SOME ASPECTS OF GLASS MANUFACTURING IN ANCIENT INDIA

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The art of the manufacturing of glass attained a high degree of technological perfection in ancient India. It was known in the other parts of the world within the period of *c.* 2500 B.C. and 1550 B.C. But in India, its knowledge was known quite later, i.e. in the first quarter of the first millennium B.C. The archaeological evidences confirm the occurrence of various glass and glass-like objects, used mainly for ornamental purposes, from a large number of excavated sites. The evidences from Hastinapur, Ruper and Alamgirpur testify its antiquity to the painted Grey ware level II (*c.* 1100 B.C.–800 B.C.), while those of Maski ascribe its occurrence from the Chalcolithic levels also. The literary sources, i.e. *Śatapatha Brāhmaṇa*, *Rāmāyaṇa*, *Bṛhatsaṃhitā*, *Suśruta-saṃhitā*, *Arthaśāstra* of Kauṭilya, *Kathāsaritsāgara* of Somdeva, *Mṛcchakaṭika*, Bhartṛhari's account, *Śukranītisāra* of Śukrāchārya and accounts of the classical writers like Pliny, Strabo, Periplus and Apollonius, not only corroborate the archaeological sources but also throw welcome light on the different aspects of technological development of glass manufacturing in ancient India. The chemical studies of their high and impure varieties not only point out the technological perfection attained by ancient Indian glass manufacturers but also highlight the advanced knowledge of decolouring glasses by means of manganese as well as the knowledge of colouring them with different metallic oxides (in the form of mixtures) consisting of alkalis, sand, saltpetre and chalk. This fusion under different heating temperature attributed a coloured glaze on the surface of the glass objects on the one hand and chemical durability on the other.

Finally, on the basis of the available evidences, the Assyrian origin theory of Indian glass making has been refuted and the indigenous manufacturing of Indian glass objects has been upheld. Indian glass manufacturers had developed, besides the knowledge of colouring or decolouring glass objects, the knowledge of moulding, annealing and working glass techniques and became a beacon light to emulate such a technological advancement in the other countries of the world.

Since time immemorial, the amorphous nature of glass and its intrinsic qualities have stimulated the ancient Indian craftsmen for the fabrication of different glass objects used mainly for domestic and ornamental purposes. In the course of time, their marvellous human dexterity evolved considerably.

The origin of the knowledge of glass manufacturing goes back to a hoary antiquity. When and where it was first manufactured is still a debatable question. Petre[1] has dated the origin of the Syrian glasses in 2500 B.C.; Egyptian glasses[2] in the middle of the second millennium B.C. (*c.* 1551 B.C.–

1527 B.C.) and *c.* 550 B.C. in China[3] and the period earlier than *c.* 2100 B.C. in Mesopotamia.[4] Whether glass had an indigenous origin in these countries or not is again a disputed question. Setting aside the validity of the indigenous Egyptian theory of glass manufacturing, Petre[5] upheld that they were undoubtedly the imports from Asia. However, right from the Badarian age (*c.* 2000 B.C.) down to the advent of blow pipe in historic times (*c.* 300 B.C.) numerous finds of datable ancient glass objects have been testified by the pick and spade of the archaeologists. Hence, in the world context, the origin of the glass manufacturing can be fixed in between *c.* 2500 B.C. and 1550 B.C.

The history of glass manufacturing in ancient India has arrested very little scholarly attention due to the paucity of available material and inaccurately dated glass specimens. Thanks to the strenuous endeavours of the scholars[6] like Varshney, Lal, Satya Prakash and Rawat, who have not only successfully compiled an authentic data on the subject but also attempted to study ancient glass scientifically.

The ancient Indian glass objects were mainly ornamental[7] in nature like beads, bangles, pendants,[8] ear-rings,[9] ear-plug,[10] signets and rings,[11] necklaces[12] and occasionally used for seals.[13] It appears that as in modern India, these ancient glass objects were generally used more as the objects of luxury than those of daily use. Their brittle nature did not favour their use as the objects of daily use because we rarely find glass flasks[14] or glass tiles.[15]

The available sources of information in this connection can be classified mainly into two heads:

A. *Literary sources*—Mention can be made of *Śatapatha Brāhmaṇa*, *Rāmāyaṇa*, *Mahāvagga*, *Cūllavagga*, *Suśruta-saṃhitā*, *Arthaśāstra* of Kauṭilya, *Kathāsaritsāgara*, the accounts of classical Greek writers, i.e. Pliny, Apollonius, Periplus, Strabo, *Mṛcchakaṭika* of Śudraka, the accounts of Bhartṛhari, etc.

B. *Archaeological sources*—The pick and spade of the archaeologists duly testify to the occurrence of artificial and true glass objects from a fairly large number of excavated sites,[16] notable among them are Ruper, Hastinapur, Alamgirpur, Maski, Taxila, Arikamedu, Nasik, Navadatoli, Kopia, Ahicchatra and Maheshwar, etc.

A. LITERARY SOURCES

In the literary sources the term *kāca* is used to denote the meaning of glass objects. According to Eggelings[17] *kāca* stands for pearls, while according to others[18] it is used for glass beads. The *Vedic Index* observes silence on its mention. It occurs in the *Śatapatha Brāhmaṇa*[19] (datable according to MacDonell[20] in between *c.* 800 B.C. and 500 B.C.) and also in many other Sanskrit works. *Śatapatha Brāhmaṇa*[21] refers to 101 *kācan* being studded into a *maṇi* on the tail of a horse. *Mahāvagga*[22] and *Cūllavagga*[23] refer to shoes and bowls being studded with *maṇi, valuriya, phaṭika* and *kāca*. The evidence in the former case points out the probability that *kācan* stands for a bead and not a lump of gold, the nature of whose material is absolutely unknown, while the evidence in the later case clearly proves beyond doubt that *kāca* and pearls are two distinct objects. Supportingly, the Sanskrit dictionaries[24] unanimously connote glass, or a kind of clay called *mṛd*, as one of the different meanings of the term *kāca*. Lallanji Gopal has rightly opined that '*kāca* is a general term for a variety of matter used for ornamental purposes'[25] and 'it may be rendered better as glass beads'[26] in the *Śatapatha Brāhmaṇa*. This solitary evidence erroneously suggests that the knowledge of glass manufacturing was not a widespread one and this again led the same author to infer that 'we cannot allow a very long period for the evolution of the knowledge of glass beads'.[27] This view, however, does not seem to be a convincing one. The available archaeological evidences have in fact pushed back the antiquity of the glass manufacturing in ancient India by several centuries than can be inferred.

Besides, the following literary sources frequently refer to the term *kāca* and throw valuable light on the different aspects of the glass manufacturing in ancient India:

Rāmāyaṇa—It refers[28] to *kācakāra*, the maker of glass objects, while listing different types of traders and craftsmen, who made joint representation along with Bharata to Lord Rāma to abandon the idea of going for *vanavāsa*. Thus, it can be inferred that by this period glass manufacturing had received the stamp of industrial recognition in the society necessitating its joint representation.

Bṛhatsaṃhitā—It refers[29] to the glass objects as one of the profitable commodities of trade and commerce.

Suśruta-saṃhitā—This medical work refers[30] to different instruments made of glass, crystals and quartz, used only in the absence of other instruments. It mentions[31] of beautiful glass vessels, employed for serving food. Hence, by the sixth century B.C. glass vessels were also manufactured for domestic and other utilitarian purposes.

Arthaśāstra *of Kauṭilya*—According to Beck[32] *Arthaśāstra* also refers to *kācamaṇi*[33] and *kṣepaṇe*[34] as 'false glass gems'. The different kinds of metallic salts and oxides used for encrusting the valuable glass[35] objects have also been referred to in the text. The text alludes[36] to other highly illuminating pieces of evidence. According to it a licence fee was imposed, which was payable in advance, like modern surety money for starting the glass industry. *Arthaśāstra* undoubtedly[37] points to a flourishing condition of glass manufacturing during the Mauryan epoch. It can be inferred that during the Mauryan period the glass manufacturing industry had not only demonstrated high technological advancement but, above all, it was also recognized as a dignified and a highly lucrative profession in the industrial and mercantile arena of the society.

