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STUDY OF
VO[illegible] ORGANIC COMPOUND EMISSIONS
FROM
CO[illegible] AND COMMERCIAL PRODUCTS

[illegible] Products and Packaging Systems

REPORT TO CONGRESS

VOLATILE ORGANIC COMPOUND EMISSIONS FROM CONSUMER AND COMMERCIAL PRODUCTS

VOLUME 6

AEROSOL PRODUCTS AND PACKAGING SYSTEMS

Emission Standards Division
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The lead engineer for the consumer and commercial products study and report to Congress was Bruce Moore of the Emission Standards Division, Office of Air Quality Planning and Standards. Extensive clerical support was provided by Mary Hinson also of the Emission Standards Division.

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1.0 INTRODUCTION

1.1 THE PROBLEM

1.1.1 Ozone Nonattainment and Small Sources of VOC Emissions

National air quality monitoring data from 1986 through 1988 indicate that there are approximately 100 geographic areas which failed to attain the national ambient air quality standards (NAAQS) for ozone. Ozone is a major component of smog which poses major health and environmental concerns when present in high concentrations at ground level. It is a photochemical oxidant which is formed in the atmosphere through a series of complex chemical reactions between precursor emissions of volatile organic compounds (VOC's) and oxides of nitrogen (NOx) in the presence of sunlight.

While most of the large, stationary sources of VOC emissions are covered by existing regulations, an examination of emissions data completed in 1989 by the Office of Technology Assessment (OTA) indicates that individually small, dispersed sources of VOC's (area sources) contribute significantly to the continuing ozone nonattainment problem. According to the OTA report, *Catching Our Breath - Next Steps for Reducing Urban Ozone*[1], one area source of VOC emissions is the use of a wide range of consumer and commercial products.

1.1.2 VOC's or NOx -- Which Should We Control?

Ground-level (tropospheric) ozone is formed through a series of complex chemical reactions involving VOC's and NOx in the presence of sunlight. Reductions in the amount of ozone formed can be obtained through reducing the concentrations of VOC and/or NOx available for reaction. A recent report, *Rethinking the Ozone Problem in Urban and Regional Air Pollution*[2], published by the National Academy of Science explains that a key factor in reducing ozone formation is the ratio of VOC to NOx in the ambient air. When the VOC to NOx ratio is greater than 10:1, VOC reductions have little effect because of the excess concentration of VOC's available for reaction. In such "NOx-limited" scenarios, NOx controls may be much more effective than VOC controls alone in reducing ozone formation. Conversely, in airsheds which are not NOx-limited, VOC controls can be effective in reducing ozone formation.

Although VOC controls alone may offer little reduction in ozone formation under some conditions, there are many instances in which the VOC to NOx ratio favors VOC controls. The U.S. Environmental Protection Agency (EPA) does not anticipate abandonment of efforts to reduce ozone formation through reduction in VOC emissions, especially in the case of area sources such as consumer and commercial products. However, this new way of thinking could affect future strategies for stationary and mobile sources for which NOx and VOC controls could be tailored to specific conditions.

1.2 CONGRESSIONAL RESPONSE: THE CLEAN AIR ACT OF 1990

1.2.1 Requirements Under §183(e) -- Consumer and Commercial Products

Although control of one small source of VOC emissions may contribute little to overall ambient air quality, VOC reductions obtained through regulation of multiple small sources could have a beneficial additive effect. Section 183(e) of the Clean Air Act (CAA) as amended in 1990 requires the EPA to conduct a study of emissions of VOC's into the ambient air from consumer and commercial products. The objectives of the study are (1) to determine the potential of consumer and commercial product VOC emissions to contribute to ozone levels which violate the NAAQS for ozone; and (2) to establish criteria for regulating consumer and commercial products or classes or categories of products under the authority of §183(e) of the CAA. In establishing criteria for regulating consumer and commercial products, the EPA must take into consideration (1) the uses, benefits, and commercial demand of consumer and commercial products; (2) any health or safety functions served by the products; (3) those consumer and commercial products that emit highly reactive VOC's into the ambient air; (4) those products that are subject to the most cost-effective controls; and (5) the availability of any alternatives to such consumer and commercial products that are of comparable costs, considering health, safety, and environmental impacts. On completion of the study, the EPA must submit a report to Congress that documents the results of the study.

Upon completion of the report, the EPA must list those categories of products which are determined, based on the study, to account for at least 80 percent of the total VOC emissions, on a reactivity-adjusted basis, from consumer and commercial products in areas which violate the NAAQS for ozone. The EPA must divide the list into 4 groups by priority. Pursuant to this requirement, the EPA will publish the prioritized category list in the *Federal Register* following submittal of the report to Congress. Beginning no later than 2 years following publication of the list, the EPA must regulate one group every two years until all 4 groups are regulated.

1.2.2 Scope of Consumer and Commercial Products under §183(e)

According to the definition in §183(e), "the term 'consumer or commercial product' means any substance, product (including paints, coatings, and solvents), or article (including any container or packaging) held by any person, the use, consumption, storage, disposal, destruction, or decomposition of which may result in the release of volatile organic compounds. The term does not include fuels or fuel additives regulated under section 211, or motor vehicles, non-road vehicles, and non-road engines as defined under section 216."

The EPA has determined that the statutory definition of consumer or commercial product is much broader than just the "traditional" consumer products (e.g., personal care products, household cleaning products, household pesticides, etc.). Instead, consumer and commercial products include virtually all VOC-emitting products used in the home, by businesses, by institutions, and in industrial manufacturing operations. Among these products are a wide range of surface coatings, metal cleaning solvents, graphic arts inks, industrial adhesives, agricultural pesticides, asphalt paving materials, and many other products used in industrial manufacturing processes, many of which have been previously regulated by the EPA and/or by the States.

1.2.3 The Report to Congress -- Purpose and Structure

The primary purpose of the study and report to Congress is to educate the EPA and Congress on consumer and commercial products as contributors to ozone nonattainment and to identify opportunities for reduction of VOC emissions from the use of these products. In addition, some information obtained from the EPA studies was used to establish criteria for regulation of consumer and commercial products and utilized during the process of exercising the criteria to develop the regulatory agenda.

