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OPTICAL GLASS: ITS MANUFACTURE IN INDIA — A HISTORICAL PERSPECTIVE

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A historical perspective of optical glass industry in India has been presented in this paper. In the introduction a clear definition and understanding of optical glass is given. This is followed by world perspective. The development and production of optical glass in the country has been highlighted.

INTRODUCTION AND DEFINITION OF OPTICAL GLASS

Optical Glass is a vital and strategic material for defence, scientific research, surveys, industry and scientific education. Without this key material various instruments like microscopes, telescopes, spectrometers, surveying instruments, periscopes, gunsights, range finders, cameras, cinematographic projectors, and host of other industrial and scientific instruments would not have come into existence. In short, optical glass has extended human vision from the microscopic world to the macroscopic.

Optical Glass is the 'eye'of the modern world. It has been playing a vital role in shaping science and civilization. Its importance in defence and warfare has made the technology of optical glass a closely guarded secret. Today only a few countries in the world produce optical glass, the major producers being the USA, West Germany, Japan, U.K., U.S.S.R., G.D.R., France, Australia, Canada and India. Of the total qunatity of glass produced in the world, optical glass constitutes only a fraction of a percent. Though negligible in quantity, it overshadows the rest in importance. The value of optical glass lies in its exacting function and the technological perfection required for its production.

The properties which characterize optical glass as a prized material are its very high degree of homogeneity, transparency, chemical durability, physical stability, reproducibility and workability. Optical glass differs from ordinary window glass both in its composition and in its freedom from small amounts of impurities that would impart undesirable characteristics. It also requires a very different treatment throughout its manufacture — from the mixing of batch to the preparation of final blank that is put on the grinding machine.

Optical glass can be conveniently divided into series named after its characteristic constituent. The important series of optical glass are ordinary crown, borosilicate crown, fluor crown, barium crown, ordinary flint, borate flint, borate glass and phosphate glass. Apart from these, there is a special type of optical glass called laser glass discovered in 1961[1]. The size or shape of laser glass can be varied as desired from a fiber to a disc or to a rod. Large size discs and rods of this glass are used for developing nuclear fusion technology to generate atomic energy. Laser glass fibers are used in telecommunication. It is used for making modern sophisticated military equipment and devices. The optical quality of laser glass is superior compared to other optical glasses. The variation in refractive index of laser glass has to be within the range of 10^{-6} as compared to 10^{-4} in other optical glasses.

Glass ceramic is an inorganic non-porous material containing both glass and crystalline phases. Its development came as a necessity for large astronomical telescope mirrors. The special characteristics of glass ceramics are low thermal expansion, temperature stability, high young's modulus, excellent polishing quality and transparency. Its main application is in the field of reflective optics.

The important intrinsic properties of optical glass are refractive index n_d mean dispersion $n_F - n_C$ partial

dispersion ratios $\dfrac{n_d - n_{A^1}}{n_f - n_c}$, $\dfrac{n_g - n_f}{n_f - n_c}$ and

dispersive power $\dfrac{n_f - n_c}{n_d - 1}$ or the reciprocal

of dispersive power $\dfrac{n_d - 1}{n_f - n_c}$, γ — value also

known as the Abbe value. A^1, c, d, f and g represent the wavelengths 7682 A°, 6563 A°, 5876 A°, 4861 A° and 4358 A° respectively. Optical glasses are designated by their n_d value and the Abbe value. These properties change easily from batch to batch with small variations in raw materials, temperature of melting, quality of the melting pot and the manner of handling the melting, quality of the melting pot and the manner of handling the melt. The refractive index has to be kept within a tolerance of one-tenth of one percent and the relative optical dispersion (Abbe value) within one percent for a close match to the optical design and actual fabrications.

Method Of Making Optical Glass

In making optical glass care should be taken to see, that the distribution of permanent strain should be symmetrical and the birefringence resulting from permanent strain, should not produce higher than 10 millimicron relative retardation of path difference per centimeter of transmitted sodium D light.

