CFCs in Foam Insulation: The Recovery Experience

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A number of electric utilities have implemented residential electricity conserving programs that target the early retirement of operating, inefficient refrigerators, freezers and room air conditioners. A common element of these programs has been to develop the appliance recycling infrastructure by requiring environmentally sound disassembly and proper hazardous material management including the evacuation of refrigerants without atmospheric release, a practice that predated the mandates of the federal Clean Air Act.

There exists yet another application of CFCs in home appliances that has not, as yet, been subject to the provisions of federal legislation. This exempt material is the CFC-11 used to create the polyurethane foam insulation in the appliances. Pending analysis of the results of ongoing studies, the federal government has deferred the promulgation of regulations designed to ensure the environmentally proper disposal of polyurethane insulation.

This paper describes the results of the nation's first demonstration of a large-scale production process for recovering CFC-11 from polyurethane foam insulation from appliances retired through electric utility-sponsored DSM programs. The author describes the approach that was taken in the selection of the technology, the mechanics of the recovery process, and the results that have been achieved by this program.

This initiative is a prime example of how the interests of efficient electrical usage and prudent environmentalism have converged. The findings are expected to be instrumental in the development of a national policy pertaining to the environmentally safe disposal of polyurethane foam.

Introduction

During the late 1920's, the research department of a United States-based manufacturer of refrigeration equipment discovered that particular sets of molecules containing one or two atoms of carbon in various combination with chlorine, fluorine or hydrogen exhibited attractive properties for use as refrigerant mediums. These stable elements came to be known as chlorofluorocarbons (CFCs). The use of these CFCs rapidly expanded to replace the older generation of refrigerants, notably sulfur dioxide and ammonia, which exhibited such undesirable characteristics as explosivity, flammability and toxicity.

The initial application for the CFCs was as refrigerant mediums within the cooling systems of home appliances. By convention, the use of CFC substances as refrigerants is designated by the letter "R" as a preface to the compound number as is the case of R-12, which is CFC-12 refrigerant. The most frequently used type has been dichlorodifluoromethane, commonly referred to as R-12. Other chemically similar refrigerant compounds such as R-114, R-22, R-502 and R-503 are utilized in commercial chiller systems, air conditioning equipment and process refrigeration applications.

The CFCs, which enjoyed widespread acceptance as propellants in aerosol sprays, were also used in the creation of thermal and acoustic insulation, flexible foam and packaging materials. The CFCs are used as blowing agents in the manufacture of these materials. Rigid foam insulation such as polyurethane is produced by injecting CFCs into a liquid mass of plastic polymer, thereby creating the bubbles that provide the insulating capabilities of the material. The most frequently used blowing agent for this purpose has been trichlorofluoromethane, referred to as CFC-11. From a manufacturing perspective, CFC-11 was a highly attractive agent to use. It was chemically stable, readily available and easy to transport. When used in the manufacture of appliances it, unlike other blowing agents, does not degrade acrylonitrile-butadiene styrene (ABS) or high impact polystyrene (HIPS), the most frequently used plastics in appliance liners (UNEP 1991).

In the United States during the early 1970's, major appliance manufacturers shifted to the use of rigid foam insulation as a replacement for the previously used fiberglass materials. The use of polyurethane in the cabinets of refrigerators and freezers achieved a dual benefit. First, the material lent structural rigidity to the appliance which enabled manufacturers to reduce the amount of steel needed for each unit. Advances in the energy performance of the units were also realized due to the higher resistivity to heat transfer by the polyurethane foam when compared with fiberglass insulation. The application became pervasive within the industry. So extensive was its adoption that, according to the Association of Home Appliance Manufacturers (AHAM), nearly three quarters of all residential appliances built for the United States market by the early 1980's contained CFC-11 blown polyurethane foam insulation (AHAM 1990). The use of CFC-11 increased even further as evidenced in a report prepared by the Technical Options Committee to the Montreal Protocol. The consumption of CFC-11 for manufacturing rigid polyurethane foam used as insulation in appliances in North America grew from 9,400 tonnes (9,550 U.S. tons) in 1986 to 11,200 tonnes (1 1,340 U.S. tons) in 1990 (Technical Options Committee 1991).

