EXECUTIVE SUMMARY

0.1. REFRIGERATION COMPRESSOR

Refrigeration compressor is the heart of any refrigeration system. The compressor can be: reciprocating, rotary, centrifugal, screw or an axial flow type, based on the principle of compression. Depending upon the location of the drive, compressors are classified as hermetic, semi-hermetic and open type. Reciprocating and rotary compressors, which have the compressing element and drive motor sealed in a single, welded-housing, are called hermetically sealed compressors. Instead of single, welded-housing, if the enclosure is bolted together, then the assembly becomes semi-hermetic. In this type, in addition to reciprocating and rotary types, screw and centrifugal compressors are also manufactured. However, if the compressors and drive units are not in single housing, the compressors are called open type. Compressors manufactured in India are mostly the reciprocating type. Centrifugal compressors are characterised by large capacity, suitable for extremely low temperatures and ability to carry varying loads. Rotary compressor is a hermetic type compressor where the mechanical structure and motor assembly are directly fitted in the same shell, and where the shell is sealed by means of welding. Rolling piston and sliding vane are the main types of rotary compressors. In reciprocating compressors, a connecting rod is used to convert the rotary movement of the crankshaft to the reciprocating movement of the piston. The piston slides, in a cylinder to compress the refrigerant gas. When the difference between condensing temperature and evaporating temperature is high, the pressure ratio for compression also becomes high and conducting compression in two stages becomes desirable. A screw compressor is a positive displacement rotary machine. Depending upon mountings, there are two types viz. vertical and horizontal screw compressors. Depending upon the number of screws, there are mono- screw and twin-screw compressors.

Application of refrigeration compressors can be: for refrigerators, deep-freezers, water coolers, bottle coolers, room air-conditioners, packaged air-conditioners, water chillers, self-contained A/Cs, bus/train/ship air-conditioning, refrigerated vans and cold-storages.

End-uses of refrigeration compressors can be in: domestic, commercial and industrial sectors. In domestic sectors, the end- uses are for preserving and storing food and for comfort air-conditioning. In the commercial sector, the end-uses are: in central air-conditioning, water coolers, and commercial refrigerators. End-uses in the industrial sector include preservation of food, fruit juice concentrates, alcoholic drinks; preserving systems for meat, fish,

poultry and dairy products. Other applications of refrigeration compressors are process refrigeration such as in the drugs and pharmaceutical industry; textile industry, rubber industry and thermal power generation.

0.2. HISTORICAL DEVELOPMENT OF COMPRESSORS

For refrigeration compressors, development of technology started around the year 1865. In the period 1865 to 1875, a few types of refrigeration compressors were made each year. These were massive steam-engine driven machines with their weights in tons, considerably in excess of their capacity in tons of refrigeration. Before 1900, some compressors were equipped with cylinder by-pass valves for capacity control. Electric motor belted-drives also started to make their appearance. Rare use of sulphur dioxide as refrigerant was made. In the period from 1900 to 1925, rotating seals were tried in small compressors. Automatic capacity controls were developed. Operating speed increased to 800 rpm. Compressors came to be directly driven by synchronous motors. During the period 1925 to 1950, reed valves began to appear. The 2-pole electric motors at 3500 rpm were used for drive. Freon refrigerants such as R-11, R-114, and R-22 were invented. During the period 1950 to 1975, the refrigerant R-22 was used in place of R-12 and 2-pole motors in place of 4-pole motors were used.

The ozone depleting effects of chlorofluorocarbons (CFCs) have resulted in a large number of countries signing the Montreal Convention, according to which the developed countries have to phase out use of R-11, R-12, R-113, R-114, R-115, R-13, R-111, R-112, R- 211, R-212, R-213, R-214, R-215, R-216 and R-217 by the year 2000, and developing countries by the year 2015.. The use of new CFCs which are ozone friendly and are under development at present necessitate modifications in compressor designs in some cases. They may also affect the energy efficiency of compressors also.

