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TECHNICAL PROGRESS IN ELIMINATING THE USE OF CHLOROFLUOROCARBONS IN THE POLYURETHANE INDUSTI

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Depletion of the stratospheric ozone layer now ranks near the top among global environmental problems. As a result of the attention focused on this issue, an unprecedented international agreement has been reached which mandates curtailment of the production and use of fully halogenated chlorofluorocarbons (CFCs). That Agreement, the Montreal Protocol on Substances that Deplete the Ozone Layer, was signed in September 1987 and was subsequently ratified by the majority of signatory nations.

The phased reductions in CFC production and consumption required by the Protocol are now well known to most individuals in the industries which use CFCs. Beginning July 1, 1989 CFC production and consumption were frozen at 1986 levels; by mid-1993 and by mid-1998 CFC production and consumption must be reduced by 20 percent and another 30 percent, respectively, for a final reduction of 50 percent from 1986 levels.

The Montreal Protocol accelerated what was already a major industry effort to find suitable alternatives for CFCs. Both CFC producers and end-user industries had been researching substitutes or alternative production and processing technologies to reduce CFC use.

Although much research into substitutes remains to be done, tremendous strides have already been made toward reducing CFC use in polyurethanes and polyisocyanurates. This paper provides an overview of the industry's progress, based largely on information gathered by the UNEP Foam Technical Options Committee and compiled in a document entitled Technical Progress on Protecting the Ozone Layer: Flexible and Rigid Foams Technical Options Report. Other sources for this paper include Volumes I and II of CFCs and the Polyurethane Industry published for SPI by Technomic Publishing Company, and a study for SPI conducted by ChemSystems.

Versatile Material Yields Numerous Beneficial Products

Polyurethanes are among the more versatile plastic materials available and can be found in products ranging from elastomeric roller skate wheels to rigid foam insulation. The basic polyurethane chemistry consists of the reaction between two liquid chemicals, a polyol and an isocyanate. Polyurethanes and polyisocyanurates share this same basic chemistry; in polyurethanes the number of reactive isocyanate groups is approximately equal to the number of reactive hydroxyl groups; polyisocyanurates are characterized by an excess of isocyanate groups which react to form trimer ring structures (substituted isocyanurates).

CFCs are used in varying amounts as a polyurethane foam blowing agent to produce a network of microscopic cells throughout the polymer. CFCs perform two basic functions: they improve end-product physical properties and they facilitate foam manufacturing. The relative importance of the two functions differs with the foam type and its intended application.

Polyurethanes are categorized according to properties of the finished material and typical applications. The two main polyurethane segments that use CFCs are open-celled, flexible foams and closed-cell rigid foams. A third, catch-all, category of polyurethane foams includes packaging and flotation foams, as well as integral skin foams which are used for items such as shoe soles, computer housings, and automotive RIM parts.

CFCs are used for a variety of reasons in the manufacture of rigid, flexible and other foams, requiring different strategies for adapting substitute chemicals and alternative technologies.

Figure 1 illustrates the types and applications of CFC-blown foam plastics.

Patterns of CFC Usage in the Polyurethane Industry

During 1986, the Montreal Protocol's baseline year, global CFC usage for all applications was approximately 1.1 million metric tons. Foam plastics used 25% of the total CFC consumption (267,000 metric tons); 209,000 metric tons were used in polyurethane products. Other foam plastics which use CFCs include EPS, phenolic and polyolefin foams. Globa CFC use in all applications is illustrated in Figures 2, and 3; global usage in foam plasti shown in Figure 4. Figure 5 describes the usage in polyurethanes by geographic area.

Two world regions, North America and Western Europe, accounted for 64 percent, o 133,100 metric tons of CFCs used by the worldwide polyurethane industry (Figure 5). Table 1 categorizes by geographic region and polyurethane material type the amoun CFCs used in polyurethane applications.

In total, rigid foam insulation consumed 132,400 metric tons of CFCs in 1986, or 6 of all CFCs used in polyurethane foam production. Rigid laminate boardstock us metric tons, or about 24 percent of all CFCs used in polyurethane applications. spray, slab and pour segment followed closely, consuming 44,200 metric tons, or percent of all CFCs used in polyurethanes.

Appliance foams used 37,200 metric tons of CFCs in 1986, or roughly 18 percent of tl CFCs used in polyurethanes. North America and Western Europe used more than h: the CFCs consumed for appliance foams.

Worldwide, average annual growth rates for appliance foams are expected to be two three percent. Population growth in Africa, the Middle East and Eastern Europe, alc well as the continued substitution of polyurethane foam insulation for fibrous glass in tion will contribute to this growth. The projected growth rate also takes into consider the expected increase in refrigerator production in the People's Republic of China.

Flexible foams used 59,300 metric tons of CFCs in 1986, or 28 percent of all CFCs us polyurethanes. Slabstock foams used 45,600 metric tons and molded foams consume 13,700 metric tons.

Integral skin and miscellaneous polyurethane foams used 17,700 metric tons, or abou percent of all CFCs used in polyurethanes in 1986.

Figure 6 depicts the global usage of CFCs by polyurethane foam type. Figures 7, 8 ar describe 1986 the North American polyurethane industry's consumption of CFCs by i try segment, by the flexible foam segment, and by the rigid foam segment.

To get a better understanding of the relative usage of CFCs in the polyurethane indu is useful to look at the relative size of the market sectors. In terms of poundage, the American polyurethane market can be described as 54 percent flexible and integral s foams, 28 percent rigid foam, and 18 percent non-foam polyurethanes. Rigid foams c sume about 75 percent of all CFCs used in polyurethanes; flexible and integral skin foams consume about 25 percent.

Rigid Polyurethane and Polyisocyanurate Foams are Important Insulation Products for Construction, Appliance and Transportation Applications

Rigid polyurethane and polyisocyanurate foams fall into three primary categories: laminate boardstock, spray-applied, and poured-in-place.

These foams are the most efficient thermal insulation products widely available commercially. Their thermal efficiency is due largely to the low thermal conductivity of the chlorofluorocarbons (principally CFC-11, but also CFC-12) which are used to form the cellular structure and which remain entrapped in the fine, closed cells of the product.

In general, rigid polyurethane and PIR foams are easy to process and apply to a range of surfaces. Their ease of installation and their low thermal conductivity make rigid polyurethane and polyisocyanurate foams one of the most desirable insulation products Other properties of rigid insulating foam include high compression strength (importa roofing systems), ease of processing, good adhesion to a variety of facing materials, an good fire performance. Each of these properties is affected in some way by the choi blowing agent.