Kathāsaritsāgara—While referring[38] to one of the cases of cheating by a person, Śiva by name, for selling closely resembled imitational glass objects to a priest under the false pretext of their being the real jewel, gold and silver ornaments. The expert who examined this case finally commented[39]: 'Ha! who made these jewels was a clever fellow, whoever he was. For, this ornament is composed of pieces of glass and quartz with various colours and fastened together with brass and there are no gem or gold in it.'

Mṛcchakaṭika—In one of its court scenes,[40] the provest is directed to examine the genuineness of the true imitational glass objects for gold and silver ornaments. It was observed that 'the dexterity of the articles is no doubt very great and they readily fabricate imitation of ornaments they have once seen in such a manner that the difference shall scarcely be discernible'. This evidence points out to a highly evolved technological skill employed in the manufacturing of the imitational glass object with remarkable minuteness of details and perfection.

Bhartṛhari's Account—While referring[41] to the selling of *cintāmaṇi* at the price of glass ornament, the account also testifies to the non-availability of the glass material in the nearby mines. This suggests that glass ornaments were used in exchange for other costlier ornaments like *cintāmaṇi*, etc., and the ancient craftsmen had developed some knowledge of exploring the regions of the availability of the raw glass material.

Śukranītisāra of Śukrāchārya—The text listed glass vessels in the given list of *kalās* and refers[42] to the glass objects as a lucrative commodity of merchandise. It again refers[43] to the true imitational glass objects for jewel and gem ornaments which undoubtedly testify to the technological advancement of the glass-making industry in ancient India.

FOREIGN TRAVEL ACCOUNTS

The foreign accounts left by Pliny, Periplus, Apollonius and Strabo undoubtably testify to the flourishing condition of glass making in ancient India.

Pliny (c. first century A.D.)—He refers[44] to the superiority and incomparability of the Indian glass industry with those from other countries, on account of their being composed of broken or pounded colouring crystals, and Berlys[45] in particular, prepared by the admixture of different metallic salts and oxides. It is due to the advent of this knowledge of colouring crystals that the manufacturing of true imitational glass objects received considerable technological perfection.

Periplus (c. 73–77 A.D.)—While referring[46] to a white variety of glass objects, which was imported into the ancient trading ports of Barbaricum, Barygaza and Nelcynda, Periplus also refers[47] to the flint glasses and antimony objects which were widely known in ancient India.

Strabo (c. *first century* B.C.–*first century* A.D.)—He also mentions[48] oil flasks, probably made of glasses, and testifies to the knowledge of crystals and anthraces of all kinds being fairly known to the people.

Apollonius—He refers[48a] to glasses which hold oily inflammable things.

Thus, by the early centuries of the Christian era glass manufacturing had attained a high degree of technical skill and become a lucrative commodity of merchandise.

Dāmodargupta (c. A.D. 779–A.D. 818) and Bhāllata (c. A.D. 883–A.D. 902) also refer[49] to the frequent use of glass objects in Kashmir during the eighth and ninth centuries A.D. Hemcandra also refers to the tiny glass beads as *poṭa* which according to Dikshit[50] was a widely popular glass-bead ornament in ancient India.

The close scrutiny of the available literary sources led to the following conclusions:

A. That the antiquity of the glass can be traced back to the period of *Brāhmaṇas* as far back in c. 800 B.C. to 500 B.C. Though glass products were the products of merchandise yet we do not know whether glass making was a popular industry or not. Since so far there is only a solitary evidence it seems that it was not a popular industry during those times.

B. That by the *Rāmāyaṇa* period the glass-manufacturing industry had received the stamp of industrial recognition in the society, necessitating its representation also.

C. That glass ornaments were deemed costly and manufactured with remarkable skill. They could imitate other costly ornaments of jewels, gold, silver or gems. They were used in exchange also. This signifies to striking technological advancements accomplished by the ancient craftsmen.

D. That the evidence of the tax imposition for starting the profession of the glass industry clearly points out to the growing demand of this lucrative business in the industrial and mercantile spheres. The profession received patronage and recognition from the State.

E. That the increasing popularity of the glass-making industry definitely opened a new chapter in the commercial world. Different varieties of glass, i.e. white and flint glasses, with different shades of colours and shapes were not only widely manufactured but also imported into the ancient ports of Barbaricum, Barygaza and Nelcynda.

F. That the knowledge of glass manufacturing was fairly well known as early as the first century A.D. (if the date of *Kathāsaritsāgara*, as given by

Lallanji Gopal,[51] is to be believed). The accounts of foreign travellers belonging to this period duly substantiate this fact.

G. That the knowledge and practice of glass manufacturing continued uninterruptingly during the *Rāmāyaṇa* age, the age of Buddha and in the early centuries of the Christian era. During the Mauryan period, it had received the State's recognition and considerable prominence in the mercantile world as the glass objects were exported to other countries also. This definitely affords the inference that they must have attained a high technological perfection which necessitated their wide-scale growing demand and manufacturing and also their import in bulk.

H. That the literary sources amply throw light directly on the technological skill of the ancient craftsmen employed in the fabrication of the glass objects, but it is very unfortunate that they do not throw light on the actual *modus operandi* of the glass manufacturing in ancient India. Some information is given in the *Kathāsaritsāgara* but that too is almost negligible. Hence, on the basis of stray references available in the literary sources, it is possible to present the history of technological advancement of the glass-manufacturing industries in ancient India, if we are not able to infer their exact techniques of manufacturing.

I. That the fabrication of the true imitational glass objects and their colour techniques, by mixing metallic oxides and salts and other chemicals, clearly signifies that the techniques of glass manufacturing had definitely attained a high degree of technological perfection in ancient India.

B. Archaeological Sources

No true glass is reported from any site of the Harappa Culture.[52] However, glazed objects like beads, bangles, pottery, terracotta, etc., mostly made of steatite, or paste or faience or glazed material, have been found at several sites.[53] Vitrified white or greyish paste and faience were used for glazing the objects. Gordon Childe refers[54] to the glazed steatite seals from Dabarkot and Kulli, one of the earliest proto-historic cultures of Baluchistan. These seals were coated with thin glazing material. This glaze was prepared after mixing vitrified paste and faience. Acccording to Lucas[54a] the glassy frits formed on pottery waster or in the process of smelting metal may have necessitated the use of glazes and this may have finally led to the manufacturing of glass in ancient India. Since the nature and composition of glazing and glass making involve a common process, there is every reason to fall in line with the observations of Gordon Childe[55] that 'even glass if not worked locally is believed to have been known, though not found so early in India or in Babylonia'. Lal[56] expressed his surprise that in spite of the Harappans having contact with the Mesopotamian countries, where glass was an established industry in the third millennium

B.C., the knowledge of glass making was absent in India during this period. Dikshit[57] held that the Harappans possibly through trade contacts with ancient Sumerians had learnt the techniques of moulding and fusing 'articles of faience and glaze quartz beads with a frit akin to glass'. However, Sharma[58] also supports this view and says that the knowledge of glass manufacturing 'may have been known in proto-historic times'.

Thus, the early knowledge of paste and techniques of glazing with the combination of different colours in different fusions, as evolved during the Harappan period, indirectly points out to the early knowledge of some kind of glass making if not the true glass in the third millennium B.C. But the possibility of manufacture of true glass cannot be ruled out until the spade of the archaeologist duly confirms it.

The archaeological excavations give the evidence of the occurrence of glass objects from a fairly large number of ancient sites. The appended Table I will present a picture of the glass manufacturing through the ages.