In order to prepare the report, the EPA conducted several individual studies. Some of these studies pertain to specific categories of products for which the EPA has little or no existing information; other "generic" studies focus on topics which do not relate to any particular category of products.

Generic Studies

Inventory of VOC Emissions from Consumer and Commercial Products
Fate of Consumer and Commercial Product VOC's in Wastewater
Fate of Consumer and Commercial Product VOC's in Landfills
Aerosol Products and Packaging Systems
Economic Incentive Regulatory Strategies

Product Category Studies

Underarm Antiperspirants and Deodorants
Hair Care Products
Aerosol Spray Paints
Adhesives and Sealants
Household Cleaners
Nonagricultural Pesticides (including Antimicrobials)
Automotive Aftermarket Products
Room Deodorants
Architectural and Industrial Maintenance Coatings

The core elements of each product category report are (1) a *product category description*, which includes the scope of products in the category, typical formulations, key terminology, and other characteristics of the category; (2) an *industry profile* which discusses the history and development of the industry and the types, number, and functions of companies which comprise the industry; (3) a discussion of possible *control measures* or opportunities for reduction of VOC emissions from the category, including reformulation, substitution, labeling, directions for use, etc.; and (4) a limited analysis of *impacts* of possible control measures, including emission reductions, effects on product efficacy, etc. There generally is no information presented on cost-effectiveness of control measures.

1.3 AEROSOL PRODUCTS AND PACKAGING SYSTEMS

1.3.1 Definition of Aerosol Product

The term "aerosol product" is defined by the Chemical Specialties Manufacturers Association (CSMA) as "a sealed container pressurized with liquified or compressed gases so that the product is self-dispensing." The Department of Transportation (DOT) defines an aerosol as "a sealed package containing base product ingredients, in which one or more propellants are dissolved or dispersed, and fitted with a dispensing valve." According to these definitions, products such as trigger sprays or pump action dispensers are not considered aerosol products.

The concept of the aerosol product as a system is emphasized throughout this report. The term "system" has been defined as "a group of interrelated, interacting, or interdependent constituents forming a complex whole."[3] There are 4 primary components that comprise the aerosol system: the product, the propellant, the valve, and the container. The product and propellant collectively are referred to as the formulation. Ideally, the system is designed such that each component operates in concert with the others. Consequently, as in any system of interrelated components, modification of one or more system components must be carried out judiciously in order to preserve the functionality of the system. The individual components of the aerosol packaging system and their interactions are discussed in detail in Section 2.0, Aerosol System Components.

1.3.2 Aerosol Consumer Products as Sources of VOC Emissions

In today's aerosol industry, nearly all aerosol consumer products employ hydrocarbon (HC) propellants. These propellants (primarily propane, normal butane, and isobutane) are VOC's. The HC propellants were substituted for chlorofluorocarbons (CFC's) which were determined to contribute to the depletion of stratospheric ozone. The conversion to HC propellants was initiated by the industry in 1975 and was virtually complete by 1978, when the EPA banned the use of CFC's in most aerosol products. A discussion of this shift in propellants and its effect on the aerosol industry is presented in Section 3.1, Industry History and Development.

The CSMA publishes an annual *Aerosol Pressurized Products Survey* that reports information on aerosol containers filled in the United States. The 1989 CSMA survey reports that approximately 2.9 billion units were filled in the United States in 1989.[2] Table 1-1 presents data from the 1989 survey for several categories and subcategories of products. As the table shows, personal care products comprise the largest category followed by household products, automotive/industrial products, paints and finishes, insect sprays, and others, respectively. Hair sprays alone account for almost 18 percent of the number of all aerosol products filled in the United States. The next highest volume category includes paints, primers, and varnishes.

The total amount of VOC's contained in aerosol products in 1989 was estimated to be about 650,000 tons.[4,5] Table 1-2 presents the various categories of aerosol products and the estimated total amount of VOC's contained in each category.

1.4 REFERENCES

1. U.S. Congress, Office of Technology Assessment, *Catching our Breath: Next Steps for Reducing Urban Ozone*, OTA-O-412, Government Printing Office, Washington, D.C., July 1989.

2. National Research Council, Committee on Tropospheric Ozone Formation and Measurement, *Rethinking the Ozone Problem in Urban and Regional Air Pollution*, Washington, D.C., 1991.

3. *Webster's II -- New Riverside University Dictionary*, Riverside Publishing Company, 1984.

4. Chemical Specialties Manufacturers Association, *Aerosol Pressurized Products Survey - United States 1989*, published 1990.

5. Radian Corporation. *Control Technology Overview Report: Volatile Organic and Chlorofluorocarbon Use in Aerosol Products*. U. S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory. July 1990.

TABLE 1-1

U. S. AEROSOL PRODUCTS FILLED IN 1989 [4]

Major Category	Subcategory	Units Filled		
		Number	Category (%)	Total (%)
Personal Care Products	Hair Sprays	516,193,000	50.9	17.7
	Shaving Creams	232,476,000	22.9	8.0
	Antiperspirants/Deodorants	221,751,000	21.8	7.6
	Medicinals/Pharmaceuticals	30,845,000	3.0	1.1
	Other Hair Products	9,356,000	0.9	0.3
	Other Personal Products	3,050,000	0.3	0.1
	Colognes/Perfumes	1,338,000	0.1	0.0
	Subtotal	1,013,660,000	100.0	34.9
Household Products	Room Deodorants/Disinfectants	220,660,000	32.5	7.6
	Cleaners	173,838,000	25.6	6.0
	Laundry Products	144,850,000	21.3	5.0
	Waxes/Polishes	94,951,000	13.9	3.3
	Other Household Products	45,800,000	6.7	1.6
	Subtotal	680,000,000	100.0	23.4
Automotive/ Industrial	Lubricants	114,932,000	24.2	3.9
	Refrigerants	101,141,000	21.3	3.5
	Carburetor/Choke Cleaner	49,603,000	10.4	1.7
	Engine Starting Fluid	42,726,000	9.0	1.5
	Tire Inflator/Sealant	35,728,000	7.5	1.2
	Cleaners	33,292,000	7.0	1.1
	Brake Cleaner	31,008,000	6.5	1.1
	Engine Degreaser	27,665,000	5.8	1.0
	Other Automotive/Industrial	23,622,000	5.0	0.8
	Spray Undercoating	9,446,000	2.0	0.3
	Windshield/Lock De-icer	5,828,000	1.2	0.2
	Subtotal	475,000,000	100.0	16.3
Paints and Finishes	Paints, Primers, Varnishes	331,436,000	94.7	11.4
	Other Related Products	18,564,000	5 3	0.6
	Subtotal	350,000,000	100.0	12.0
Insect Sprays	Space Insecticides	124,538,000	63.2	4.3
	Residual Insecticides and Repellants	72,462,000	36.8	2.5
	Subtotal	197,000,000	100.0	6.8
Food Products	All Types	175,000,000	100.0	6.0
Animal Products	Veterinarian and Pet Products	8,000,000	100.0	0.3
Miscellaneous	Other Products	12,000,000	100.0	0.4
TOTAL		2,910,660,000		100.0

