by flanges. The upper two sections are heated by diphyl in the jackets by electric immersion heaters located directly at the reactor jacket. The lower parts of the V.K. tube reactor are heated by diphyl circulation system consisting of diphyl pumps and heaters. All the diphyl jackets are connected to the expansion vessels which are blanketed with nitrogen.

A small distillation column and a reflux condenser are provided at the top of the V.K. tube reactor. Water vapours leaving at the top of the reactor carry some lactam vapours. The lactam content gets fractionated in the distillation column. A portion of the vapours is condensed in the reflux condenser and sent back as reflux. The remaining water vapours are condensed in a separate condenser. The condensed water is discharged through to a receiver which acts as a seal against the atmosphere.

The melt flows through the tube continuously, running down on baffles. The residence time in the reactor is roughly twenty hours. The polymer outlet at the lower part of the reaction is fitted with metering pumps. The pumps deliver the polymer to the spinning head through a diphyl jacketed pipe. The pumps are coupled to the adjustable drives which provides for a control of polymer discharge from the V.K. tube. The polymer gets filtered in the spin packs and is extruded in the form of spaghettis through spinnerets. The spaghettis pass through a cooling pan containing demineralized water. The temperature of cooling pan water is controlled by means of a recirculation system consisting of a pump and heat exchanger.

The strings are drawn off via a squeezing (take off) device and fed to the chip cutter. A roller pulls the strings in the cutter and they are out by the blades into chips of about 2 to 3 mm. The chips from the cutter are led to chip silo from where they are fed to the extractor.

## D. Chip washing and drying

At polymerization equilibrium about 90 % of monomer is converted to polymer. The rest of 10 % consists, mainly, of the monomer and some cyclic dimers and trimers. The unreacted monomer and other low molecular components should be extracted in order to avoid difficulties in spinning and yarn processing operations. This is done by boiling water extraction. The extraction is carried out in three stages by a counter current cycle.

The water for extraction is supplied from three tanks by a free flow pump and the hot water temperature is maintained by the heat exchanger. The washing is started with the maximum monomer enriched water from previous batch and ends with fresh demineralized water. In this way every batch of chips is washed thrice. After each washing, water is transferred to the next tank. Monomer enriched water, from the final tank, is sent for recovery of monomer.

The chips, after washing, are pneumatically conveyed to the batch centrifuge where their moisture content is reduced to less than 1 %. Centrifuged chips are transferred to intermediate storage silos from where they are charged into jacketed vacuum drier. The chips must be completely free of moisture (0.1% max. allowable moisture) as the presence of moisture causes breakages during filament spinning. The jacket of the drier is supplied with hot water from a circulation system consisting of a surge tank, a heat exchanger and a pump, and it maintains drier temperature at 90° to 95°C. Vacuum to the drier is applied by low and high vacuum pumps and the final vacuum is of the order of 1.0 torr.

An oil scrubber in the vacuum system prevents chips powder/dust from getting into the vacuum pumps. After drying, chips are pneumatically conveyed to the chips silos. Pure nitrogen is used as the medium for conveying. The conveying system consists of the lift gas blower, dust catcher, filters and coolers. The chips from the storage silos are pneumatically conveyed to the extruder feed silos for spinning the filament yarn.

## E. Spinning

The dried chips are fed to horizontal extruders via chips feed silos, kept free of oxygen by purging with pure nitrogen. The screw casing in the extruder is electrically heated in independent zones and kept at uniformly

constant temperatures. The molten, homogeneously mixed polymer, is supplied to the spinning boxes by distribution pipes. The spinning box houses the metering pumps which supply the polymer melt to the spinnerets through spin packs for filtering the melt. The melt comes out of the spinnerets in the form of filaments. The holdup time in the distribution pipes, spinning boxes etc. is short and constant from one spinning position to the other which is important for similar characteristics of all the filaments. The melt solidifies as the filaments come into contact with the nitrogen flowing co-currently in the blow ducts. The nitrogen in the ducts is blown at definite velocity, temperature and humidity. Crystallinity in the yarn is dependent on the rate of cooling in the blow ducts. The uniform treatment is very essential for good denier consistency.