TABLE I

Glass manufacturing through the ages

Sl. No.	Name of the site	Period/Phase	Date	Remarks, if any
1	Ruper[59]	II P.G.W.	c. 1100 B.C.–800 B.C.	
2	Hastinapur[60]	II P.G.W.	1100 B.C.-800 B.C.	
		III	600 B.C.–300 B.C.	
		IV	200 B.C.–A.D. 300	
		V	A.D. 500–A.D. 1100	
3	Alamgirpur[61]	II P.G.W.	1100 B.C.–800 B.C.	
4	Maski[62]	Chalcolithic phase, historical phase	1 millennium B.C. c. 400 B.C.–A.D. 1000	Polychrome and monochrome glass specimens are reported
5	*Madras Dist.*[66]			
	A. Tirukhamuliyur		1 millennium B.C.	
	B. Uraiyur			
	C. Tiruchi			
6	*Taxila*			
	A. Bhir Mound[63]	Buddhist phase	c. 600 B.C.	Earliest authentic glass specimen. Dikshit[64] dated few samples to 700 B.C. and others between 500 B.C. and 400 B.C.
	B. Sirkap[65]	Mauryan levels	c. 300 B.C.	
7	Arikamedu[67]		500 B.C.–200 B.C.	
8	Kopia[68]		c. 500 B.C.	Nagar[69] dated the industry to about fifth century B.C. while Dikshit[70] dated it in 100 B.C.–A.D. 100

TABLE I (*concld.*)

Sl. No.	Name of the site	Period/Phase	Date	Remarks, if any
9	Navadatoli [71]	IV	*c.* 400 B.C.–100 B.C.	In phase II [73] glass was also known. Only traces have been found. Lal [74] confirmed the date of origin to fourth century B.C. on the stratigraphical grounds
10	Nasik [72]	II III	400 B.C.–A.D. 50 A.D. 59–A.D. 200	
11	Maheshwar [75]	IV	*c.* 300 B.C. *c.* 100 B.C.–A.D. 100	Datable about[76] fourth century B.C. and demonstrated high technical skill [77]
12	Ahicchatra [78]		*c.* 300 B.C.–A.D. 1000	
13	Kosam [79]	Kushan and Suṅga phase	*c.* 200 B.C.	
14	Brahamagiri [80]		*c.* 200 B.C.–A.D. 200	
15	Chandravalli [81]		*c.* A.D. 100	
16	Ujjain [82]	III	*c.* 200 B.C.–A.D. 1300	Banerji [83] reported the occurrence of glass from NB. P levels at this site
17	Prakesh [84]		*c.* 200 B.C.–A.D. 600	
18	Kondapur [85]	Satavahana phase	*c.* 100 B.C.–A.D. 300	
19	Amravati [86]		*c.* 100 B.C.	
20	Nevasa [87]	V	*c.* 50 B.C.–A.D. 300	
21	Rajaghat [88]	III	*c.* A.D. 100–A.D. 300	
22	Pataliputra [89]	III	*c.* A.D. 100–A.D. 300	
23	Sisupalagarh [90]	II	*c.* A.D. 100–A.D. 200	
24	Chandraketugarh,[91] Calicut	IV	First century A.D.	
25	Bellary [92]	Medieval	A.D. 1400–A.D. 1500	
26	Kolhapur [93]	Medieval	A.D. 1400–A.D. 1500	
27	Nalanda [94]	Medieval	A.D. 1400–A.D. 1500	
28	*Miscellaneous sites* [95]			
	(1) Dargai in Matakand Agency, N.W. Provinces (2) Kurukshetra (3) Assam (4) Udaigiri, Gwalior (5) Rairh, Jaipur (6) Agra	Late medieval period	Fourteenth, fifteenth and sixteenth centuries A.D.	

Among the above listed 33 sites, the names of Ruper, Alamgirpur, Hastinapur, Maski and the sites at Madras district deserve special mention in establishing the antiquity of glass making in ancient India.

Ruper[96]—The occurrence of glass objects immediately after the Harappan levels in phase II of P.G. ware people who were Aryans, according to Lal,[97] and who flourished in between *c.* 1100 B.C. and 800 B.C. is well known.

Sharma[98] observed that 'glass which was unknown to the Harappans seems to have been introduced by the P.G. ware people', and that 'it may have been known in proto-historic times'.[99] Supporting this, Banerji[100] also indicates 'that glass could be produced at this time is a thing to wonder about and is the earliest evidence India has so far known'. This clearly suggests that glass manufacturing originated some time in the first quarter of the first millennium B.C. in ancient India.

Hastinapur—Lal[101] has reported that at Hastinapur also, in phase II of the P.G. ware people, glass bangles have been found in a stratified manner datable to *c.* 1100 B.C.–800 B.C. and particularly in bulk in period V. Lal[102] has commented that 'the occurrence of glass bangles in period II is noteworthy. Evidence of glass bangles being in use in so remote a past is not available'.

Alamgirpur[103]—Similar evidence is reported from this site.

Maski—Dikshit[104] reported the occurrence of glass from the Chalcolithic levels datable to the first millennium B.C.

Similarly, three sites[105] of Madras district also testify to the occurrence of glass objects belonging to the first millennium B.C.

The literary sources point out that the knowledge of glass making was originated in the period of *Brāhmaṇas* in *c.* 800 B.C. and 500 B.C. The direct archaeological sources testify that the industry originated in P.G. ware phase (*c.* 1100 B.C.–800 B.C.). The lower limit of the archaeological dating corresponds to the upper limit of the literary sources. The indirect evidence from Mohenjo-Daro, i.e. paste, faience, glaze, etc., supports to an early origin of glass manufacturing, i.e. third millennium B.C., which is yet to be confirmed by the archaeological evidences. Hence, from the cumulative evidence culled from the literary and archaeological sources it can be legitimately inferred that glass manufacturing had started in India some time in the first quarter of the first millennium B.C. Deshpande[105a] also confirms such an inference.

TECHNOLOGY OF GLASS MANUFACTURING

Technology can be defined as the systematic knowledge of any industrial art. In ancient India glass manufacturing was definitely an industrial art. The available literary sources no doubt point out to only a few technological aspects, i.e. glass material, colour associated with the glass making in ancient India, but they do not furnish any direct evidence regarding a definite technique and method of glass manufacturing. We can make plausible inferences regarding the growing technological skill and craftsmanship of ancient glass makers. No doubt, recently Lal[106] and Varshney[107] have attempted to study the ancient glass specimens on scientific lines, i.e. the study of refractive index, strain and specific gravity, the chemical properties, colours, their formations, etc.

TABLE II

Chemical analysis of Taxila glass specimens[117]

Sl. No.	Description	SiO_2,	Fe_2O_3	Al_2O_2	Pbo	SnO_2	Sb_2O_3	MnO	Cu	CuO	Cu_2O	CaO	MgO	Na_2O	K_2O	H_2O	Total
1	Red opaque glass	37·09	—	3·16	34·85	—	—	0·11	—	—	7·20	6·46	0·70	10·33	0·87	—	100·07
2	White opaque glass	61·32	—	1·70	—	—	5·08	0·26	—	—	—	9·74	1·64	—	20·24	—	100·00
3	Thin drawn out strips of haematinum	39·79	—	2·45	8·93	0·22	—	—	5·31	—	—	2·81	—	10·02	0·57	—	100·10
4	Greenish blue glass	70·57	1·60	2·46	—	—	—	0·05	—	0·55	—	4·60	2·68	14·99	2·65	—	100·15
5	Turquoise blue powder of decomposed glass	67·48	—	3·64	—	—	2·42	—	—	3·63	—	4·92	1·80	2·48	0·55	14·15	101·07
6	Light green fragment of flask	68·34	1·20	1·67	—	—	—	0·34	—	—	—	8·44	1·44	17·76	0·94	0·43	100·56
7	Greenish blue glass	71·01	1·84	3·74	—	—	—	0·05	—	0·24	—	3·73	2·32	14·99	2·65	—	100·57
8	Amethyst glass	58·12	1·74	5·74	—	—	—	0·17	—	—	—	8·85	4·01	16·74	4·83	—	100·20
9	Brown glass	53·81	8·47	1·51	—	—	—	0·08	—	—	—	6·27	4·50	23·52	2·35	—	100·51
10	Light blue glass	70·69	0·81	2·88	—	—	—	0·01	—	—	—	7·05	0·50	12·86	4·85	—	99·65
11	Blue glass bangle	68·11	2·27	2·22	—	—	—	—	—	0·44	—	4·91	3·74	19·10	—	—	100·79

Glass, being brittle non-crystalline substance, is produced by the mixture of three chemical substances—soda, lime and sand or quartz powder—and in ancient India it was used to be heated in an oven fuelled only with wood into a vitreous fluid up to 1,000° high temperature. It must have been shaped by blowing or pressing in a hot liquid state as soon as it came from the melting-pot. The quality of the glass depended on the component material, on the admixture of colouring agents or decolourizing agents for transparent glass, on the temperature at which the fusion occurs, and on the methods employed to shape the vessels into different forms and finally on the atmospheric conditions such as those which cause the decomposition that produces iridescence among the glass objects in ancient India.

