White Paper – Advance Technologies in Glass Manufacturing

Technology Cluster Manager

Technology Centre Systems Program (TCSP)

Office of DC MSME, Ministry of MSME

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Table of Contents

List of Figures

List of Tables

Abbreviations

AIGMF	All India Glass Manufacturers' Federation
ARC	Anti-Reflecting Coatings
CAGR	Compound Annual Growth Rate
CapEX	Capital Expenditure
CDGI	Centre for Development of Glass Industry
CGCRI	Central Glass and Ceramic Research Institute
dB	The Decibel
DIC	District Industries Centre
EHS	Environment, Health and Safety
GDP	Gross Domestic Product
GW	Giga Watt
HVAC	Heating, Ventilation, And Air Conditioning
IBEF	Indian Brand Equity Foundation
IIT	Indian Institutes of Technology
INR	Indian National Rupee
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MSME	Ministry of Micro, Small And Medium Enterprises
OpEx	Operating Expenses
PLC	Programmable Logic Controller
PPM	Parts Per Million
PRMA	Protected Roof Membrane Assembly
PRV	Pressure Reducing Valve
PV	Photovoltaic
TC	Technology Centre
TCM	Technology Cluster Manager
TCSP	Technology Centre Systems Programme
TPD	Tonnes Per Day
USD	United States Dollar
VFD	Variable Frequency Drive

1. Objective of the White Paper

Technology Centre Systems Programme (TCSP) is a national programme undertaken by the Ministry of Micro, Small and Medium Enterprises with the assistance of the World Bank. The programme seeks to enhance the technological and skill base of MSMEs in certain manufacturing sectors to improve the competitiveness of MSMEs, via upgraded and new Technology Centers (TCs).

The objective of the programme is to enhance the productivity of selected MSME clusters by improving their access to manufacturing technology, establishing a strong focus in providing business & technical advisory services and improving the availability & employability of skilled workforce through TCs[1]. As part of the programme, KPMG has been appointed as the Technology Cluster Manager (TCM) to support TCs and undertake technology and cluster development activities.

The objective of TCM is to increase business opportunities for MSMEs through market linkages, enhance competitiveness of the cluster business environment, increase the number of MSMEs utilizing the services of TCs, develop a financially self-sustainable business model for cluster related services provided by TCs, identify technologies (Industry 4.0) of selected sector for TCs, evaluate existing training programs & develop new training programs for roll out at TCs, conduct gap analysis of TCs, strengthen the capabilities of TCs to provide technical advises to their clients, increase awareness amongst stakeholders on Environmental, Health, and Safety (EHS) requirements[2].

Center for Development of Glass Industry (CDGI), Firozabad is one of the TCs selected under the TCM project. CDGI, Firozabad was established to support the glass and allied industries with the objective of developing human resources for the glass industry through various tailor-made training programs and to introduce modern technology in glass designing & manufacturing and provide consultancy & job work services to the enterprises in the sector.

As part of the project, White Papers in different sectors are being prepared to help identify the future roadmap for the sector in general and the TCs in specific. This White Paper focuses on the glass sector. This White Paper aims to showcase the current scenario in the glass sector, highlight the degree of alignment of the current services of the TC with the market needs, and recommend a future course of action for the TC to be better able to serve the sector in synergy with the ongoing trends.

2. Overview of the glass sector

2.1. Global Scenario

Glass is a (usually) transparent, non-crystalline amorphous solid that has many important applications worldwide in a variety of industries. It is perhaps most widely known for its extensive use in windows, partitions and bottles. The most common types of glass are made primarily with soda ash and silica, as well as other additives. Recycled glass is also often used in the production of new glass. There are two main methods of producing glass. The first is the float glass process that is used to manufacture architectural glass. The second is the glassblowing process that produces containers such as bottles and jars.

[1] http://www.dcmsme.gov.in/tcsp/TCSP%20-%20Concept%20Note.pdf
[2] http://www.dcmsme.gov.in/tcsp/Program%20Overview/Technology_cluster_man.html

The glass industry is one of the continuously growing sectors. Global demand for fabricated flat glass is growing at a fast pace and is expected to reach nearly 140 billion U.S. dollars in 2023, more than double its value since 2008. More than two-thirds of the overall flat glass production is used in construction and the rest is used in the automobile industry and other assorted areas. China, Western Europe, and North America regions are top consumers of glass.

List of 15 countries that exported the highest value worth of glass and glassware during 2019[3]. The listed 15 countries exported 76.2% of global glass/glassware in 2019 by value.

Figure 2-1: Glass Export by top countries in 2019

In the United States, the glass manufacturing industry was about 31 billion U.S. dollars in 2019, and growing at a rate of 2.9 percent annually. The value of the U.S. flat glass market is projected to increase considerably, from an estimated 22 billion U.S. dollars in 2018 to an expected 44 billion U.S. dollars in 2025[4].

According to the latest research report published by Global Market Insights, Inc., the glass manufacturing market size was estimated at $238.39 billion in 2018 and is expected to surpass $320 billion by 2026, registering a CAGR of 3.8% from 2019 to 2026[5].

2.2. Indian Scenario

The glass industry in India has made steady progress since independence and has matured a lot over the last few decades. The glass making methodologies prevalent in the country ranges from traditional mouth-blown basic hand-made practices to modern electric techniques of glass melting/making. This reflects the diversity and expanse in the sector with a varied range of entrepreneurial establishments including Micro, Small, Medium and Large enterprises in the sector.