The filaments are drawn off, after passing through spinning tubes, by the take-up machine. Before being wound up on take-up bobbins, spin finishes are applied by finish rolls to the yarn to give the filaments antistatic properties, smoothness, adhesiveness and adequate moisture pick up. The finish solutions are made in a separate system and are supplied to the finish rolls by a circulating system.

Godets, drive rolls and traverse motion for making yarn packages in the take-up machines are driven at very uniform speeds with the help of synchronous motors. The speeds are controlled by frequency converter sets.

The filament take-up bobbins are retained in a conditioned room for 12-16 hours for yarn conditioning, before sending to the draw twister for stretching of the yarn.

## F. Draw twisting

The take-up bobbins carrying undrawn yarn are loaded onto the draw twisting machine. The filaments are cold stretched and are drawn approximately four times to obtain longitudinal orientation of the molecular chains. The stretching is carried out at controlled temperature and humidity. During this process the yarn gets its specific strength and elongation properties.

After being drawn off the bobbin, the yarn runs through a thread guide and tension bars for adjustments of tension in the yarn. The yarn then passes through the feed roller and goes to the chromium plated godet. This region between the feed roller and the godet is the drawing zone. A mechanical pull

is exerted because of the difference in speeds of the feed roller and the godet. The yarn is then taken-up on a rotating cop. The build up of the cop is regulated by a traverse mechanism of the ring rails. A traveller, through which the yarn passes before being wound up on the cop, runs circumferentially on the ring and gives a uniform package build up.

G. Caprolactam recovery section

The polymerization waste from spinning, take-up and draw twisting sections together with a non-volatile acid, like phosphoric is charged in lots in a depolymerization reactor where it is treated with superheated steam. The steam promotes depolymerization, vaporizes reconstituted caprolactam and acts as a carrier for the vapour. The vapour is condensed, and stored in a tank. If necessary, it is treated with potassium permanganate ($KMnO_4$) which helps in improvement of permanganate number in the recovered lactam. The treated solution is filtered and collected in an intermediate tank and then sent to a three stage evaporator.

The wash water from the extraction section is received in a separate tank and pumped to the three-stage evaporator. The wash water and depolymerized solution are evaporated either together or separately, depending upon the quality of the depolymerized solution and the product specifications desired. It is concentrated to a 70 % lactam solution in the evaporator and then treated with NaOH solution which acts as a stabilizer during distillation. The treated solution is transferred to the distillation still which is operated batch-wise and under vacuum and is heated by steam coils.

The distillation is carried out in four cuts. The first cut is collected up to 110°C. It is mainly water and is drained out. The second cut is collected between 110°C and 115°C. It is mainly water along with some quantity of lactam. When the temperature becomes steady at 115°C, pure laotam starts coming out and is transferred to the jacketed lactam tank under nitrogen blanketing. When the temperature starts rising again the fourth cut is collected which is lactam with some oligomers. This operation is carried up to 165°C after which the portion remaining in the still, which is mainly unconverted polymer, is drained out.

The second and fourth cuts are mixed with the next batch. Pure lactam from the lactam tank is passed to the powdering machine where it solidifies on a cooled roller and is powdered. The powdered lactam is filled up in bags, weighed and transferred to the polymerization section.