The glass specimens of Taxila,[108] Arikamedu,[109] Ahicchatra,[110] Kopia,[111] Nasik,[112] Kohlapur,[113] Maheshwar,[114] Nalanda[115] and other sites[116] have been chemically studied with a view to assess the technological perfections attained by ancient craftsmen in their art of fabricating glass objects for domestic and ornamental purposes.

The chemical analysis given in Table II[117] reveals that the Taxila glass specimens are soda-lime glasses having the following chemical substances, each attributing different chemical reactions.

Substances[118]	*Chemical reactions*[119]
1. Magnesia (lower percentage)	Rapid melting rate, easily workable.
2. Potash (small percentage)	Increasing chemical durability. Diminishes its tendency to devitrification.
3. Lime (large percentage—6% to 7%)[120]	Increasing chemical durability.[121] Morey held that when lime is used in a small percentage then it will lack durability and an easy melting rate would be achieved.[122]
4. Silicon oxide (no high percentage)	High content above 72% has got a chemical durability to melt and tends to devitrify. Such a high percentage of silicon oxide is not testified from the Taxila specimens.[123] But Sanahullah[124] reported this fact in one of the specimens (71·14%) found at Nippur. But this solitary example is an exception and is chemically par with Taxila glass specimens.

5. Lead (high percentage in red opaque glass and thin strips of haematinum)	Resembling with Roman haematinum glass. The use of such a high percentage of lead was absent in earlier or contemporary glass-manufacturing industries of the world except in some blue Chinese glass beads of the Han period (second century B.C.).[125] No doubt, it is a practice of modern growth. These two stray evidences warrant us to infer that it was not widely practised in the fabrication of glass objects in ancient India. Lal[126] rightly observed that 'it is therefore significant that as early as in the fourth century B.C. craftsmen of Taxila were acquainted with the use of this compound in glass manufacturing'.
6. Antimony (high percentage in two specimens—white opaque glass and turquoise blue powder of decomposed glass)	This also signifies the practice of modern growth.
7. Free from air bubbles	

Hence, the Taxila glass-manufacturing industry was technologically far ahead than the contemporary known glass-manufacturing industries of the Orient. Besides, the other glass specimens from Sirkap, i.e. three conical flasks from Pre-Mauryan levels[127] and their chemical analysis, clearly point out to the definite glass blowing technique of glass making and also to an advanced technique of decolouring glass by means of manganese and colouring it by means of mixing various metallic oxides.[128] Here our chemical analysis undoubtedly confirms and remarkably corroborates Pliny's[129] observations that Indians were skilled in the art of colouring glass to imitate precious gem ornaments. Again, a floor of transparent glass tiles is also reported[130] to have been found at Taxila in the Dharmarājikā stūpa, datable to *circa* third century B.C. These specimens are the earliest evidences revealing that Indians could also manufacture clear transparent glasses and they had certainly accomplished considerable skill in the art of glass blowing in ancient India. These specimens do not possess any mark of fracture and devitrification; this clearly signifies that the knowledge of the art of annealing was also considerably developed by this time because the internal strain of such heavy glass objects cannot be otherwise removed. Hence, the technique of glass blowing and annealing were widely known and practised in glass manufacturing in ancient India by the beginning of the third century B.C.

Chemical analysis of Arikamedu glass specimens (*see* Table III)[131]:

Located at the Coromandal coast near Pondicherry in South India the site has yielded a large number of rods of glass-like materials[132] which were once thought to be fossil-wood on the evidence of a large number of river-beds containing fossilized wood near the Pondicherry area.[133] But Lal's[134] chemical analysis has firmly established that they are true glass specimens.

Some features of physical, microscopic and chemical analysis of Arikamedu glass specimens are as follows:[135]

A. *Length*—2 cm to 2·4 cm; 4·6 cm.

B. *Shape*—Cylindrical, circular, solid without holes, core of sand.

C. *Colours*—Olive green, bottle green, cobalt blue, greenish, blue, brick- and liver-red colour, some of them are transparent and most of them are opaque.

D. *Refractive index:*

Soda-lime 1·53.
Quartz varies from 1·5442 to 1·5533.
Chalcedony varies from 1·531 to 1·535.
Opal varies from 1·40 to 1·46.

E. *Specific gravity:*

(1) Green opaque specimens from 2·60 to 2·91.
(2) Green transparent specimens from 2·52 to 2·74.
(3) Red opaque solid specimens from 2·51 to 2·64.
(4) Red opaque perforated specimens from 2·54 to 2·72.

The average specific gravity of soda-lime is 2·5. Although most of the specimens are higher than quartz whose specific gravity is higher than soda-lime specimens.

F. *Molecular weight*—The molecular weight of the components of glass varies over a large range and their results indicate that the rod-like material is not quartz but it is akin to glass. The vitreous lustre and conchoidal fracture further substantiated their glassy nature.

G. *Hardness*—It varies from 5 to 7 and according to Lal it was caused due to the higher proportion of silica, alumina and lime, heat treatment, poor annealing and uncontrolled cooling at a high rate.

H. *Chemical analysis*[136]—It shows that the alkali percentage belongs to 13·22 which agrees with the alkali content of common glass specimens. The examination of specimens II and III reveals that both of them are potash glasses, containing very little aluminia content and high silica content.

TABLE III

Chemical analysis of Arikamedu glass specimens[131]

Sl. No.	Description	SiO_2	Fe_2O_3	Al_2O_2	PbO	MnO	CuO	CaO	MgO	CO_2	Na_2O	K_2O	Total
1	Deep violet glass ..	73·62	3·84	1·38	0·07	5·01	—	1·96	0·30	—	1·30	12·78	100·26
2	Bluish violet glass ..	72·49	6·50	1·12	0·07	1·99	—	2·94	0·68	—	0·20	14·14	100·13
3	Blue glass ..	73·60	1·10	1·90	—	0·40	—	3·90	1·40	2·00	2·10	13·40	99·80

The violet transparent glass contains high proportion of manganese which attributed deep violet colour to it. Specimen III also contains manganese as the colouring agent. It can be pointed out that the north Indian glass-manufacturing industries with the exception of Udaigiri glass industries were mostly soda-lime glass industries, whereas the Arikamedu glass-manufacturing industries in the South were mainly potash glass industries. Why there is such an anomaly? Lal[137] argues that being nearer to the sea it may have been convenient to use the wood-ash (potash) for glass making rather than to collect soda elements from the drier interior for this purpose. But the solution for such an anomaly is still open for further investigations.

I. *Microscopic examination*[138]—The examination has revealed that they are not fossilized wood as there is no trace of plant structure except a core surrounded by a glassy material has been detected. The grains of the core are anisotropic while the surrounding glassy material is perfectly isotropic between crossed nicols. From these evidences it has been suggested that had these glass-like specimens been composed of fossilized wood, the cellular structure of wood would have been present between the crossed nicols. But no structure of such type is found, rather the core shows some anisotropic grains of quartz and sand surrounded by the compact glassy and colouring materials; all combined together suggest that the rod-like glassy materials are not fossilized wood. They are the pieces of artificial glass specimens.

J. *Moulding techniques*—It is on the basis of the marks of wavy bands found on the Arikamedu glass-like material during the microscopic examination, it has been suggested that the material seemed to have been drawn out in the form of tubes in the molten condition. Thus, the technique of moulding, too, was fairly known in ancient India during the early centuries of the Christian era.