The growth in glass sector has been primarily driven by India's booming automotive and construction sector. As per ASSOCHAM report, glass industry was estimated at around USD 4.9 bn in 2015 with the share of organized market standing at 55%. Exports of glass & glassware in India decreased to 100.54 USD million in 2016 from 385.36 USD Million in 2015. Exports of glass

[3] http://www.worldstopexports.com/top-glass-and-glassware-exports-by-country/
[4] Statista.com
[5] https://www.gminsights.com/industry-analysis/glass-manufacturing-market

& glassware in India averaged 294.37 USD Million from 1996 until 2016, reaching an all-time high of 701.82 USD million in 2014 and a record low of 53.22 USD million in 1998.[6] Majority of the items that are exported from Indian market are bottles and jars, glass fibres, glass beads, float glass and sheets, electrical fittings, etc. Lately, the growth has been sluggish in the glass sheet and glass fibre whereas the growth in the glassware sector has been on an upscale.[7] The glass industry is mostly confined to Uttar Pradesh, Maharashtra, West Bengal, Bihar, Jharkhand and Punjab. Glass industries in Uttar Pradesh mainly produce sheet glass, hollow and pressed wares (bulbs, chimneys, reflectors and motor headlights), while Bengal and Maharashtra are famous for glass tubes, test- tubes, beakers and flat glass. Punjab dominates in the production of hollow wares, scientific and precision goods.

Most of the common types of glass are made with soda ash and silica, along with other additives. Indian is one of the world's fastest-growing soda ash markets, driven by India's high economic growth rate. The per capita consumption of container glass in India is 1.8 kg[8] as compared to 17 kg consumption in the developed countries. This reflects a huge potential to be capitalized upon in the Indian glass market.

2.3. Firozabad Glass Cluster

Firozabad, a city in Uttar Pradesh, has been famous since Mughal era for its exquisite glasswork and production. It is popularly known as the Glass City or "Suhag Nagri" and is located about 240 km from Delhi, the capital of India, and about 40 km from Agra. The city has a history of glass manufacturing and is also involved in making utility and decorative glass items. It is also estimated that the glass industry caters to over 50 % of Firozabad's population directly or indirectly.

Figure 2-2: Firozabad District Map

Firozabad is the central hub for many glass manufacturing industries and is one of the leading manufacturers and exporters of glass products. 70% of the total glass production in the unorganized sector in India is contributed by the Firozabad glass industry. Over the years Firozabad has turned into a premier center of glassware manufacturing in India. Some of the glass products manufactured are glass toys, candle stands, Christmas hangings, flower vase glass, chandeliers, bangles, automobile glassware, street ware, scientific lab products, etc. Nearly 35% of the total glass products produced in Firozabad are exported to other countries.

It is estimated that Firozabad has close to 4000-5000 manufacturing and household units that generate employment for more than 5, 00,000 people[9]. The glass industry in Firozabad is spread across the city and has a total production capacity of close to 5000-6000 TPD. As per the report from AIGMF, the Firozabad glass cluster generating an annual business of more than INR 2000

[6] Exports of Glassware – Trading Economics
[7] CARE Ratings
[8] CARE Ratings – Glass Industry, June 2018
[9] AIGMF Report

crore[10]. The glass industry in Firozabad caters to not just the domestic demand but is also an important contributor to total glass exports from the state of Uttar Pradesh. As per data obtained by DIC Firozabad, in 2017-18, glass products of over INR 278 Cr, have been exported from Firozabad.

The glass industrial units in the region are spread across different areas and can be broadly divided into 3 major categories:

1. **Household units**: The household units are mostly run by the family members of the owners who use basic machines and tools to decorate glass products (primarily bangles). Each unit has an employee strength ranging from 3-10 employees with most of the employees being contractual workers hired based on orders received and requirements. These units are estimated to be over 4000 and are spread across the city.

2. **Pot furnace-based units**: There are about 130-140 pot furnace-based units in Firozabad. Bangle is the main product that is manufactured by these units along with some decorative glass items (through mouth blowing process). On average, pot furnace-based units have an employee strength ranging from 70-100 workers out of which close to 95% are hired on daily contractual basis. A large informal bangle decoration and finishing industry thrive on the raw bangles produced by these units. These units cater to local market and produce raw bangles which are subjected to decoration and finishing at a later stage.
   .

3**. Tank Furnace based units:** Tank Furnace based units are relatively large units and are involved in the manufacturing of tableware, containers and scientific glass-related items. There are close to 40-45 Tank furnace-based units and with each unit having a workforce ranging from 150 – 200 workers. Similar to Pot furnace-based units, these workers are also hired on contractual basis but are hired for a longer duration. Apart from meeting the local demand, these units also cater demands of the domestic and international market.

2.4. Key trends – Indian Market

The India flat glass market is expected to register a CAGR of 8% over the forecast period 2020 to 2025. The growth of the market can be attributed to the high demand from the construction & infrastructure industry and emerging application industries such as automotive, construction & solar energy.

- Rapid industrialization and urbanization in India, combined with the adoption of smart and energy-efficient technology as advanced construction practice have a positive influence on the flat glass demand. Moreover, India's construction sector is likely to outpace other countries.
- According to the Indian Brand Equity Foundation (IBEF), the Indian real estate industry is likely to reach USD 1 trillion by 2030 and may contribute approximately 13% to the country's GDP by 2025. This is likely to increase the demand for flat glass and propel its market in the region.
- Besides the construction industry, which represents a sizeable share of product demand, the solar industry is predicted to be a lucrative application segment for the coming years.