## Annex VII

## EQUIPMENT LIST FOR NYLON-6 PLANT

| Number required | Description | Material |
|---|---|---|
| | A. Monomer melting | |
| 1 | Feeding device with built-in lump crusher | SS |
| 1 | Lactam melter jacket for hot water heating, inner steam heating coil | SS with CS jacket, SS coil |
| 2 | Lactam pumps centrifugal type, jacket for hot water heating | SS with CS jacket |
| 2 | Lactam filters basket type, filter jacket for hot water heating | SS with CS jacket, SS wire mesh |
| 1 | Mixing tank jacket for hot water heating, with agitator | SS with CS jacket, SS agitator |
| 1 | Compensation vessel jacket for steam heating | SS with CS jacket |
| 1 | Sealing tank | CS |
| 1 | $TiO_2$ preparation tank, with agitator | SS |
| 1 | Colloid mill for micro grinding, with sealing liquid system and built-in drive | SS |
| 1 | $TiO_2$ mixing and settling tank, with agitator | SS |
| 1 | $TiO_2$ surge tank, with agitator | SS |
| 2 | Two-component metering pumps for proportioning of lactam and $TiO_2$ suspension, jacket for steam heating, with DC-drive and electrical control for the DC motors | SS |
| 1 | Run down tank, jacket for hot water heating | SS with CS jacket |
| 1 | Metering tube jacket for hot water heating | SS with CS jacket |
| 1 | Mixing chamber jacket for hot water heating | SS with CS jacket, SS internals |
| 2 | Hot water circulation pumps (1 (stand by) | CS |
| 1 | Heat exchanger for hot water system | CS |
| 1 | Expansion vessel for hot water system | CS |
| 1 | Dust exhaust fan | SS |
| 1 | Lactam filter, with jacket for hot water heating | SS with CS jacket, SS wire mesh |
| | B. Polymerization | |
| 1 | V.K. tube with internals to guide the melt flow, diphyl heated by heat exchangers flanged between the V.K. tube sections and by heating jackets | SS with CS jackets, SS internals |
| 1 | Overhead distillation column filled with rasching rings | SS |

| Number required | Description | Material |
|---|---|---|
| 1 | Vapour condenser | Shell-side SS, tube-side CS |
| 1 | Reflux condenser | SS |
| 1 | Seal pot | SS, glass |
| 3 | Metering pumps precision gear pumps, jacket for diphyl heating | CS, special steel |
| 3 | Slide valves for the spinning pumps | SS |
| 3 | Pump shafts (1 spare) for the spinning pumps, complete with shear pin and coupling | CS |
| 2 | Adjustable drives with DC motors, including electrical control for the DC motors | |
| 1 | Diphyl storage tank with internal coil for steam heating | CS |
| 1 | Diphyl condenser | CS |
| 1 | Diphyl feed pump, centrifugal type | CS |
| 3 | Diphyl heaters for electrical heating | CS |
| 3 | Expansion vessels for diphyl cycles | CS |
| 1 | Spaghetti spinning head, for 2 spinneret packs, jacket for Dowtherm heating | SS with CS jacket |
| 4 | Spinneret packs with distribution plates and spinnerets | SS |
| 1 | Cooling pan, for cooling strands from 2 spaghetti spin packs | SS, CS frame |
| 1 | Take-off device, complete with drive and infinitely variable gear | SS, CS |
| 2 | Chip cutters, complete with drive and infinitely variable gear | SS, CS |
| 1 | Quench water cooler | Shell-side SS, tube-side CS |
| 2 | Quench water circulation pumps, centrifugal type | SS |
| 5 | Diphyl circulation pumps, canned motor pumps | CS |
| | C. Discontinuous extraction | |
| 2 | Chip silos | SS |
| 1 | Extractor, with internals for guiding the chip flow and a steam heating jacket at the vessel bottom | SS |
| 2 | Free flow pumps | SS |
| 1 | Centrifuge | SS |
| 2 | Chip silos | SS |
| 4 | Extraction water tanks | SS with CS jacket |