The process of optical glass making has been described in an article by K.D. Sharma (1979)[2]. It has been normally found that the process does not exactly confine to the theoretical predictions due to the continuous loss of the ingredients on account of volatilisation and corrossion of the ceramic pot. Silica sand or crushed quartz is the basic component of glass. The composition and the proportion of other ingredients vary from glass to glass depending upon the requirements that the glass should satisfy. It was largely to Joseph Van Fraunhofer (1800) that we owe the important innovation of making optical glasses with differing refractive indices by varying the proportions of the raw material. The constituents must be of high purity. The compositions of two typical glasses Borosilicate Crown 517641 (n_d = 1.517; and V = 64.1) and Extra Dense Flint 648338 (n_d = 1.648; and V = 33.8) are given below:

Ingredients	BSC 517641	EDF 648338
Sand or Powdered quartz	72.5	41.2
Borax	30.0	—
Red lead	—	51.9
Potash	16.0	3.7
Soda ash	2.7	2.1
Pot. nitrate	—	8.4
Sod. nitrate	8.4	—
Barium Carborate	3.2	—
Arsenic Oxide	0.7	0.5

The composite material is melted either in ceramic pots or in platinum pots. The ceramic pots are heated to a temperature of 1350°C-1450°C in a gas fired furnace. The platinum pots are heated in an electric furnace or by high frequency induction heating. The molten glass is stirred mechanically to obtain homogeneity.

The glass is then subjected to the important process called annealing. Annealing of optical glass is a complex subject which influences the stability, uniformity, value of refractive index and the strain of the glass. Annealing temperature is usually near the transformation point on the thermal expansion curve. A lower annealing temperature gives higher and more stable index of refraction, although the time required for soaking and cooling is longer than for a higher annealing tempature. In commercial practice, however the annealing schedules selected for various types of glass, are a compromise, so that the total annealing is usually between 3 to 10 days, although thicker pieces require a much longer schedule. A typical annealing schedule is shown in *Fig. 1*.

For large scale production, commercial plants melt the glass in a continuous tank furnace. The method consists of melting glass in a refractory tank which is made of high quality zirconia alumina fusion cast blocks. The tank is an all electric or mix melter