Laminate boardstock is used for commercial roof insulation and for residential she Approximately 60 to 75 percent of the boardstock produced is used in commercial insulation; most of the remainder is used for sheathing. Other applications inclu tion of tanks and solar collectors. Spray-applied foams are used to insulate roofs pipes and tanks; the poured-in-place form is used to insulate doors and major appliances such as refrigerators, freezers, water heaters and supermarket display cabinets. Of all rigi polyurethane foam used in appliances, 90 percent is used in refrigerators and freezers.

Flexible Polyurethane Foam is the Predominant Cushioning Materials for Upholstered Seating

Flexible polyurethane foams appear in two main forms: slabstock and molded. Slabstock i used primarily for furniture cushioning, carpet underlay and mattresses; molded foam is used widely in automotive applications and contract furniture. As open-cell materials, flexible foams do not entrap CFC gas that was used to create the cells in the first place. In thi respect flexible foams are very different from rigid polyurethane foams, in which the CFC blowing agent is trapped within the closed cells and contributes to the thermal performanc of the foam insulation.

CFCs Improve Polyurethane Processing and Products

CFC-11 and CFC-12, which are the chlorofluorocarbons used by the polyurethane industry are nonflammable, noncorrosive, chemically inert, and very low in toxicity, making them ideal for many industrial applications. CFC-11 is most prominently used in the polyurethane industry, though CFC-12 is also used to a limited extent. CFC-11 is used as an auxiliary blowing agent for flexible polyurethane foams.

CFC-11 and CFC-12 have several characteristics that are of tremendous value to polyurethane foam processing and for imparting critical end-product physical properties. In fact, no single blowing agent has been identified to date that can match CFC-11's versatility across the range of polyurethane foams.

In insulating foams, the low thermal conductivity of CFC-11 makes it possible to achieve high insulation efficiency with only thin layers of foam. In appliance applications, CFC-11 facilitates foam adhesion to cabinets and liners, yielding a sandwich structure with high flexural strength. The foam also fills all the voids in the cavity between the wall and the liner, providing good thermal insulation efficiency.

In addition to low thermal conductivity, the blowing agent used for appliance foams must be nonreactive with plastic liners used in refrigerator cabinets. CFC-11 has been the blowing agent of choice because it meets both these criteria.

For slabstock and molded flexible foams, CFCs are used as a "heat sink" to provide foam cooling during the highly exothermic manufacturing process and to reduce foam density Also, CFCs are used to manufacture so-called "supersoft" slabstock foams.

Integral skin foams and miscellaneous polyurethane products use CFCs to improve prod performance, and to ease processing by reducing the viscosity of the polyurethane syste CFCs are essential in the process of creating the "skin" of integral skin foams.

Technical Options for Reducing CFC Use in Rigid Polyurethanes

The polyurethane industry has made significant strides in reducing CFC use. Some ments of the industry are further along in terms of switching from CFCs to altern nologies or substitute chemicals. The rigid foam segment -- the largest CFC- usin of the polyurethane industry -- has more technological barriers to reducing CFC other industry segments.

CFC-11 is the primary blowing agent for rigid polyurethane and polyisocyanurate foams, though some CFC-12 is used for certain formulations to achieve specific processing properties not possible using CFC-11 alone. Ninety to 95 percent of the CFC-11 blown into laminate boardstock during manufacturing is retained within the foam insulation and will remain there until the foam is destroyed.

One substitute for CFC-11 that's being explored is increased use of water in polyurethane and polyisocyanurate foam formulations. The water reacts with isocyanate in the polyurethane system to produce carbon dioxide, which in turn yields a microcellular foam structure. Water is already used to some extent as an auxiliary blowing agent to improve the flowability of some rigid foams. Increased use of water is expected to substitute for some CFC-11, though the amount will be dependent on the type of foam, type of facer and end-use properties, such as combustibility and thermal insulation performance. In polyisocyanurate foams, however, higher water content may result in foams that are too friable, in turn reducing adhesive properties and harming physical properties.

Polyurethane or polyisocyanurate foams protected by permeable facings or used without facings (slabstock and spray-applied foams) exhibit some diffusion of blowing agent gas. Carbon dioxide exhibits a higher gas diffusion rate than CFC-11, making high amounts of carbon dioxide blowing agent in these products potentially infeasible.

For spray-applied, slabstock and poured-in-place foams, CFC-11 provides low thermal conductivity, improved system viscosity, good foam reactivity, flow and adhesion. CFC-11 also acts as a heat sink for the exothermic reaction, which is critical for preventing scorching and splitting in thick section foams.

The amount of water that can be substituted for CFCs varies according to rigid foam typ In the U.S., for laminated boardstock, it's estimated that increased use of water can redu CFC usage by up to 15 percent without deterioration of long-term thermal performance. In Europe, tests have shown that increased water substitution can reduce CFC usage by to 50 percent. Actual percentages will vary by region. The reductions achievable must b viewed in terms of the present formulations - the percent CFC content is a more instruct data point in terms of comparing foam technology being utilized.

Some poured-in-place products protected by impermeable facings may be able to reduce CFC use by up to 50 percent by substituting with water, depending on the region. With permeable facings, or unfaced foams, such as slabstock or spray foams, high water substit tion will accelerate gas diffusion, leading to reduced energy efficiency. In these applications, it's reasonable to believe that between 15 and 20 percent increase in water substitu tion is possible, though even at this level thermal properties of the foam may be reduced

Some progress using fully water-blown systems has been made for district heating pipe foam insulation. Maintaining energy efficiency comes from increasing the thickness o water-blown foam. The resulting foam has better compressive strength than CFC-blo foams and better thermal aging properties. The performance comes at a 20 percen crease in costs.

In general, substituting water for CFC-11 will only be possible to a limited exten will be a main technique used to attain short-term reductions in CFC use. The water that can be substituted is limited by several considerations:

- foam friability;
- dimensional stability;
- thermal insulation performance;
- combustibility performance;
- increased operating and raw material (isocyanates) costs;
  and
- processing difficulties caused by increased foam system viscosity.

Appliance foams will also, in the short-term, increase the use of water to partially replac CFC-11. In appliance manufacturing, liquid chemicals are injected into an appliance cavity, in an automated process, where they react in-situ to form polyurethane foam. Th process requires high fluidity so that the liquid can flow and fill all spaces of the cavity.