As regards the compressor typewise development; the reciprocating compressors were the pioneers, followed by, centrifugal, rotary and screw compressors. Among these types, the reciprocating compressors have almost reached their technological development limits. Regarding the future trend, scroll and eccentric cam compressors are being developed in advanced countries.

0.3. STRUCTURE OF THE REFRIGERATION COMPRESSOR INDUSTRY

a) Manufacturers

The manufacture of the refrigeration compressors started in India around the year 1960 for small hermetic compressors for

refrigerators as well as the larger capacity open type compressors. Today, a wide variety of compressors are produced in India with the capacity as high as 700 HP. The industry is composed of both organized sector of medium and large-scale manufacturers and an unorganized sector of small-scale units. The small units produce slow-speed compressor models, which are still used in India for limited purposes.

There are 14 manufacturers in the organized sector. They are:

i) Sanden Vikas (India) Ltd., Faridabad (Haryana) - A/C compressor for motor cars.

ii) Kirloskar Brothers Ltd., Karad (Maharashtra) - Hermetic compressors.

iii) Shriram Refrigeration Industries Ltd., Hyderabad (A.P.) - Hermetic compressors.

iv) Godrej & Boyce Mfg. Co. Private Ltd., Bombay - Hermetic compressors.

v) Kelvinator of India Ltd., Faridabad (Haryana) - Hermetic compressors.

vi) Hyderabad Allwyn Ltd., Hyderabad (A.P.) - Hermetic compressors.

vii) Voltas Ltd., Bombay & Warora (Maharashtra) - Hermetic, Semi- hermetic and Open type compressors.

viii) Kirloskar Pneumatic Co. Ltd., Pune (Maharashtra) - Open type compressors.

ix) Vulcan Laval Ltd., Satara (Maharashtra) - Open type compressors.

x) Frick India Ltd., Faridabad (Haryana) - Open type compressors.

xi) Air Control & Chemical Engineering Co. Ltd., Nandej (Gujarat) - Open type compressors.

xii) Utility Engineers (India) Ltd., Dharuhera (Haryana) - Open type and Semi-hermetic compressors.

xiii) Blue Star Ltd., Bombay (Maharashtra) - Open type compressors.

xiv) Batliboi & Co., Udhna (Gujarat) - Semi-hermetic compressors.

b) Installed capacity and its utilisation

At present, the total licensed capacity of these companies is 13,87,250 Nos. per annum, whereas the total installed capacity is 10,22,170 Nos. As regards the utilisation of installed capacity, the industry presents an unbalanced picture for different types of compressors as shown in the following table.

Utilisation of capacity

(in numbers)

Compressor type	*Total Production (1985-86)*	*Total Installed capacity (1985-86)*	*Capacity utilisation*
Air-conditioning compressors for automobile	10,000	25,000	40%
Hermetic compressors	7,78,614	8,81,000	88.4%
Open type and Semi hermetic compressors (all varieties)	2,444	15,440	15.8%

c) Demand and supply forecast

Depending on the type of compressor, there are different segments of the market. For fractional horse power and below 5 HP compressors, the end-products are : auto air-conditioner, refrigerators, water coolers, room type air-conditioners, bottle coolers, deep-freezers, etc. For higher capacity compressors the end-uses are air-conditioning and refrigeration in a variety of industries like food preservation and processing; dairy, fish, poultry, meat industry, pharmaceutical and chemical industry, electronics, fertilizer, textile industries and commercial establishments like offices, telephone exchanges, computer

installations, theatres and hotels. The future demand for these different segments is as follows:

Future demand of compressors

(In numbers)

Compressors type	*1990-91*	*1994-95*
Car A/C compressors	35,340	59,690
Hermetic compressors	15,17,605	26,96,430
Open type compressors	3,428	4,493

If the future demand is compared against the current and potential installed capacity, the following picture emerges:-

Demand - Supply position in 1994-95

(In numbers)

Compressor type	*Demand*	*Installed capacity*	*Capacity surplus/ shortage*
Car A/C compressors	59,690	1,00,000	+40,310
Hermetic compressors	26,96,430	13,46,000	-13,50,430
Open type compressors	4,493	15,890	+11,397

The table shows that additional capacity will be needed to the extent of nearly 1.4 million numbers for hermetic compressors. In terms of value, the total demand at present is approximately Rs. 950 million for hermetic compressors and Rs. 200 million for open type compressors.

d) *Import and export*

Refrigeration compressors are imported in India as part of initial import in the phased production programme under the collaboration agreements or some special types or capacities, which are not manufactured in the country. Some compressors are also imported as part of projects awarded to foreign companies.