Thus, it can be safely concluded, firstly, that the Arikamedu glass-manufacturing industries were indigenous manufacturing industries because not a single feature connected with it can be accounted from the known Western glass industries. Hence, on the basis of this evidence the Assyrian origin theory of Sanahullah can be safely refuted and the indigenous glass-making industries in ancient India can be safely upheld. Secondly, the technique of moulding was also known to the Arikamedu glass-manufacturing craftsmen during the first century A.D. though it was known much earlier in the third and fourth centuries B.C.[139]

Chemical analysis of Ahicchatra glass specimens (see Table IV)[140]:

Ahicchatra is located in the Bareilly district, U.P. It was the capital of north Pāñchāla and was in occupation from the third century B.C. to the tenth/eleventh century A.D.[141] Lal's analysis[142] has revealed that the colour of blue glass specimen is due to the content of copper oxide and that of

TABLE IV

Chemical analysis of Ahicchatra glass specimens[140]

Sl. No.	Description	SiO_2	Fe_2O_3	Al_2O_2	PbO	MnO	CuO	CaO	MgO	Na_2O	K_2O	P_2O_3	Total
1	Blue glass	61·49	5·29	0·66	—	—	2·39	6·60	4·61	15·32	2·67	1·94	100·97
2	Green glass	59·56	5·40	0·05	4·23	0·06	1·82	6·54	4·34	14·19	2·41	1·36	99·96

TABLE V

Chemical analysis of Kopia glass specimens[146]

Sl. No.	Description	SiO_2	Fe_2O_3	Al_2O_2	MnO	CaO	MgO	Na_2O	TiO_2	Total
1	Tin black glass beads ..	62·24	7·20	8·48	0·20	3·13	1·55	16·70	0·51	100·01
2	Other specimens	70·30	1·20	5·30	0·08	2·38	1·20	10·51	tr.	99·97
3	,, ...	64·80	0·95	7·35	0·06	3·10	2·10	20·59	0·45	100·01
4	,, ...	67·18	1·50	7·00	0·07	3·10	1·60	19·15	0·40	100·00
5	,, ...	66·13	0·86	7·26	0·10	2·24	1·33	21·67	0·41	100·00

TABLE VI

Chemical analysis of Nasik glass specimens[148]

Sl. No.	Description	SiO_2	Fe_2O_3	Al_2O_2	MnO	CaO	MgO	Na_2O	K_2O	H_2O	Total
1	Green bottle ..	65·28	4·78	5·75	1·73	11·88	1·48	7·88	1·06	0·18	100·02
2	Worked glass specimen	55·55	3·06	9·89	tr.	5·59	2·93	6·26	16·12	0·56	99·96

green is due to the combined effects of copper and lead oxides. According to him,[143] 'It is very probable that these substances are fruits employed for glazing pottery.' It is a pleasing fact to notice that the use of lead is confirmed by only two specimens from Taxila and one from Ahicchatra, but the use of barium is conspicuous by its absence. The Chinese glasses[144] of the Han period, as discussed earlier, do contain large quantities of lead (24·5%) and barium oxide (19·2%). Indian glass seems to have occupied a distinctive character. The sizes of Ahicchatra glass beads vary much, i.e. cylindrical, circular, hexagonal, square, elliptical, bicone, rectangular circular and elliptical circular.

Two special types[145] of glass beads deserve special mention. Firstly, a gold-foil glass and, secondly, a glass having a millifiori pattern. The technique of the former is that a layer of gold-foil is pressed on a glass matrix, coupled with another coating of transparent glass over it, while the latter suggests that it is a folded bead having a blue core and decorations demonstrated by several vertical hatchings in red, white and black in a double black border, thus, laying the pattern slanting across the body of the bead. In the Gangetic basin, similar glass beads have been reported in a fairly large distribution.

Chemical analysis of Kopia glass specimens (*see* Table V)[146]:

The glass specimens contain clay crucibles (with glass sticking to them) in which the glass was presumably melted. Large lumps of glass and tiny beads with very fine threading holes are, indeed, of distinctive character. They have a close resemblance with the Piprahawa glass samples (Sp. gr. from 2·33 to 2·68), 36 miles from Kopia. Nagar[147] dated Piprahawa glass industry to about fifth century B.C.

Among the five samples examined, No. II contains highest silica percentage and the lowest ferrous oxide, calcium oxide, magnesium oxide and sodium oxide percentages, while sample No. I shows the highest percentages of use of MnO, CaO, TiO_2, Fe_2O_3 and aluminum oxide.

Chemical analysis of Nasik glass specimens (*see* Table VI)[148]:

Lal[149] has reported a vermilion-coloured glass object with a grove from Matichi Gadhi, Nasik, belonging to the early historical period (*c.* 300 B.C.–A.D. 100). It is of a conchoidal fracture of glass and it is translucent to opaque but shows red colour in reflected light. Chemical analysis shows that the colour of this object is due to the mixture of copper oxide. Lal[150] observed: 'Certainly early glass-like materials, such as grooved discs found usually with the Buddhist objects, are neither made of glass nor chalcedony but are made with a paste of the latter and resemble in their composition to the objects of similar materials from Mohenjo-Daro.'

TABLE VII[152]

Chemical analysis of Maheshwar glass specimens[154]

Contents	Circular object No. 692, Nasik	Disintegrated glass, Nasik	Disintegrated glass	Paste from Mohenjo-Daro[153] VS. 195	Paste from Mohenjo-Daro[153] H.R. 3572	Paste from Mohenjo-Daro[153] Paste from Mohenjo-Daro
SiO_2 ..	80·17	87·55	85·58	85·90	88·12	84·66
Fe_2O_3 ..	2·00	1·49	1·96	6·74	1·82	6·31
Al_2O_3 ..	4·35	3·17	3·61		3·20	
MnO ..	tr.	—	—	—	—	—
CuO ..	—	—	—	—	—	—
CaO ..	—	—	—	0·46	0·46	0·97
MgO ..	2·72	1·44	1·66	1·73	1·26	1·40
Na_2O ..	2·12	0·53	0·41	0·38	—	tr.
K_2O ..	By diff. 2·41	By diff. 2·58	By diff. 3·03	3·70	5·04	5·48
H_2O ..	6·23	3·24	3·75	1·49	—	1·18
Total ..	100·00	100·00	100·00	100·00	100·00	100·00

TABLE VIII

Chemical analysis of Nalanda glass specimens[157]

Sl. No.	Description	SiO_2	Fe_2O_3	Al_2O_2	FeO	MnO	CuO_2	CuO	CaO	MgO	Na_2O	K_2O	H_2O	CO_2	Total
1	Light blue glass	62·62	1·61	2·05	—	0·06	0·57	—	6·95	4·17	17·85	5·04	—	—	100·91
2	Sky blue glass	61·21	1·60	1·81	—	—	0·75	—	8·15	3·83	18·25	4·98	—	—	100·58
3	Green glass	70·74	1·54	6·13	—	tr.	—	—	2·11	0·26	15·80	2·94	—	—	99·52
4	Opaque bead of red glass	61·50	9·82	—	7·01	—	0·49	—	5·20	0·06	—	15·92	—	—	100·00
5	Blue glass	63·44	6·90	—	—	tr.	—	1·13	8·00	4·14	15·69	1·54	—	—	100·84
6	Decayed glass	56·72	1·50	2·77	—	tr.	—	0·09	11·95	3·17	3·62	0·49	7·16	12·80	101·06

The chemical properties of disintegrated glass objects of Nasik and Mohenjo-Daro paste[151] show slight variation in their chemical composition but the most astonishing fact is that their total percentages of chemical properties are exactly equal in number (i.e. 100·00) in all the three samples examined. This evidence also indirectly substantiates to the possibility that the Harappans had the knowledge of glass making during those periods of hoary antiquity.

In this connection Table VII would highlight the aforesaid close resemblances between Mohenjo-Daro and Nasik glass specimens.

Chemical analysis of Maheshwar glass specimens (see Table VII)[152]:

Lal[155] has analysed a glass tablet of Maheshwar having weathering crack marks all around it and showing an elephant design in relief. Being composed of dark, amber-coloured soda-glass, a whitish deposit of silica is also noticeable inside the cracks. Chemical analysis shows that the colour of the glass tablet is due to the iron compounds and it has specific gravity of 2·41. The specimen is of considerable artistic merits. It amply demonstrates that it had been moulded with meticulous care. Although the surface of the tablet is traversed with several fine cracks and weathering marks yet it is remarkably immune from devitrification. It is therefore evident that after moulding the tablet was subjected to annealing process with a view to removing the internal strain. The art of moulding glass objects and annealing them was therefore highly developed during the third century B.C. (date of glass tablet on palaeographical and stratigraphical grounds).[156] Hence, this evidence clearly proves that the fair knowledge of the art of moulding, annealing, working glass and styling with relief designs was known and practised in ancient India during the fourth century B.C.