| Number required | Description | Material |
|---|---|---|
| 2 | Lactam water pumps, centrifugal type | SS |
| 1 | Heat exchanger | Shell-side CS, tube-side SS |
| 1 | Chips silo | SS |
| 1 | Cyclone | SS |
| | D. Chip drying, transportation and storage | |
| 2 | Tumbling driers, 16 $m^3$ volume, with special gear motor | SS, CS |
| 1 | Oil scrubber, with heating device and a bed of rasching rings | CS |
| 1 | Oil pump of special design | CS |
| 1 | Low vacuum pump, roots type | CS |
| 1 | Condenser, with condensate collecting vessel | CS |
| 1 | High vacuum pump, rotary oil seal type | CS |
| 1 | Heat exchanger | CS |
| 2 | Hot water circulation pumps | CS |
| 1 | Expansion vessel | CS |
| 1 | Gate valve for emptying the chips out of the drier, special vacuum-tight design | SS |
| 2 | Liftgas blowers, roots type, complete with motor, belt drive, silencers, compensator, safety valves for over and under pressure | CS |
| 1 | Dust catcher, with gear motor for change of the filter bags | SS<br>CS |
| 1 | Liftgas filter before blower | CS |
| 1 | Liftgas filter after blower, candle filter type | SS, Al, CS |
| 1 | Liftgas cooler for cooling | CS |
| 3 | Rotary gates below the chip silos, complete with gear motor | SS |
| 7 | Pipe switches, piston operated (pressurized air of 5 to 8 atm) with operating pistons and limit switches | SS |
| 9 | Cyclones at the inlets of 3 storage silos and 6 extruder feed silos | SS |
| 3 | Chip storage silos | SS |
| | E. Spinning | |
| 6 | Extruder feed silos | SS |
| 6 | Connection pieces between extruder feed silos and extruders | SS |

| Number required | Description | Material |
|---|---|---|
| 6 | Extruders (melting capacity approx. 105 kg/hr) electrically heated, pressure controlled, cooled chips feeding system, including drive and motor, control center and measuring head | Barrel lined with X-alloy, CS |
| 6 | Melt distribution pipes, for distribution of melt to 4 spinning boxes each | SS with CS jacket |
| 24 | Spinning boxes, each equipped with two spinning positions, provided for Dowtherm heating | SS with CS jacket |
| 6 | Spinning pump main drives with DC motor, gear, connection shaft and coupling, each to drive 8 spinning positions (16 quadruple spinning pumps) | |
| 3 | Dowtherm evaporators for electrical heating | CS |
| 48 | Blow ducts | Al, CS |
| 48 | Spinning tubes | Al, CS |
| 3 | Take-up machines for textile yarn, double-sided design, equipped with traverse motion system<br>Each machine has 8 spinning positions per side, 16 in total, separate drive for finishing and moistening, also separate for each side and includes:<br>Generator set for godets, drive rolls and travers motion system.<br>One additional generator set for machine 3 for different take-up speed on each side.<br>One additional set of change parts for the traverse motion system of one side for machine 3 to change the winding from multifilaments to monofilaments. | |
| 144 | Spinning accessories comprising quadruple spinning pumps 4 x 0.6 $m^3$/rev (96 in operation, 48 stand by) | |
| 384 | Spinnerets, 50 mm ∅, 10 holes (round) to den (max. 192 in operation, 192 stand by) | |
| 384 | Spinnerets, 50 mm ∅ holes (round) for 15 and 20 den (max. 192 in operation, 192 stand by) | |
| 64 | Spinnerets, 70 mm ∅, 34 holes (round) for 100 den and 70 den (max. 32 in operation, 32 stand by) | |
| 100 | Spinneret packs for 2 spinnerets 70 mm ∅ (max. 16 in operation, 16 stand by)(alternatively 64 spinneret packs for 1 spinneret) | |
| 1 | Preheating oven for pumps and spinnerets | |
| 3 | Precision scales, 0-100 g | |
| 1 | Air velocity meter | |
| 4 | Stop watches | |