The resulting rigid foam has high flexural strength and adheres strongly to the applianc cabinet and liner. This combination contributes to structural strength and permits the u of lightweight, thin gauge steel for the outer case and thin plastic liners (ABS or SB/HI and aluminum paper for the back walls. Alternative appliance insulation products cann contribute the same structural integrity afforded by polyurethane foam. As a result, cab net walls would have to be made with thicker, heavier and costlier materials, which wou increase exterior dimensions or reduce interior volume.

CFC-11 also imparts excellent thermal insulation properties with long-term performanc In addition, because CFC-11 is nonreactive, it does not attack the plastic liners used in refrigerator cabinets.

Because energy requirements and appliance wall thicknesses are different in different pa of the world, the CFC content in appliance foams must be higher in North America and Japan. In North America and Europe the ratio between CFCs and CO_2 in foam cells is 7 percent to 30 percent; in Japan the ratio is 90 percent to 10 percent.

Reducing CFC-11 in appliance foam formulations may increase the initial thermal conductivity of the foam, perhaps by five percent. Consequently, the energy consumption of the appliance unit may increase. Because air diffusion does not readily take place, due to impermeable facing materials such as steel and plastic liners, long-term thermal efficienc may not be drastically affected. However, in the U.S., the initial increase in thermal conductivity may conflict with federally mandated energy efficiency standards.

Other possible difficulties of a high water content include reduced flowability, a critical tor for completely filling the cabinet, and poorer foam friability, dimensional stability cabinet structural stability. Also, the ability to remove exothermic heat from the chem reaction will be impaired.

The extent to which water substitution is permissible depends on the type of isocyan used [toluene diisocyanate (TDI) or diphenylmethane diisocyanate (MDI)], the initi gy efficiency value of the insulation, and the size of the appliance. More isocyana required for foams blown with higher amounts of water, resulting in a possible 10 increase in foam manufacturing costs.

In Western Europe, refrigerator and freezer manufacturers have begun to redu by 50 percent using water as a substitute with minimal harm to energy consump manufacturers have helped their cause by adopting new foam technology tha size, which reduces thermal conductivity. In Japan, new foam technology has already bee adopted, but only a 15 percent reduction in CFC use is feasible without deleterious effect to physical properties and energy efficiency. In North America, a 15-30 percent reductio in CFC use is possible, depending on the isocyanate base used and the initial thermal conductivity of the foam. Foams based on MDI will be able to achieve higher CFC substitution without significantly harming energy efficiency.

Vacuum technology is known to provide excellent insulation efficiency (Thermos bottles are an example of this). Use of vacuum panels in conjunction with 100 % percent water-blown foam is being evaluated as a means of reducing CFC use in appliance insulation. The foam would serve to protect the vacuum panel and to attach the panel to the cabinet and liner. Much refinement of the current technology must be done before such applications can be commercialized.

Technical Options for Reducing CFC Use in Flexible Foam

Several options are available for flexible foam manufacturers to reduce the use of CFCs. Among the alternatives to CFCs being studied for the manufacture of flexible slabstock foam are chemical substitutes, including the "AB Process" and methylene chloride. The "AB Process" uses the formic acid/isocyanate reaction in conjunction with the standard water/isocyanate reaction to effectively double the quantity of gas that's produced and th acts as a blowing agent.

Although "AB Process" foams can be softer than all-water-blown foams, some low density foams still require CFCs, especially to avoid scorch and possible ignition during manufacture. In addition, the "AB Process" requires increased ventilation and safety precautions and significant investment in equipment.

Methylene chloride is another technically and commercially feasible option to replace fr 80 to 100 percent of CFCs used in slabstock production (except in very low density, supe soft foams), though local and environmental safety restrictions may limit the chemical's use. Some investments in ventilating and personal protection equipment would be nece sary to accommodate the use of methylene chloride.

New "soft" polyol technology is being developed to expand the range of grades of polyurethane slabstock foams with reduced use of CFC-11, though these polyols may not effective for producing foams with densities below 1.3 lb./ft^3. Also greater amounts of T must be used, increasing raw material costs. These new formulations have the potential reduce CFC use by up to 50 percent in some slabstock foams.

CFC-11 is used in approximately 10 percent of all molded foam production, typically for soft foams used for seat backs and in low-density grades (1.4 lb./ft^3). Chemical options available to flexible slabstock foam manufacturers, such as the AB process and methylen chloride, are not available for molded foam production. New polyol technology, howeve is being developed that could reduce CFC consumption by 50 percent in soft molded fo grades.

Increased use of water may also be able to reduce CFC consumption by 50 percent density foams, though changes in chemical use could increase operating costs by app mately 5 percent. The U.S. automotive industry has been able to consistently prod density foam seats with increased use of water. By 1991, it's possible that the U.S. tive industry will have eliminated CFC use in the production of flexible molded fo

Technical Options for Reducing CFC Use in Other Polyurethane Foams

Integral skin foams and other foams consist of a number of varied products, such as: rigid integral skin foams for computer cabinets, skis, and tennis rackets; flexible or semi-rigid foams for steering wheels, headrests, shoe soles, etc.; microcellular high-density foams for exterior automotive parts; energy-absorbing foams; floral foams; and rigid flotation foams.

A small amount of CFC-11 is used to manufacture all rigid integral skin foams, principally to ease processing and to produce a "self-skinning" effect during molding. This "skin" is formed by reduced vapor pressure of CFC-11 at the mold surface, which cannot be achieved using water. Use of HCFC-22 may allow some reduction of CFC-11 in the short term. Using HCFC-22 would require increased investment costs for appropriate processin equipment. A combination of water and HCFC-22 substitution may reduce by up to 80 percent for the amount of CFC-11 used in integral skin and other foam molding.

CFC-11 use in flexible (semi-rigid) integral skin foams may be reduced by 15 to 20 percent through water substitution. Hydrocarbon blowing agents, such as isopentane and butane are technically feasible and can replace 100 percent of CFC-11. However, flammability concerns would require extensive modifications of manufacturing plant and equipment, including for increased ventilation. Also, hydrocarbons are photochemically reactive, volatil organic compounds that contribute to ground level ozone pollution. Their use may be curtailed or prohibited.

Methylene chloride may be suitable as a partial replacement for CFC-11 in flexible integra skin foams, but environmental and health effect concerns may curtail or prohibit the chemical's use.

In terms of other foams, microcellular foams require insignificant amounts or no CFCs in their manufacture. Packaging foams already use a significant amount of water and with reformulation, may be able to eliminate all CFC-11 use. Energy absorbing, floral and flot tion foams can use a combination of water, HCFC-22 and other options to eliminate CFC use.