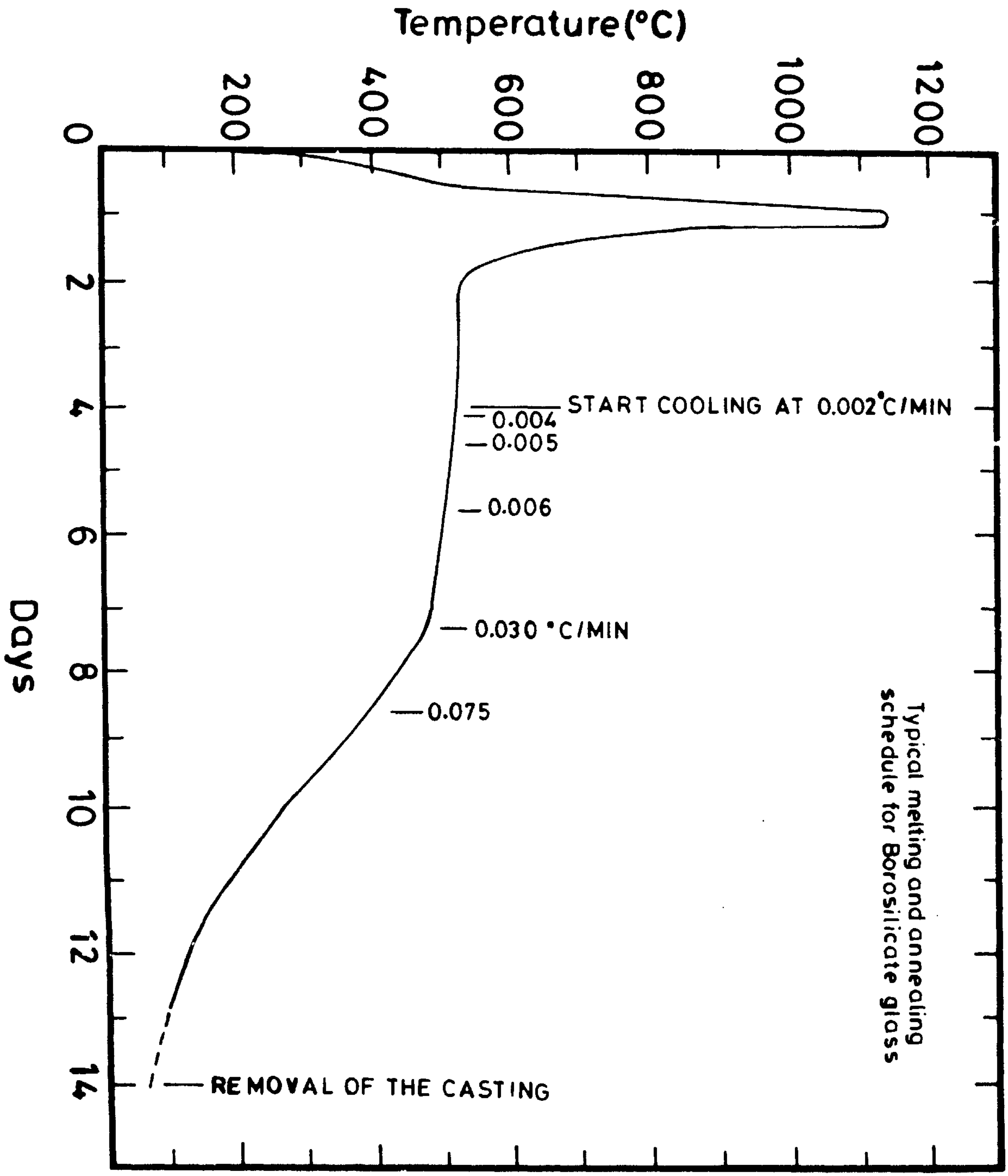

Fig. 1. Typical melting and annealing schedule for Borosilicate glass.

type, from which the molten glass through a riser to a refiner which is lined with platinum and heated electrically. The glass is then stirred by a platinum stirrer and is allowed to flow through an electrically heated platinum tube at a controlled temperature. The glass flowing from the platinum orifice is either sheared into gobs of controlled weight which are pressed or is extruded continuously through rectangular or prism section dies to give a bar of controlled section. The glass may also be drawn from an orifice to give a fire polished rod or it may be cast in a mould kept inside a hot chamber, to give large sized slabs or blocks. Glass coming out of the platinum tube feeder of a continuous tank furnace is sheared into gobs and pressed on an automatic press. Most of the requirements of lens and prism blanks are met by hand moulding or pressing. Moulding is done by reheating the end of an optical glass rod, cutting the softened glass by a hand shear and pressing it in a mould. Large telescope mirror blanks which require deep surface curvature are casts in a rotating furnace.

Optical Glass : A World Perspective

Until the beginning of the nineteenth century, only two types of glass were known — ordinary crown and ordinary flint. The basis of both is a mixture of sodium and potassium silicates, but the former contains calcium in addition and the latter contains lead. With so little variety in the choice of optical glass, it was impossible to satisfy all the conditions of achromatism[3]. The glasses were defective from the optical point of view and it was difficult to find a piece good enough to make a satisfactory lens.

In the latter part of the eighteenth century, a major contribution to improve the quality of glass itself was made by Pierre Louis Guinand of Switzerland.[4] He used new methods of stirring to produce homogeneous flint glass. After many trials Guinand achieved success by cooking the melt very slowly and stirring it continuously. At first, he used a wooden pole as the stirrer, but this mixed the ingredients unequally and caused streaks. In 1805 he used porous fire clay rod for stirring and discovered that is not only kept the mass thoroughly mixed but also brought bubbles to the surface. Guinand later moved to Germany to take charge of a glass works and there he taught his new method to a young apprentice, Joseph Fraunhofer. Between 1809 and 1813 Guinand Fraunhofer's important process for melting optical glass in sheets of considerable size was developed and put to test[5]. Fraunhofer made accurate measurements of refractive indices for different colours and found that with flint glass the results depended on the conditions of manufacture. He obtained flint and crown pieces with reduced secondary spectrum but no attempt was made to produce the glasses on a large scale.