Thus, there are two varieties of CFCs to be found in a typical piece of home food storage equipment; those contained within the refrigeration loop and those used in the creation of polyurethane foam insulation.

The potential linkage of the deleterious environmental effects attributable to the release of CFCs into the atmosphere became a matter of world-wide concern beginning in the mid-1970's. The concern was formally expressed in the 1987 Montreal Protocol, a multinational policy that provided a time table for the phase out of the production of CFCs and other ozone-depleting substances.

The measure of a substance's potential impact on the Earth's ozone layer is expressed in terms of its Ozone Depletion Potential (ODP). This calculation is based on the amount of ozone destroyed by steady state emissions of a gas compared to that destroyed by the emissions of the same amount of CFC-11. The ODP accounts for the number of chlorine or bromine atoms in a substance and their lifetime once reaching the stratosphere after being released. The accepted ODP calculation is as follows (UNEP 1992):

$$ODP = \frac{\text{Globally averaged ozone depletion due to "X"}}{\text{Globally averaged ozone depletion due to CFC-11}}$$

The international strategy to stabilize ozone depletion is being accommodated in a variety of manners by the signatories to the Montreal Protocol. Seventy (70) countries, representing 90% of the world's CFC production agreed to cease the manufacture of CFCs by the year 2000. However, most European countries have a set deadline of 1997 for their phase out. A number of nations including Germany, Sweden and the United States have accelerated their schedule even more ambitiously by targeting a 1995 deadline to cease the production of certain types of CFCs.

In the United States, the proper management of CFCs was addressed legislatively in Section 608 of the Clean Air Act of 1990. The regulation directed the United States Environmental Protection Agency (EPA) to reduce chlorofluorocarbon and the chemically related hydrochlorofluorocarbon (HCFC) emissions to the lowest achievable level. The assessment of how to achieve the objective of the legislation culminated in the publication of the Protection of Stratospheric Ozones Refrigerant Recycling; Proposed Rule by the EPA in the Federal Register in late 1992.

The scope of the proposed rule was to establish a recycling program for ozone depleting refrigerants recovered during the servicing and disposal of air conditioning or refrigeration equipment. This included residential applications such as air conditioners, refrigerators and freezers, as well as commercial, industrial process and other specialized applications that contain CFC or HCFC substances.

The EPA posited that polyurethane foam insulation in appliances contained roughly the equivalent amount of ozone depleting substances as was likely to be found in the refrigeration system. However, citing the existence of significant financial and technical obstacles, the Agency elected to defer the promulgation of regulations regarding the retrieval of foam insulation from appliances (Federal Register 1992). The EPA has since expressed their interest in establishing demonstration projects, the goal of which is to investigate the feasibility and effectiveness of foam insulation management techniques (EPA 1993).

The majority of opportunities for the conduct of demonstrations as to the relative efficacy of differing approaches to foam processing have arisen in association with electric utility-sponsored appliance turn-in programs.

Programmatic Issues

A number of large scale appliance turn-in programs have been sponsored by electric utility companies in the United States. These programs, designed to conserve electricity by permanently removing inefficient energy consuming equipment have been responsible for the early retirement of hundreds of thousands of appliances. The programs generally provide for the removal from service of operating, energy inefficient refrigerators, freezers and/or room air conditioners. A common feature of these innovative demand-side management programs has been the offering of environmentally sound processing of the various components at the time of disassembly. However, due to the early retirement of large numbers of appliances in relatively short periods of time, and the manner in which they are processed, some of these programs hold the potential for worsening environmental conditions.

The hazardous and/or regulated substances found in appliances from these programs include polychlorinated biphenyls (PCBs) in capacitors, mercury containing switches, batteries from back-up alarms and clocks, as well as ballasts and bulbs from fluorescent lights. Additionally, compressor oils and refrigerants of all types; CFCs, HCFCs, ammonia, sulfur dioxide and methyl formate have been encountered. The proper management of these recovered materials is now mandated by a number of federal, state and municipal regulations and enforced to varying degrees by the agencies of record.

