Understanding Glass Recycling

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PREFACE

This paper is one of a series published by Volunteers in Technical Assistance to provide an introduction to specific state-of-the-art technologies of interest to people in developing countries. The papers are intended to be used as guidelines to help people choose technologies that are suitable to their situations. They are not intended to provide construction or implementation details. People are urged to contact VITA or a similar organization for further information and technical assistance if they find that a particular technology seems to meet their needs.

The papers in the series were written, reviewed, and illustrated almost entirely by VITA Volunteer technical experts on a purely voluntary basis. Some 500 volunteers were involved in the production of the first 100 titles issued, contributing approximately 5,000 hours of their time. VITA staff included Betsey Eisendrath as editor, Suzanne Brooks handling typesetting and layout, and Margaret Crouch as project manager.

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VITA is a private, nonprofit organization that supports people working on technical problems in developing countries. VITA offers information and assistance aimed at helping individuals and groups to select and implement technologies appropriate to their situations. VITA maintains an international Inquiry Service, a specialized documentation center, and a computerized roster of volunteer technical consultants; manages long-term field projects; and publishes a variety of technical manuals and papers.

I. INTRODUCTION

The first glass vessels were formed over 3,500 years ago using the sand core method. In this method, a clay-sand core of material was formed on a metal rod and dipped several times into a bath of molten glass. The vessel was then formed by digging out the core, leaving the hollow glass shell. These containers were as valuable as gold and were used until broken. Glass blowing techniques, invented about 1,500 years ago, made glass objects more widely available, but they were still relatively precious.

The Industrial Revolution changed all that. Glass, which had begun as a luxury, became a common commodity. The glass industry now produces billions of bottles and millions of tons of flat glass each year. With that increase in production has come the problem of disposing of or reusing the glass. In industrial countries, the low cost of glass raw materials has frequently made it cheaper to produce new glass objects than to reuse old glass. Nevertheless, despite the relatively low cost of glass, it is still quite expensive in many areas of the Third World. Recycling glass refuse may be a way to provide jobs and produce usable products at lower cost than new manufacture.

This paper briefly describes the production of glass and its properties, and gives some methods for recycling it. The uses of glass are not limited to these examples and there may indeed be far more inventive ways to reuse glass than are cited here. It is important to remember that any effort to recycle glass must be geared to the demand for either the glass itself or objects made from it. Because of this, it is critical to work at identifying potential markets.

II. OPERATING PRINCIPLES

Glass is a hard, transparent or translucent brittle material that is insoluble and nonflammable. It is capable of withstanding high temperatures and many corrosive substances.

The primary raw material of glass is high silica sand (silicon dioxide), which is heated until it melts and then allowed to cool in a controlled process. The temperature needed to melt sand is very high--about 1,700[degrees] C--so materials are added to the sand to reduce the melting point to about 800[degrees] C. The commonest of these materials is sodium oxide ([Na.sub.2]O), which is obtained from sodium carbonate (soda ash, [Na.sub.2][CO.sub.3]. Potassium oxide ([K.sub.2]O) is also used frequently. This mixture is unstable, however, so a stabilizer such as calcium oxide, derived from calcium carbonate (limestone, [CaCO.sub.3]), or magnesium oxide (dolomite, MgO) is added to the mix.

A number of other materials may added, depending on the type of glass desired. Metal oxides, for example, such as iron, manganese, chromium, or copper, may be used to produce glass in colors ranging from light green to deep blue to topaz yellow. Lead oxide or potassium oxide (obtained from potash, [K.sub.2][CO.sub.3]) are used to make very clear glass.

Another important ingredient in glass manufacture is cullet, which is scrap or recycled glass that is cleaned and crushed specifically to be remelted and reused. The principal source of most cullet is waste or reject glass from the manufacturing operation. However, glass from other sources can be used. This is particularly true in the glass container industry, where composition does not vary substantially from one manufacturer to another. It is evident that when uniform composition must be maintained, the composition of the cullet must be the same as the composition of the glass being produced. Cullet is normally crushed and stored in much the same way as the other raw materials are.