Export of compressors is usually as a part of an end-project or a part of an air-conditioning or refrigeration project. The export performance of the industry is not very encouraging.

The main reasons for this are:

Price The international prices are at least 40% cheaper than the Indian export prices.

Quality The quality of products of advanced countries is superior and more reliable.

Models The advanced countries do continuous product improvement and are able to bring new models every year in the market.

Marketing The marketing and after sale service are not properly undertaken by the Indian manufacturers, barring a few exceptions. The Indian manufacturers will have to improve on all these disadvantages with appropriate help from the Government.

e) *Financial status and scale of operation:*

Most manufacturers are multi-product companies producing compressors as one of their products: hence the data of separate investment and costs for compressors vis-a-vis income is not available. The financial health of a company as a whole has, therefore, been studied. It was observed that all companies, except ACCEL, are making profit. ACCEL had been making losses for some years and it has been taken over by Best & Crompton Ltd., since 1986 and is under rehabilitation. Amongst the companies, Frick India Ltd., Vulcan Laval Ltd., Blue Star Ltd., and Kelvinator of India show sound financial health with the return on capital employed is consistently above 10% and return on share capital above 35%.

0.4. TECHNOLOGICAL STATUS OF INDIAN INDUSTRY

a) Sources of technology

Since the beginning of the refrigeration industry in India, refrigeration compressors have been manufactured with foreign technical collaboration. Even today, most of the established manufacturers continue to enter into fresh foreign collaborations for producing new types of compressors or for updating and expanding the present range. The only notable exception in this regard is Godrej & Boyce Mfg. Co. Ltd. which has developed a hermetic compressor for its refrigerator entirely with its own research and development. The details of foreign collaborations of the Indian manufacturers are shown in the following table.

FOREIGN COLLABORATIONS

	Manufacturer	*Collaborator*	*Year*	*Type of compressor*
1.	Sanden Vikas (India) Ltd.	* Sanden Corporation (Japan)	1983	Open type reciprocating compressor with clutch for motor car air-conditioner
2.	Kirloskar Brothers Ltd.	Tecumseh Products Co. Inc. (U.S.A.)	1963	Hermetic compressors (1/8 HP-5 HP)
3.	Shriram Refrigerration Industries Ltd.	Westinghouse Industries Corpn. (U.S.A.)	1961	Hermtic compressors (1/8 to 2 1/2 HP)
		Lec Refrigeration Corpn. (U.S.A.)	1979	- do -
		Daikin Industries Ltd. (Japan)	1981	Rotary hermetic
		* Tecumseh Co. (U.S.A.)	1987	Hermetic compressors (1/8 to 7 1/2 HP)
4.	Kelvinator of India Ltd.	Kelvinator International Corpn. (White Consolidated Industries, U.S.A.)	1960	Hermetic 1/8 & 1/6 HP reciprocating
		* - do -	1987	Hermetic reciprocating