[10] AIGMF Report, 2011

- The Indian renewable energy sector is the fourth most attractive renewable energy market in the world and looks to meet its energy demand on its own, which is expected to reach 15,820 TWh by 2040. As a part of its Paris Agreement commitments, the Government of India has set an ambitious target of achieving 175 GW of renewable energy capacity by 2022. These include 100 GW of solar capacity addition and 60 GW of wind power capacity. The growing solar energy market in India is likely to propel the growth of the market[11].

The manufacturing sector has been worst hit with the current pandemic situation of COVID-19 as manufacturers of non-essential goods have shut down their manufacturing facilities in compliance with the government norms for lockdown in India. Also decreasing automotive production and unfavorable conditions like fluctuating raw material prices, coupled with weak supply chain management due to COVID-19 outbreak are expected to hinder the growth of the market.

2.5. The Opportunity

Market conditions for the glass sector seems favorable, especially in the construction sector and the solar glass for green energy generation. But to make fine quality glass (foam glass, solar glass and other glasses) many of the process improvement plans need to be deployed in glass manufacturing and processing. To overcome this challenge, computer simulation could be one of the solutions which could contribute to the manufacturing of a variety of glass and also improve competitiveness by providing savings in energy, raw materials, reduce wastage, etc.

Below mentioned technologies can certainly improve the quality of glass making and can help MSMEs in becoming competitive in the national and international market.

Process improvement: Computer Simulation for glass manufacturing

New product development using advanced technologies

- **Foam glass**
- **Solar Glass**

3. Computer Simulation for Glass Manufacturing

The process of computer simulation tries to capture the very same logic and principles that a skilled designer or operator uses to design a new furnace or to operate an existing furnace at maximum efficiency.

Computer simulation in design follows below methodology.

1. Type of Glass – Container Glass, Flat Glass, Solar Glass, Art Glass
2. Production capacity – 1 to 50 TPD, 50 to 200 TPD, Above 200 TPD
3. Quality Requirements – functionally High, Visually High, Average quality
4. Fuel consumption with typical Calorific Value – Natural Gas, Furnace Oil, Coal

Glass designers evaluate the above data with software and prepare an initial draft termed as First Design Review. The steps followed for data evaluation are given below:

[11] https://www.mordorintelligence.com/industry-reports/glass

S. No	Description	Remarks
1	Basic Information	Collection of information regarding the product, quality, quantity, fuel, and site details from Client
2	Basic Design	Basic Dimensions using standard design factors as determined by standard computer software (Brainwave, GS 3, GFM, NOGRID, Batch Maker, ILIS etc)
3	First Design Review	First details of dimensions, costs, efficiencies, etc to be shared with the client and approved for further action
4	First Computer Analysis	The basic design is subjected to detailed computer analysis which will highlight weak points for corrective action.
5	Corrections to the Basic Design	Based on the computer simulation feedback corrections will be applied to the design which may involve changes in dimension, refractory selection, geometry and shape of the furnace etc
6	Second Computer Analysis	The revised design is once again subjected to computer analysis for verification and confirmation.
7	Corrections to the Revised Design	Required changes are incorporated.
8	Second Design Review	The second design review will approve detailed design and engineering.
9	Design Finalization and Detailed Engineering	The detailed design is a long process and could take several weeks involving finalization of specifications, dimensions, load data that considers soil load-bearing capacities, wind velocities, seismic and rainfall data of the location.
10	Final Design Review	The completed design and engineering details are presented to the technical team of the client and clarifications are provided as necessary.
11	Submission of drawings and Bill of Quantities	The drawings are printed out along with specifications of all refractories, steel and equipment and the required Bill of Material and quantities.

Table 3-1: Steps followed for Data Evaluation

Computer simulation in operation follows below methodology.

1. Furnace Operation
    - Combustion monitoring and control
    - Batch Charging monitoring and control
    - Melting quality monitoring and control
    - Temperature monitoring and control
    - Energy Efficiency monitoring and control
    - Management Information Systems
2. Batch Plant Operation
    - Raw Material Storage, Handling, and control
    - Batching Operation, accuracy and precision, monitoring and control

- Cullet handling
- Batch – cullet proportioning systems
- Pilferage, Dust and spillage control
- Management Information Systems

3. Forehearth Operation and control
4. Production Operation and control
5. Inspection and Quality Assurance
6. Packing and storage

3.1. Changing expectations

The demands from the industry concerning furnace design, as listed below, have undergone tremendous changes in the last fifty years.

1. The need for speed for production (glass pull)
2. The need for accuracy
3. The need for prediction with regard to quality levels
4. The need for accuracy in CapEx (Capital Expenditure) and OpEx (Operating Expenditure)
5. The need for drawings in 3 Dimensions, in layers, with 360 Degree rotation for better understanding and with a walkthrough facility where one can visualize even the insides and inaccessible areas of the furnace.
6. The need for advance prediction of possible and probable fouling of steel, refractories and equipment to eliminate the need for rework and repair.

