EXECUTIVE SUMMARY

E.1.0 INTRODUCTION

E.1.1 Product and Applications

Polypropylene (PP) is a thermoplastic material and was first produced in 1957 by Gulio Natta in Italy. It is produced by polymerization of propylene in presence of the Ziegler-Natta type catalysts. Only crystalline (isotactic) form of polypropylene is of commercial importance. PP is available as a homopolymer (PPHP) and copolymer (PPCP) of ethylene-propylene comonomers. The copolymer may further be random copolymer in which ethylene is randomly distributed in the polymer matrix or as a block copolymer in which blocks of ethylene and propylene are attached to the main chain. Block copolymers are also known as impact copolymers.

PP is a very versatile polymer having low density (0.89 gm/cc) and superior rigidity amongst various thermoplastic materials. Its superior strength to weight ratio, combined with resistance to chemicals, and thermal stability has rendered the plastic as most popularly used after polyethylene and polyvinyl chloride.

Commercial grades of polypropylene homopolymers are available in a wide variety with the melt flow index varying from 0.5 to 70 MFI. The copolymers are also available in this range and have an ethylene content of upto 25%. These grades have superior, low temperature impact strength and improved clarity over PP homopolymers.

Polypropylene has a wide range of application in packaging, home products, consumer goods, automotive products, industrial products, textile yarns, fibres and fabrics. Polypropylene can be processed into a wide variety of end products using commonly used plastic processing techniques such as injection moulding, blow moulding, extrusion, compression moulding and thermoforming.

Some of the popular applications of polypropylene are for films, fibres and filaments, injection moulded goods and extruded sheets, profiles and pipes. Films are either Tubular Quenched or Biaxially Oriented and are mainly used for packing food products, textiles, garments, cigarettes, etc. In the fibre and filament sector, PP filament yarns and staple fibres are very popular for carpet yarns, carpet backing, upholstery, apparels, filter cloth, disposable diapers, automotive interiors, etc. Injection moulded products, especially in automotive, electronics and office automation, furniture and domestic appliances sectors, are very popular.

E.1.2 Manufacturing Processes

The manufacturing process for polypropylene can be classified into three categories based on the phase in which reaction takes place.

A. Solution Polymerization

B. Slurry Phase Polymerisation

1. Loop reactor process
2. Stirred tank heavy diluent process
3. Boiling monomer process

C. Gas Phase Polymerisation

1. Fluid bed process
2. Mechanically agitated process

Amongst the processes mentioned, solution polymerisation process and the stirred tank heavy diluent process are obsolete and existing production capacities using these processes are being revamped for using other competing technologies. The loop reactor process and gas phase process are popularly used.

A. **Solution Polymerization** : This process uses the first generation of catalysts which have poor productivity and selectivity to crystalline polymers. The polymerization is carried out in a series of stirred tank reactors containing liquid propylene, heavy hydrocarbon diluent and catalyst. The resultant slurry is flash concentrated to remove unreacted propylene. The polymer is filtered, dried and extruded in a pellet form. The diluent is recovered in the process and purified by atactic polymer (amorphous) removal and recycled back in the reactors. Propylene from flash concentration also has to be purified before recycle. This process is unsuitable for block copolymier production. Disadvantages of the process include poor monomer conversion ratio due to high atactic polymer formation, high catalyst residuals in the polymer which must be deashed, and high utilities consumption due to diluent recovery, purification and recycle steps.

B. **Slurry Phase Heavy Diluent Polymerisation** : In this process, two jacketed stirred tank reactors are used in series. The reaction is carried out in hexane/heptane heavy diluents. Reaction is carried out at 75°C and 240 psi pressure. The resultant slurry is flashed, centrifuged and purged with nitrogen before drying in fluidized bed dryers. The powder is subsequently mixed with additives and pelletized.

Loop Reactor and Boiling Monomer Polymerisation : The loop reactor process involves a series of loops for carrying out polymerisation while the boiling monomer process involves a simple stirred tank reactor. Though the boiling monomer process has a simple reactor design, it has a very complex reaction medium (3 phase system due to boiling monomer). Both the processes involve a second gas phase reactor for block copolymer production. The reaction is carried out in liquid propylene medium itself and High Yield, High Stereospecificity (HYHS) catalysts are employed. Reaction is usually carried out at 75^{o}C and 650 psi pressure. The heat of reaction is removed by condensing and recycling propylene to the reactor. The slurry is flashed and volatiles, after purification are recycled to the process. The polymer is purged and dried before pelletization. For block copolymer production, the slurry from first reactor is transferred to a gas phase reactor where ethylene is added in controlled ratio. Reaction is carried out at lower temperature and pressure (60^{o}C and 240 psi pressure). Block copolymerisation can also be carried out in the loop reactor itself. Subsequent operations are similar.