HCFCs: The Long-term Option for Reducing CFC Use in the Polyurethane Industry

Polyurethane foam manufacturers are relying on short-term options to reduce the use of CFCs, but long-term options remain problematic.

For laminated boardstock, HCFC-141b is currently the leading candidate as a CFC substitute. Because it is a more efficient blowing agent, up to 15 percent less HCFC-141b is needed per unit volume of foam compared to CFC-11. Nevertheless, foams tested using HCFC-141b show a 10 percent reduction in thermal performance compared to CFC-11 blown foams. HCFC-22 is under consideration as a replacement for the minor use of CF 12 in laminated board manufacture. Spray-applied, slabstock and poured-in-place foa show similar performance changes as rigid laminated boardstock when HCFCs are substituted for CFCs.

In appliance foam formulations, HCFCs increase thermal conductivity by 5 to 10 pe though refinements in formulations may overcome the loss in energy efficiency. In tion, HCFCs act as a solvent on plastic cabinet liners (HCFC-123 being worse th 141b in this regard). Blending HCFCs 141b and 123 may eliminate potential fla and solvency problems.

New partially halogenated blowing agents, HCFCs, may be commercially available as early as 1992. The HCFCs of potential value to the polyurethane industry, HCFCs-141b and HCFC-123, have much lower ozone depletion potentials than CFCs. However, several issues remain to be resolved before HCFCs can be considered suitable CFC substitutes in the polyurethane foam industry. For example, HCFCs must:

- o must be technically suitable for the intended application
- o show satisfactory long-term toxicity testing results;
- o be proven environmentally acceptable;
- o be cost-effective

Even if toxicity testing demonstrates the safety of HCFCs, questions linger about their environmental impact. Though HCFCs are considerably less harmful to the ozone layer than CFCs, international pressure could result in restrictions similar to those placed on CFCs. In addition, product formulations with HCFCs are largely untested in terms of insulation efficiency and long-term performance, though initial tests indicate that HCFCs will be able to yield a quality insulating product.

Estimated Cutbacks in CFC Use

By incorporating all of the substitute and alternative technologies currently available, the polyurethane industry can significantly reduce its CFC consumption in the near term. For example, by 1993 the flexible molded and slabstock foam segment should be able to reduce CFC consumption by 80 to 100 percent; flexible integral skin foams should reduce consumption of CFCs by 50 percent; and rigid polyurethane packaging should reduce consumption by 80 to 100 percent.

Rigid insulating foam will not achieve as rapid a reduction in CFC use. Until HCFCs are available, the short-term projection is for reductions of 15 to 50 percent. Future reductions will be dependent on the availability of HCFCs, but if they are available in quantity by 1993, it's conceivable that all CFCs can be eliminated from polyurethane foam production by 1995.

Although percent reduction in CFC usage as compared to 1986 levels is a useful tool for evaluating overall progress in protecting the stratospheric ozone layer, it should not be used for the purpose of making product comparisons. For example, a product which claims a 50% percent reduction in CFC content may in fact contain a higher percentage of CFC than a similar product which claims only a 25% reduction. Actual CFC content should be noted.

The Outlook of the Industry

At their meeting in Helsinki in May 1989 the parties to the Montreal Protocol issued a no
binding declaration committing to the elimination of CFCs by the end of this century. A reassessment of the Protocol now underway will be completed in mid-June 1990. Expec
tions are that revisions will be made; the revisions may include adding other ozone-depleting chemicals to the Protocol, and establishing a faster timetable for phasing out
halogenated CFCs.

Anticipating further regulation, and sensitive to both the environmental and econom
aspects of CFC usage, the polyurethane industry is working diligently to eliminate its
pendence on fully halogenated CFCs. The timetable for this achievement cannot be

specified precisely, because the date for commercialization of the alternative blowing agents is still unknown as is the schedule for completion of other technical developments which will eliminate the need for halogenated blowing agents. The general view is that CFC usage by the polyurethane industry will cease within three years following the commercialization of HCFC-123 and HCFC-141b. Industry is currently evaluating both of these chemicals, and various blends of them, in the spectrum of polyurethane products which have traditionally used CFC-11 or CFC-12.

BIBLIOGRAPHY

Technical Progress on Protecting the Ozone Layer: Flexible and Rigid Foams Technical Options Report, UNEP Foam Technical Options Committee, 1989.

CFCs and the Polyurethane Industry: Volume 2: A Compilation of Technical Publications 1988-1989. Edited by Fran W. Lichtenberg. Copyrighted by The Society of the Plastics Industry, Inc. Technomic Publishing Company, 1989. (Includes UNEP Foam Technical Options Report).

CFCs and the Polyurethane Industry: A Compilation of Technical Publications, 1986-1988 Edited by Fran W. Lichtenberg. Copyrighted by The Society of the Plastics Industry, Inc. Technomic Publishing Company, 1988.

The North American Markets for Polyurethane Products - 1988/1989. Final Report for th Polyurethane Division of the Society of the Plastics Industry, Inc. Chem Systems Inc., 198