Electric utility-sponsored programs have historically been the proving grounds for the testing of new technologies. Examples of this leadership include the introduction and promotion of compact fluorescent lighting products and high efficiency space conditioning equipment. In a similar market-shifting manner, utility sponsorship of appliance turn-in programs has contributed to the development of the appliance recycling infrastructure. For example, the non-atmospheric venting of refrigerants was required by electric company programs in the United States well in advance of being mandated by the provisions of the Clean Air Act.

Determination of the amount of refrigerant contained in the cooling system of a refrigerator is a relatively straightforward procedure that can be quantified by evaluating the results of the evacuation process. Determining the amount of CFCs present in the foam insulation is not as easy, A report prepared for an electric utility regarding the projected impacts of the phase out of CFCs estimated that a typical model refrigerator, current to the year of the study, contained about a half of a pound (216g) of refrigerant (CFC-12) and 2.5 pounds (1080g) of CFC-11 in the foam insulation (Meier 1988). Another frequently referenced estimate for the amount of CFCs in foam is from the proceedings of a workshop in 1988, where development of alternatives for CFC-containing insulation was discussed. At this venue, it was stated that there exist five times more CFCs in the insulation as there are in the cooling system (Christian and McElroy 1988). Estimates of the percentage of CFCs in foam insulation relative to the weight of the foam itself were also developed. These included a 10 percent figure cited in an electric utility company sponsored research project (Hall and Hutchinson 1993) and a range of from 7.4 to 16.9 percent from research by an independent appliance recycling company (Schatz 1993). It appears that differences in the amounts of CFC-11 found in polyurethane foam insulation result from the interaction of variables which include: the manner in which it was manufactured, the actual application and the age of the material. Determination of the CFC-11 content as a percentage of weight basis is also effected by the amount of moisture in the insulation material being evaluated.

In research conducted to establish the baseline for the development of a production oriented CFC-11 recovery program, a United States based appliance recycling company determined that on average, the before disassembly weight of a refrigerator was 230 pounds (104.5 Kg). Continued disassembly of the units yielded an average of 15.5 pounds (7 Kg) of plastic liner material and an additional 8.4 pounds (3. 8 Kg) of other loose plastic. An average of 7.3 pounds (3.3 Kg) of polyurethane foam was recovered from the refrigerators that contained the insulation. The remaining weight consisted of ferrous and non-ferrous metals.

Analysis of the percentage of CFC-11 found in the insulation from a sampling of appliances manufactured in different years reveals a wide diversity in the amounts of CFC-11 present. It neither challenges nor confirms the concept that as much as 1% of the CFC-11 in polyurethane foam escapes to the atmosphere annually. The research suggests that variations in manufacturing techniques and the specific locations where the insulation was resident within the appliances (i.e., door versus back panel) may effect the concentrations of CFC-11 (Schatz 1993). The figure below summarizes the findings.

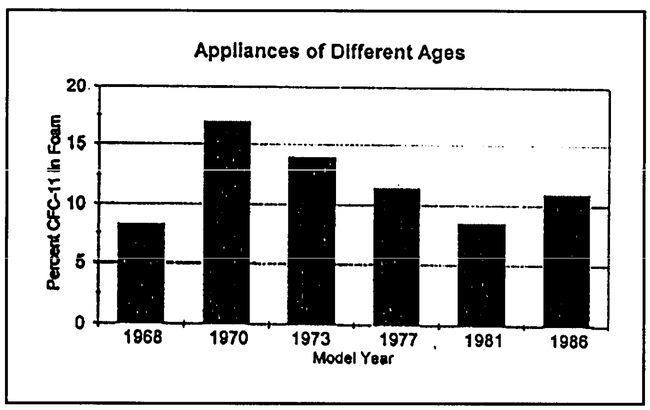

Figure 1. % CFC-11 Polyurethane Foam

Given that the CFC-11 in the foam has approximately the same Ozone Depletion Potential value as the refrigerant R-12 in the cooling system, large scale appliance turn-in programs that do not address foam insulation may produce some untoward effects. The magnitude of the environmental impact due to the release of the CFCs is significant. For example, using United States EPA estimates of the more than 10 million appliances that entered the waste stream in the United States during 1990, approximately 1.21 to 2.93 MKg (2,662,000 - 6,446,000 pounds) of CFC-11 in insulation could be recovered compared with 0.4 to 2.0 MKg (880,000 - 4,400,000 pounds) of the available CFC-12 refrigerant (USEPA 1992).