Scientists in several countries began to show increasing interest in the glass industry. In 1824 at the instigation of the Royal Society, Michael Faraday in collaboration with Sir John Herschel and G. Dollond, succeeded after several years of intensive study, in producing some good glasses by melting glass batches in platinum trays and using platinum rakes for stirring. The resulting glasses gave objectives which were fairly achromatic. In 1834, Rev. William Vernon Harcourt of England in collaboration with Sir George Stokes used new chemical method to investigate various types of glass and as a result of these extensive studies over a period of about a quarter of a century obtained phosphate glasses containing titanium which showed better achromatization.

The next major advance occurred between 1874 and 1891 as a result of collaboration between Otto Schott, a Chemist and Ernst Abbe, a Physicist. In 1880, Abbe and Schott aided financially by the Prussian Government, began experimenting at Jena with Zeiss, an instrument maker. Their main objective was to develop compositions with which it could be possible to design lens doubtless in which chromatic and spherical aberration could be corrected to a much higher degree. Schott made a very wide ranging study of the effects of glass composition on the optical properties introducing components which had not been previously used such as compounds of boron, barium, fluorine, phosphorus and other elements. Some elements did not impart new properties and others made the glass soft or cloudy, but a few were found to impart desirable optical properties to the glass without affecting it. After six years of research, they produced optical glasses in which the dispersion varied with the wavelength in such manner that some thing approximating complete achromatism was achieved. This work represents the first major scientific study of glass properties.

The association of instrument maker, Physicist and glass maker proved advantageous and by the early 1900s the factory was manufacturing about 80 different optical glasses and had introduced into their mixtures 28 elements not previously used. The Jena organization enjoyed almost a world monopoly for about 30 years, upto the outbreak of First World War, although France and England had started the manufacture some fifty years earlier than Germany.

In 1940 George W. Morey of United States discovered rare earth optical glasses. By introducing rare earth oxides, especially those of lanthanum and thorium into the melt, he obtained optical glasses possessing very high refractive index and low dispersion. The lenses made of rare earth glasses are used in sensitive and special cameras.

During the World War I, the supply of optical glass to the Allies was extremely scarce. England and France embarked upon research and produced optical glass while USA with the help of their Scientists and Engineers succeded in developing the technology of optical glass in the country and started its production. Japan also started producing optical glass. The pressure of World War II compelled Canada and Australia to establish their own optical glass industries. With the supplies cut off from England, India faced a similar problem and a need from indigenous production was felt.

Indian Glass Industry And Optical Glass

Indian glass has a respectful history[6,7,8]. The use of glass was known in India from Vedic times. Glass (*Kāca*)is mentioned in *Yajurveda* (1200 B.C.) and in early Sanskrit and Buddhist Literature, such as *Śatapatha Brāhmaṇa* and *Vinaya Piṭaka*. In the great epics, *Rāmāyaṇa* and *Mahābhārata* there are references to glass. Its reference has continued in various ancient Indian Literature.

True glass came to be known in India at the beginning of the historical period. In the proto-hisroric cities of Harappa and Mohenjo-Daro, some vitreous material was found. The Harappans were able to fabricate articles of faience and also to glaze their quartz beads with frit, a material akin to glass. The glass beads discovered at Maski, in Southern Deccan belong to the Chalcolithic period datable to the first millenium B.C. Specimens of glass bangles have been recovered by excavations at Hastinapur and Rupar at a stratum dated 9th to 8th century B.C. At Taxila, glass beads of 7th century B.C. and of the 5th to 4th century B.C. have been unearthed.

The next important phase in the history of ancient Indian glass, is the Mauryan period (313-100 B.C.). Several glass articles of Indian as well as of foreign origin belonging to Mauryan period were found in the excavations at Taxila and other places.

Sātavāhana reign (c.200 B.C.-200 A.D) in Deccan marks a definite stage in the history of glass making in India. A number of Sātavāhana sites have yielded valuable information about the glass having high percentage of silica content. After the downfall of the Sātavāhanas, the tradition of making glass was continued by the Ikṣvākus in the South-Central India and Kṣatrapas on the west coast of India.

After the Arab conquest of Sind in the 9th century A.D a new era ushered into Indian glass. Several new techniques like glazed pottery, glazed tiles unknown to Indian soil and a new technique in layered bangles were some of the chief contributions made by the new settlers.