Manufacturer	*Collaborator*	*Year*	*Type of compressor*
5. Hyderabad Allwyn Ltd.	Prestcold Ltd. (U.K.)	1957	Slow speed hermetic Hermetic (FHP)
	* Hitachi Ltd. (Japan)	1981	High speed Hermetic (1/8 & 1/6 HP)
6. Voltas Ltd.	Carrier Corpn. (U.S.A.)	1963 &1972	Open type reciprocating (18 TR to 120 TR)
	* Danfoss A/S (Denmark)	1984	Hermetic reciprocating (1/8 to 1/6 HP)
	* Carrier Corpn. (U.S.A.)	1983	Semi- hermetic reciprocating (7 - 14 TR)
	* Danfoss A/S (Denmark)	1987	Product of refrigeration compressors
7. Kirloskar Pneumatic Co. Ltd.	Grasso Products	1961	Open type (10 - 200 TR)
	B.V. Holland	1965	Recip.
	-do-	1973	Semi-hermetic
	* -do-	1985	(45 - 180 TR)
	Westinghouse Elec. Intl.Co. (U.S.A.)	1962	Semi-hermetic (5 TR & 7 TR)
	Hitachi Ltd. (Japan)	1969	Centrifugal (200 TR & 600 TR)
	Sutrak (West Germany)	1973	Open type reciprocating (7 to 15 TR)
	* Howden Compressors Ltd. (U.K.)	1988	Screw compressors (20 - 200 TR)
8. Frick India Ltd.	Frick Waynesboro Inc. (U.S.A.)	1962 &1979	Open type reciprocating 15 - 200 TR)
	Fedders Corpn. (U.S.A.)		Screw compressors (1100 - 300 TR) Centrifugal (300-600 HP)
9. Utility Engineers (I) Ltd.	* The Trane Co. U.S.A.	1983	Open type reciprocating (10 to 80 TR) Hermetic (5 TR & 7.5 TR) Hermetically sealed centrifugal (100 - 800 TR)
10. Vulcan Laval Ltd.	* Star Refrigeration AB (Sweden)	1982	Open type reciprocating (6.5 TR - 230 TR)
	* -do-	1984	Screw type

Manufacturer	*Collaborator*	*Year*	*Type of compressor*
11. Blue Star Ltd.	* Borg Warner Air-conditioning Inc. (U.S.A.)	1983	Centrifugal (150 - 700 TR)
12. Batliboi & Co.	* Daikin Industries Ltd. (Japan)	1984	Semi-hermetic compressors (10 TR - 50 TR)
13. Air Control & Chemical Engg. Co. Ltd. (ACCEL)	Sabroe & Co. (Denmark)	1965	Open type reciprocating (5.6 - 70.4 TR)
14. Gujarat Ind. Inv. Co. Ltd.,	* Dressar Industries Inc. (U.S.A.)	1984	Refrigeration compressors
15. Shiv Shakti Engg. Co. Pvt. Ltd.	Rotocold Ltd. (U.K.)	1989	Rotary compressors
16. Pradeep Kumar New Delhi	Industrie Riuuite Eurodomostical SPA (Italy)	1985	Sealed compressors

Note: Collaborations, still current, are indicated by an * (asterisk)

There is no example of technology transfer among Indian manufacturers. Moreover, collaborations with the same foreign companies have been concluded at different times for updating or manufacturing new types of compressors. All this goes to show that there is hardly any original design and development work undertaken in India; or, whatever has been attempted so far has not met with much success. The R&D effort in India is mainly aimed at indigenisation of the compressors as per the collaborator's specifications and according to the phased manufacturing programme.

b) Selection of foreign collaborator

The selection of foreign collaborator was found to be based on many factors such as:

i) Quality of products

ii) Financial participation of collaborator

iii) Willingness of collaborator

iv) Previous trading relations i.e. the Indian company importing the collaborator's compressor for use in own products or projects

v) Availability of collaborator for collaboration in India.

There are three companies, namely, Sanden Vikas (India) Ltd., Kelvinator of India Ltd. and Frick India Ltd., in which there is a financial participation of the collaborator in addition to technical collaboration.

c) Restrictive clauses in collaboration agreements

The restrictive clauses pertain to export, use of collaborator's brand name and transfer of technology to other Indian manufacturers. Regarding exports, most collaborators have barred the Indian manufacturers to export to countries where the collaborators have their own licensing arrangements or trade interests.

Regarding the use of collaborator's brand-name, in most cases the words "manufactured under license of." etc., can be used during the period of agreement.