C. Gas Phase Process : Commercial gas phase processes involve either a fluidized bed reactor, vertical stirred reactor or a horizontal stirred reactor. Polymerisation is carried out in the gas phase at 50- 105^{o}C and 350-550 psi pressure, depending on the polymer grades. The catalyst employed is usually a HYHS 3rd generation catalyst. The process is suitable for homopolymers as well as copolymer production. A second gas phase reactor is usually added in series for block copolymer production, where ethylene is added. For random copolymers, ethylene-propylene stream is reacted in the first reactor itself.

E.1.3 Catalyst

Catalysts are very important in PP polymerisation as they control the reaction rate and stereo-specificity of the polymer. They are usually modified titanium chloride or supported (inorganic support) titanium compounds. Several co-catalysts and additives are required to prepare the final catalyst system. Three generations of catalysts have been developed, starting with a very poor activity of 0.5 kg PP/gm and isotactic index of less than 90% to 30-40 kg PP/gm and 99% isotactic index. A Number of companies such as Himont, Solvay, Mitsui, Shell, BASF, Toho, Phillips, Amoco, etc. are involved in catalyst development.

E.1.4 Pollution Hazards

Most processes have adequate built in safety and alarm facilities in case of gaseous leaks or power failures. Ethylene and propylene are highly flammable and suitable steps have to be taken in their storage and handling. There are two main sources of pollutants in the PP process viz. polymer lumps produced in the extrusion step, and liquid effluents from steaming/drying operations. The liquid effluents are treated before discharging while the polymer lumps may be combusted or sold.

E.2.0 INDIAN INDUSTRY STATUS

E.2.1 Polypropylene is the fourth most popularly consumed thermoplastic in India after LDPE/LLDPE, HDPE and PVC. It was first produced in India by Indian Petrochemicals Corporation Limited (IPCL) at Baroda in 1978-79. There was a lag of 21 years between India and the first plant commissioned abroad. In spite of this, there has been a healthy growth in consumption of PP over the last decade. Production and import figures are given in next page.

PRODUCTION,IMPORTS & CONSUMPTION OF POLYPROPYLENE

(Tonne)

Year	Production	Import	Total Consumption	Growth %
1977-78	7000	-	7000	-
1979-80	13400	1700	15100	115.7
1980-81	16700	1400	18100	19.8
1981-82	20600	1300	21900	20.9
1982-83	24000	3000	27000	23.2
1983-84	24400	8600	33000	22.2
1984-85	27000	8900	35900	8.7
1985-86	23600	18000	41600	15.8
1986-87	23500	22000	45500	9.3
1987-88	26000	30000	56000	23.0
1988-89	29000	36000	65000	16.0
1989-90	46634	47242	93876	44.4
1990-91	49789	51000	100789	7.4

Source : Petrochemical Data Service

E.2.2 In 1989, the minimum economic scale for polypropylene plant was revised to 100,000 tpa from 50,000 tpa. Worldwide, new PP projects have similar capacities and this MES would ensure economical operations.

E.2.3 Consumption Pattern

PP is very popular in India, in the packaging films and injection moulding sectors. Together, these two sectors account for more than 60% of the total consumption. The share of various processing sectors in PP consumption is film (34%), woven sacks (16%), monofilaments & ropes (4%), strapping & sutli (6%), injection moulding (28%), fibre/filament (8%) and others (4%).

Unlike the worldwide consumption pattern of polypropylene, the consumption of PP in India is low in the fibre and filament sectors. The figures are as follows :

CONSUMPTION PATTERN COMPARISON - WORLD vs INDIA

Application	Worldwide, %	India, %
Injection Moulding	40	28
Fibres and Filaments	32	8
Films	17	34
Others	11	30
TOTAL	100%	100%

E.2.4 Demand Projections

The Committee for Perspective Planning of the Petrochemical Industry published a report in 1986. The demand estimates of polypropylene in the terminal years of the 8th and 9th plan are given in the table given in next page.