CFC-11 has also been determined to be a contributor to the global warming phenomenon. According to a report prepared for the United States Environmental Protection Agency, a single pound of CFC-11 released to the atmosphere has the approximate global warming potential as 1,600 pounds of carbon dioxide USEPA (1992). Thus, the body of research to date suggests that improper management of polyurethane foam insulation holds the potential to produce similar undesirable environmental effects as those that caused the adoption of regulations for proper refrigerant management.

Foam Disposal Options

There exist four primary options that are used by utility appliance turn-in programs for the processing of polyurethane foam insulation. Under the first scenario, appliance carcasses are simply landfilled after the removal of the regulated substances. There are two major drawbacks to this approach. First, appliances are bulky. A typical refrigerator is about 33 cubic feet in size. Placing multitudinous retired appliances in a landfill can accelerate the closure of the facility by displacing space available for other materials. Due to the lack of landfill space, bans on landfilling appliances have been enacted in many jurisdictions. The landfill approach also eliminates the possibility of recycling the ferrous and non-ferrous metals and plastics. The demand for such materials continues to grow as markets expand due to the premium placed on using post-consumer materials in the manufacturing process.

The second option is one which is primarily used by appliance turn-in programs. Since the processing of polyurethane foam is not yet subject to regulatory scrutiny, metals processors routinely shred appliances in their facilities. Appliance turn-in program operations deliver appliances to shredders after the removal of the CFC refrigerants and other regulated substances. In the shredding operations, the shells of the appliances are processed by machinery that compacts, cuts and separates the metals from the other materials. In preparing the metals for entry into the recycling stream in this manner, knife-like blades pass through the foam insulation, liberating the CFCs from within the material which, as reported in the proceedings from a workshop, results in the release to the atmosphere of 50% of the CFCs in the foam insulation (Christian and McElroy 1988). The remaining insulation material, a constituent of shredder fluff is then landfilled or incinerated.

The third option for the disposal of polyurethane foam is incineration. Many localities in the United States are served by Resource Recovery Facilities (RRFs) or waste-to-energy plants that utilize refuse as the primary fuel. The incineration services provided by these Resource Recovery Facilities are augmented by those offered by the operators of cement kilns.

The production of cement within the kilns calls for limestone, clay and sand to be mixed with minute amounts of ferrous materials and heated at very high temperatures to cause a chemical breakdown and recombination into what is termed “clinker” material. The clinker is then mixed with gypsum and ground into powder to make cement. Cement manufacturers often supplement their traditional oil, gas or coal fuels with organic chemical wastes which reduces their usage of the primary fuels and, due to the high incineration temperatures (2,450° to 3500°F, 1330° to 1907°C) destroys many of the waste materials.

Variable factors that affect the operation of these RRFs and cement kiln facilities include the type of waste being burned, the moisture content of the material, the amount of combustion air available to the fire, the temperature of the fire and the residence time of the material within the fireball.

In addition to not always fully destroying the CFCs, products of incomplete combustion (PICs), can result from the escape of organic compounds from thermal destruction within an incinerator (UNEP 1993). Examples of these PICs were identified in research compiled to measure the toxicity of specific materials resultant from the thermal destruction of polyurethane foam. Predominant among them was carbon monoxide. Lesser, but still toxicologically significant levels of hydrogen cyanide, dioxins and difurans were also found (Paabo and Levin 1985).