TABLE 1-2

TOTAL VOC CONTENT OF U. S. AEROSOL PRODUCTS IN 1989[2,3]

Major Category	Subcategory	Volatile Organic Compounds		
		Amount Used (Tons)	Category (%)	Total (%)
Personal Care Products	Hair Sprays	131,085	73.1	20.1
	Shaving Creams	12,070	6.7	1.9
	Antiperspirants/Deodorants	21,265	11.9	3.2
	Medicinals/Pharmaceuticals	845	0.5	0.1
	Other Hair Products	12,635	7.0	1.9
	Other Personal Products	425	0.2	0.0
	Colognes/Perfumes	950	0.6	0.1
	Subtotal	179,275	100.0	27.3
Household Products	Room Deodorants/Disinfectants	40,095	36.2	6.2
	Cleaners	9,125	8.2	1.4
	Laundry Products	31,640	28.6	4.8
	Waxes/Polishes	22,870	20.6	3.5
	Other Household Products	7,050	6.4	1.1
	Subtotal	110,780	100.0	17.0
Automotive/ Industrial	Lubricants	47,895	36.6	7.4
	Refrigerants	0	0.0	0.0
	Carburetor/Choke Cleaner	18,600	14.2	2.8
	Engine Starting Fluid	10,870	8.3	1.7
	Tire Inflator/Sealant	12,280	9.4	1.9
	Cleaners	2,135	1.6	0.3
	Brake Cleaner	17,540	13.4	2.7
	Engine Degreaser	11,740	9.0	1.8
	Other Automotive/Industrial	5,835	4.5	0.9
	Spray Undercoating	1,770	1.4	0.2
	Windshield/Lock De-icer	2,110	1.6	0.3
	Subtotal	130,775	100.0	20.0
Paints and Finishes	Paints, Primers, Varnishes	117,890	94.7	18.1
	Other Related Products	6,605	5.3	1.1
	Subtotal	124,495	100.0	19.2
Insect Sprays	Space Insecticides	34,290	54.8	5.2
	Residual Insecticides and Repellants	28,300	45.2	4.3
	Subtotal	62,590	100.0	9.5
Food Products	All Types	42,415	100.0	6.5
Animal Products	Veterinarian and Pet Products	1,755	100.0	0.2
Miscellaneous	All Other Products	2,350	100.0	0.3
TOTAL		654,435		100.0

SECTION 2.0

AEROSOL SYSTEM COMPONENTS

2.1 INTRODUCTION

The purpose of this section is to describe the components of the aerosol system, to discuss the issues that are considered critical when designing a product, and to explain how these issues can affect VOC emissions. There are 4 primary components that comprise the aerosol system: the product, the propellant, the valve, and the container. Each of these components must be designed so that the product will meet the needs of the consumer. The formulation (product and propellant) is the most important part in that it must perform as designed, while being chemically compatible with the can and valve materials. The propellant must provide enough pressure so that the entire contents of the can will be expelled, yet not so much pressure that the product becomes dangerous or the spray pattern deteriorates. The valve design must achieve the desired spray pattern and delivery rate. The container must be designed for safety, cost effectiveness, and attractiveness.

2.2 FORMULATION

Almost all products that are available as aerosols are also available in other packaging forms such as creams, gels, or liquids. A product is packaged as an aerosol because of benefits to the consumer. To benefit the consumer, the product must be efficacious, i.e., it must perform the function for which it is designed. The product should be convenient, safe, and aesthetically pleasing (i.e., it should have little or no offensive odor, not be messy, and be attractively packaged). The success of the marketed product depends on how well the system meets each of these criteria.

An aerosol formulation is made up of 3 major components: the active ingredients, the solvent, and the propellant. The active ingredients are the materials essential for the specific application for which the aerosol was designed. For example, the active ingredient in a paint is the suspended solids, and the active ingredient in an insecticide is the toxin. Solvents are usually present to act as diluents or to bring the active ingredients into solution with the propellant. Typical solvents include ethanol, odorless mineral spirits, and in some cases, water. The propellant is the third part of an aerosol and is discussed in more detail in Section 2.3, Propellants.

The active ingredients are designed for a specific purpose such as odorizing (perfumes or deodorizers) or killing insects (insecticides). The chemicals that make up the active ingredients are almost as diverse as the number of products that are available. Because of this diversity, it is difficult to make generalizations about formulations. Any detailed discussion on formulations must take into consideration specific applications. Therefore, more information on formulations for specific applications is included in Section 5.0, Characteristics of Selected Aerosol Products.

While solvents perform a number of functions in aerosol products, their primary purpose is to mix the active ingredients with the propellant. Solvents are also added to control the particle size of the spray. For example, if the formulation consists of chemicals that rapidly evaporate after discharge, a solvent may be added to retard the rate of evaporation, resulting in a larger droplet size. In some cases, solvents are also added to reduce the vapor pressure of the propellant system so that the aerosol product will comply with Department of Transportation (DOT) regulations.