Glass articles of finer quality were produced in the Vijayanagara and Bahmani Kingdoms of South-Central India.

Mughal period (1526-1707 A.D.) constitutes a very prominent landmark in the history of glass making in India. Many Persian craftsmen were attracted to the Mughal court and under their influence Indian art and architecture took a new form. Some of the best specimens of Mughal glass were made during the regime of Jahangir (1605-1627 A.D.) and Shahjehan (1628-1657 A.D.).

Spectacles of glass came to be used in India in the first quarter of the 16th century A.D. On the history of spectacles in India, P.K. Gode has marshalled some evidence regarding the use of this aid. The following evidence from P.K. Gode's article[9], "Some notes on the invention of specatacles and the history of spectacles in India between 1500 and 1800 A.D." clearly proves the use of spectacles in Vijayanagar about 1500 A.D.:-

Vyāsayogī-Carita, a biography of the great Mādhava Ponṭiff Vyāsarāya (1446-1539 A.D.) composed by Somanātha Kavi mentions *Upalocanagolak* (spectacles with convex eye-glasses) used by Sri. Vyāsarāya at Śrī Kṛṣṇadevarāya's court in about 1520 A.D due to his old age.

As regards the question about the source of the spectacles used by Vyāsarāya about 1520 A.D., P.K. Gode suggests that they were perhaps presented to this influential pontiff by the Portuguese along with numerous other presents which are referred to by Somanātha in *Vyāsayogī-Carita*.

Since at that time production of optical glass was not known, people tried to make use of naturally existing crystal for optical purposes. A reference to this is given in the Imperial Gazetteer of India[10], regarding the manufacturing of spectacles from quartz crystals:-

"Vallam Vadakuseṭṭi, Town in Tajore Taluka, 7 miles from Tanjore, captured by the British under Joseph Smith in 1771 — The quartz crystals (pebbles) found here are made into spectacles of which the natives think highly".

Prior to the outbreak of the Great World War the condition of Indian Glass Industry was not in good shape. There were only a few glass manufacturing units in the country. Due to the lack of required technology, the quality of the products and the requirements were mostly met by imports. Several committees were appointed by the Government of india to study the position of Glass Industry.

In 1916, the Government appointed the Indian Industrial commission headed by Sir Thomas Holland. The report of Holland commission contained observations regarding the responsibility of the state taking the lead and making appropriate provision for the impovement of the glass industry, particularly its technical standards. But no action was taken by the Government on the recommendations of the commission[11].

On continued demand of the glass manufacturers, the Government appointed a Tariff Board in 1931 under the Chairmanship of John Matthai, to enquire into the case of glass industry for protection. The Board made a strong case for establishment of a Glass Technologist's Department as one of the conditions of giving protection. The Board also recommended setting up of an organization for research and training at the Harcourt Butler Technological Institute, Kanpur. But the Government did not respond to recommendations of the Board.

In 1934, the Government of India established the Industrial Intelligence and Research Bureau under the India Stores Department to act as a clearing house of technical information and for undertaking some investigations to help local industries. In the Bureau's program, survey of glass raw-materials, working out methods of producing some glass decorating materials and helping in the introduction of better glass melting furnaces was also included. Its activities were limited because of very small funds provided for its research program, glass was only a part of it.

In 1937, the Uttar Pradesh Government appointed a Glass Technologist to the Government and located his establishment in the Department of Glass Technology of the Banaras Hindu University. However, a full fledged organization for glass research was yet to be established.

The Government of India established the Board of Scientific and Industrial Research (BSIR) in early 1940 at the pursuation of Ramaswamy Mudaliar. To make a quick survey of the problems and to mobilize the great potential of the Universities particularly of trained persons, the Board appointed several committees.

One of the committees was an exploratory committee for glass and refractories with the following personnel:- Sir C.V. Raman, N.C.Nag, I.D. Varshney, A. Nadel and M.L. Joshi. The attention of the committee was mainly confined to investigations on the production of optical glass, purification of glass sands and manufactured of high temperature refractories required for the glass industry. The BSIR in 1941-42 financed a number of research schemes for working out the processes of optical glass production[12]. M.L. Joshi of Lahore had worked on one such project. The optical glass prepared by M.L. Joshi was subjected to tests at the Mathematical Instruments Office, Calcutta. The specimens examined were found to possess the required dispersion for the use in optical instruments but improvement was necessary as regards the removal of veins.