Figure 1

Types and Major Uses of CFC-Blown Foams

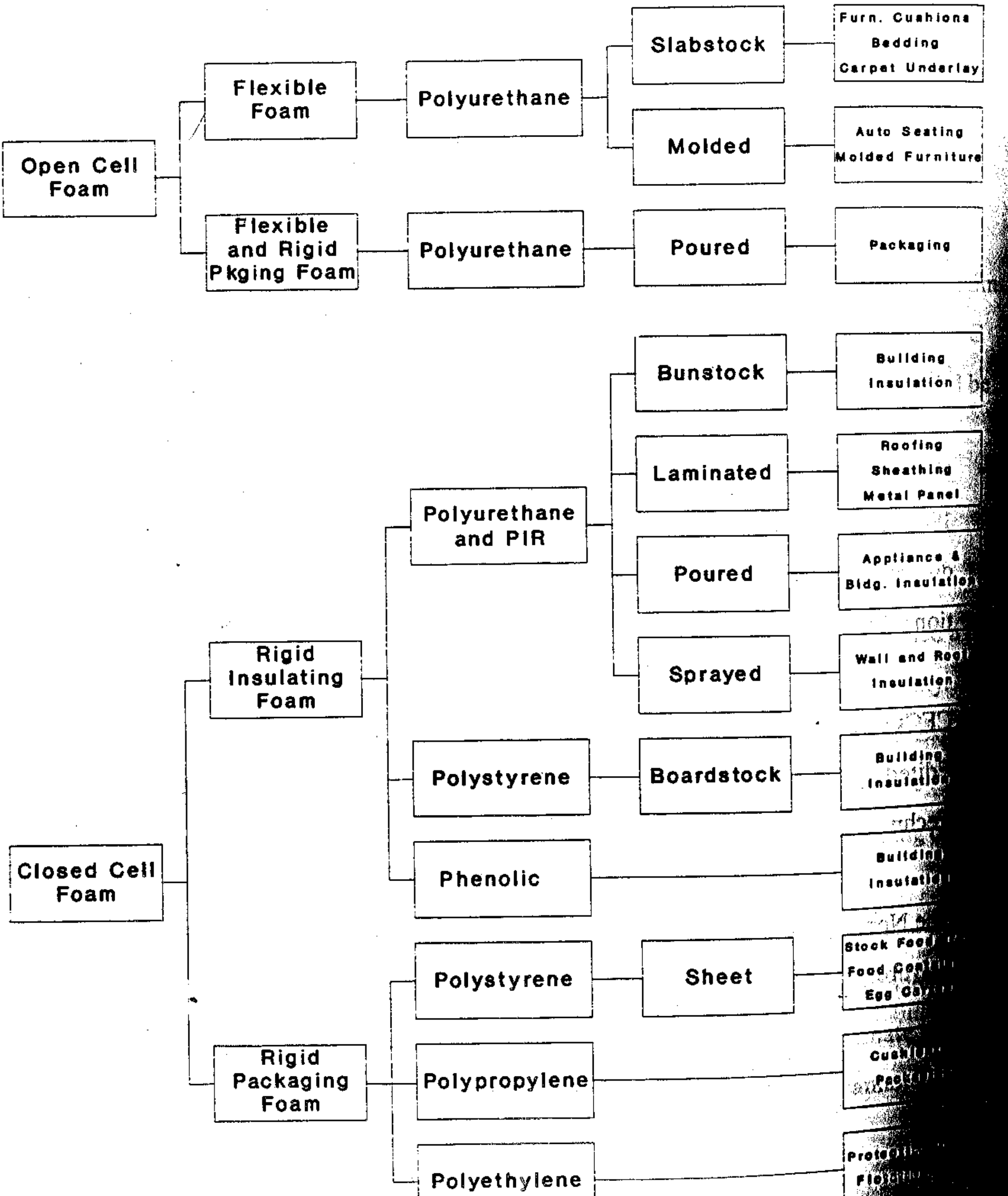


Table 1

Estimated Global and Regional CFC Use by Polyurethane Industry

(in metric tons)