The use of cullet serves two purposes. The first is that reusing the scrap glass saves the cost of raw materials. The second is that cullet aids in the melting process. Some glass melting operations use up to 60 percent cullet. For some purposes, it is possible to make glass entirely of cullet.

TYPES OF GLASS

While it is possible to form glass out of many materials, almost all high volume commercial glass is formed from silica as the major constituent. Specialty glasses may be formed from phosphates, borates, germanates, etc. Because these glasses have high performance applications that make recycling difficult, this paper is restricted to silica-based glasses.

Commercial silica glass can be classified into several categories. The person considering recycling glass must be aware of these categories, as each has different properties and applications. The types of glass include:

1. Fused silica glass: A pure silica or silicon dioxide ([SiO.sub.2]) glass with excellent chemical durability and very low thermal expansion. The very low thermal expansion results in excellent thermal shock resistance. However, high processing temperatures limit use of this glass to special applications. This kind of glass is not commonly recycled.
2. Soda-lime-silica glass: The earliest glass made and still the most common. It is used for plate glass, window sheet glass, container glass, and electric lamp bulb glass. Typical compositions are given in Table 1. Soda-lime-silica glass is, by far, the most important glass economically and is the target of most glass recycling operations. It is relatively easy to melt and fabricate.

Table 1. Typical Composition of Window Sheet Glass, Plate Glass, Container Glass, and Electric Lamp Glass

Type of Glass Oxide(*) (percent by weight)

Alumina(**) Silica Sodium Oxide/ Calcium Oxide/ Potassium Oxide Magnesium Oxide (Al 0) (SiO) (Na O/K CO) (CaO/MGO)

Window Sheet 0.5-1.5 71-73 12-15 9.5-13.5

Plate Glass 0.5-1.5 71-73 12-14 11-16

Container Glass 1.5-2.5 70-74 13-16 10-13

Electric Lamp 73-74 16-17 8-9

(*) Iron oxide is normally held in the range of 0.1 percent. (**) Increased alumina in the container formulation improves the chemical durability.

1. Lead oxide-alkali silicate glass: The calcium oxide normally in other glasses is replaced in these glasses by lead oxide (PbO). These glasses can have up to 80 percent lead oxide, and are popular for artistic ware because of their brilliance and ease of working. The common glass "crystal" is normally a lead oxide-alkali silicate glass containing 15 to 30 percent lead oxide. These glasses have unique optical and electrical properties that compensate for the added cost of using lead oxide. Television faceplates, thermometer tubing, and neon tubing are commonly made of this type of glass, as are engraved, etched, or otherwise decorated glass objects.
2. Borosilicate glass: Boric oxide is both a glass former and a glass modifier. Heat-resistant glasses (such as Pyrex) are commonly of this type. These glasses are typically about 80 percent silica, 4 percent sodium oxide, 13 percent boric oxide, and 2 percent alumina.

There are, of course, a large number of other glasses used in specialized applications. However, these are the four most likely to be encountered in a glass recycling project.

MAKING GLASS

There are four basic steps in manufacturing a glass article: melting, forming, annealing, and finishing.

1. Melting: The mixed raw materials are placed in a refractory vessel and heated to the melting point. The typical operating temperature is 1,500[degrees]C. Heating may be done in batches or in a continuous operation. In batch furnaces, the size of the melt can vary from very small to several tons. Continuous furnaces typically have capacities ranging from 10 to 1,500 tons. Since a unit of glass stays in the furnace approximately 24 hours on the average, these capacities are the average daily output. Two small-scale glass furnaces are shown in the drawings below.

From the standpoint of reycling, it is important to note that large-scale operations require constant attention, sophisticated controls, and a steady supply of raw materials (mined materials or cullet) of unvarying quality. Suppliers of cullet must be able to assure plant operators of the reliability of both the quantity and the quality of their product.

1. Forming: The liquid glass is next fabricated into a useful product. There are a number of ways in which glass can be formed. The most straightforward are to press, blow, roll, or draw the glass into the desired shape. Glass containers are commonly formed in a two-stage operation by blowing into a mold. Flat glass is drawn into sheets.