| Number required | Description | Material |
|---|---|---|
| 2 | Revolution counters, 0-1,000 rev./min. | |
| 1 | Communication system between spinning and take-up | |
| 4 | Table scales, 0 - 10 kg | |
| 1 | Set of operating tools (hooks, scrapers, etc.) | |
| 4 | Assembly fixtures for spinneret packs | |
| 2 | Assembly fixtures for spinning pumps | |
| 1 | Complete set of general and special tools for spinning plant | |
| 1 | Spinneret testing device | |
| 4,500 | Sets of filters and gaskets | |
| 8,000 | Take-up bobbins | |
| 20 | Spray-cans for spinnerets | |
| | Molykote paste, 4 kg | |
| 1 | Finishing and wetting system, complete with 3 preparation tanks for finish oil and 3 preparation tanks for moistening emulsion | |
| | F. Draw-twisting | |
| 17 | Draw-twisters for textile filaments, each with 156 stretching positions, complete with machine frame, drive with transmission gears, bobbin holders, inlet filament guide, feeding mechanism, draw godets, hydraulic ring-rail motion | |
| | Draw-twister accessories | |
| 102 | Sets of change gear wheels for draw ratio (6 sets/machine) | |
| 85 | Sets of change gear wheels for draw-twisting speed (5 sets/machine) | |
| 51 | Change pulleys for spindle speed (3/machine) | |
| | 3,000 run-off covers | |
| 1 | Lubrication device for spindles | |
| 20 | Electrically heated waste cutting knives | |
| 10 | Traveller pixers | |
| 1 | Set special tools | |
| 1 | Spindle band sewing machine | |
| 1 | Waste cutting unit | |

| Number required | Description | Material |
|---|---|---|
| | G. Caprolactam recovery section | |
| 2 | Steam superheaters | SS |
| 1 | Depolymerization reactor | SS |
| 1 | Condenser cum cooler | SS |
| 1 | Raw monomer receiving tank | SS |
| 2 | Transfer pumps | SS |
| 1 | Mixing vessel with agitator | SS |
| 1 | Treatment tank with agitator | SS |
| 2 | Filter feed pumps | SS |
| 1 | Filter | SS |
| 1 | Intermediate tank | SS |
| 2 | Transfer pumps | SS |
| 1 | Wash-water receiving tank | SS |
| 2 | Wash-water feed pumps | SS |
| 1 | Three stage evaporator | SS |
| 1 | Concentrated solution storage tank | SS |
| 2 | Concentrated solution transfer pumps | SS |
| 1 | Shell and tube condenser | CS |
| 1 | Mixing vessel with agitator | CS |
| 1 | Treatment tank with agitator | SS |
| 1 | Distillation still, with heating coil and jacket | SS with CS jacket and SS coil |
| 1 | Distillation overhead condenser | SS |
| 1 | Protective condenser | SS |
| 2 | Intermediate jacketed tanks | SS with CS jacket |
| 1 | Multi-stage steam jet ejector system | CS |
| 1 | Sealing tank | CS |
| 2 | Recovered lactam pumps | SS |
| 2 | Jacketed lactam tanks | SS with CS jacket |
| 1 | Powdering machine | SS |
| 1 | Flash drum | CS |
| 1 | Distilled-water tank | CS |
| 1 | Distilled-water transfer pump | CS |
| 1 | Bagging and weighing machine | CS |