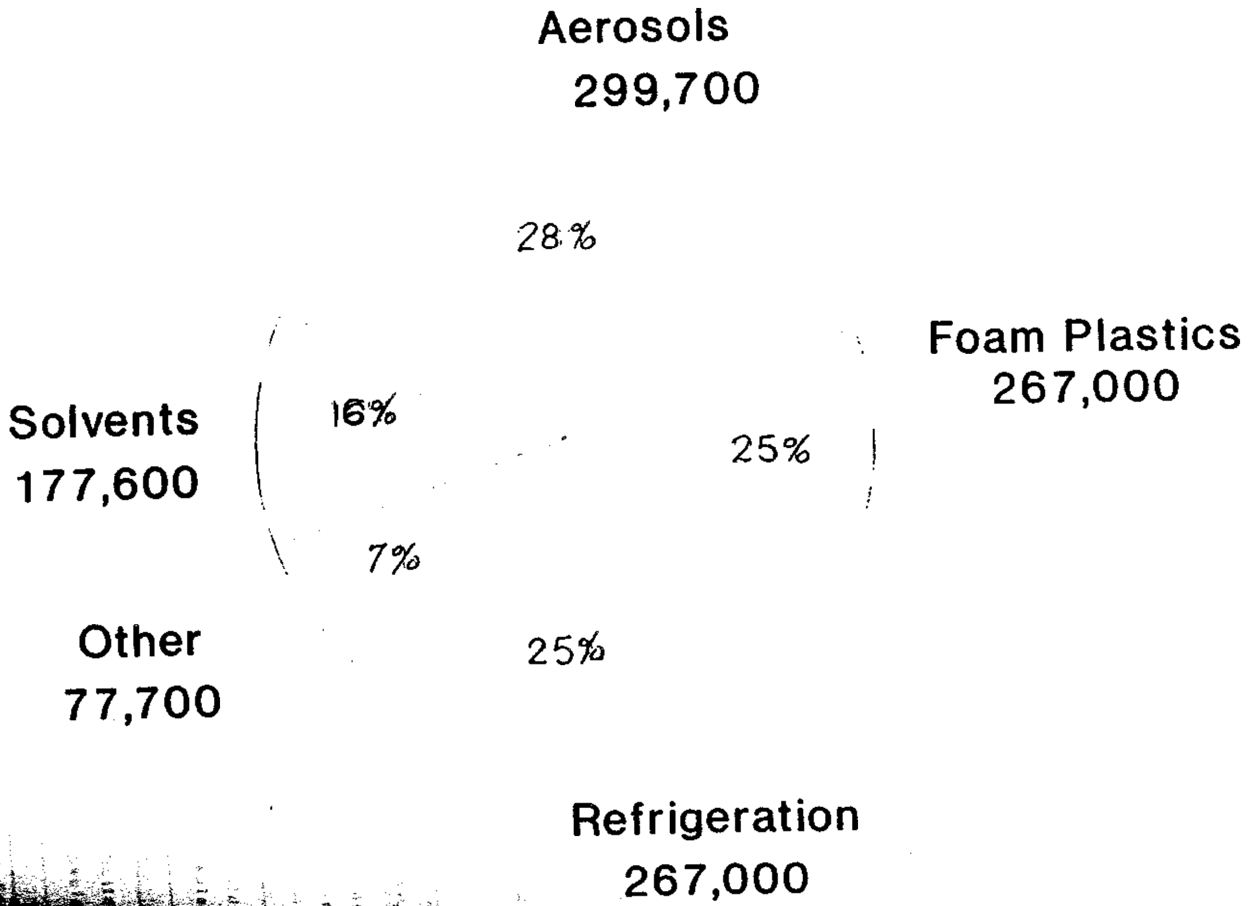
1986

	Global	North America	Western Europe	Eastern Europe	Middle East & Africa	Central & South America	Japan	Rest of Asia Australia & New Zealand
XIBLE FOAMS								
Slabstock	45,600	10,000	10,800	4,400	6,200	5,300	2,000	6,900
Molded	13,700	2,200	6,000	800	300	700	2,400	1,300
FLEXIBLE SUBTOTAL	59,300	12,200	16,800	5,200	6,500	6,000	4,400	8,200
ID FOAMS								
Laminate boardstock	51,000	21,700	17,100	4,000	1,800		2,600	3,800
Appliance	37,200	9,400	9,900	4,300	2,000	2,700	4,700	4,200
Spray-applied slabstock & pour-in-place	44,200	19,000	14,900	1,700	600	900	6,400	700
RIGID SUBTOTAL	132,400	50,100	41,900	10,000	4,400	3,600	13,700	8,700
EGRAL SKIN & ISCELLANEOUS	17,700	4,500	7,600	2,000	500	900	900	1,300
TAL CFC USE IN POLYURETHANES	209,400	66,800	66,300	17,200	11,400	10,500	19,000	18,200

Figure 2

986 Global CFC Use - by Application

(in metric tons)



1986 Global CFC Use - by Region

(in metric tons)

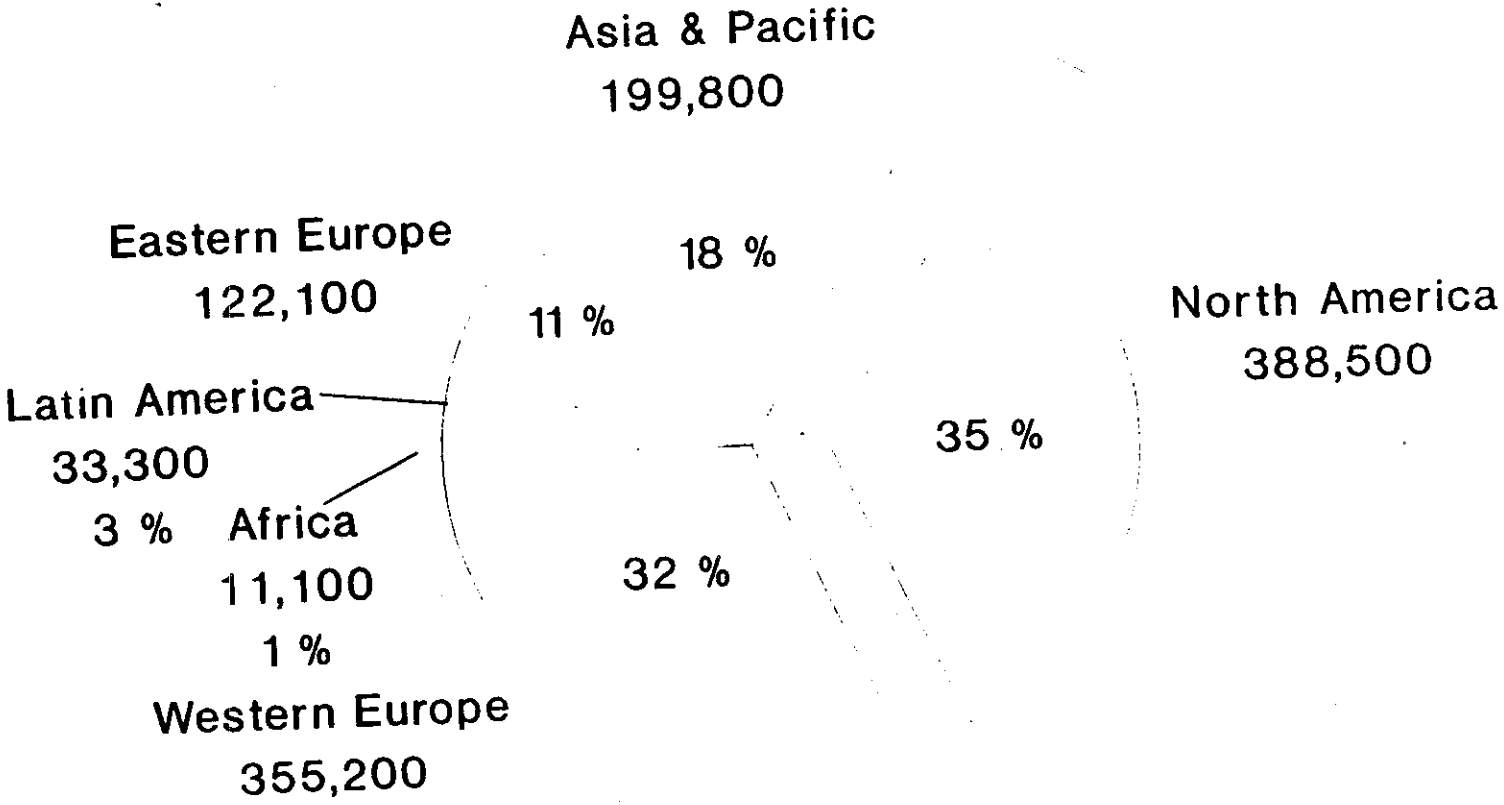
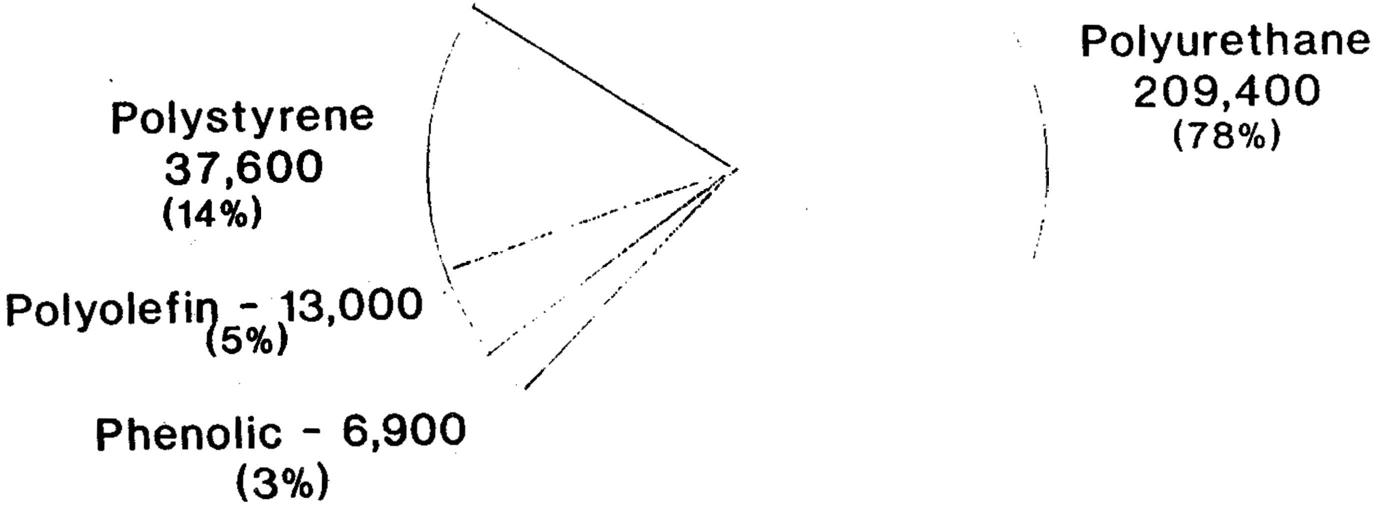