The transfer of technology has not been allowed during the tenure of agreement in the case of any company. After the tenure is over, the Indian company is free to transfer technology to others.

d) Technical support of collaborator

In all the collaborations, the collaborator has agreed to give all technical support for indigenisation of the compressor. Adequate training in collaborator's plant as well as in Indian company's plant is provided.

e) Research and development activities

The research and development carried out by the Indian manufacturers is of applied nature. The main effort is to indigenise the collaborator's design within the agreement period. Once this is

achieved, many manufacturers have done development in compressor components by way of change of material, little modification in design and such other improvements. Some have developed compressor models of intermediate capacities in the range by making suitable dimensional changes. No manufacturer has designed a compressor on his own except Godrej & Boyce. The reasons for this state of affairs are :

i) The low volume of turnover of business does not permit sizeable investment in original research.

ii) It is faster to update technology through collaboration than through own research.

f) R&D organization and expenditure

Most compressor manufacturing companies in India are multi-product companies, manufacturing allied refrigeration products or components or other engineering products not connected with refrigeration. The research and development activities are, therefore, commonly undertaken in a central R&D establishment. Separate R&D organization and expenditure on compressor development were therefore not available in most cases.

The following table shows the annual R&D expenditure of the companies.

R&D Expenditure

(Rs. in million)

Company	*Expenditure (Year)*
Shriram Refrigeration Industries	2.3 (1985-86)
Kelvinator of India Ltd.	11.89 (1987-83)
Voltas Ltd.	21.7 (1987-88)
Vulcan Laval Ltd.	6.0 (1985-86)
Kirloskar Pneumatic Co. Ltd.	6.3 (1986-87)
Hyderabad Allwyn Co. Ltd.	17.0 (1987-88)
Kirloskar Brother Ltd.	11.2 (1988-89)
Godrej and Boyce	17.2 (1987-88)

The other companies like Sanden Vikas (India), Utility Engineers, Batliboi & Co. and Blue Star Ltd. are getting all R&D support from their collaborators. Frick India Ltd. will soon have its own R&D centre which is at present under construction.

0.5. INTERNATIONAL STATE-OF-THE-ART SCENE

To understand the international state-of-the-art, 26 major manufacturers were contacted on the basis of their collaborations, in India, import of compressors, into India and also on the basis of reputation. In response, product literature from some, like GRASSO, HITACHI, HOWDEN, MITSUBISHI, COPELAND and LINDE was received. Few copies of product literature of STAL and DAIKIN were also received from their Indian collaborators. Apart from this, the Japan Refrigeration and Air-conditioning Industries Association and American Society of Heating, Refrigeration and Air-conditioning Engineers Inc. were also contacted. Publications of Purdue University, U.S.A., on Compressor Engineering were also referred to.

a) Manufacturers

GRASSO PRODUCTS

This is an internationally independent, operating company in the field of refrigeration, air-conditioning and stop valves for the last 125 years. Businesswise, the company's net sales were in 1984 - 69,503,000 Dutch Guilders, in 1985 - 63,928,000 Dutch Guilders; and in 1986 - 135,987,000 Dutch Guilders. Expenditure for R&D in 1985 amounted to 3.5% of net sales.

COPELAND CORPORATION

This is an American, refrigeration compressor manufacturing group of companies, building accessible hermetic compressors since 1957. The range includes 50 W to 540 W compressors. It is the largest manufacturer of compressors in terms of monetary value. Its products are mainly in range of 2 HP and 4 HP.

LINDE REFRIGERATION LTD.

For over 100 years, this company has developed and manufactured a range of refrigeration equipment. Linde manufactures open type, screw and reciprocating compressors.

HOWDEN COMPRESSORS LTD.

This company (founded over 125 years ago) was the first in the world to commercially produce screw compressors for refrigeration purposes. Howden manufactures compressors with capacities in the range of 340 m^3/hr to 1200 m^3/hr.

MITSUBISHI HEAVY INDUSTRIES LTD.

This is a Tokyo based company, established 45 years ago. Mitsubishi manufactures : hermetically sealed rotary and reciprocating compressors, semi-sealed reciprocating compressors and open type screw compressors.

MANEUROP

It is well known French manufacturer upto 12 hp. capacity compressors.

CARRIER, TRANE, YORK AND SNYDER

They are large U.S. based manufacturers of reciprocating and centrifugal compressors both of open and semi-hermetic designs.