3.2. Challenges in glass manufacturing process

The biggest challenges faced in glass manufacturing and processing can be categorized below.

i. The sensors

- Thermocouples for ambient temperatures, glass immersed temperatures
- Pyrometers such as Optical, infra-red, non-contact areas
- Close circuit cameras or Thermal imaging cameras which work on non-contact infra-red systems that enable a peek into the furnaces along with actual temperatures at specific locations. This system may become one of the most widely used and reliable sensors of the future.
- Pressure sensor for furnace, gas trains, fan air, compressed air, water etc
- flow sensors for cooling water, gas, fan air, furnace oil etc.
- Oxygen Measurement
- Glass level measurement,

- Chimney suction,
- leakages and air ingress

ii. Glass Analysis

If the sensed values are out of the specified range, appropriate action such as adjustment of fuel, electric boost energy, regulators, valves, flows etc will need to be adjusted in infinitely small steps to restore the desired values. This analysis is carried out by the computer software using the "What if" condition and methodology by using appropriate factors for every type of condition. The analysis is effectively used to cover all the inputs from all the sensors as listed above.

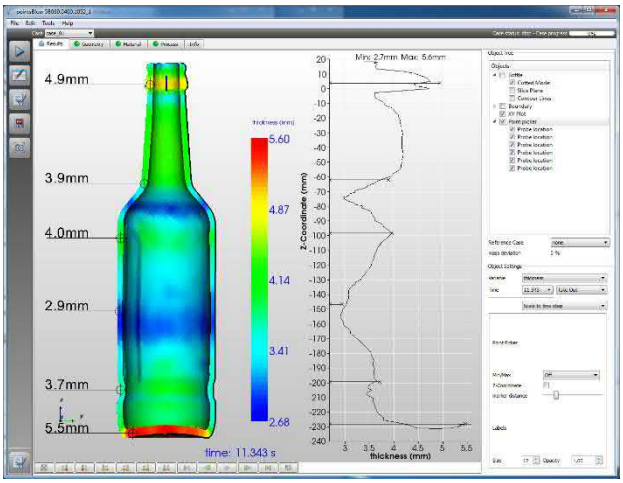

Figure 3-1: Indicative use of simulation software

iii. The control signal to the hardware adjusting the concerned parameter

The computer software or PLC (Programmable Logic Controller) converts the analysis and action to be taken into a signal which is then delivered to a hardware component such as

- Solenoid valve for open/close action
- Proportional control valve for increase or decrease of flow
- Variable frequency drive to increase or decrease a motor speed,
- Pressure control valve for increase or decrease of pressure in air, water, or gas line
- Pressure control damper for increase or decrease of pressure in the furnace

iv. The adjustment hardware like VFD, Solenoid Valve, PRV, Flow control valve, etc

The advantage and benefits of such a computer-based operational control are the systems work tirelessly on a 24 x 7 basis within infinitely small intervals like milliseconds or lower and the corrective action too is in real-time meaning instantaneous. This ensures that a near-perfect consistency is achieved and variation in the system due to external conditions or factors is eliminated. This results in the elimination of defects and improvement of product quality and efficiency.

3.3. Emerging solutions

The challenges as mentioned above are in the development of sensors that can accurately detect the measurable parameters in the harsh and hazardous environments such as

- High temperatures,
- Corrosive chemicals,
- In-accessible locations where repair and replaceability become difficult in a running plant,
- Calibration of the sensors to ensure that degradation due to continuous working is not taking place.

Currently, the price of this technology is on the higher side but in due course of time, it will become economical.

3.4. Adoption methodology

Adoption of new technology into a running system is generally quite easy and can be retrofitted enabling the industries to carry out the adoption sequentially to save on cost and also to verify that the systems are effective and efficient.

In case of the glass melting furnaces where glass contact thermocouples need to be installed, it is not only expensive but also risky and hazardous to drill holes into a refractory block at a temperature of over a thousand degree Celsius and insert a sensor. But such installations have been done and with proper safety precautions, they have been done with zero accidents and negligible damage to equipment.

4. Foam Glass

Foam glass is also known as cellular glass insulation, developed by Pittsburgh Corning and was later acquired by Owens Corning. It is made of cullets, foaming agent, modified additive and foaming accelerator. It is melted at high temperatures, foamed and annealed after fine pulverisation and uniform mixing. It consists of a vast number of uniform bubble structures with a diameter of 1 to 2 mm and is an inorganic non-metallic glass element. Sound-absorbing foam glass insulation is more than 50 percent open cell bubbles, and heat-insulating foam glass is more than 75 percent closed-cell air bubbles that can be changed by adjustments in product technological specifications according to the criteria of usage.

Figure 4-1: Foam Glass

Often known as porous glass, foam glass is packed with many small pores that are open or closed. The area of the pores is 80% ~ 90% of the overall amount, and the size of the pores is 0.5~ 5 mm, and others are as small as a few microns.

Foam glass insulation aggregate is used as coated clay aggregate in the same manner but may be used as a hardcore load-bearing aggregate. It also provides stronger insulation (lambda/k value = 0.08-about 20 percent lower thermal conductivity than extended clay aggregate lightweight). Therefore, for equivalent thermal efficiency, it requires less depth.

4.1. Properties

- In the foam glass, inner bubbles are closed, but there is no capillary phenomenon and no penetration, so the most suitable thermal insulation content is currently foam glass.
- The mechanical strength is high and the change in force is equal to the apparent density. It has exceptional resistance to strain, corrosion, and load of the external environment. The combination of excellent compression resistance and moisture barrier properties makes foam glass an ideal thermal insulation material for underground pipelines and tank foundations.

- Foam glass has good thermal and moisture permeability, so thermal conductivity is stable for a long time, and it does not change due to environmental influences, and the thermal insulation performance is good.
- Foam glass is a matrix wet glass, so it will not burn spontaneously. It is an excellent fireproof material. Foam glass has an operating temperature range of -200 to 430 °C, a small expansion coefficient (8 × 10°C) and is reversible, so the material properties are unchanged for a long time, are not easy to embrittle, and have good stability.
- Foam glass has excellent sound insulation efficiency and sound waves have high absorption. The total penetration loss of 60~400 Hz is 28.3 dB.
- The dyeing property of foam glass is strong, so it can be used as a material for insulation decoration.