To successfully market a product, the manufacturer (marketer) must go through a series of steps. First, the product must be developed. The active ingredients, inactive ingredients, and the propellant system must be selected. The next step is to determine if the formulation is compatible with the packaging system and if it is chemically stable. It is important to ensure that the formulation will not corrode the can or dissolve the valve. It is equally important that the formulation remain stable throughout the lifetime of the product. Next, the marketer must test the product to ensure that it is safe. This entails flammability testing and toxicological studies. Once it is determined that the product is safe, the product must be tested for performance in the field to ensure that the product performs as expected in the hands of the consumer. The next step is consumer testing, in order to determine whether the product is likely to be accepted by the consumer. The marketer is then ready to initiate the purchase of equipment or the negotiation of contracts to produce the product, etc.

Concurrently with the last 3 phases, the marketer usually obtains the necessary governmental approval. For example, insecticides, insect repellents, disinfectants, disinfectant cleaners, fungicidal sprays, and herbicides are regulated by the EPA under the Federal Insecticide and Fungicide and Rodenticide Act (FIFRA). The regulations require all products subject to the Act to be registered with the EPA before interstate shipment can occur. The regulations also contain labeling requirements for the products that are affected.

The Food and Drug Administration (FDA) regulates foods, drugs, cosmetics, and medical devices. The FDA must approve all ingredients in food products. Food additives, including propellants, must be on the FDA's "Generally Recognized as Safe" list. The FDA must also approve all drugs. An extensive new drug approval (NDA) process is required of each new pharmaceutical product. Although non-prescription, or "over-the-counter" (OTC), drugs do not require such pre-market approval, they must meet the criteria of an existing drug monograph. Any drug product that deviates from an existing drug monograph is subject to the more extensive NDA process. Personal care products that affect bodily functions (e.g., antiperspirants, sunscreens, eye drops, etc.) are regulated by the FDA as drugs. Although the FDA does not require pre-market approval of cosmetics, it has authority to regulate cosmetic products. It can ban or restrict ingredients for safety reasons, mandate warning labels, inspect manufacturing facilities, issue regulatory letters, seize illegal products, and engage in nationwide recalls.[1]

In general, it takes 2 to 5 years to get an aerosol product to the market. This time frame depends on the degree of product development, the extent of the required testing, regulatory requirements, and production needs. Figure 2-1 shows the critical path for the development, approval, and marketing of an aerosol insecticide. In this case, the Federal registration would take approximately 5 years.

2.3 PROPELLANTS

An aerosol propellant is defined as "a fluid capable of exerting a pressure when held in a sealed container at room temperature."[2] There are 3 major classes of propellants: fluorocarbons, hydrocarbons (HC's), and compressed gases. The fluorocarbons can be further divided into chlorofluorocarbons (CFC's), hydrochlorofluorocarbons (HCFC's), and hydrofluorocarbons (HFC's). The VOC's include HC's (propane, normal butane, and isobutane) and dimethyl ether. The non-VOC compressed gases that are typically used as aerosol propellants are carbon dioxide (CO_2), nitrous oxide (N_2O), nitrogen (N_2), and compressed air.

The first significant aerosol product was an insecticide produced in 1943 for use by U. S. combat troops. This product and subsequent aerosol products used CFC's as propellants primarily because they are nontoxic and nonflammable. The HC propellants did not enter the market until about 1954. Studies conducted in the 1970's implicated the CFC propellants as contributing to the depletion of stratospheric ozone. Therefore, in 1975, the aerosol industry began substituting HC's and compressed gases in those aerosol products being manufactured that used CFC's. In 1975, approximately 50 percent of all aerosols were filled with HC propellants. This conversion was costly to the aerosol industry because many existing plants were not designed to handle flammable propellants. By 1978, when CFC's were banned by the EPA for use in most aerosol products, the conversion from CFC's to HC's was virtually complete.[3]

A propellant functions by exerting pressure inside the container and forcing the product through the dip tube and into the rest of the valve assembly. When the valve is opened, the product is forced out of the container by this pressure. Liquified gas propellants (e.g., fluorocarbons or HC's) are used because they will maintain a relatively