Hall and Hutchinson describe the results of incinerating polyurethane foam appliance insulation that measured the effectiveness of the destruction of the CFC-11 in the samples burned. The effects of flame temperature and residence time of the samples within the fireball are apparent in the results. Ninety percent of the CFCs remained at the temperature of 400°C (837°F) at a residence time of one second. Increases in temperature caused a reduction in the detectability of the CFCs until, at 900°C (1,678°F) no CFCs were found. The same test revealed that dioxins were not detectable at temperatures of 800°C (1,498°F). This series of laboratory test burns was conducted to simulate the effects of incinerating polyurethane foam in a waste-to-energy RRF, where large scale burning of the insulation materials was proposed to occur. The hydrochloric and hydrofluoric acids formed from the chlorine and fluorine compounds in the CFCs as they were burned were projected to be neutralized by the acid gas scrubbing equipment at the incineration station Hall and Hutchinson (1993).

Unlike the recover, recycle and reclaim practice that is the cornerstone of CFC management in the United States, Germany and the Netherlands have adopted policies that provide for the destruction of these ozone depleting substances. The techniques for the CFC destruction include both primary and secondary thermal decomposition processes. The primary process is the direct incineration of foam insulation while the secondary provides for super heating and rapidly cooling the CFCs after they have been separated from the foam. The secondary process was developed to overcome the potential incomplete destruction of CFCs observed in the primary process.

In order to process polyurethane foam insulation from appliances, it is first necessary to separate the foam by removing the steel skins and plastic liners that surround the insulation. Even in Europe, where the appliances are much smaller than in the United States, this is a time consuming, manual process. The standard practice has been to mechanically saw the appliance boxes into panels and then separate the steel and plastic components using hand tools. This disassembly technique releases some CFC-11 into the atmosphere due to the breakage of the insulation during the removal. To date, the amounts of release caused in this manner are unquantified. Once the foam has been separated from its surroundings, the processing can begin.

The foam can be delivered to an incinerator where it is added to the fuel mix. However, the incineration of foam as a means of destroying the CFCs has proven to be problematic. A sampling of incinerator emissions in Germany revealed the presence of dioxin, phosgene and nitric oxides in addition to measurable quantities of CFC-11 that remained undestroyed by the incineration process. The highly corrosive nature of the foam insulation due to the presence of chlorine products were found to be potentially damaging to the incinerator facilities (de Haan 1992). The policy of a large operator of cement kilns in the United States echoes this concern, While the facilities do accept organic waste products such as paint thinners, inks and some industrial cleaning solvents, high chlorine content fuels such as polyurethane foam insulation are not acceptable for use as fuels in the manufacture of cement (Southdown 1992).

The newest trend in Germany has been to destroy the CFC-11 after it has been recovered from foam insulation through a secondary, high temperature fission process. This technology features placing CFCs in a sealed chamber where they are superheated, which separates the compounds, and then cooled quickly to prevent possible recombination that can occur during a prolonged cooling process. This process is in the early stages of implementation and evaluation of the efficacy and cost-effectiveness has begun.

After investigation and weighing the merits of different techniques in use in Europe, one of the CFC-11 from foam insulation extraction technologies developed in Germany was imported to the United States in 1992. The equipment had then been in use in 18 locations in Germany, the Netherlands, Switzerland and Austria. This type of equipment was selected by the importing appliance recycling company based on a thorough review of alternative technologies and foam disposal options. Prior to the arrival of this piece of equipment, there was no large-scale facility for the recovery of CFC-11 from polyurethane foam insulation on the North American continent. The machine was originally installed in an appliance recycling center located in Hartford, Connecticut. It was there, in partnership with a number of electric utility companies that sponsored appliance turn-in programs, that Phase One of the national effort to demonstrate the efficacy of recovering CFC-11 from polyurethane foam insulation was conducted. Introduction of this technology represents the fourth foam processing option that is currently in use in the United States.