4.2. Applications

Foam Glass is preferred for applications in rugged conditions such as heat insulation, deep cooling, underground, open-air, flammable, humid, and under chemical attack, since this material is moisture-proof, fireproof, and anti-corrosive, and the glass material has the advantages of long-term use efficiency. It is commonly used in wall insulation, petroleum, chemical industry, noise control in the computer space, barrier for highway sound absorption, energy, military goods, etc. and consumers call it green environmental safety insulation material.

It can be used as an insulation agent in different fields of construction engineering, as well as in shipbuilding, nuclear, cryogenic, and high-temperature technologies, depending on the properties of foam glass. They also use white and stained glass as sound-absorbing and decorative materials. Waste in processing can also be used as fillers for decorative light concrete and other uses for foamed glass powder and waste. Foam glass products produced by the respective processes can be classified into four types, based on the application, namely insulating foam glass, decorative sound-absorbing foam glass, facing foam glass, and granular foam glass.

Foam glass is a kind of lightweight, high-strength construction material and decorative material that is both moisture-proof and fireproof, with outstanding performance (insulation) and sound absorption. The spectrum of temperatures is from 196 to 450 degrees. While other new insulation materials appear in an infinite wave, due to their continuity, protection, and high reliability, foam glass occupies an increasingly important role in the fields of low thermal insulation, moisture-proof engineering, and sound absorption. Its development consists of the disposal of solid waste products, which is an example of saving the environment and gaining major economic benefits.

Lava foam glass: As the basis stone, natural lava such as obsidian and industrial waste slag is used, and a certain volume of glass powder may also be added as a foaming agent to lower the foaming temperature and foam glass made of or equivalent. For building and manufacturing machinery, it is commonly used as insulation materials and wall materials.

4.3. Manufacturing process of Foam Glass

Foam glass is a foam substance constructed from porous glass. As a construction material, its benefits include its lightweight, high strength and thermal and acoustic insulating characteristics. A combination of crushed or granulated glass and a blowing agent (chemical foaming agent) such as carbon or limestone are heated to create it. The blowing agent emits a gas above the melting point of the glass, creating a foaming effect within the container. The mixture hardens into a rigid substance after freezing, with gas-filled closed-cell pores that form a significant portion of its thickness.

S. No	Description	Remarks
1	Waste-Glass	Glass in any form can be used as input for the manufacture of foam glass. This is also an effective method to obtain “Wealth from Waste”.
2	Primary Grinding	Size 1 to 3 mm, the big chunks of cullet can be crushed in jaw crushers or roll crushers to a granular form which can then be fed into disintegrators or pulverizers for converting into powder.
3	Secondary Grinding	75 to 150 microns which would be suitable for creating cellular glass with desirable cavities
4	Screening and Classification	To screen out the coarse particles and fines. Just as large particles are not desirable it is seen that even excessive fines are harmful too since the particles end to get packed and obstruct the formation of cavities of desirable size.
5	Store	The material should be stored in a manner that ensures that segregation does not take place. Storage should not be for too long a period nor should the stack be too high which can cause the bottom to pack into lumps.
6	Weighing and addition of Foaming Agent	The weighing of the material with electronic online systems along with the addition of foaming agents is a precise and accurate process and must be automated for best results
7	Mix	The mixing is generally carried out in 1000 or 2000 kg mixers with horizontal paddles which ensures that the mixing is uniform throughout the mass
8	Heat /and Foam	The forming and processing in the furnace convert the product into slabs or blocks which can then be cut to the desired size and shape. It is also possible to crush the blocks int large gravel size particles which can be recast into specific shapes with a binder
9	Anneal	The annealing process is to relieve internal stresses so that the chances of cracking or breaking up in the future are eliminated.
10	Cut to size	The final process is to cut the blocks or shapes to the desired size and finish for shipping to the customer for its final intended usage and application.

Table 4-1: Methodology for manufacturing of Foam Glass

The manufacture of Foam Glass uses waste glass from bottles/jars/containers or can include flat glass. The cullet is crushed and processed to remove gross contamination of metal packaging, labels, plastics, cork etc. Limited ceramic contaminants can be present in the feedstock. To extract water and decrease the organic carbon content to a minimum, this partly processed cullet is then dried using the exhaust gas from the processing kiln. Via a ball mill and a sieving procedure, the dried cullet is then reduced in size to eliminate any residual plastic contamination and produce a powder with a particle diameter below 100µm (0.1mm).

4.4. Changing expectations

In the current scenario, energy saving is one of the important aspects and receiving maximum attention across the globe, and research for new technologies to develop better insulation materials (like foam glass) is going on.

Foam glass is widely used as an insulating material in sound and thermal insulation as it has resistance to withstand the harsh corrosive actions of many chemicals. Foam glass is a relatively cost-effective product because it is made up of almost 100 percent waste glass and its manufacturing process is not as energy-intensive as regular or conventional glass making.

These properties have enabled its use in a range of applications with a proven track record principally as insulation like floor slab for buildings, roof gardens, backfill around swimming pools and pipelines, low-density fill above tunnels and structures, and construction of sports fields etc.