2. Annealing: The stresses that have been left in the glass object must be removed. This process is called annealing and requires that the glass be heated to the annealing temperature (about 600[degrees]C for soda-lime) and slowly cooled. Failure to anneal a piece will usually cause failure (cracking) of the object. The large amount of stored energy can cause the piece to explode, sending sharp fragments of glass flying over 10 meters.
3. Finishing: Any sharp edges or stresses developed during forming are removed and surface coatings are applied if needed. Grinding or fire polishing, in which a flame is played over the surface to remove sharp edges, are other frequently used finishing processes.

III. RECYCLING

The basic difficulty in making glass recycling profitable is that glass itself does not have a high value as a material. The value of the materials from which glass is made represents only a small fraction of the value of a finished glass product (approximately 10 to 20 percent, and this percentage falls as the product becomes more complex). In other words, the cost of an item made of glass is determined largely by the complexity of the processing that the item requires, and by the volume of production.

APPROACHES

Waste glass can be put to new use in several ways:

- by reusing it for its original purpose;
- by altering the original item to make new products;
- by using it as cullet in the manufacture of new glass;
- by using it as a substitute for a raw material that is currently used in the manufacture of some product; or
- by using it as a raw material in a newly invented product.

Reuse

The most direct method of making use of waste glass is to return it to its original purpose.

Flat glass or tubing can be salvaged, cleaned, perhaps cut, and then placed back in service. This process tends to be labor intensive, but is usually straightforward. In the flat glass industry it means, for example, cutting window panes from large sections of broken glass. (Note that tempered plate glass cannot be cut.)

In the case of a glass container, an example of straightforward reuse is to again fill the container with the same kind of material that it originally held. A soda bottle, for example, would be returned to the bottler, cleaned, and refilled with soda. In many areas, bottles and jars are reused for everything from beverages to medicines because the goods are produced at home or sold unpackaged. That is, the purchaser must provide the container. Local markets throughout Africa and other parts of the Third World usually contain at least one stall where glass bottles and jars are sold to be reused in this way.

Beverage bottles refilled by commercial bottlers must be designed for reuse. Even so, such reuse eventually causes even bottles designed for it to weaken, and frequently to fail. A bottle failure while the bottle is in the filling line can result in an expensive short-term shutdown of the system, and a failure while the bottle is in the consumer's possession can result in personal injury. Large product liability settlements in the United States have reduced the economic feasibility of container reuse. Bottles must be checked carefully before reuse to be sure they are free of nicks, chips, cracks, or other defects.

Adequate cleaning is another problem. A bottle used to contain only the intended product can be cleaned thoroughly enough, but consumers sometimes use bottles to store insecticides, poisons, etc. In those cases, standard cleaning techniques may not be suitable or sufficient.

In many areas, beverage bottles are not intended to be reused. It is likely that governmental action in such places would be necessary to require large-scale introduction (or re-introduction) of recyclable bottles. If you seek governmental action to require container recycling, be sure that it applies to all materials (i.e., to plastic, paper, and metal containers as well as to glass ones). If the law applies only to glass, it will tend simply to eliminate the glass container industry in your area.

Alteration

Sometimes glass containers and other objects can be made into new useful or novelty items. Bottles can be cut to make drinking glasses, funnels, candle holders, vases, etc. Preparation of such items requires very little capital investment, and they can be sold for cash. As with any item to be produced for sale, it is necessary to determine first of all if a market exists and if a regular supply of raw material can be obtained.

Examples of such uses in developing countries are numerous. An organization in Colombia manufactures solar water heaters that use recycled fluorescent light bulbs as tubing. A volunteer in Papua New Guinea used burned out incandescent light bulbs to make beakers, specimen dishes, and other equipment for his science classes. A small shopkeeper in Recife, Brazil, makes and sells lamps and other items made from bottles and jars that are cut and painted with floral designs or traditional motifs.

Glass bottles can be cut with an electric wire, with an ordinary glass cutter, or by wrapping them with a string and burning the string. Special cutters for use on bottles are also available in some areas and may be worth the investment if enough of a market for the glass products exists.