Chemical analysis of Nalanda specimens (see Table VIII)[157]:

Sanahullah[158] and Lal[159] had examined the Nalanda glass specimens and observed that the prolonged burnt has caused the removal of the alkali content and carbonation of lime and magnesia. The glass specimens are free from lead and antimony. Few examined specimens are similar in composition to the Taxila specimens. Lal[160] has observed: 'With the exception of the absence of these two elements (i.e. lead and antimony) the recipes of glass manufacture as used in Taxila did not undergo notable modifications down to the time of Nalanda.'

Colouring Techniques

The extant glass specimens show that the ancient glass makers were highly competent in the art of using multicoloured shades, in attributing a better finishing and outlook to the glass objects (*vide* Table IX).

TABLE IX

Colour schemes of ancient glass specimens[161]

Sl. No.	Name of the site	Objects	Colour schemes
1	Taxila	°Beads	Blue from pale to dark, sea green, amber, violet, black, yellow, brown, amethyst.
		† Bangles	Opaque-red, white, yellow, green, blue, purple, cobalt blue, pale blue, brown, turquoise blue, orange.
		△ Tiles	Greenish blue, bright azure red; black-white, yellow.
		* Flasks	Light green.
2	Nalanda	Beads Bangles	°† Blue, green, opaque, red, sky blue and light blue colours.
3	Arikamedu	Beads Bangles	° Blue-green, copper red, white, black, yellow, violet, brown grey, opaque and translucent. † Red opaque, deep violet, green opaque colours.
4	Ahicchatra	Beads Bangles	°† Blue, green, opaque black, black and white, gold-foil, opaque red, dark red, bright red (opaque); red with white core; deep and light blue, green, blue millifiori, orange.
5	Kopia	Beads	° Black coloured.
6	Hastinapur	Beads	° Black opaque, deep blue, green.
		Bangles	† Brownish black (opaque), translucent, deep blue and green.
7	Maski	Bangles	† Translucent green, multicoloured bangles.
		Beads	° Blue translucent, opaque, blue, opaque black, translucent, yellow, white, amber, green, shellac, red.
8	Maheshwar	Beads	° Greyish black, deep blue, ashy blue, light blue (opaque).
		Bangles	† Black, jet black, red, blue, cobalt blue, lemon yellow, light yellow, ultramarine blue, turquoise blue, deep chocolate, cream colours.
9	Nasik	Beads	° Green, blue, gold-foil.
		Bangles	† Black, yellow, orange, chocolate, blue, green, purple, white, monochrome and polychrome, opaque and translucent (*c.* A.D. 1300–A.D. 1400).
10	Nevasa	Beads Bangles	° Yellow, lemon-yellow, yellow-green, yellow-ochre, buff-yellow; raw-sienna; chrome-yellow, black, white, blue, ultramarine, turquoise, cobalt, gold-foil, lemon-yellow matrix, green, Persian green, sap green, emerald green, copper red, brilliant red. † *Monochrome*—Blue, Persian blue, ultramarine, royal yellow, black, green (translucent), red (opaque), scarlet, brunt-sienna; vermilion, yellow colours in combination with green, lemon, chrome, separately; green, blue. *Polychrome* (A.D. 1400–A.D. 1700)—Yellow lemon; gamboz; chrome, red, black, green, blue.
11	Brahmagiri and Chandravilli	Beads Bangles	°† Deep and light green; sky-blue (opaque) black, translucent, light-green, sky-blue.
12	Kondapur	Beads Bangles	° Deep green, bluish green, yellowish green, blue, deep blue, pale-blue, amber, ruby-red colours.
13	Prakesh	Beads Bangles	° Opaque yellow, opaque green, blue. Black with multi-coloured patterns. † Black, green, opaque blue, polychrome and biochrome, translucent and opaque colours.
14	Kolhapur	Beads	° Green, yellow-matrix with green, coating, yellow having sulphuric imitation, gold-foil, blue, black, copper red. † *Monochrome type* (A.D. 1000)—Black, yellow, green, dark green, brown, navy blue greenish, light blue. *Polychrome type* (A.D. 1000)—Green or brown, yellow green, bluish green with yellow patches, bluish (transparent, third or fourth century A.D.).
15	Bellary	Bangles	Multicoloured-pale-brownish, yellow, lemon yellow, black, dark-red, etc. (A.D. 1300–A.D. 1400).

The chemical analysis clearly reveals that the ancient glass makers knew the techniques of both decolouring glass objects by means of fusing manganese content and in the case of colouring them, various metallic oxides were admixtured. The metallic oxides were prepared after forming the mixture of alkali, sand, saltpetre and chalk which formed a coloured glaze on the surface of the glass objects. Coloured glasses were prepared by mixing silicates of soda, lime and appropriate metallic oxides. It is by using gum or by some perishable organic substance, the slips or the well-preserved coatings were prepared on the glass objects. The levigated ignited-steatite in water coupled with the silicate of soda as its medium is extremely helpful in procuring durable coatings and slips. This liquid was applied on the slips and then the objects were dried in an oven and glaze was produced by means of firing it at a high temperature. Coloured vitreous paste consisted of the mixture of soda, silica, lime and colouring agents, i.e. metallic oxides, was prepared after firing which finally reduced the mixture into the powder. This powder was applied for glazing purposes after an addition of a little more soda content in order to serve as flux. But before the firing of slips, the powder was again mixed with an oil and was painted on the body of the glass objects.

The glass colouring and glazes are achieved by means of applying suitable colouring agents which consisted mostly of oxides of different metals like iron, manganese, cobalt, copper, etc. Opaque glasses and their glazes were prepared by the mixture of oxides of tin and antimony.

TABLE X

Chemical analysis of glass

Sl. No.	Colours	Reaction of chemicals and different colours/shades to the glass objects
1	Bottle green	FeO
2	Amethyst	$MnO+Fe_2O_3$
3	Bluish violet	$MnO+CuO$
4	Deep violet	MnO in high proportion
5	Brown	$FeO+MnO$
6	Orange (opaque)	Cu_2O+SnO (?)
7	Yellow	Fe_2O_3
8	Turquoise blue	CuO
9	Greenish blue	$CuO+Fe_2O_3$
10	Deep blue	CuO
11	Bluish green	$CuO+Fe_2O_3$
12	Greenish	FeO
13	Green	CuO
14	White	$Sb_2O_3+SnO_2$
15	Black	$FeO+MnO$ (?); $FeO+CuO$
16	Red haematinum	Cu
17	Red	Cu_2O
18	Chocolate	$Cu_2O+Fe_2O_3$

The chemical analysis has revealed that the colouring or decolouring agents were derived generally from the befitting metallic ores and different chemicals added to them finally led to attribute different shades of colours and glazes to the ancient glass objects.

The colours vary from deep light shades due to the variation of the quantity of the colouring agents and the temperature of fusion.

Rosenthal[162] has attempted to classify some of the oxides and the colours they produce:

Ferric oxide	..	yellow, red, brown and black.
Cobalt oxide	..	blue depending upon concentration, bluish-green in the presence of chrome oxide.
Copper oxide	..	green, blue, green and red.
Chromium oxide		green, red, pink and brown.
Nickle oxide	..	brown and violet.
Uranium oxide	..	yellow.
Gold (colloidal)	..	red and purple.
Tin oxide	..	(in colloidal suspension) white.

The craftsmen of Maheshwar[163] and Navadatoli had excelled themselves in the use of various combinations of colours in the fabrication of glass bangles. The Nevasa[164] glass specimens remarkably demonstrated the use of nine colours with different shades in them. The Nasik beads[165] technologically called 'blotched' datable to first century A.D. consist of yellow matrix covered over by a green-coloured glass. A late specimen (*c.* A.D. 1300–A.D. 1400) is of black colour which exhibited the designs, having bands of different colours, on the body of the glass bangles. This technique of using different bands in different shades of colours undoubtedly demonstrates a considerable mastery over the art of glass manufacturing attained by the Nevasa artisans during the early centuries of the Christian era.