4.5. Scope of Foam glass

Foam glass is a commodity that can fulfill all the specifications of good insulators. Nontoxic in nature, Foam Glass has stable chemical properties and strong heat insulation efficiency that protects against oxidation from ultra-low temperature to high temperature. It is celebrated as a permanent heating substance with no renewal requirement, as it is not only stable but also durable in a stringent state of decreased and cryogenic temperature, underwater, open atmosphere, flammability, susceptibility to moisture and chemical degradation. Consequently, Cellular Glass is implemented extensively as follows:

- **Chemical Industry:** Reaction equipment, chemical pipes, oil pipes, LNG pipes, LPG pipes, tank bottoms and insulation projects, etc.
- **Architecture:** refrigerator, ship-building industry, roof heat-preservation, inside and outside wall heat-preservation, parking lot and insulation of inner layer of chimney, etc.
- **Underground Projects:** subways, underground storerooms and tunnels, etc.
- **Others:** Military industries, pumice, air-separator pipes, cold liquid tank bottom insulation, etc.

The first thing people focus on after seeing foam glass for the first time is how light it is, followed by getting a go-to crush it and then saying what it might all be used for. The truth is that there are already plenty of applications to be found. Compared to other types of polymeric and fibreglass insulation materials, Foam Glass has major benefits. High compressive strength, low density and strong thermal insulation without capillary action are primarily these advantages. Some of the desirable properties include

- High pressure resistant (ca. 3-9 N/mm2)
- light (120-190 kg/m3)
- Insulation Lambda value 0.08 – 0.09
- Fast, easy and without problems to install. Weather independent placing
- Stabilizing on weak construction ground e.g. peat
- Thermal insulation mitigating frost damage
- Capillary breaking layer High drainage capacity
- Incombustible and Chemical resistant. Minimal leaching
- Adapts perfectly to the terrain
- Does not rot and keeps in shape
- 100% Recyclable. Good Life Cycle Analysis

- Electrical and sound insulating
- Pest proof

In Europe, the foam glass industry is dominated by its use as a sub-base for road building. The absence of capillary activity, quick draining, structural integrity in bad soil conditions and the separation of the asphalt layer from frozen soil prevent the deterioration of the road surface from freezing. Compared to insulation usage in specific commercial and residential buildings, use of the road sub-base consumes substantial amounts of foam glass.

4.6. Emerging solutions

Foam glass has begun to provide solutions for challenges related to insulation, corrosion under insulation, pest-infested problems under insulation etc and today Foam glass has come a long way with what is called cellular glass-based foam glass that can be cast into complicated shapes in different sizes. It is no more a one size fits all type of solution. Consultants of foam glass have developed customized solutions for the following:

To meet the unique demands of critical missions and buildings and the high-value processes they house, cellular glass insulation is a high-performing choice for specifiers of mission-critical roofs. The tyranny of time, the assault of nature's elements, and the requirements of sustainability criteria all weigh on the assembly that "covers it all" — the commercial roof.

4.7. Adoption methodology

Within the cluster, the CDGI could develop a pilot plant with a limited capacity to demonstrate the technology and its inherent benefits. The advent of Foam glass could also be included in the several training programmes conducted by the Technology Center.

To start with, Foam Glass can become an important part of the syllabus of certification and diploma programmes conducted by the TC. Since foam glass in India is still in its infancy it would be wise for the TC to have a tie-up with some institution such as the IIT or CGCRI who can help in developing the syllabus and also provide the necessary Course material.

At some point of time, it would become necessary for the TC to set up a pilot plant by investing in a state of the art modern ready to install facility that can get into operation mode without any time delay. The fiberglass industry too has been quite active in cellular glass research and development and the TC could associate with companies like Owens Corning in India.

5. Solar Glass

Solar Glass is the term generally used when one wishes to speak of Solar Photovoltaic (PV) cover glass applications. Photovoltaic glass (PV glass) is a technology that enables the conversion of light into electricity.

To do so, the glass incorporates transparent semiconductor-based photovoltaic cells, which are also known as solar cells. The cells are sandwiched between two sheets of glass. Photovoltaic glass is not perfectly transparent but allows some of the available light through.

Buildings using a substantial amount of photovoltaic glass could produce some of their own electricity through the windows. The PV power generated is considered green or clean electricity because its source is renewable, and it does not cause pollution. In addition to energy cost savings, potential benefits from the use of photovoltaic glass include reducing the carbon footprint of facilities, contributing to sustainability and consequently, enhancing branding and public relations (PR) efforts.

Figure 5-1: Use of Solar Glass

The heart of a photovoltaic system is the solar cell which receives light from the sun or ordinary daylight and converts the light energy into electrical energy which is then routed into an inverter from where the electrical energy can be used as and when required. The whole assembly is housed in a metal box where the bottom consists of a metal plate on which the solar cell is located. Above the solar cell at a specific is a high light transmitting glass sheet which acts a protection from wind and rain and also focuses sufficient light on to the cell for conversion into electrical energy. The glass is termed as “Cover Glass” which is what is commonly referred to as solar glass in common man’s language. The specifications of the cover glass in order to provide adequate protection and ensure maximum efficiency of conversion must satisfy the following requirements.

- Must be tempered or toughened to be able to withstand the impact of dust and stones and even hail stones which may occur during storms.
- Must be able to transmit a minimum of 91.6 % of incident light. In fact, with addition of anti-reflecting coatings (ARC) the transmitted light is enhanced to around 93.5 % or more. This is achieved by usage of patterned glass with a specific Pyramid design on a glass of maximum 3.2 mm thickness. Current technologies also permit glass thicknesses of 2 mm to be used for solar cover glass applications.
- Must be self-cleaning to ensure that dust and dirt do not reduce efficiency.