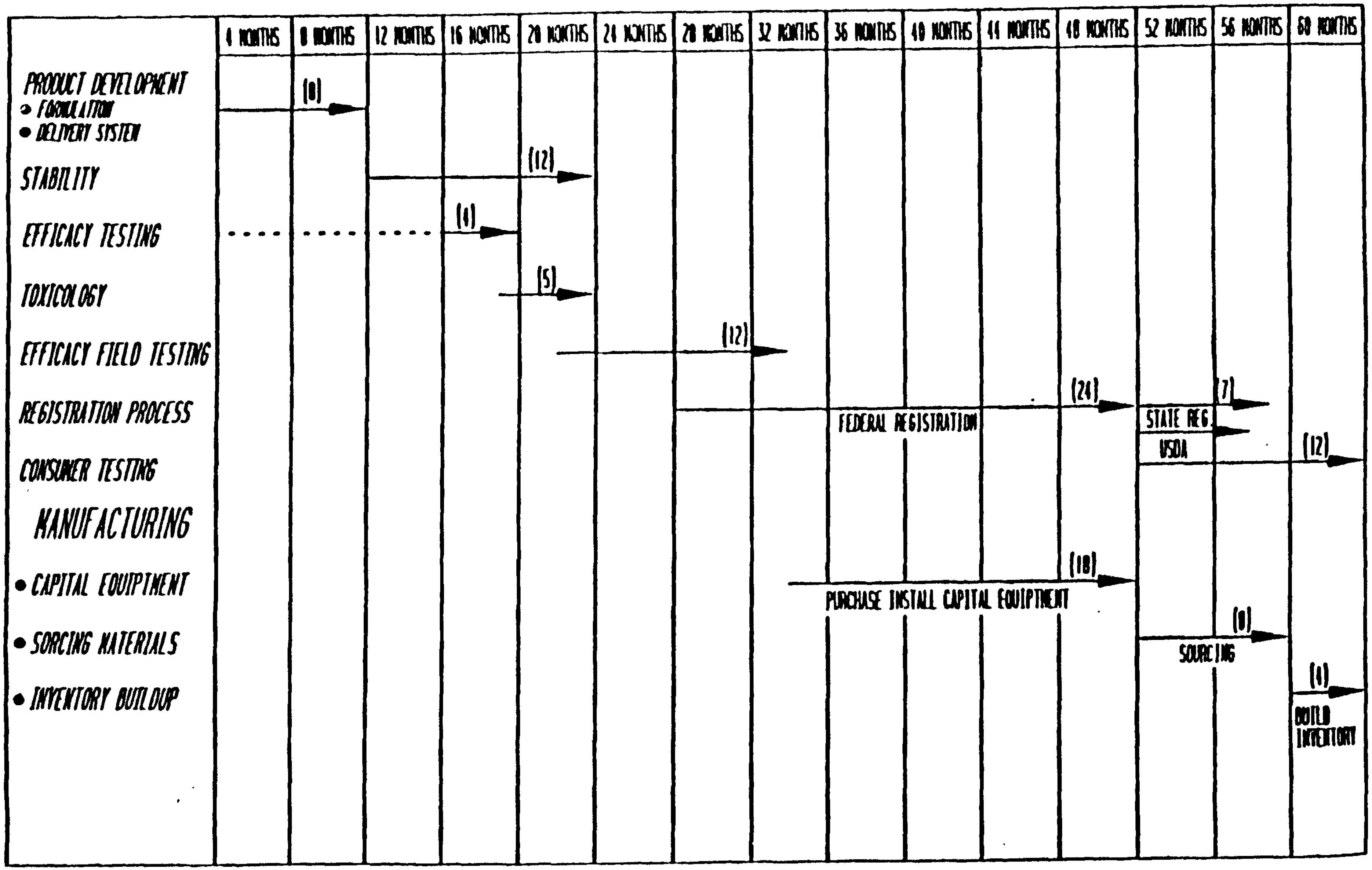

Figure 2-1 Typical Critical Path For Development of an Aerosol Insecticide[16]

constant pressure as the contents of the can are expended. A constant pressure is maintained because the liquid propellant is constantly vaporizing into the head space of the container. As the liquid level of the container drops, more liquid-phase propellant vaporizes until equilibrium is established. The liquid serves as a reservoir to maintain the total pressure as the product level drops. This mechanism is contrasted with the compressed gases that lose pressure as the head space inside the container increases. Consequently, when a compressed gas is used, the container must be initially "over-charged" so that there will be sufficient pressure to expel the entire contents.

The physical properties that affect how a propellant functions in a specific application are the propellant's vapor pressure, solubility, and viscosity. The vapor pressure determines how much pressure is exerted on the liquid inside the container which, in turn, will affect the spray characteristics of the product. The solubility affects the manner in which the product must be used by the consumer. If the propellant is not soluble in the formulation, it is a two-phase formulation, and the container must be shaken in order to mix the propellant and product. If the propellant is soluble in the product, then it is a single-phase formulation, and no agitation is necessary. This is important because some products, such as wall dispenser air fresheners, cannot be shaken. Therefore, they must be single-phase formulations. The solvent properties of the propellant in relation to the valve components, such as gaskets and dip tubes, can also be important. If the propellant dissolves the valve components, the container may leak or the valve may not function correctly. Furthermore, the propellants must be pure. Impurities can result in problems such as inoperable valves or container corrosion. The propellant must be chemically stable in the formulation so that the propellant and product or solvent do not react to form undesirable compounds. The spray characteristics are affected by the viscosity. A high viscosity formulation may be discharged as a stream and not a spray. The propellant also influences whether the product is discharged as a foam, stream, or spray.

In addition to the propellant's physical properties, the formulator must consider its flammability, toxicity, odor, and cost. If the propellant is flammable, precautions must be taken during storage and the filling process to minimize the possibility of explosion. If the propellant is toxic, specific procedures must be implemented to protect employees, and the propellant is unsuitable for some applications such as food or personal care products. If the propellant has an undesirable odor, the consumer is less likely to use the product. If the propellant is very expensive, the cost of the product may affect consumer acceptance. When selecting a propellant for a product, the marketer must be aware of the ramifications of each of these issues.

The following sections discuss the characteristics of the 3 major classes of propellants and their respective advantages and disadvantages. For each specific application, these characteristics must be considered before a decision can be made to use a specific propellant.

2.3.1 Hydrocarbon Aerosol Propellants

Propane, n-butane, and isobutane are the principal VOC propellants used in today's aerosols. An additional VOC propellant, dimethyl ether (DME), is gaining more acceptance in the aerosol consumer product market. Table 2-1 presents some of the physical properties of these VOC propellants.[4]

The HC propellants are used because they have several very attractive properties. They are nontoxic, noncarcinogenic, noncorrosive, abundant, and cost effective (currently $.19 per pound, plus freight). These liquified gas propellants provide a consistent pressure over the life of the product, and they can be blended to achieve a wide range of vapor pressures. They are easy to transport, store, and handle. The major disadvantages are that they are flammable and that they are photochemically reactive in the atmosphere (i.e, they contribute to the formation of tropospheric ozone).

Isobutane is the most prevalent of the HC propellants. It has a vapor pressure between that of n-butane and propane. A disadvantage is that it is the most

TABLE 2-1

PHYSICAL PROPERTIES OF HC PROPELLANTS[4]

Property	Propane	Isobutane	n-Butane	Dimethyl Ether
Formula	C_3H_8	C_4H_{10}	C_4H_{10}	CH_3-O-CH_3
Molecular Weight	44.1	58.1	48.1	46.1
Vapor Pressure (psig at 70°F)	108	31.1	16.9	63.0
Freezing Point (°F at 1 atm)	-305.9	-255.3	-216.9	-217.3
Boiling Point (°F at 1 atm)	-43.7	10.9	31.1	-12.7
Solubility in Water (wt % at 70°F)	0.000	0.008	0.008	34.17
Flammability in Air (Vol %)	2.2 - 9.5	1.8 - 8.4	1.9 - 8.5	3.4 - 18
Ozone Depletion Potential	0	0	0	0
Greenhouse Potential (relative to CFC-12 at 1.0)	0	0	0	Insignificant
Photochemical Reactivity* (g O_3/g VOC)	0.23	0.57	0.42	Pending

* As of December 1991, the EPA had not determined that a suitable relative reactivity scale was available.

photochemically reactive of the HC propellants. Isobutane is typically used in products such as antiperspirants, window cleaners, starches, and hair sprays.