The colours of the Arikamedu[166] glass specimens are free from metallic copper but they contain cuprous oxide which imparts a brick-red to liver-red colour to the specimens. High proportion of manganese amounts to afford a deep violet colour. The green colour had been obtained due to the mixture of copper and iron and blue colour due to cobalt oxide. The Nalanda[167] colours owe their colours due to the presence of ferrous silicate and cuprous oxide. The colouring matter of the glass is copper oxide. Lal[168] opined that 'no such material has been discovered elsewhere in India so far'. The Ahicchatra[169] colours, for instance, blue was obtained due to copper oxide, green was obtained due to copper oxide and green was obtained due to the mixture of copper oxide and lead oxide.

Hence, it can be safely inferred that ancient glass makers had evolved a highly advanced technique of colouring and decolouring glass objects with different shades of colours.

So far as the question of the origin of Indian recipes for glass making is concerned, Sanahullah upheld that the recipe for glass manufacturing employed in Assyria bears a close resemblance with those known in ancient India. While, on the contrary, Varshney upheld that the Taxila glass samples of Sanahullah's analysis are quite distinct from those of Assyria, Egypt, Babylonia and Rome. He shows that the Taxila glasses have high silica content and about 6 to 7·55% of magnesia and lime while the alkalies are about 17·5% which cannot be claimed by any specimen from the western region. It is not without significance to point out that the chemical analysis of glass specimens from Arikamedu, a centre of trade with the Roman world, where one would expect features connecting the industry with the West, has revealed that they are of indigenous manufacturing. Hence, Assyrian theory of ancient Indian glass manufacturing can be safely refuted and indigenous origin theory of glass manufacturing in ancient India can be safely maintained.

In a nut-shell, direct archaeological evidences proved that glass manufacturing in ancient India originated in the first quarter of the first millennium B.C., while the date of the third millennium B.C. based on the indirect archaeological evidences of Harappan knowledge of paste, glaze and frits, etc., need further confirmation from the spade of the archaeologist, though the possibility cannot be entirely ruled out. The earliest stray evidence of glass from *Śatapatha Brāhmaṇa* testifies that during *c.* 800 B.C.–500 B.C. glass manufacturing had not received considerable recognition in the professional and industrial fields. By the fourth century B.C. the ancient glass-making industries took a sudden turn towards technological advancement. They developed the fair knowledge of moulding, annealing and working glass techniques. The evidence of a glass tablet from Maheswar is the best cited example already discussed in this regard. Besides, the ancient craftsmen had developed a fair knowledge of precised chemical treatment for attributing different colour shades and glazes by varying the degrees of mixing the quality of the colouring or decolouring agents and also its temperature of fusion at different degrees of heating, condusive to their chemical stability.

All these technological developments amply demonstrate that ancient Indian glass makers had excelled themselves remarkably by rapidly scaling up the ladder of technological accomplishments in the sphere of glass manufacturing in ancient India. Finally, in spite of foreign contacts with the Middle East countries, the chemical analysis of Taxila and Arikamedu glass industries clearly proves to the possibility of an independent indigenous manufacturing of glass in ancient India and it is on this ground the theory of Assyrian origin of Indian glass making becomes untenable. Hence, glass manufacturing had reached a high pitch of technological skill and perfection in ancient India and became a beacon light to emulate such an advancement in the other countries of the world.

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ABBREVIATIONS

1.	A.I.	= *Ancient India*, Archaeological Survey of India.
2.	A.S.I. (Ann. Reptt.)	= Archaeological Survey of India (Annual Report).
3.	Artha.	= *Arthaśāstra*, tr. by Shamasastri.
4.	B.D.C.R.I.	= Bulletin of Deccan College of Postgraduate Research Institute, Poona.
5.	Bṛ. Saṃh.	= *Bṛhatsaṃhitā of Varāhamihira*, ed. by S. Dwividi, Benaras, 1895, tr. by H. Kera (*J.R.A.S.*, 1870–75).
6.	E.W.A.	= *Encyclopaedia of World Art*, McGraw-Hill.
7.	I.A.R.	= *Indian Archaeological Review*, A.S.I., New Delhi.
8.	J.S.G.T.	= *Journal of the Society of Glass Technology.*
9.	J.B.O.R.S.	= *Journal of Bihar and Orissa Research Society.*
10.	J.N.S.I.	= *Journal of the Numismatic Society of India.*
11.	Kathā.	= *Kathāsaritsāgara*, ed. by Pandit Durga Prasad and K. P. Parab, fourth ed. Revised by W. L. S. Pansikar, Bombay, 1930.
12.	Mṛcch.	= *Mṛcchakaṭika of Śūdraka*, ed. by R. D. Karmarkar, Poona, 1950.
13.	Rāmā.	= *Rāmāyaṇa*, ed. by R. Labhaya, Lahore, 1923; tr. by M. N. Dutt, Calcutta, 1892–94.
14.	Śukra.	= *Śukranītisāra of Śukrāchārya*, ed. by G. Oppert, Madras, 1882; tr. by B. K. Sarkar, Allahabad, 1923.
15.	Suśrut.	= *Suśruta-saṃhitā*, ed. by Jodavji Trikumji Acharya, Bombay, 1915.
16.	S.B.E.	= *Sacred Book of the East.*
17.	Śat. Brāh.	= *Śatapatha Brāhmaṇa*, ed. by A. Weber, London, 1885; tr. by J. Eggling, Oxford, 1882–1900.
18.	T.N.S.	= *Transactions of the Newcomen Society.*

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[2] Lucas, 'Ancient Egyptian Material and Industries, 1934', p. 408 (q. in *A.I.*, No. VIII, p. 17).

[3] Sarton, G., *Isis*, XXV, 1936, p. 73; also see *White Tomb of Old Lo-Yang*, 1934, p. 14.

[4] The earliest specimen of Blue Glass in Humps as yet rendered in Mesopotamia comes from ABU SHEHREIN in a deposit earlier than the third dynasty of Ur (*c.* 2100 B.C.); *see* Hall—*The Civilization of Greece in Bronze Age*, 1928, pp. 74, 104. But Petre assigns its date to *c.* 1500 B.C.; see *T.N.S.*, V, 1924–25, p. 72.

[5] *T.N.S.*, V, 1924–25, p. 72.

[6] Varshney, Y. P., *The Glass Industry*, 1950.
Lal, B. B., 'Examination of Some Ancient Glass Specimens'. *A.I.*, No. VIII, 1952, pp. 17–27.
Prakash, S., and Rawat, N. S., *Chemical Study of Some Indian Archaeological Antiquities*, 1965.

[7] Ann. Reptt., A.S.I., 1929–30, p. 97.

[8] *Ibid.*, 1912–13, p. 41.

[9] *Ibid.*, 1924–25, p. 48.

[10] *Ibid.*, 1936–37, p. 39.

[11] *Ibid.*, 1914–15, pp. 19, 22, 24.

[12] Sankalia, H. D., *Pre-History and Proto-History in India*, p. 209. Sankalia recorded that amidst various semi-precious stones found at Nevasa, glass pieces were also one of them and 'all these were certainly strung into necklaces'.

[13] Ann. Reptt., A.S.I., 1925–26, p. 49; *ibid.*, 1927–28, p. 139.

[14] *Ibid.*, 1919–20, p. 19; *ibid.*, 1922–23, p. 157.

[15] Marshall, John (Sir), *Guide to Taxila*, 1936, p. 59.

[16] *See* Table I. For references, *see* Ref. Nos. 59 to 95.

[17] *S.B.E.*, **XLIV**, p. 313.

[18] *J.B.O.R.S.*, X, p. 194.

[19] *Śat. Brāh.*, XIII, 2.6.8; *see also* Deo, S. B., 'Indian Glass—Some Considerations', *Summaries of Papers, International Conference on Asian Archaeology*, New Delhi, p. 3.

[20] MacDonell and Keith, A. B., *A History of Sanskrit Literature*, p. 202.

[21] *Śat. Brāh.*, XIII, 2.6.8.

[22] *Mahāvagga*, VIII, 3.

[23] *Cūllavagga*, IX, 1.