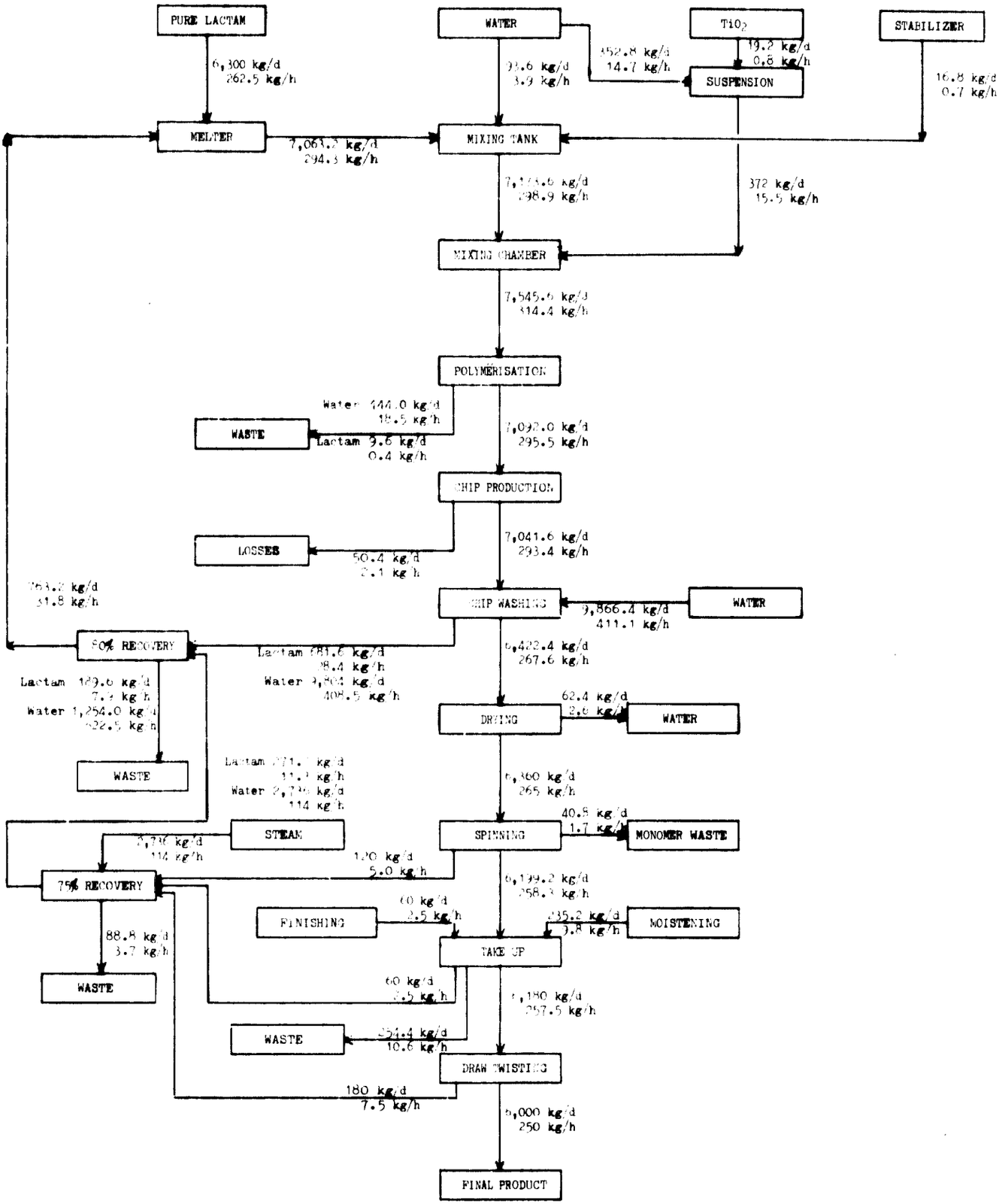
| Number required | Description |
|---|---|
| | **H. Auxiliary units** |
| 1 | Nitrogen purification unit, complete with nitrogen storage tank purification system, pressure reducer, oxygen tracer, switchboard with hydrogen analyser |
| 1 | Complete cleaning unit for cleaning spinning pumps and spinneret packs |
| | **I. Textile laboratory** |
| 1 | Analytical balance, weighing range: 0-1000 g, accuracy: 10 mg |
| 1 | Microscope, binocular, with object micrometer, graduated dial and objective revolver<br>objective 3.2/012<br>10/0.25<br>40/0.65<br>ocular 10 x<br>ocular 6 x |
| 1 | Microtome |
| 2 | Precision yarn reels with meter control, reel circumference: 1 m, with 5 reeling positions |
| 1 | High-speed scale for table mounting, weighing range: 0-10 kg |
| 3 | Denier balances, weighing range: 0-100 den<br>filament suspension: 90 m |
| 2 | Precision yarn reels, motor driven, with meter control, reel circumference: 1 m, with 5 reeling positions, draw-off device for pirns |
| 1 | Automatic strength tester, with multiple bobbin attachment |
| 1 | Yarn evenness tester (seriplane), motor driven, with winding boards 600 x 260 x 160 mm |
| 5 | Winding boards 600 x 260 x 160 mm |
| 1 | Electronic "USTER" evenness tester, model C, with rotafil and integrator |
| 1 | Research microscope, binocular, with polarizator and analysator lenses, objective revolver and complete attachment for camera<br>objective: 6.5/0.18 3.5/10<br>11/0.25 10/25<br>11/0.45 40/65<br>ocular 6 x<br>ocular 10 x |
| 1 | Torsion precision scales, weighing range: 0-50 mg |
| 2 | Mechanical filament tension meters, range: 1-12 g |
| 2 | Mechanical filament tension-meters, range: 5-50 g |
| 1 | Stroboscope for 600-14,000 rev/min. |
| 1 | Densimeter for 0-100° shore-hardness |
| 1 | Balance for table mounting, range 0-10 kg, with high speed |