Figure 4

Global CFC Use in Foam Plastics

(in metric tons)



1986 CFC Use in Polyurethanes

(in metric tons)

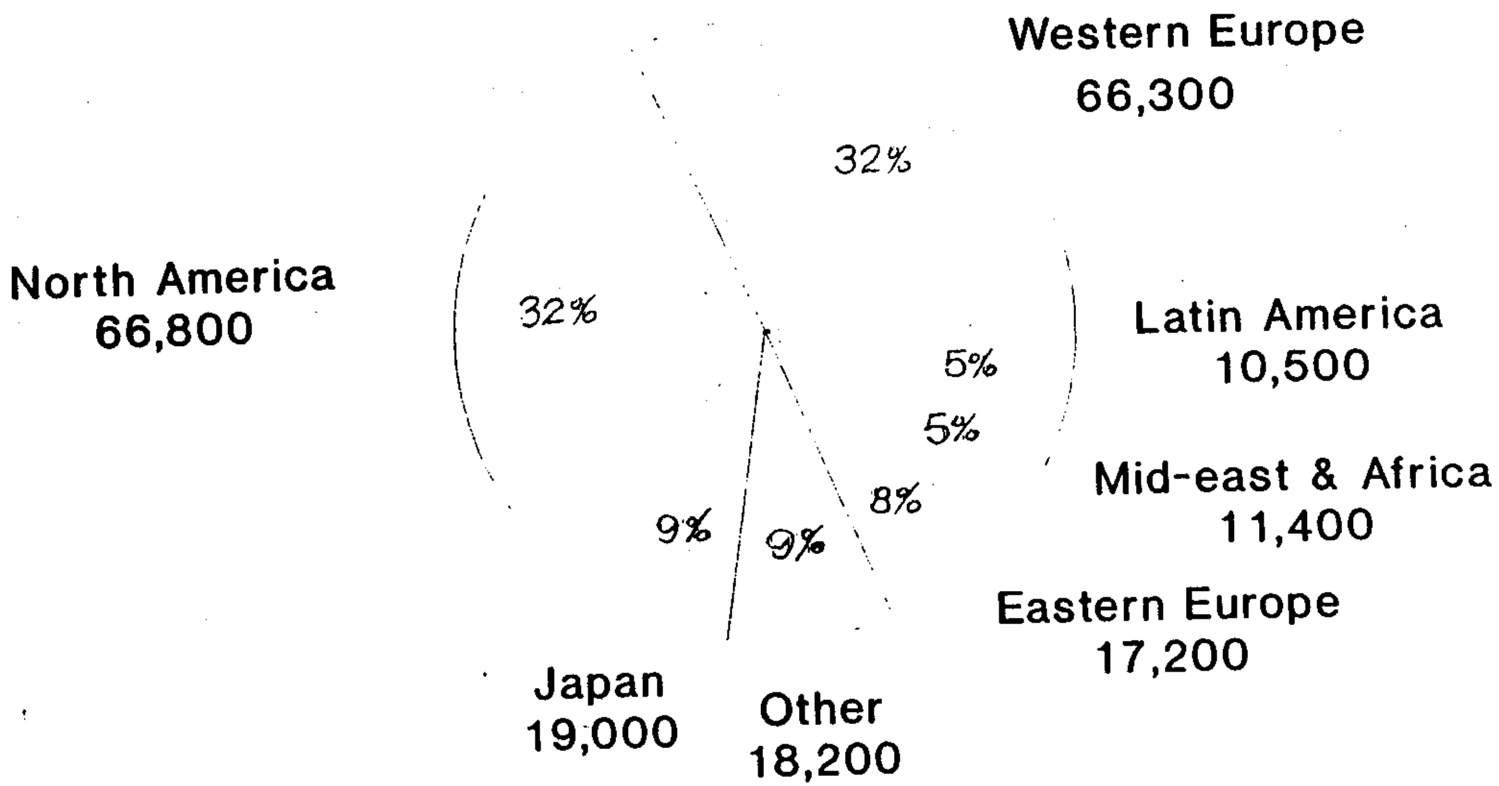
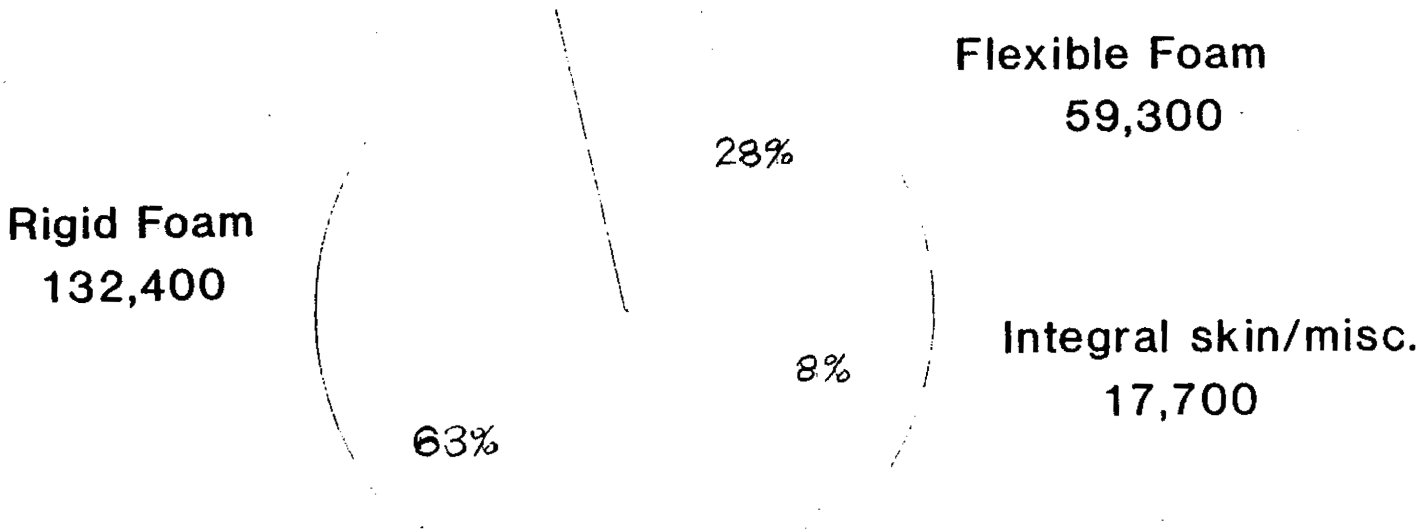