The electric wire method requires a small electric transformer that reduces the usual 230 or 240 volts to about 15 volts. The wire, which can be taken from an electrical appliance such as an iron, is wrapped tightly around the bottle or jar at the exact place where the cut is desired. The wire is attached to the transformer and the electric current is turned on. After a minute or so, when the wire is red hot, the current is turned off, the wire quickly removed, and the bottle plunged into cold water. The bottle will crack along the line where it was heated.

Precautions must be taken with this method. The transformer can deliver a fatal shock if any of the live metal parts on the 230 volt side are touched. And the red hot wire can cause serious burns.

When using an ordinary glass cutter, a groove is made along the line where the cut is to be made. The area along the groove is heated with an alcohol lamp or similar burner and the bottle is immediately dipped in cold water, where it will crack at the groove (it may have to be helped along with a slight tap).

The "burning string" method uses the same principle as the electric wire. A fairly fine string is wrapped tightly around the bottle and set afire. When the string has burned, the glass piece, again, is plunged into cold water and will crack along the heated area. This method is probably most successful with thinner glass, such as the lightbulbs used to make lab equipment for schools.

With all of these methods, the sharp edges of the cuts must be smoothed away. A carborundum stone, used for sharpening knives and tools, is probably the best material for working glass. Drinking glasses and similar containers should have the entire edge smoothed and rounded so they will be safer and more comfortable to use.

Cullet

Another approach is to sell the glass as cullet to a local manufacturer of container or flat glass, assuming that there is one.

Economic Feasibility. The economic feasibility of this approach depends on the cost of cleaning and crushing the glass, and of transporting the cullet, which is heavy. It also depends on the price that the manufacturer is willing to pay; the manufacturer's access to alternative raw materials will play a large part in determining this. Anyone considering recycling glass as cullet needs to prepare a careful cost analysis.

Reliability of Supply. The reliability of the cullet supply that you can offer is another important factor. Glass tanks are difficult to control; changing a batch by increasing or decreasing the percentage of cullet may not be economically feasible. Therefore, the cullet supply must be dependable in quantity and in quality. Container glass is usually the most suitable kind of glass for use as cullet, because its composition tends to be essentially the same from manufacturer to manufacturer.

Markets. The primary market for cullet is the manufacturer of bottles and jars for packaging food, but there may be other types of glass objects that can be made with cullet. These include handicrafts, fiber glass, household goods such as vases, beads, etc. Cullet may also be used as a portion of the materials that go into concrete or ceramic products, as described below.

Glass as a Substitute for a Raw Material

With this approach too, economic feasibility and reliability of supply must be carefully considered. Since glass does not have great material value and since raw materials must be processed to manufacture it, it will probably not win a place as a substitute for plentiful natural minerals like silica or feldspar. However, it can be used in several classes of product.

Coarse Aggregate for Concrete. Concrete contains a substantial quantity of aggregate, often crushed stone. Low alkali glasses (not container glass or flat glass) can be substituted for much of the crushed stone. (Only low alkali glasses should be used for this purpose, because alkali released from the glass often causes the concrete to expand and crack.)

The substitute of glass for crushed rock can help solve a waste disposal problem, but represents virtually the minimum product value possible.

Lightweight Aggregate for Structural Concrete. Since the late 1960s, the U.S. Bureau of Mines has been doing research on ways to put municipal wastes to use. One of their findings has been that waste glass can be used as the principal raw material in producing lightweight aggregate suitable for use in structural concrete.

A mixture of 78 percent waste glass, 20 percent clay, and 2 percent dry sodium silicate fired to 1,550[degrees] F for 15 minutes produced aggregate with a bulk density of 38 pounds per cubic foot. Glass aggregate concrete with an average unit weight of 104 pounds per cubic foot had an average compressive strength of 2,550 pounds per square inch after steam curing for 28 days. After one year of exposure to weather conditions, the unit weight was 102 pounds per cubic foot, and the compressive strength was 3,025 pounds per square inch. To meet ASTM (American Society for Testing and Materials) standard C-330-69, concrete having a unit weight of 105 pounds per cubic foot must have a minimum compressive strength of 2,500 pounds per square inch. The study concluded that alkali reactivity did not appear to be a problem when this technology was used.