5.1. Manufacturing process of Solar Glass

The technology employed in the manufacture of the Photovoltaic solar panel cover glass has been around for several decades now, but the single most important difference is that the specifications, the accuracy and precision levels are way above the conventional patterned glass limits of acceptance. The simplified process flow diagram will give the layman a rough idea of the technology and controls involved.

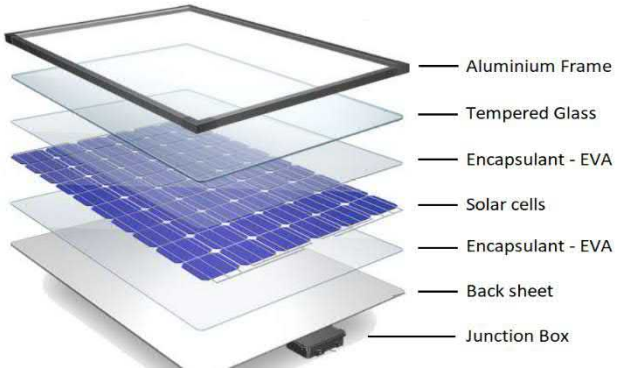

Figure 5-2: Layers in Solar Glass

S No	Title	Description
1	Raw materials	The raw materials are generally common to any soda-lime glass chemistry, but the purity demands are very stringent and contamination in the form of Iron oxides whether physical or

S No	Title	Description
		chemically combined must be typically below 100 PPM or less than 0.01%
2	Batching Systems	The batching systems like the storage silos, the feeders, the diverters etc. must be totally insulated from any form of iron contamination. The MS (mild steel) components and members must be protected with anti-rust epoxy paint or lagged with polymer linings, or maybe fabricated with stainless steel. However stainless steel must be nickel free because nickel even in ppm levels is poison for glass that needs to be tempered. The weighing and control system for batch consistency, accuracy and precision must be of the highest order with zero tolerance for deviation.
3	Furnace - Glass melting	The furnace design is the heart and soul of the melting process. Computer simulation before design finalization has become a regular feature of advanced design capabilities. It is imperative that the desired quantity of glass be melted to perfection without any solid or gaseous defects like stones and bubbles. To achieve the type of accuracy and perfection desired it may be necessary to include bubblers or electric boosting in the furnace. In the current state of the art furnaces, nothing is left to chance and the most advanced instrumentation with real-time monitoring and control has become mandatory. Additional features such as close circuit thermal imaging cameras, and infrared sensors coupled with online computer analyzers and associated hardware for immediate corrective actions in case of any deviation have become necessary.
3	Glass conditioning	Glass conditioning which is a term used to define the temperature control wherein gaseous bubbles and seeds are released in the initial stages and reabsorbed at the cooler temperatures plays a vital role in achieving the desired glass quality levels. From temperatures above 1550 Degrees Celsius in the main furnace the temperature drops to around 1250 Degrees in the distributor and finally around 1000 Degrees when it enters the rolling machine. The temperatures are extremely critical and need to be controlled within very narrow bands for best quality levels.
4	Patterned Glass Forming	The machine that forms the glass sheet, maintaining the thickness and the integrity of the Pyramid pattern is the Rolling machine. The molten glass at the desired temperature enters the machine between two rollers with a plain roller on top and the patterned roller beneath. The rollers rotate at precisely defined speeds which controls the thickness of the glass sheet. The rollers while rotating need to be cooled continuously so that glass does not stick to them. At the same time the rollers are also subjected to continuously cleaning with dry steam to maintain the integrity of the pattern.

S No	Title	Description
5	Annealing	The formed sheet passes on to a roller table before entering the annealing lehr where internal stresses are released, and the glass becomes strong to resist minor mechanical forces. To become suitable for solar glass applications however the glass after cutting and sizing will need to pass through a tempering furnace.
6	Edge trimming and cutting	The glass sheets after annealing are cut to standard sizes and the edges are trimmed off. The edge cut is a standard requirement and approximately 50 to 100 mm on each side it cut off and goes to cullet.
7	Inspection and packing	The inspection process involves visual and dimensional inspection and statistical evaluation for remnant stresses in the glass after annealing. The glass sheets are temporarily placed on frames to cool down to room temperature with interleaving separators such as paper, jute ropes or anti sticking “graphical” cold end sprays or coatings. At this stage, the hot process is complete, and the glass becomes ready for the finishing process.
8	Precision Sizing	The actual dimensions of the final cut pieces are very critical since there is no possibility of changing a dimension once the glass is tempered. The sizes are defined by the customer and manufacturer of the final solar panel assembly module.
9	Edge grinding and beveling	The cut edges must be perfectly ground and leveled before the tempering process since the conditions in the tempering furnace are extremely turbulent and violent and any sharp edges, uneven cracks or fractures can cause the glass to shatter into smithereens.
10	Washing	After cutting and grinding the glass is washed under high pressure water jet using special nozzles that ensure 100 % coverage of the glass surface.
11	Drying	The last process before the tempering furnace is the drying of the glass after the thorough washing cycle. Unless every trace of moisture is removed, there is every risk of the glass shattering during the thermal cycle of tempering.
12	Tempering	Tempering of the glass is a process whereby the glass is very uniformly heated up to a temperature of over 700 Deg C and then very rapidly chilled to room temperature in a process that is known as “Splat Cooling”. The very high intensity cooling cycle is achieved by blowing very high-pressure blower air on to both sides of the glass so that the glass temperature goes down from around 799 Degrees Celsius to room temperature within seconds. The intense cooling causes a buildup of very high compressive stresses on the glass surface which can withstand very high mechanical impact forces without shattering.
13	Packing and Dispatch	The finished glass pieces are packed with interleaving paper separators and dispatched to the final customers.