An editorial[13] on 'Need for a school of glass technology in India' and an article[14] 'The Indian glass Industry' in Science and Culture (April 1941) appealed to the Government to establish a centralized institution for glass research.

A report was submitted to BSIR by M.N. Saha and S.S. Bhatnagar after visiting the Banaras Hindu University with the object of exploring the possibility of organizing an Institute of Glass Research using the University Department. The Board appointed a Central Glass Research Institute Committee in March 1942, to advise the Board in this regard with S.S. Bhatnagar as Chairman.

At its first meeting in the Forman Christian College, Lahore, the committee unanimously resolved that the Central Glass Institute should be devoted to research in glass and to the introduction of the industrial processes new to India by technical means. The institute should include sections of glass technology, glass chemistry, glass physics, furnace construction, refractories, glass engineering, labour control and statistics. The committee recommended bringing experts under the Indo-American co-operation in technical and industrial matters. The committee also suggested bringing the processes of manufacture of safety glass, heat resisting glass, fiber and insulating glass, mechanical stirring of optical glass, etc., from USA. In regard to the location of the institute the committee suggested either in Calcutta, Delhi, Banaras, or a place in Uttar Pradesh other than Banaras and Lahore.

The BSIR and the Governing Body of CSIR considered the report of the committee in 1943 and decided to name the proposed Institute for glass reserch as the Central Glass and Silicate Research Institute (CGSRI) and to appoint a secretary to carry out a survey of raw materials needed for the industry and find out problems a committee with S.S. Bhatnagar as Chairman for giving guidance and advice to the secretary.

The Government of India sanctioned a sum of rupees one crore towards the capital expenditure on the establishment of the five National Laboratories including the Central Glass and Silicate Research Institute. A very small amount of two lakhs was sanctioned for CGSRI. Atma Ram was appointed as the secretary of the committee in 1944. He visited Calcutta, Bahjoi, Bombay, Ceramic Section of the Tata Laboratory at Jamshedpur and the Departments of Glass Technology and Ceramics of the Banaras Hindu University. On the basis of the information and impressions gathered during the visits and study of publications on the development of such Institutions in other countries, specially Prof. Turner's extensive writings in the Journal of the 'Society of Glass Technology', Germany and USA, Atma Ram prepared a report for the consideration of the committee. The report set out the position of the industry, its problem, its place in national development, and the need of a research institute to ensure speedy post-war development of the industry. It also, described briefly the standards achieved by the industry in the advanced countries. The functions of the Institute, possible locations, anticipated requirements of staff, equipment, buildings and estimates of expenditure were discussed.

The committee held its meeting in Calcutta in June 1944 to consider the secretary's report in Saha's Cyclotron Laboratory. The proposals submitted were accepted unanimously. The proceedings of this committee were considered by the BSIR and the Governing body of the CSIR on August 1, 1944. After discussion of the various points raised on the subject by S.S. Bhatnagar, the BSIR and the Glass and Silicate Rasearch Institute committee in their respective reports, decided that the Glass and Silicate Rasearch Institute should be located in Calcutta, adjacent to the Jadavpur College on the Gariahat Road. The name of the Institute was changed from Central Glass and Silicate Research Institute to Central Glass and Ceramic Research institute (CGCRI) in 1945[15].

In 1949, Atma Ram submitted to the Government of India a scheme for the production of optical glass, based on the knowledge acquired by him at the experimental optical glass plant of the National Bureau of Standards,USA.