Propane is used whenever a propellant is needed with a pressure greater than that of isobutane (31 psig at 70°F). With a vapor pressure of 108 psig at 70°F, it provides the highest pressure of the HC propellants. At 130°F, propane has a vapor pressure of about 255 psig and, when used alone as a pure propellant, does not satisfy the DOT requirements for normal can pressure. Therefore, it is usually employed in a blend rather than as the sole propellant. Propellant blends are further discussed below. Products that generally use propane as a propellant include heavy oils, greases, and undercoatings, because these products are very viscous and require higher pressures for product delivery.

The third HC propellant, n-butane, is rarely used alone because it has such a low vapor pressure (17 psig at 70°F). It is used primarily in a blend with propane so that the resulting propellant will have an acceptable vapor pressure.

Other HC's that have been used as propellants include ethane, n-pentane, and isopentane. The pentanes are not usually employed as propellants because they develop no positive gauge pressure at room temperatures. Their normal boiling points range from 82 to 97°F.[5] Ethane, on the other hand, is a gaseous vapor under typical aerosol temperatures and pressures. It could be more correctly classified as a compressed gas. Because of ethane's very high pressure (543 psig at 70°F), it has no significant use in the aerosol industry.[3]

Although not a true hydrocarbon, dimethyl ether (DME) is also used as a HC propellant. Its major advantage is that it is soluble in water (see Table 2-1). Accordingly, it is the only liquified gas propellant that can be combined with a product containing a significant amount of water to yield a single-phase formulation. By using DME, formulators may be able to reformulate some products to reduce their total VOC content. Its major disadvantage is that it is more expensive ($0.38 per pound, plus freight) than the true HC propellants. Examples of products that can be propelled by DME are colognes, hair sprays, room deodorizers, insecticides, and waterborne coatings. Blends of HC and DME can be used for hair sprays, household cleaners, and adhesives.

To achieve desirable spray characteristics, the formulator may require a propellant that has a pressure different from the vapor pressures of any of the pure compounds. This can be achieved by blending two propellants. The most common mixture is a propane/isobutane blend. For example, a mixture of 41.9 percent (by weight) propane and 58.1 percent isobutane results in a propellant with a pressure of 70 psig at 70°F. A significant problem associated with a HC blend is that the more volatile component of the mixture vaporizes into the headspace more quickly than the lower volatility component. As the product is expelled (and the higher volatility component is expended more rapidly than the lower volatility component), the lower volatility component accounts for an increasing percentage of the liquid propellant mixture. Consequently, the total pressure of the mixture decreases with product usage. This problem is exacerbated with the use of vapor tap valves because the higher volatility component is lost not only to the headspace but through the valve as well.

To be able to distinguish among the different mixtures, the industry has established a convention for identifying HC propellants and blends. The name begins with an "A" (indicating aerosol grade) and is followed by a number which indicates the pressure of the propellant in psig at 70°F. For example, A-70 is a mixture of 41.9 percent propane and 58.1 percent isobutane and has a total pressure of 70 psig at 70°F. Although Phillips Petroleum Company copyrighted the "A" designations for blends during the 1950's, today this terminology is used generically by the industry. The HC blends account for almost half of the HC propellant market.[2] The most common blends are A-70 and A-46, which are propane and isobutane mixtures. Table 2-2 shows the most common HC propellant blends and their market shares.[3]

In conclusion, HC propellants are used in aerosol products because they have the properties that allow the manufacturer to achieve a wide variety of results. They can be

TABLE 2-2

TYPICAL HC PROPELLANT PRESSURES AND MARKET SHARES[3]

Propellant	Blend (mol %)	Pressure (psig @ 70°F)	Market Share (%)
Isobutane (A-31)	100	31	5-10
Propane/Isobutane (A-46)	19/81	46	5-10
Propane/Isobutane/ n-Butane (PIN-46)	27/29/44	46	*
DME (A-63)	100	63	2-3
Propane/Isobutane (A-70)	50/50	70	5-10
Propane/Isobutane/ n-Butane (PIN-70)	55/18/27	70	*
Propane (A-108)	100	108	10-15

* PIN-46 and PIN-70 together account for approximately 2/3 of the market

used alone or as blends to provide specific pressures. They can be used with foods and personal care products because they are nontoxic and odorless. With a price range from $0.19 to $0.38 per pound, plus freight, they are very cost effective. When a water soluble propellant is desired, DME can be used. In general, the HC propellants are the most versatile propellants and enable the marketer to deliver the most efficacious and cost-effective products. Their primary disadvantage is that they are VOC's and contribute, to some degree, to formation of tropospheric ozone.

2.3.2 Non-VOC Compressed Gases

Compressed gases (e.g., CO_2, N_2O, N_2, and air) are used as propellants for some aerosol products. One company is experimenting with using hydrogen as a compressed gas. These gases are not VOC's and are not considered photochemically reactive. It may appear advantageous, with respect to air quality concerns, to replace HC propellants with non-VOC compressed gas propellants. However, in a typical direct replacement formula, the compressed gas is present in small amounts (2 to 4 percent), and the remainder of the formula must include additional VOC's which may have a higher ozone formation potential than the original HC propellant.[3] This is because the HC propellant is an integral part of the product formulation and generally functions both as a propellant and a solvent. Consequently, removal of the HC propellant must be accompanied by addition of a solvent.

Compressed gases are defined as "high-pressure propellants that must be injected into the aerosol container in gaseous form instead of as a liquid under pressure."[2] A compressed gas differs from a liquid HC propellant in that the vapor pressure of the HC propellant remains constant (at a given temperature) as long as there is liquid propellant in the container. When a compressed gas is used, the can pressure decreases as the contents of the can are expelled. As the volume of head space in the can becomes larger, the pressure decreases. Since the pressure decreases as the product is used, the filler must "over-charge" the can to ensure that the system will provide sufficient pressure to expel the entire contents.