DEMAND ESTIMATE OF POLYPROPYLENE BY COMMITTEE FOR PERSPECTIVE PLANNING ON PETROCHEMICAL INDUSTRY

Year	Demand Projections by Trend Analysis		Demand Projections by End use		Demand Projections by Substitution Potential (by Addl. 3% growth rate than end use analysis)	
	Demand in TPA	CARG %	Demand in TPA	CARG %	Demand in TPA	CARG %
1994-95	1,76,000	18%	2,86,000	18%	3,24,000	21%
1999-2000	2,59,000	8%	4,20,000	8%	5,46,000	11%

E.2.5 Present Manufacturers and New Capacities

At present, IPCL is the only manufacturer of Poly-propylene. It has three plants, two, located at Baroda and the third at the Maharashtra Gas Cracker Complex (MGCC), Nagothane. Their production capacity is given below:

EXISTING POLYPROPYLENE PRODUCTION CAPACITIES

Sr. No.	Location	Year of Start-up	Annual Capacity MT	Polymer Type
1.	IPCL, Baroda	1979	30,000	PPHP
2.	IPCL, Baroda	1988	25,000	PPHP, RCP, Block CP
3.	IPCL, Nagothane	1991	60,000	PPHP, RCP
	Total		1,15,000	

Several new capacities have been planned. They include those of Polypropylene India Limited (PPIL), Reliance Petrochemicals Limited (RPL), National Organic Chemical Industries Limited (NOCIL) and Gas Authority of India

Limited (GAIL). IPCL also has plans to scrap the two old plants at Baroda and replace them with a 75,000 TPA plant using the latest technology.

E.2.6 Demand Supply Gap

Based on the implementation of various PP projects and demand projections made by the Committee for Perspective Planning (Level II), the demand-supply gap is estimated to be 1,82,500 MT by 1994-95 and 3,71,500 MT by 1999-2000.

E.2.7 Technology Selection By Indian Companies

Currently, only IPCL has polypropylene plants, which are located at their Baroda complex and MGCC, Nagothane. The technology employed at IPCL's three plants is given in the following table.

TECHNOLOGY SELECTION BY IPCL

Sr. No.	Project	Technology
1.	30,000 TPA PP Homopolymer project at Baroda Complex	M/s. Technimont International, Italy. Technology offered from Montedison's (Italy) conventional slurry process based on 1st generation catalyst.
2.	25,000 TPA PP Homopolymer, Random Copolymer and Block Copolymer Project at Baroda Complex	M/s. Technimont International, Italy. Technology offered from Montedison's (Italy) slurry phase heavy diluent process based on HYHS catalyst.
3.	60,000 TPA PP Homopolymer project at MGCC, Nagothane	Technimont, Italy. Technology of Himont,Italy (Earlier Montedison) liquid phase loop reactor process based on HYHS catalyst.

Among the new projects, PPIL will be employing the technology of Solvay, Belgium; Haldia Petrochemicals has tied up with Himont, Italy (Spheripol process) and IPCL is presently evaluating Himont's new Valtec Technology for their planned 75,000 TPA plant at Baroda.

E.2.8 Polypropylene Grades Available in India

At present, limited grades are available in India as IPCL is the only manufacturer. Both homopolymers and copolymers are made in India by IPCL.

Homopolymers with MFIs of 3.0, 5.6 and 10 are manufactured in India. Five different grades of 3.0 MFI are used in monofilaments, raffia, BOPP, injection moulding, and UV stabilised outdoor applications. The 10 MFI grade is used for TQ films. Besides, these IPCL also supplies UV stabilised homopolymer grades with MFIs of 14 and 18 for use in the fibre and filament sector as well as five block (impact) grades in the 0.8 to 13 MFI range. At the moment, IPCL is not producing any random copolymer grades. Reinforced and filled PP products are available through compounders processors located in different parts of the country. When compared to developed countries, the PP grade availability is very poor.

E.2.9 Technology Status of IPCL Plants

The technology employed at the two Baroda complex plants may now be termed obsolete as compared to worldwide developments. Both these plants involve heavy diluents in which the reaction is carried out. The Spheripol technology at MGCC plant is the latest and the most popular PP process in the world today.

The first plant at Baroda (30,000 TPA PPHP) involves a number of process steps such as catalyst deashing and solvent recovery. The catalyst employed is a first generations catalyst having a poor productivity of 1 kg PP/gm of catalyst and 92% isotactic index. This results in large atactic formation and consequently consumes more of propylene monomer.

The second plant (25,000 TPA PPCP) is designed for copolymer production. IPCL has made substantial progress in adopting the high yield high stereo-specific catalyst systems in this plant. The plant involves hexane diluent which must be separated, purified and recycled. Atactic polymer formation, is considerably reduced as compared to the first plant. The catalyst employed has a much higher activity of 10 kg PP/gm catalyst and high selectivity of 96% crystalline PP.