The CFC-11 recovery rate of the equipment had been tested in Germany by an independent testing institute (Rheinisch-Westfalischer TUV 1990). Using newly manufactured polyurethane foam with a known content of CFC-11, the equipment was certified to have achieved a gas recovery rate of 99.0%. The capture efficiency (CE) was calculated as follows:

$$CE = \frac{\textit{Recovered CFC}-11}{\textit{CFC}-11 \textit{ Used in Making the Foam}}$$

In the demonstration program, appliances containing polyurethane foam are first processed to remove the refrigerants, capacitors, ballasts, mercury switches, compressor oils and batteries. The glass and metal shelving, drawers and any interior doors are also removed. The wiring harness is stripped out of the units and the compressor is removed from the appliance shell. The carcass of the appliance is then ready to begin the foam separation process.

Using proprietary equipment developed specifically for this purpose, the appliance shells are rendered into panels. The metal skins and plastic liners are then peeled away to expose the polyurethane foam. The foam is placed in the processing machine for recovery of the CFC-11.

At the first stage of the CFC-11 recovery, the foam is placed in an air tight chamber where a rotary cutter reduces the size of pieces. Next, the foam is subjected to high pressure compression followed by a densification process. Quantities of CFC-11 recovered at each stage of the process are passed into a multi-stage condensation unit. There are three by-products resultant from the processing of foam by this equipment; compressed polyurethane foam, liquid CFC-11 and water. The CFC-11 is reclaimed to Air Conditioning and Refrigeration Institute (ARI) standards and made available to the HVAC service industry. The briquette foam matrix has been tested and found to be well within the established Federal Toxicity Characteristics Leaching Procedure (TCLP) limits (Twin City Testing 1992). Initially, the compressed foam was used as landfill cover by the local solid waste management agency. Research for the development of other applications for this material continues. The water generated in the process was tested and found to be acceptable by the local municipal waste water system.

The operation of the equipment during the first phase of the demonstration program yielded a number of findings and identified new challenges. Among them were:

- Establishing operational guidelines for the CFC-11 recovery equipment to accommodate the seasonal differences found in the moisture content of the foam processed
- Incorporating refinements to the appliance disassembly techniques to reduce the time needed to separate the foam from between the steel shell and liner
- Optimizing the processing of the polyurethane foam to enhance the recovery rate of CFC-11
- Automating the infeed product line
- Development of a production oriented means of identifying and sorting the various types of plastic recovered
- Development of markets for the CFC recovered polyurethane foam matrix from the appliances

In mid-1993, the processing equipment was relocated from the East coast to the Southern California market where Phase Two of the national demonstration is being conducted. Refinements to the process and improvements in the processing techniques identified in Phase One are being implemented.

For example, equipment has been developed and manufactured that automates the foam separation process. This technology has replaced the former manual method of removing the insulating foam using hand tools. Entire panels (i.e., sides or tops) are placed on the machine and the steel shell and plastic liner are peeled away from the foam insulation as the panel moves through the equipment. The new equipment has reduced the amount of time needed to separate the foam by 75%.

Discussion

The processing of polyurethane foam on a large-scale, production basis has been demonstrated as being a viable solution to the problems presented by properly disposing of the material. The CFC-11 recovered in the process could help to meet the continued need for the product after its production ceases in 1995. The Edison Electric Institute projects that as early as 1996, demand for CFC-11 in the United States will exceed supply by about 2.7 U.S. tons (2.4 metric tonnes) (EEI 1994).

Currently, the range of refrigerators and freezers which contain polyurethane foam insulation received at the processing centers of one appliance recycling company ranges from 15 - 35% (Cameron 1992). This percentage will gradually approach 100% as the population of older models insulated with other materials are eliminated from the market.

Landfilling of appliances is a diminishing opportunity. Many states have enacted bans to prohibit the entry of appliances into these facilities. The laws have been adopted with the dual purpose of conserving scarce landfill space while reducing potential environmental problems associated with the burial of the appliances. The landfill option also obviates the realization of recycling the various structural components from the units. Appliances have proven to be a consistently reliable source of ferrous and non-ferrous metals for the recycling industry. There exists a great deal of promise with regard to the recycling of plastics from the liners, drawers and shelves as the demand for post consumer engineered plastics continues to grow. A major plastics manufacturer reported in 1992 that the appliance industry's use of engineered thermoplastics is growing at an annual rate of 10 to 15 percent (Simpson 1992). There is also growing interest in the development of applications for the post CFC-11 recovery polyurethane foam material. According to a report in Plastics Engineering, options for newer products being investigated include packaging materials and other fabricated, molded parts and boards for the furniture and acoustical industries (1993). This approach has reached the commercialization stage in Germany where the production of boardstock from processed polyurethane foam has begun to be used in the manufacture of outdoor furniture.