Although compressed gases cost substantially less than HC propellants ($0.03 to $0.10 per pound versus $0.19 to $0.38 per pound, plus freight), their use results in no cost advantage over HC propellants. In most cases, replacing the HC propellant with a less costly compressed gas would not reduce total product cost. For example, in a formula which uses a 3 percent CO_2 fill to replace a 25 percent HC propellant fill, the remaining 22 percent volume must be replaced with a solvent to achieve desired spray characteristics. The cost of the solvent would be greater than that of the HC propellant.[3]

Several concerns must be addressed when considering switching from a HC propellant to a compressed gas. Some concerns are related to the pressure characteristics of compressed gas propellants, while other problems arise because of the properties of the compressed gases themselves.

One concern is directly related to product performance. As the product is expended and the internal pressure decreases, the spray pattern can deteriorate. This may be a significant issue because many aerosols are marketed by their spray pattern characteristics. For example, wasp and hornet spray products must be capable of delivering a stream of insecticide at a range of 16 to 20 feet. If a compressed gas were to be used, the pressure may not be consistent enough to provide the required stream of insecticide over the life of the product. To overcome this problem, the can would have to be pressurized enough to be able to deliver the product at these distances when nearly empty; however, with this degree of over-charge, the higher pressure would cause the stream from a full can to break up and extend to only 6 or 7 feet.

Another problem is that compressed gases are not compatible with all products because of their varying solubility. Both CO_2 and N_2O are soluble in water. Water and CO_2 can react to form carbonic acid which will severely corrode a metal container. This kind of problem makes the use of compressed gases unsuitable for water-based formulations such as paints, hard surface cleaners, and other products.

Another limitation of compressed gases is that, because the can must be initially more highly pressurized than when using a HC propellant, a thicker-walled and more expensive can must be used to satisfy DOT requirements. This increased container cost results in a less cost-effective product.

Another disadvantage of compressed gases is that aerosol products propelled by compressed gases generally cannot be used in an inverted position. Actuation of the valve with the can inverted so that the end of the dip tube is in the head space would result in the compressed gas escaping, leaving no propellant to expel the remaining contents of the can. This would severely affect the performance of products such as insect repellants, carpet cleaners, and hard surface cleaners which are discharged routinely in an inverted position. Although valves do exist that will allow for inverted operation, they are substantially more complicated and more expensive than the conventional valves now in general use.

It is apparent that manufacturers cannot switch to compressed gas propellants for all applications. Each category of consumer products must be evaluated individually to determine whether compressed gas technology would be suitable for specific products. Currently, only 7 to 8 percent of the aerosol market uses compressed gases.[6] This percentage could only be increased to 12 to 18 percent with existing technology.

2.3.3 Fluorocarbons

Fluorocarbons, specifically CFC's, have been used as aerosol propellants for many years. These chemicals are nontoxic and nonflammable, which makes them attractive for use in aerosol consumer products. However, the use of these compounds in most aerosol propellant applications was banned in the United States in 1978 because of their potential to deplete the stratospheric ozone layer. The "Montreal Protocol on Substances that Deplete the Ozone Layer," a protocol to the "Vienna Convention for the Protection of the Ozone Layer," has been ratified by 65 countries and calls for a reduction in the production and consumption of CFC's. The Clean Air Act Amendments of 1990 (CAAA) require a phaseout of most CFC production by the year 2000.

Since CFC's are being phased out of production, HCFC's are being used as substitutes in some cases. Currently, the HCFC's in use are HCFC-22 and HCFC-142b. Three other HCFC's, HCFC-123, HCFC-124, and HCFC-1416 are under development. Because these compounds still contain chlorine, the principal culprit in destroying ozone, the Montreal Protocol limits their production to 1986 production levels. Furthermore, the CAAA will prohibit the use of HCFC's in virtually all applications beginning in 2015, with a complete phaseout of HCFC production by 2030. Therefore, for all practical purposes, CFC's and HCFC's are not viable long-term alternatives to HC propellants.

Another class of fluorocarbons, the HCFC's, can be used as propellants for aerosol consumer products. These compounds contain no chlorine; therefore, they have no potential for stratospheric ozone depletion. Currently, the only HFC commercially available is HFC-152a. Two additional HFC's that are being developed are HFC-143a and HFC-125.[7] Table 2-3 presents the properties of the HCFC's and the HFC that are currently available.[7,8] The primary disadvantage of HCFC's and HFC's is that their cost is as much as 20 times that of HC propellants.

2.3.4 Propellant Blends

While HC propellants (Section 2.3.1) are mixed to meet specific pressure requirements, other propellant blends have been formulated to maximize the desirable characteristics and minimize the drawbacks of particular propellants. For example, a blend of a flammable propellant with a nonflammable propellant may result in a nonflammable blend. Or, a blend of a costly propellant having the required physical properties can be mixed with a less costly propellant resulting in a more cost-effective formulation.

TABLE 2-3

PHYSICAL PROPERTIES OF FLUOROCARBONS[7,8]

	HCFC-22	HCFC-142b	HFC-152a
Formula	$CHClF_2$	CH_3CClF_2	CH_3CHF_2
Molecular Weight	86.5	100.5	66.1
Vapor Pressure (psig @ 70°F)	121	29	62
Solubility in Water (wt % @ 70°F)	30	0.5	1.7
Boiling Point (°F @ 1 atm)	-41.1	15.1	-11.2
Freezing Point (°F @ 1 atm)	-256	-204	-179
Flammability Limits in Air (vol %)	nonflammable	6.3 - 14.8	3.9 - 16.9
Ozone Depletion Potential	0.05	0.06	0.0
Greenhouse Potential (relative to CFC-12 at 1.0)	0.10	0.02	0.01
Photochemical Reactivity*	0.0	0.0	0.0

* As of December 1991, the EPA had <u>not</u> determined that a suitable relative reactivity scale was available.