| Number required | Description |
|---|---|
| 4 | Sets, preparation and lancet needles |
| 300 | Specimen holders 76 x 26 mm |
| 300 | Coverslips 18 x 18 mm |
| 300 | Coverslips 18 x 36 mm |
| 20 | Bottom dies 80 x 25 mm, 6 holes 0.8 mm diameter |
| | J. Chemical laboratory |
| 1 | Melting point apparatus, with test tubes |
| 12 | Colour comparison tubes with shadowless bottom, 10 ml volume (Nessler tubes) |
| 1 | Constant temperature bath for 20°C |
| 5 | Reitmeier tops of special design |
| 5 | Liebig condensers |
| 5 | Absorption receivers to Fresenius of special design |
| 3 | Magnetic stirrers |
| 15 | Teflon stirring bars |
| 3 | Hydrometers, range 1,000-1,070 °Bé |
| 2 | Acid pumps |
| 3 | Stirrers with motor |
| 1 | pH meter with electrodes, with temperature compensator |
| 3 | Platinum dishes, 8-9 cm diameter |
| 1 | Photometer, Elko II, complete |
| 2 | Filters 490 Nm |
| 5 | Bulbs, depth of bed 2 mm |
| 1 | Muffle furnace |
| 1 | Analytical balance, Model 5B, Mettler |
| 1 | Karl Fischer titrator, complete, with one spare electrode unit |
| 30 | Titration cells |
| 2 | Pipet filling attachments |
| 1 | High speed incinerator |
| 1 | Hot-plate for Erlenmeyer flask |
| 20 | Suepension cylinders |
| 1 | Immersion refractometer, Zeiss, with Prism 1 (not temperable), range 1.325-1.366, complete, with a spare prism and 20 refractometer glasses |

| Number required | Description |
|---|---|
| 1 | Constant temperature bath for tempering the flasks |
| 1 | Constant temperature bath for immersion, refractometer with thermometer, with a joint scale for 0-50°C, length of stem 10 cm, 1/10 graduation |
| 1 | Shaker |
| 10 | Ubbelohde viscosimeters II, diameter of capillary approx. 1 mm |
| 10 | Metal frames for viscosimeters |
| 1 | Viscosimeter, constant temperature batch with 5 suspension |
| 1 | Diagonal cutting pliers or mill to disintegrate the chips |
| 10 | Extraction apparatuses, complete |
| 10 | Attachments for the recovery of the petroleum ether |
| 25 | Squibb funnels, 250 ml, with ground stopper |
| 3 | Water baths, with 4 heating points |
| 12 | Support rings, split type, 10 cm diameter |
| 2 | Clocks, interval timers, for 60 minutes |
| 5 | Desiccators for 5 flasks, approx. I.D. 300 mm |
| 3 | Drying ovens |

Annex IX

BALANCE OF MATERIAL[a/]




a/ Source: Engineers India Limited, New Delhi.