Table 5-1: Methodology for manufacturing of Solar Glass

5.2. Changing expectations

The visual and dimensional attributes of the solar cover glass have been well understood but there has always been a trade-off between the light transmission and the glass thickness. The light transmission depends on the following factors

- The pyramid pattern which must have extremely sharp edges since the light rays by reflection bounce off the pyramid surfaces and are redirected into the glass rather than getting lost by excessive reflection.
- The light rays falling on the glass surface are subjected to reflection and transmission which in way are indirectly proportional.
- For this reason, it is important to keep the reflection to a minimum which is achieved by the design of the pyramid structure.
- The light rays that get transmitted into the glass can either pass through which is desirable or get absorbed by the glass which would happen if the glass is colored or if it is too thick. For this reason, it is preferred to keep the thickness of the glass as low as possible.

Glass thickness desired is as low as possible but technology has hit a roadblock at 3.2 mm. Below the thickness of 2.8 mm to 3.00 mm the glass shatters due to the tempering process, so for years all solar glass thicknesses have been set at a limit of 3.2 mm.

The search is on for a process whereby the limit of 3.2 mm can be overcome so that lesser thicknesses become possible. This will deliver a multi-pronged benefit such as:

- Thinner glass will allow more light transmission which will enable a higher rate of conversion of light energy to electric energy which will be a direct benefit.
- The weight of the glass per assembly will drastically reduce so the same glass weight can accommodate more glass panels yielding a tremendous cost advantage.
- The lower weight per panel will enable the civil and mechanical structures to be re-designed and can deliver major cost advantages with major savings in steel, concrete and control systems.

5.3. Challenges faced / the opportunity

As described above the challenge has been thrown to the technologists to come up with a solution to the glass thickness limit.

Technologists all over the world have been on the job for several years now and the problem has been studied at the elemental and molecular level to understand the mechanism of tempering, the generation of compressive stresses and the cause of the glass shattering at thicknesses below 3.00 mm. Chemical toughening as compared with thermal tempering has been a solution, but it is affordable at thicknesses well below 1.00 mm. As the thickness increases its prohibitive cost renders it un-acceptable for solar cover glass applications.

The solution must come only from thermal tempering and the good news is that the technologists have cracked the problem and today it has become possible to have solar cover glass below 3 mm, but the technology is still in its infancy and is yet to mature to the levels to make it affordable for all users.

5.4. Solutions and emerging solutions

The solution to the problem of overcoming the glass thickness limit has come by way of a totally new concept of tempering by carrying out the toughening on a vertical plane instead of the

horizontal plane on rollers. The glass sheets pass through the tempering chamber while being held vertically with a different air blasting technique.

It has become possible to go down to 2.00 mm which in itself is a major technological breakthrough.

Of course, the new tempering furnace is extremely expensive as compared with the conventional furnaces, but it is believed that as time goes by and the patents and proprietary licenses get exhausted by efflux of time, the knowledge will spread and the equipment will become more affordable.

5.5. Adoption methodology

Within the cluster the TC could develop a pilot plant with a limited capacity to demonstrate the technology and its inherent benefits. The advent of Solar Cover Glass could also be included in the several training programmes conducted by the Technological Center.

To start with Solar Cover Glass can become an important part of the syllabus of certification and diploma programmes conducted by the TC. Since Solar Cover Glass in India is still in its infancy it would be wise for the TC to have a tie up with some institution such as Celsian in Netherlands or Glass Services in Czech Republic who can help in developing the syllabus and also provide the necessary Course material.

6. Conclusion

Glass making will never be the same once computer simulation in operations becomes a total reality and realized to its full potential.

- Glass quality will dramatically improve
- Efficiencies will reach never-before levels
- Operating costs will plummet
- Application of glass into new areas such as medical applications such as replaceable body parts may become a reality
- Usage of Glass in space technology may become possible.

Foam Glass is a product whose time has come. It is here to stay and compete with products that offer insulation characteristics of the highest order with corrosion resistance, facility to be delivered in special shapes and sizes and the many other properties discussed above.

The TC should step in to propagate the knowledge in the form of training courses so that candidates can be trained and industry ready when the industries enter this segment in a big way.

CDGI should aim to become a hub of knowledge and become an enabler of providing trained manpower to not only the existing solar glass plants but also new proposed entrepreneurs who wish to come into this area. With the government support for solar and other forms of renewable energy this product has a very good potential for exponential growth in India.

MSMEs of Firozabad glass cluster should also step ahead and plan addressing the market needs. As mentioned in the previous sections, computer simulation could help in improved competitiveness in form of optimized use of raw material, energy and manpower and the next level quality of final products. The cluster mainly focused on glass bangles, containers and tableware, but the time has come to provide more product specific diversity in the cluster. Driven

by associations and leading manufacturers, few plants for foam and solar glass could be established and in association with giants like CelSian Netherlands, Glass Services Czech Republic, FIC United Kingdom, IIT BHU Varanasi, CGCRI Khurja; CDGI Firozabad could help them in the area of technical assessment, specification finalization, plant layout etc. and training of the manpower and students.

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