Recycled Glass in Ceramic Products. Recycled glass is similar in composition to feldspar, a naturally occurring material and a common ingredient in the clays used to make ceramic products. Consequently, glass can be added in varying amounts to most ceramic products. Studies have shown that face brick can be produced on a commercial scale without difficulty. Similar studies have shown that recycled glass can be substituted for feldspar in porcelain bodies, tile bodies, and decorative artificial stone. Some energy saving is associated with the use of recycled glass in these applications.

Most of the ceramic products into which recycled glass can be substituted are relatively low performance materials. The strengths of the bodies are well in excess of those needed to perform their functions, and exterior appearance is the primary factor. Consequently, the substitution of a similar raw material (recycled glass) in small quantities is harmless. However, the advantages are at best marginal. With only slight value added to the product, it is difficult to overcome the expense of collecting, crushing, and cleaning the glass. That, and the possible uncertainty of supply, has made most manufacturers unwilling to switch their processes to utilize waste glass.

Glass as Raw Material in a New Product

The most promising approach is to find a process for which glass is the most suitable raw material. To do this, you need to understand the basic vitreous, inorganic nature of glass, and take advantage of it to create a unique product that meets a need of the local market.

The creation of inorganic foams is an excellent example of this approach. The process requires glass as a starting material; there are no natural minerals that can be substituted for the glass; and the resulting product has distinct advantages over competing products in the marketplace.

When glass is mixed with a foaming agent that gives off its gas at the same temperature at which the glass softens, that gas will cause the glass to foam. The result is a product that, when properly processed, can be used for thermal and acoustical insulation. One version of foamed glass is made by crushing waste glass to a uniform fine particle size, and then mixing it with bentonite, calcium carbonate, and water. The pressed mixture is then placed in a furnace where it foams. The finished product resembles a slab of polystyrene foam except that it is rigid. It is fireproof, impervious to water or acid damage, and can be easily cut with a saw. Several different foaming agents have been used in this process. Cow manure is the most straightforward.

There may be a number of applications of this type. It takes imagination and an understanding of glass to invent a product that is appropriate for a given place.

OPERATIONS

As the basis of a small business, glass recycling requires a reliable source of raw materials and a minimum amount of equipment. It also requires space for sorting, cleaning, and storing the glass. Before making any kind of investment, it is very important to try to determine what the market is for recycled glass, whether in the form of refillable bottles or jars, cullet, or glass items to be turned into usable products.

Raw Materials

Collecting unbroken bottles or jars to be sold for reuse or alteration will be difficult. In most developing countries such containers are used and reused until they break and have to be discarded, and finding them depends mostly on chance. Possible reliable sources might be breweries or soft drink bottlers that throw away containers that are still in basically good shape but which could not withstand another round in the factory's equipment. Hotels, restaurants, and schools; and trash dumps in wealthier neighborhoods are other possibilities.

The most plentiful type of recyclable material is likely to be broken glass that can be sold as cullet. Cullet can be collected from such places as hotels and restaurants; food processing plants that package products such as preserves or fruits and vegetables in glass bottles or jars; dairies and bottlers of both beer and soda; trash dumps; glass cutting shops and window factories; and so on. If enough of these types of establishments exist to make the effort worthwhile, the collector might even provide containers for workers to use for the broken glass when they throw it away.

To bring the best price, cullet usually has to be sorted by type and color and given at least a preliminary cleaning. It is a good idea to check with potential customers about the types of glass they are most interested in (and thus will pay most for). Do not include such things as car and truck window glass, light bulbs, glass reinforced with wire, or dark colored glass.

Equipment

Collecting glass requires a means of transporting it, facilities for sorting and storing, and tools for cleaning and handling. Glass is heavy and potentially dangerous, and a large quantity will likely bring a better price than a few bags or boxes full. A sturdy cart or wagon, preferably one that can be tipped easily for dumping, will make quantity hauling easier. Glass should be sorted as it is put into storage: different types and colors should be placed directly into containers. In this way the glass will only have to be handled once, reducing risk of injury and labor costs, and the containers can be loaded directly into the wagon for delivery.