The incineration option also presents some possible environmental drawbacks, despite laboratory research that suggests that polyurethane foam and CFC-11 can be destroyed with minimal damage to the environment. The variables that affect the emissions of full scale, commercial incinerators are more difficult to manage and monitor than those found in a laboratory setting. For example, due to the high BTU content of polyurethane foam, the ratio of the mix of the polyurethane foam to other waste materials is critical. A high percentage of foam could consume the available oxygen and result in an increase of products of incomplete combustion (Hall and Hutchinson 1993). This may be particularly true of older plants in which state-of-the-art monitoring technologies are not employed. Incineration also eliminates the harvesting of CFC-11 from polyurethane foam to meet the expected need for the refrigerant in the absence of its continued production.

The cost of the various options is a necessary component of the evaluation of the differing approaches. The landfill option varies as to tipping fees charged by the facility operator. The fees can range from zero to upwards of $200 per ton depending on the jurisdiction.

Incineration of the foam insulation is usually done in one of two manners; burning the insulation after it has been removed from the appliance cabinet or by sawing the appliance into pieces and introducing the panels into the incinerator. In the latter method, the plastic appliance liner and the polyurethane foam are consumed leaving the ferrous and non ferrous materials to be recovered downstream of the combustion chamber.

Incineration costs also vary widely. One facility in Southern New England offers incineration of foam at $600 per ton. The insulation from an average refrigerator containing 7.3 pounds (3.3 Kg) of foam would cost approximately $2.18 to dispose of in this manner, exclusive of foam separation disassembly costs.

The same facility also accepts panelized appliances for incineration at a tipping fee of $300/per ton. At an average gross weight of 160 pounds per appliance after removal of the compressor, the unit cost is approximately $24. This figure is also exclusive of any processing and disassembly costs.

The cost for the processing of polyurethane foam to capture the CFC-11 in the national demonstration program has declined from initial levels owing largely to improvements in disassembly techniques. These actual per unit costs are proprietary but, net of the disassembly and capital costs for the equipment, are within the parameters of the incineration costs.

Shipping the appliances directly to metals processors for shredding or baling after the removal of the CFC refrigerants usually results in a positive cash flow for the generator represents the value of the ferrous and non-ferrous materials. Although prices for the recycled metals vary regionally and in response to other market factors such as proximity to steel mills, appliance carcasses can produce revenues from $30 to $90 per ton.

Conclusion

The development of a cohesive national policy on the disposal of polyurethane foam presents a variety of environmental concerns and technical challenges. The significant technical and practicable uncertainties with the removal of CFC-11 from polyurethane foam were cited by the United States Environmental Protection Agency in their decision to forego the inclusion of CFC-11 recovery in the Final Rule of Protection of Stratospheric Ozone Policy (1993),

Continued analysis of the variety of foam treatment activities that are underway will provide the necessary documentation leading to the establishment of a national policy on this issue. Significant opportunities for research remain. Notable among the considerations is the extensive monitoring of smokestack emissions at facilities where polyurethane foam is being incinerated. The scope of a study of this type would ideally account for the analysis of a broad spectrum of emissions as well as an assessment of the disposal of waste materials from the process including ash and spent scrubbing mediums. Refinements to the current disassembly and CFC-11 extraction process also merit further study. Additionally, new methods of processing polyurethane foam may emerge. Predominant among them are chemical treatment or pyrolysis techniques that may be developed for commercialization. From the financial perspective, consideration must be given to the relative costs of the various approaches studied.

Electric utilities, environmental advocacy groups, contractors, appliance manufacturers and the recycling community are the primary agents working with federal and state governments to evaluate the effectiveness of the differing approaches and enact the changes necessary to achieve the appropriate balance of environmental and economic interests.

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