[24] Williams, Monier, p. 268; *Amarkoṣa*, III, 3.28; *Medinikoṣa*, p. 28, No. II; *Nānārthasaṃgraha of Āryapath*, p. 26.

[25] Gopal, L., *Economic Condition of Northern India* (c. 400 B.C.–A.D. 700), D.Phil. thesis, Allahabad University, p. 329. (*Unpublished*).

[26] *Ibid.*, p. 330.

[27] *Ibid.*

[28] *Rāmā.*, II, 90.27.

[29] *Bṛ. Saṃh.*, LXXVI, 23; also XLIV, 12.

[30] *Suśrut.*, VIII, 15.

[31] *Ibid.*, XXXXVI, 452.

[32] Bech., H. C., *Economic Life in Ancient India*, **I**, 1924.

[33] *Artha.*, II, 11, p. 77.

[34] *Ibid.*, II, 13, p. 87.

[35] Heavy fines were imposed on account of robbery of glass, copper, bronze and brass objects, etc. (*see ibid.*, II, 17, p. 197). This suggests that glass objects were recognized as costly objects. It is stated that once a king managed to escape in disguise in a carrier filled with the commodities of glass objects (*see ibid.*, VII, 17 *Kācakambha Bhanadhāra Vyaujanah*).

[36] *Ibid.*, V, 2, p. 243.

[37] *Ibid.*, II, 14, p. 92; XIV, 1, p. 411.

[38] *Kathā.*, XXII, 216; p. 89:

न काचस्य कृते जातु युक्ता मुक्तामणेः क्षतिः ।
न चाप्यहं गमिष्यामि कथां कुलकलङ्किताम् ॥

Ibid., XXIV, 178–79; p. 98:

तत्रैतद्रत्नतत्त्वज्ञाः परीक्ष्य बणिजोऽब्रुवन् ।
अहो कस्यास्ति विज्ञानं येतैतत्कृत्रिमं कृतम् ॥
काचस्फटिकखण्डा हि नानारागो परञ्जिताः
रीतिबद्धा इमे नैते मणयो न च काञ्चनम् ॥

Ibid., XXIV, 185; p. 99:

काचस्फटिकयोः खण्डै रीतिबद्धैः सुरञ्जितैः
रचितं देव ततैव व्याजालंकरणं महत् ॥

Ibid., XXIV, 194; p. 99:

सत्यं यदि न तत्वर्णं न च रत्नानि तानि तत् ।
रीति स्फटिककाचानां प्रदानादस्तु मे फलम् ॥

[39] *Kathā.*, XXIV, 178–79, 185, 194.

[40] *Mṛcch.*, Act IX; pp. 285–86.

[41] *Kācamulyeṇa vikritōhantā cintāmanir māyā* and *Akare padmarāgānām janma kācamanah kūtah* (q. in Bohtlingh and Roth, S. V., *Kāca*).

[42] *Śukra.*, IV, 3.191.

[43] *Ibid.*, IV, 4.21–22; Śukra refers to *kalā* as an artificial gem which bears striking similarity to the glass objects.

[44] Pliny, *Natural History*, XXXVI, 66, tr. by McCrindle.

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[46] *Periplus of the Erythian Sea*, 49, 55, tr. by W. H. Schoff, London, 1912; *see also* Majumdar, R. C., *The Classical Accounts of India*, 1960, pp. 304–305.

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[48] *Geography of Strabo*, Bk. XV.I, 67, tr. by H. C. Hamilton and W. Falconer, London, 1854–57; *see also* Majumdar, R. C., *The Classical Accounts of India*, 1960, p. 279.

[48a] Majumdar, R. C., *The Classical Accounts of India*, 1960, p. 394.

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[50] *Ibid.*

[51] *See* Ref. No. 25, p. 333.

[52] Marshall, John (Sir), *Mohenjo-Daro and Indus Civilization*, II, 1931, pp. 469, 574–82.

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[59] *Ibid.*

[60] Lal, B. B., 'Excavations at Hastinapur and other Explorations', *A.I.*, Nos. X–XI, 1954, p. 12, Table I, and also p. 90.

[61] I.A.R., 1958–59, p. 54.

[62] *See* Ref. No. 57. Dikshit dated the glass objects of Maski to one millennium B.C.; *see also* Thaper, B. K., 'Maski 1964, A Chalcolithic Site in S. Deccan', *A.I.*, No. XIII.

[63] *A.S.I.* (Ann. Reptt.), 1919–20, p. 19 (1922); 1921–22, p. 125 (1924); 1922–23, p. 157 (1925). Some of the glass objects represent the largest intact examples so far recorded in this country.

[64] *See* Ref. No. 57, p. 367.

[65] *See* Ref. No. 15. At Sirkap in the Dharmarājika *stūpa* glass tiles and complete conical glass flasks are found, datable to third century B.C.

[66] I acknowledge this information from an unpublished paper of Shri B. K. Gururaja Rao, Department of Archaeology in the University of Madras, Madras.

[67] *See* Ref. No. 58, p. 84; see also *A.I.*, No. II, 1946, p. 96.

[68] Rawat, N. S., and Prakash, Satya, *Chemical Study of Some Indian Archaeological Antiquities*, 1965, p. 44. It is observed that 'part of clay crucibles (with glass sticking to them) in which glass was presumably melted, large lumps of glass and tiny beads with fine threading holes are definitely of a distinctive character'.

[69] *Ibid.*, p, 44.

[70] *See* Ref. No. 57, p. 373.

[71] *See* Ref. No. 58, p. 73.

[72] *Ibid.*, pp. 74–75.

[73] *Ibid.*, p. 75.

[74] Lal, B. B. (Dr.), 'Studies in Early and Medieval Indian Ceramics', B.D.C.R.I., XIV, No. 1, June, 1952, Poona, p. 48.

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[76] *See* Ref. No. 74, pp. 57–58.

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[79] *See* Ref. No. 57, p. 373.

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[89] *Ibid.*, p. 64.

[90] *Ibid.*, p. 82.

[91] *Ibid.*, p. 80.

[92] *See* Ref. No. 74, pp. 49–50.

[93] *Ibid.*, pp. 50–51.

[94] *See* Ref. No. 56, pp. 22–24.

[95] *Ibid.*, pp. 24–25; *see also* A.S.I. (Ann. Reptt.), 1922–23 (1925), pp. 157–58; 1924–25 (1927), p. 139.

[96] *See* Ref. No. 58.

[97] On the basis of the stratified evidence, Lal has associated P.G. ware people with Aryans. *See* Ref. No. 60, p. 12, Table I.

[98] *See* Ref. No. 58, pp. 8–9.

[99] *See* Ref. No. 58, p. 76.

[100] *See* Ref. No. 83, pp. 198–99.

[101] *See* Ref. No. 60.

[102] *Ibid.*, p. 90.

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[104] *See* Ref. No. 62.

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[106] *See* Ref. No. 6.

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[108] A.S.I. (Ann. Reptt.), 1921–22 (1924), p. 125; 1922–23 (1925), p. 158; *see also* Ref. No. 56, p. 21 and Ref. No. 15.

[109] *See* Ref. No. 56, p. 25; *A.I.*, No. XIV, 1958, pp. 139–144.

[110] *See* Ref. No. 56, p. 25.

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[115] *See* Ref. No. 56, p. 24; *see also* A.S.I. (Ann. Reptt.), 1922–23 (1925), p. 158.

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[123] *See* Ref. No. 56, p. 22.
[124] A.S.I. (Ann. Reptt.), 1921–22 (1924), p. 125; 1922–23 (1925), p. 158.
[125] *Nature*, **CXXXIV**, 1934, p. 982. Seligman and Beck's analysis shows that in Chinese specimen the percentage of lead oxide goes up to 24·5, while Taxila glass specimens possess considerably lower percentage of lead oxide.
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[138] *See* Ref. No. 135, p. 141.
[139] *Ibid.*, p. 141; *see also* Ref. No. 56, pp. 17–27.
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[156] For details, *see* Sankalia, H. D., 'A Seal Impression on a Glass Tablet', *J.N.S.I.*, XV, No. II, Plate VII, i; *see also* Ref. No. 74, pp. 57–58.
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[168] *See* Ref. No. 56, p. 24.
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