Figure 6

Global Polyurethane Industry
1986 CFC Use by Industry Segment

(in metric tons)



North American Polyurethane Industry 1986 CFC Use by Industry Segment

(in metric tons)

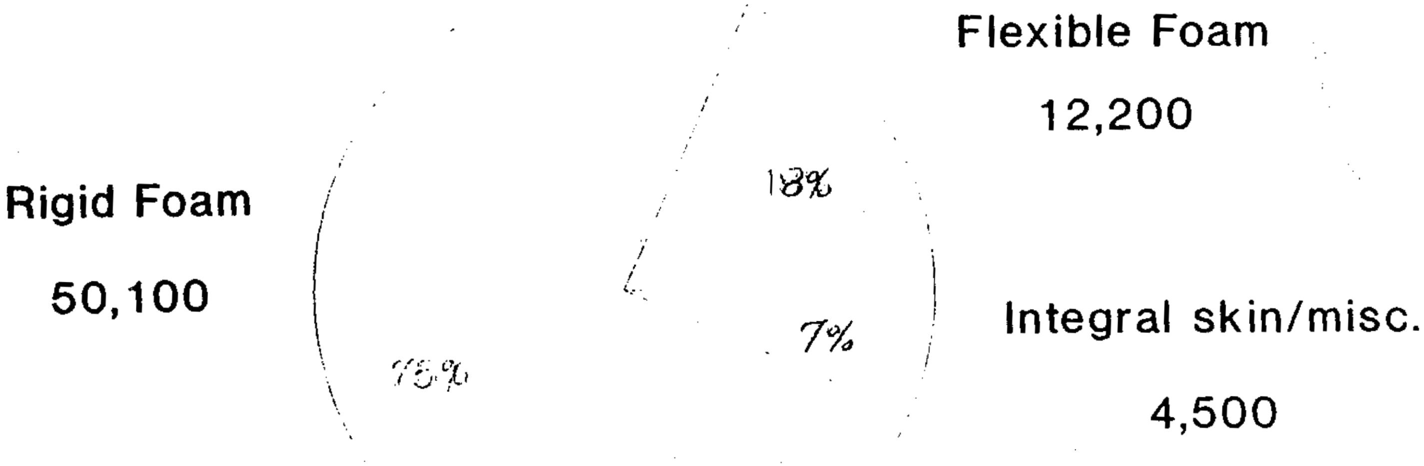
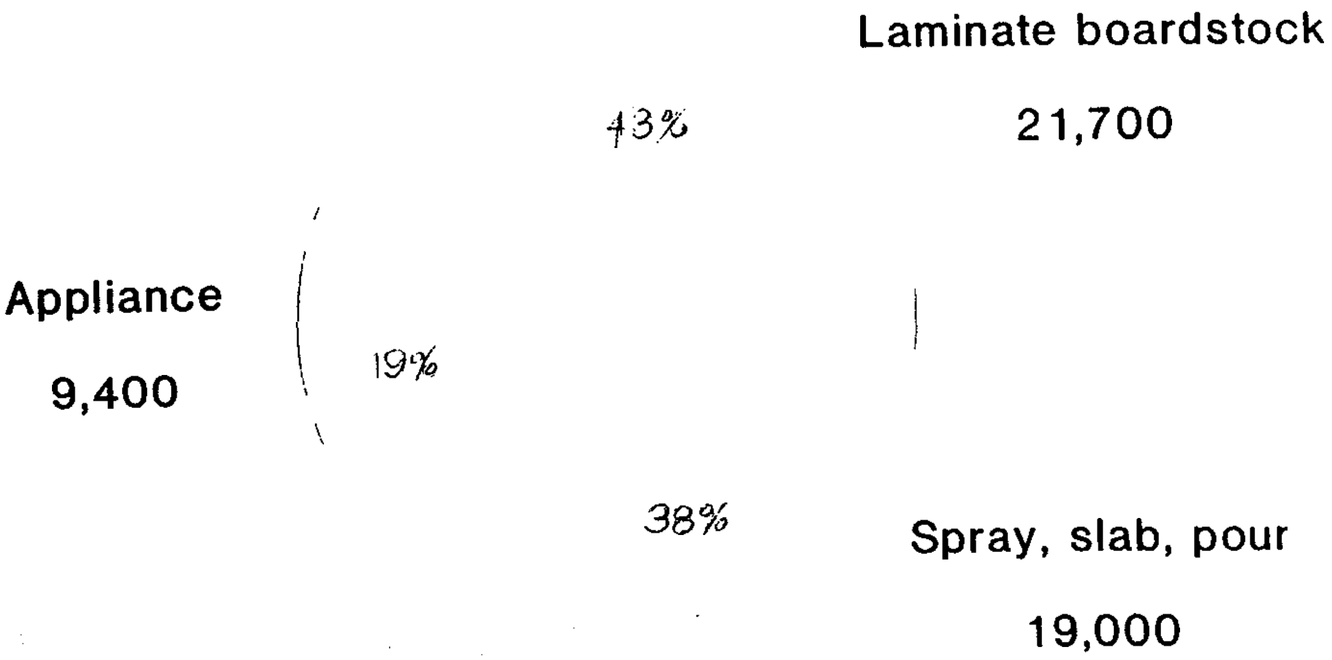


Figure 8

North American Polyurethane Industry 1986 CFC Use in Rigid Foams

(in metric tons)



North American Polyurethane Industry
1986 CFC Use in Flexible Foams

(in metric tons)