FRICK AND DUNHAM - BUSH

They are large manufacturers of screw compressors in U.S.A.

b) Latest developments at International level

i) Semi-hermetic reciprocating compressor

Improvement in part-load efficiency of semi-hermetic reciprocating compressor has been developed by using block suction unloading by Borg Warner Air-conditioning Inc. (York) U.S.A.

Copeland Corporation, Sydney, has developed, a new valves system. This valve is made from a high temperature polymeric material, together with a laminated steel valve plate and ring type suction valve. It provides large flow areas, low clearance volumes and high efficiency. Discharge valves are of polymide resin. With this valve

system, the company claims that EER has increased by 16% and compressor capacity by 25%.

ii) Hermetic Reciprocating Compressor

A unit that encloses a motor compressor and a condenser of refrigerant fluid in a single hermetic casing has been tested by NECCHI SPA, PAVIA, ITALY.

iii) Compressor Valves

Material for compressor valves has been recently selected and tested. The best material for this use is the Martensetic Stainless Steels with preference for UHBSS-716.

iv) The Eccentric Cam Compressor

This new product has been tried by Copeland. The eccentric cam compressor fulfills the required need for a low-cost, high efficiency and durable air-conditioning for 1.5 to 2 ton capacity range.

v) Single Screw Oil Flooded Refrigerant Compressor

This is a rotary positive displacement compressor. The compressor gets its name from the single screw rotor that meshes with 2 sealing rotors called star rotors or gate rotors. The advantages of single screw compressors are compactness, versatility, reliability, maintainability, less weight, less noise and vibration as compared to existing reciprocating units.

Rotary and Screw Compressors are not developed or manufactured in India. Hermetic Rotary Compressors are not suitable for Indian conditions where repairs are mostly done in the small service shops, which are, often, ill equipped. Special precautions required during manufacturing, installation, and use of rotary compressor are not observed in India. Further, in India, low evaporating temperature applications are more popular in the refrigeration field where the use of rotary compressors is unsafe and unavoidable. With the present taxes and general economic conditions in India, a tendency to repair compressors and re-use them is more common, and rotary

compressors are most unsuitable from this point of view as they cannot be easily repaired but are replaced with new ones in advanced countries.

Screw compressor is a positive displacement rotary machine combining the characteristics and suitability of a reciprocating unit with the compactness and smooth running of a rotary compressor. Hence, this should become a new thrust area in India. Recent trends at international level indicate development and extensive commercialization of screw compressors by leading companies. Horizontal and Vertical screw compressors are manufactured by STAL Refrigeration in the range of 245 m^3/hr to 4700 m^3/hr. Hitachi has developed horizontal semi-hermetic screw compressors in the range of 137 m^3/hr to 209 m^3/hr. Mitsubishi has developed a tiny screw compressor for Bus A/c with 9 m^3/hr capacity. Howden manufacturers screw compressors in the range of 340 m^3/hr. to 12000 m^3/hr.

vi) Refrigerants

Refrigerants are a medium of heat transfer in a refrigerating system which pick up heat by evaporating at low temperature and give up heat by condensing at high temperatures and pressure. Upto 1985, only R-11, R-12, R-22, and NH_3 were the manufactured and available refrigerants in India. High pressure refrigerants R-13, R-502, R-503 were imported. As on today, refrigerants like : R-13 B1, R-13, R-500 and R-114, which are used at an international level are not available indigenously.

The chlorofluorocarbon refrigerants, have been, at centre of environmental controversy because of their Ozone depleting properties. As per the Montreal Convention, the existing CFC's, R-11, R-12, R- 113, R-114, R-115, R-13, R-111, R-112, R-211, R-212, R-213, R-214, R-215, R-216 and R-217 are to be phased out in developed countries by the year 2000 and in developing countries by the year 2010. R-22 has not been included in the list due to be phased out. New substitute which are emerging, are R-123, R-1416 and R-134, but they are yet to complete long term toxilogical trials. Developing countries have to phase them out by year 2015. Use of new Refrigerant will entail change in compressor designs.