The MGCC plant (designed for homopolymers and random copolymers) has the latest Spheripol technology imported from Himont, Italy. Commercial production was delayed due to an explosion in the complex in November 1990, and hence began, only in 1991. World scale performance is expected from this plant due to process simplifications and use of the latest 3rd generation catalyst systems. This plant does not involve any liquid diluent and the reaction is carried out in loop reactors, which are considered to be highly efficient for PP polymerization in the world today. The space time yields of such reactors are very high and IPCL will benefit considerably due to adoption of this latest technology.

E.3.0 INTERNATIONAL SCENARIO

E.3.1 Polypropylene is the third most popular thermoplastic material in the world, after polyethylene and PVC. Consumption of PP in 1991 is estimated to be around more than 11.5 million tonne and represents an average growth of approximately 10% a year.

E.3.2 The sharp increase in demand for polypropylene during 1986-88 combined with ready availability of process know-how has resulted in an explosion of new capacities worldwide.

The world PP production capacity is likely to go upto 19.2 million tonne by 1992 from current level of 13 million tonne. The distribution of this capacity to reflected in table below:

WORLD POLYPROPYLENE CAPACITY

	End-1989	End-1992*	Growth (%)*
Western Europe	3.9	5.5	40
North America	4.2	5.4	30
Japan	1.8	2.1	17
Others/SE Asia/Australia	1.9	3.4	80
Middle East/Africa	0.15	0.8	430
Central/South America	0.35	1.1	215
Eastern Europe	0.7	0.9	30
TOTAL	13.0	19.2	

Figures in Million Tonne Per Annum
* : Estimated, Source : Ferruzzi, Italy

E.3.3 Western Europe is the largest consumer of PP (3.84 million tonne in 1991) followed by U.S.A. (3.1 million tonne) and Japan (1.92 million tonne). The major process licensors are also based in these countries. The consumption pattern in developed countries indicate that injection moulded goods (40% share) are the most popular applications, followed by PP fibres and filaments (32% share).

E.3.4 Among over ten commercial processes developed world-wide, Himont's Spheripol process, Union Carbide's Unipol process and BASF's Novolen process are the most popular. A number of projects are planned using these technologies, a summary of which is given overleaf.

POLYPROPYLENE TECHNOLOGIES IN PLANTS UNDER CONSTRUCTION - WORLDWIDE

Sr. No.	Process Licensor	No. of Plants under Cons-truction	Capacity '000 MT/Yr.	% of Total Capa-city	Techno-logy Employed
1.	Himont (Spheripol)	20	2150	38.0%	Bulk Phase
2.	Union Carbide (Unipol)	11	1280	22.6%	Gas Phase
3.	BASF	10	840	14.8%	Gas Phase
4.	Shell (Lippshac)	5	550	9.7%	Liquid Phase(Bulk)
5.	Sumitomo	3	300	5.3%	Bulk & gas phase
6.	Mitsubishi Kasei	2	205	3.6%	Diluent & gas phase
7.	Amoco/Chisso	2	190	3.3%	Gas Phase
8.	Mitsui (Hypol)	2	110	1.9%	
9.	Solvay	2	110	0.5% 1.4%	Bulk Phase Gas Phase

Source : Process Literature of various companies

E.3.5 Himont, Italy

Himont is the world's largest producer of PP with its own capacity of nearly 1.8 million TPA. Himont is also the world's most popular process licensor, having licensed nearly 50 plants world wide. Himont has developed the Spheripol technology in which polymerisation is carried out in the liquid phase using loop reactors. It has developed catalysts in collaboration with Mitsui, Japan with very high activity of nearly 35 kg PP/gm of catalyst and a selectivity of 98-99%. Himont has opted for the hybrid liquid phase homopolymerisation and gas phase copolymerisation. The reasons highlighted are:

Liquid Phase

- Maximum monomer concentration
- catalyst solubility and homogeneity in the slurry
- Maximum reactor volume utilisation
- Uniform temperature distribution and higher heat transfer rates than in gas phase.

Gas Phase

- Avoids extraction of copolymer into a liquid diluent
- Stable reaction conditions due to gas diffusion control
- High reactivity of ethylene reducing, the reaction volume in a gas system

E.3.6 Union Carbide, USA

Union carbide adopted its gas phase polyethylene Unipol technology for polypropylene in 1983. For polypropylene, Unipol technology is the most popular amongst gas phase processes. Union carbide has licensed more than 15 such plants worldwide. Unipol process involves a fluidized bed reactor for polymerisation and the process is suitable for all ranges of PP products. Union Carbide collaborates with Shell for catalyst development. High monomer recovery, low utility consumptions, simplified process steps and precise control over process variables has made this technology highly versatile for PP production. Union carbide has been able to produce very high melt flow products in the range of 0.05 to 3000 MFI, high ethylene content copolymers, products with comonomers other than ethylene, etc.