The Government of India approached almost all the optical glass manufacturing firms in Europe and Japan for technical collaboration. As these negotiations failed to secure a foreign collaboration in India, Pandit Jawaharlal Nehru, the then Prime Minister of India and President of the CSIR who was very keen on the development of optical glass in the country largely influenced the decision of assigning the task of developing and producing optical glass to the Central Glass & Ceramic Research Institute. In the meantime, two senior officers K.D. Sharma and J.C. Banerjee of the Institute were deputed to acquaint themselves with the working of the plant at the Glass

Division of National Bureau of Standards. In 1956, the Planning Commission assigned the CGCRI the task of evolving the necessary technology. After about 18 months of systematic work on raw materials and on designing and fabricating of equipment and furnaces, studying details of pot making, working out different schedules such as stirring and annealing, fixing up suitable compositions, the Institute was able to produce optical glass on a pilot scale in 600 lb meltings. The samples were examined by Prof. P.K. Kichlu, Professor of Experimental Laboratory, New Delhi and by the Technical Development Establishment (TDE) of the Minisitry of Defence, Dehradun and were found to be satisfactory. TDE, which is the biggest consumer of optical glass in the country certified the Institute samples as 'A' grade.

On the completion of pilot trials, the Government of India and the Planning Commission reviewed the position with respect to the manufacture of optical glass and early in the year 1960 entrusted its production to the Institute. A plant with sufficient capacity to meet the requirements of the country was fabricated and erected in the institute premises. It went into production in the later part of 1960. Since then, different varieties of optical glasses have been developed and are being produced to meet the requirements of the defence establishments and optical instrument manufacturers in the country. It is the tireless efforts and able guidance of Atma Ram that brought successful production of optical glass in the country.

Early investigations at the Institute[16] were confined to the development of borosilicate crowns, hard crowns and light flints. At a later stage light, medium and dense barium crowns, barium flints, dense flints, extra dense flints and double extra dense flints were developed. These glasses are required for defence needs like tank periscope prisms, binocular prisms and for achromatic combination in optical lenses, for cameras, telescopes, microscopes etc.

Among the recent developments there are stabilized glasses for radiation shielding windows (RSW) and laser glasses. RSW glasses are used for attenuation of harmful high energy radiations in nuclear reactors. These glasses possess the same optical quality as the other types of optical glasses. In addition they are characterized by high lead content and high degree of stability. CGCRI is also involved in the work of developing some new varieries of crown and flint glasses stabilized against gamma radiation, intended for use in imaging systems without transmission losses. Apart from these glasses, CGCRI has developed lead phosphate glass capable of registering tracks due to impingement of heavy nuclei. Since the quantum of requirement of particular variety of optical glass is not large enough, presently optical glasses are being produced by intermittent pot melting process. The continous melting process is yet to be adopted. CGCRI has been playing a significant role in attaining self sufficiency in the development and production of optical glasses and ceramic materials.

Apart from fundamental research, one of the functions of the Institute is to transfer the technology and to provide necessary help and assistance for the industry in the improvement of the quality of its products. The industry identified thus is Bharat

Ophthalmic Glass Limited (BOGL).

BOGL is a Government of India undertaking established with technical help from USSR for the production of ophthalmic glass[17]. It is a part of much bigger deal in which Bhilai Steel Plant was also involved. The reason for establishing BOGL at Durgapur was due to the availability of gas from Durgapur projects at a reasonably low price. The unit went into production in the year 1968 and was the first to produce ophthalmic glass in India. The products intially included white ophthalmic glass blanks and flint buttons for bifocal lenses. Subsequently BOGL with partial technological transfer from CGCRI and partly their own efforts diversified their activities towards optical glasses and other special glasses such as stabilized glasses for protection from gamma radiations, special filter glasses for furnace operation etc., BOGL started its R & D department in the year 1985. This department has since been able to develop stabilized optical glasses used for RSWs, special cobalt blue glass for blast furnace, barium glasses etc.,

The article[18] by Kamalesh Ray on Indian know-how and optical glass industry needs a mention in the present context. The views of Kamalesh Ray and our investigations prove that the development of highly specialized technology has been within the competence of Indian artisans, scientists and engineers. The method of indigenous optical glass production in Kamalesh Ray's words should be an eye opener. Certainly the optical instrument making, the systems designs including the optical components should go hand-in-hand with optical glass manufacturing. It is also felt that the pace with which our technological developments are taking place in the country, we may require still larger quantities of optical glass in a broad spectrum. The days are not so far off when we may have to go for continuous processes of large quantity optical glass manufacturing.

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