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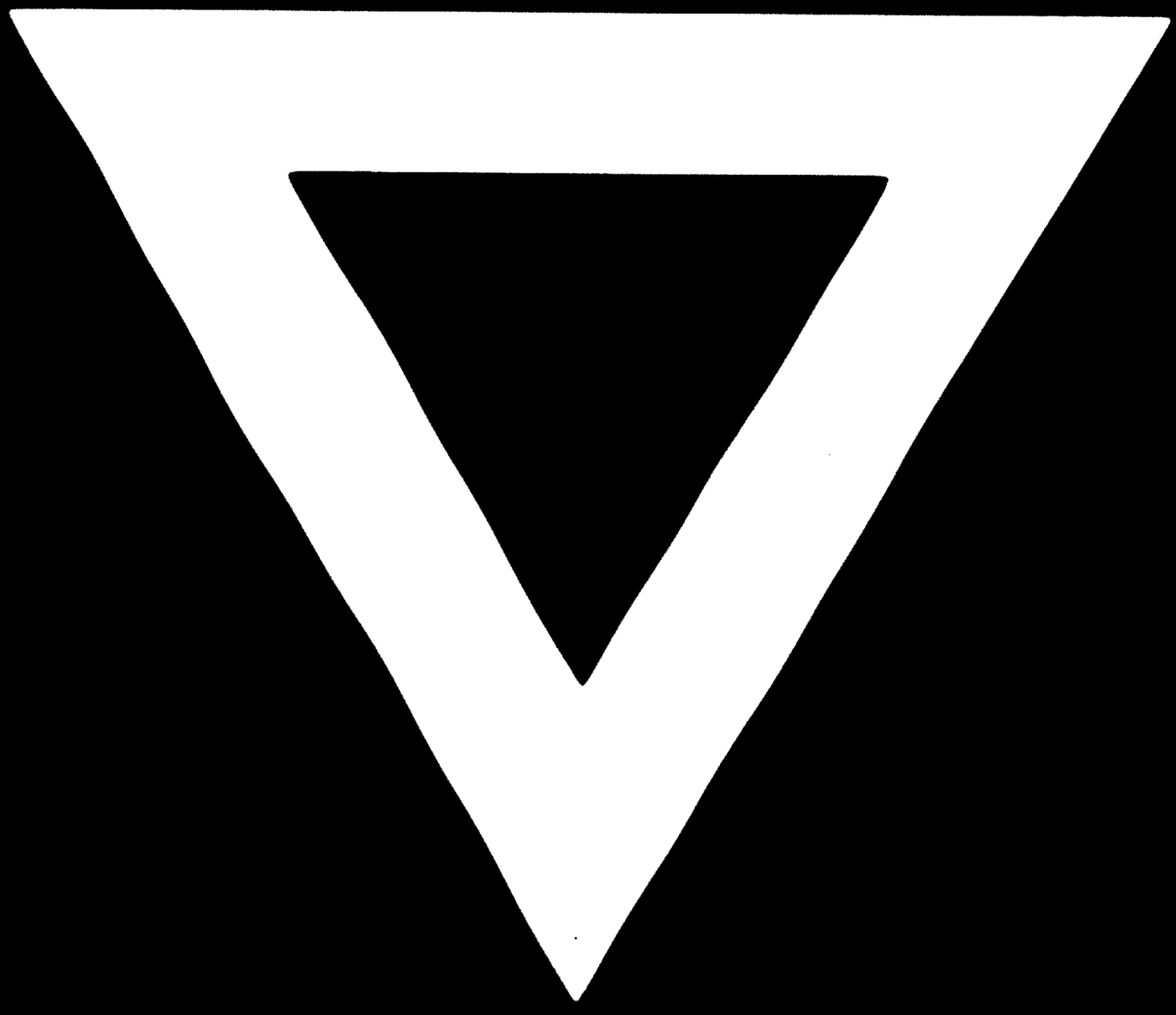

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