Containers should be large enough to be useful and small enough to be manageable; one half of a standard petrol drum is a good size. Handlers should wear gloves and footwear (preferably boots), and goggles and other protective clothing as necessary, to minimize the chance of injury. A first aid kit should be kept at hand, and any cuts should be treated immediately, no matter how small, to avoid potentially deadly infections. A stiff broom and a flat shovel or scoop are needed to keep the area clean--absolutely essential for the protection of workers and any children or animals that may come along, as well as to avoid flat tires on vehicles that may be used.

Customers may insist that the cullet be washed before sale. In this case, water must be available, and this can be a considerable expense in some areas.

Legal Considerations

Before starting into this or any business, it is a good idea to check out any legal restrictions. In some areas glass recycling may be regulated by law. Health and sanitation laws may restrict the activity to certain areas or neighborhoods. Safety precautions may be required. This is true even in the big cities in developing countries, where a large percentage of the people may make their living as trash pickers. Cairo is one such city, attempting to reduce health and sanitation threats by, for example, requiring trash collectors to use small tractor-drawn wagons instead of donkey carts that obstruct traffic and generate their own clean up problem. Other regulations may apply in other areas, and should be investigated.

OTHER OPTIONS

As noted above, some objects can be made entirely of cullet. The final product is not a high quality glass, but it can be servicable. If your area is not served by a glass manufacturer, and if sufficient waste glass is available, it may be possible to set up a small furnace to remelt the cullet and produce jars, bottles, drinking glasses, or other products. Be advised that even a simple operation requires a fair amount of capital and a great deal of skill, and may require months or years to bring a return on the investment. If you have the money and skill, and if you think the necessary markets and raw materials are available, consult a technical assistance organization like VITA or the Intermediate Technology Development Group for guidance in setting up shop.

Bibliography

Augustinik, A.I., Sintsova, I.T., "Manufacture of High Strength Porcelain," Silikattecknik, 19(4), 111-114, 1968.

Bell, J.M., "The Physical and Chemical Composition of Municipal Refuse," American Public Works Association Reporter, 29, 1, 11, 1962.

Borax Consolidated Limited, Glasses, London, 1965.

Cutler, Ivan, "Insulation from Recycled Glass," Department of Materials Science, University of Utah.

Holscher, H.H., "Hollow and Specialty Glass: Background and Challenge," Vol. 46, June-November, 1965.

Johnston, C.D., "Waste Glass as Coarse Aggregate for Concrete," Testing and Evaluation, 2, 950, 344-350.

Liles, K.J., "Lightweight Structural Concrete Aggregate From Municipal Wastes," Proceedings of the Fifth Mineral Waste Utilization Symposium, E. Aleshin, Ed., U.S. Bureau of Mines, 1976.

Ott, W.R., "Recycled Wastes--An Energy Source," New Jersey Trends, Institute for Environmental Studies, Rutgers University, New Brunswick, New Jersey, 514-533, 1974.

Rivkind, L.E., "Improved Technology for Rigid Inorganic Foams," J. Cellular Plastics, July 1967, p. 329-33.

Roeder, Johannes (Deutsche Akademic der Wissenschaften zu Berlin), "Porous, Decorative Artifical Stone" Germany 1,280, 126, (Cl. C. 04b), 10/10/68, Appl. 7/61; 3pp.

Shand, E.B, Glass Engineering Handbook, McGraw Hill Book Co., New York, New York, 1958.

Tooley, F.V., Handbook of Glass Manufacture, Volume 1 and II, Ogden Publishing Company, New York, New York, 1960.

Tyrrell, M.E., Feld, I.L., Barclay, J.A., "Fabrication and Cost Evaluation of Experimental Building Brick from Waste Glass", Report 38 BuMines-RI-7605, U.S. Bureau of Mines, Washington, D.C.

University of New Mexico, The Utilization of Waste Glass in Secondary Products, A Review of the Literature, Cumulative Volume, June 30, 1973, Technology Application Center, Albuquerque, New Mexico.

Vogler, Jon. Work from Waste. London: Intermediate Technology Publications, 1981.

Waldplattenfabrik Engers, "Ceramic Composition for Making Floor Tiles," Germany, 1, 231-155 (Cl. C04b), December 22, 1966, Appl. 10/27/62; 2 pp.