Salient features of Unipol technology are :

- Gas phase fluidized bed reactor system is used. A second similar reactor is employed for block copolymer production.
- Very high catalyst activity levels of upto 40 kg PP/gm of catalyst have been achieved.
- Comonomer other than ethylene, such as butene may be used to improve physical properties of the end product.
- High melt flow, high impact strength grades can be manufactured.
- Specially designed lock hopper product discharge system eliminates troublesome cyclones, dip-tubes and liquid flashing devices.

E.3.7 BASF, Germany

BASF developed the gas phase Novolen process in 1967. It collaborates with ICI, U.K. and Quantum Chemicals, USA for process licensing and nearly 2 million TPA production capacity has been planned, using BASF's Novolen Process. Unlike Union Carbide's fluidized bed reactor, BASF uses a vertical stirred bed reactor for polymerisation. The BASF process is considered to be very economical in terms of capital investment and production cost. Like in the Unipol process, BASF too has been able to develop speciality products in its process. Salient features of this technology are :

- Gas Phase vertical stirred bed reactor system. A second gas phase reactor in cascade for block copolymer production.

- Commercial plant produces homopolymers in the 0.5 to 70 MFI range. Block copolymers with high (25 wt %) rubber content.

- Products with a high isotactic index of 98-99%.

- HYHS catalysts are employed with activity in the 10-15 kg PP/gm of catalyst range.

- The process has high monomer efficiency and low energy consumption.

E.3.8 While plant investment costs are comparable in most new processes, they have a clear advantage over older conventional slurry and high yield slurry processes. Similar trends are observed in operational expenses. A comparison of leading process licensors is given overleaf.

E.3.9 **New Developments Abroad**

Technology developments abroad are focused on improving the process efficiency, catalyst development and product applications development. Important developments in the process has been that of Himont's Valtec technology in which spherical beads are formed directly in the reactor (alongwith suitable additives) eliminating the power intensive extrusion step. Both, Himont and Union Carbide have developed processes that can incorporate new comonomers (other than ethylene) for superior physical properties. Various catalysts have been developed with vary high selectivity (99% crystalline) and upto 40 Kg PP/gm of catalyst activity. There have been numerous product developments, prominent among them are in field of extrusion blow moulding, easy flow fibre grades, very high impact grades and reinforced, filled product sectors.

E.4.0 R&D EFFORTS, TECHNOLOGY ABSORPTION AND GAPS

E.4.1 Research And Development

R&D activities in the area of polypropylene are mainly limited to IPCL at Baroda. RPL also has a Product Applications Research Centre at Bombay where applications development is carried out. IPCL has a pilot plant for polyolefin synthesis. Various catalysts have been tried out in this plant for propylene polymerisation. IPCL also has a separate Catalyst Development Centre and Product Applications Centre. Currently, the major focus of IPCL's research work is on catalyst development, development of new grades, and indigenisation of components involved in the production of catalyst compounds. The catalyst development activities have been partially successful and IPCL is likely to start producing its own catalyst for the slurry process. In the area of product applications, certain nucleated and controlled rheology grades have been developed, UV stabilized grades have been introduced and a special high impact car bumper compound has been developed.

E.4.2 Technology Absorption

Technology of both the plants at Baroda has been absorbed by IPCL. Since both the plants utilize processes which are now obsolete, the same cannot be used for other new projects. Hence, at MGCC, technology was again imported.

E.4.3 Technology Gaps

Various technological gaps exist with respect to process and products which are highlighted below.

1. No indigenous technology is available.

2. Technology employed at IPCL Baroda Complex plants are now outdated as they are based on heavy diluent technologies. The first plant uses first generation catalyst systems with poor performances.

3. Dependence on imports for certain special plant and machinery is likely to continue such as extrusion/ pelletization, fluidized bed dryers, process instrumentation and control systems etc.

4. Number of grades manufactured and available in India are very less as compared to developed countries.

5. Suitable grades for a number of applications such as in textiles, blow moulding, very high impact grades for injection moulding, etc. are not available.

6. The area of composites and alloys has yet to develop.

E.5.0 RECOMMENDATIONS

1. Three to four worldscale plants along with smaller plants be taken up for immediate implementation to meet long term requirements of the Indian market.

2. Catalyst research, product applications development and grade development needs to be augmented and institutes such as NCL and SRI need to be associated with manufacturers. A separate polymer research institute may be established to carry out research in close liaison with producers.

3. Export to neighbouring countries needs to be considered.

4. Proper grades for textile applications, blow moulding, high melt flow, high impact applications need to be developed.

5. Composites and alloys of PP need to be developed. Manufacturers are recommended to involve themselves in their development.