Propellant blends can be divided into two classes: azeotropic and nonazeotropic. Nonazeotropic blends are usually less desirable because their properties change as the propellant is dispensed, in contrast to pure propellants or azeotropic propellant blends. For example, when a binary (two-component) nonazeotropic blend is discharged, the more volatile component is depleted first, and the pressure decreases with product usage. Ultimately, this fractionation process continues until eventually the remaining propellant consists largely of the less volatile component. This may be a problem if the propellant blend is designed to be nonflammable but becomes flammable when the can is almost empty and only the lower-pressure (and flammable) propellant remains. About 20 percent of aerosol products use a valve system with a vapor tap. A vapor tap is a small hole in the dispensing valve in the vapor space of the aerosol container. This tap allows vapor to be discharged with the product to give added aerosol dispersion. The use of vapor tap valves with nonazeotropic blends may cause problems in some cases and the pressure drop may be more severe.

Despite the potential problems, various formulations using nonazeotropic propellant/solvent blends have been used. These blends are listed below.

- HCFC-22/HCFC-142b (40/60) -- This blend is especially suited for aerosols in glass bottles because of the moderate pressure of the mixture (37 psig at 70^{o}F). The other advantages of the blend are that it is soluble with ethanol, it has a faint odor that does not interfere with fragrances, and it has a high solvent power. This blend would provide reduced flammability compared to propellants such as isobutane or DME. As formulated, the 22/142b blend is nonflammable, but once 70 percent of the blend is discharged as vapor, the remaining blend is flammable.[9]

- HCFC-22/HC -- Mixtures of HFC-22 and HC's could possibly provide a less flammable alternative to HC blends.[10,11] The high vapor pressure of HCFC-22 results in a relatively rapid fractionation of the nonazeotropic blend.

- DME/HC -- This blend is less expensive but marginally more flammable than the DME/HFC-152a blend.[10,12]

- HFC-152a/HC -- This blend provides unique foam properties (improved cell structure) in products such as hair mousses.[10] In addition, its low flammability characteristics have been valuable in indoor insect foggers.

- HFC-22/Methyl Chloroform -- This nonflammable system is used with the newer insecticides and insect repellents.[10]

- DME/Water -- New technology has been developed for water-based insecticides.[10] This low-cost nonazeotrope could be used for other water-based formulations.

- CFC-12/113/114/HC -- This blend has been used in tire inflators.[10]

There are several azeotropic propellant blends reported that avoid potential problems with fractionation and changing composition. These propellant blends offer the possibility of tailoring the properties of solvency, pressure, and flammability. Azeotropic propellants can utilize vapor tap valves that allow inverted use and improve droplet breakup.

- HFC-152a/DME (30/70) -- This blend is flammable. It has a wide range of applications due to its range of solubility in water.[13]

- HCFC-22/DME -- Nonflammable and flammable blends exist. The blend must have 12 percent or less DME to be nonflammable.

- HCFC-22/Propane (68/32) -- This is a flammable blend and a high-boiling point azeotrope (higher vapor pressure than HCFC-22 alone).[9]

- CFC-12/DME -- The 90/10 blend is nonflammable and is used in foam insulation and caulking.[10,14]

- CFC-12/HFC-152a (known as "R500") (73.8/26.2) -- This blend is nonflammable and has a relatively high vapor pressure.[15]

- HFC-152a/Isobutane (75/25) -- This blend is flammable and has a vapor pressure of 72 psig at 70°F.[15]

2.3.5 Summary of Propellant Selection Considerations

Any change in the propellant used for a specific product must be carefully considered. The pressure of the propellant must be matched to the desired spray characteristics. The flammability of the propellant must be considered. The role of the propellant in the formulation must be matched with the attributes of the propellant, and water solubility must be considered. With all these variables, it is critical that the effects of any changes be understood so that the final product will be safe and marketable.

2.4 AEROSOL VALVE ASSEMBLY

This section describes the various valve components and the general types of valves. Most aerosol valve assemblies consist of 7 components: actuator, mounting cup, stem, stem gasket, spring, body (or housing), and dip tube. Figures 2-2 and 2-3 are diagrams of a vertical action valve. In general, the valve opens when a downward force is applied to the actuator, and it closes when the force is released. There are several different kinds of valves: vertical valves, tilt valves, female valves, "total release" valve systems and other special application valves. Valves must be designed to perform specific functions. Many aerosol products must deliver a fine spray. For these products the valve must be designed to break the liquid up into small particles. Products that are to be sprayed on a surface, whether it be a hard surface (paint) or the body (underarm deodorant), must have a valve that optimizes transfer efficiency. Some other types of valves include metering valves (dose inhalants), inverted use valves (compressed gases) and total release valve systems (indoor foggers), female valves (paints), and tilt valves (starches). In addition to the different valve types, there are over 300 varieties of valve bodies, a wide variety of stem gasket materials, 6 different sizes of valve springs, 5 variations of dip tubes, 2 materials for valve cups, and several types of valve gaskets. Each combination is designed to fulfill a set of specific functions.

2.4.1 Vertical Action Valve

With a vertical action valve, the product is dispensed when the consumer pushes down on the actuator which, in turn, presses down on the valve stem (see Figure 2-3). The stem gasket covers the hole in the narrow portion of the valve stem. Figure 2-2 shows the hole in the valve stem. The outside edge of the stem gasket is trapped between the body (housing) and the mounting cup (see Figure 2-3). When the stem is forced down, the inside edge of the stem gasket is bent, and the hole in the stem is opened to the product reservoir in the body. The product is then free to flow into the stem through the actuator and out of the can.

2.4.1.1 *Actuator*

The actuator is designed to operate the valve and regulate the spray rate, spray pattern, and particle size. Some actuators provide a direct flow path for the product. Other actuators have a mechanical breakup (MBU) system, consisting of swirl chambers and bends in the flow path, to mechanically enhance the breakup provided by the propellant. Some products, such as starches and other high-water-content products, could not be marketed as aerosols without an MBU to break up the solid stream of liquid.[17] Various MBU's are available, and by selecting the correct MBU, the manufacturer or marketer can choose the desired spray characteristics for the specific product.

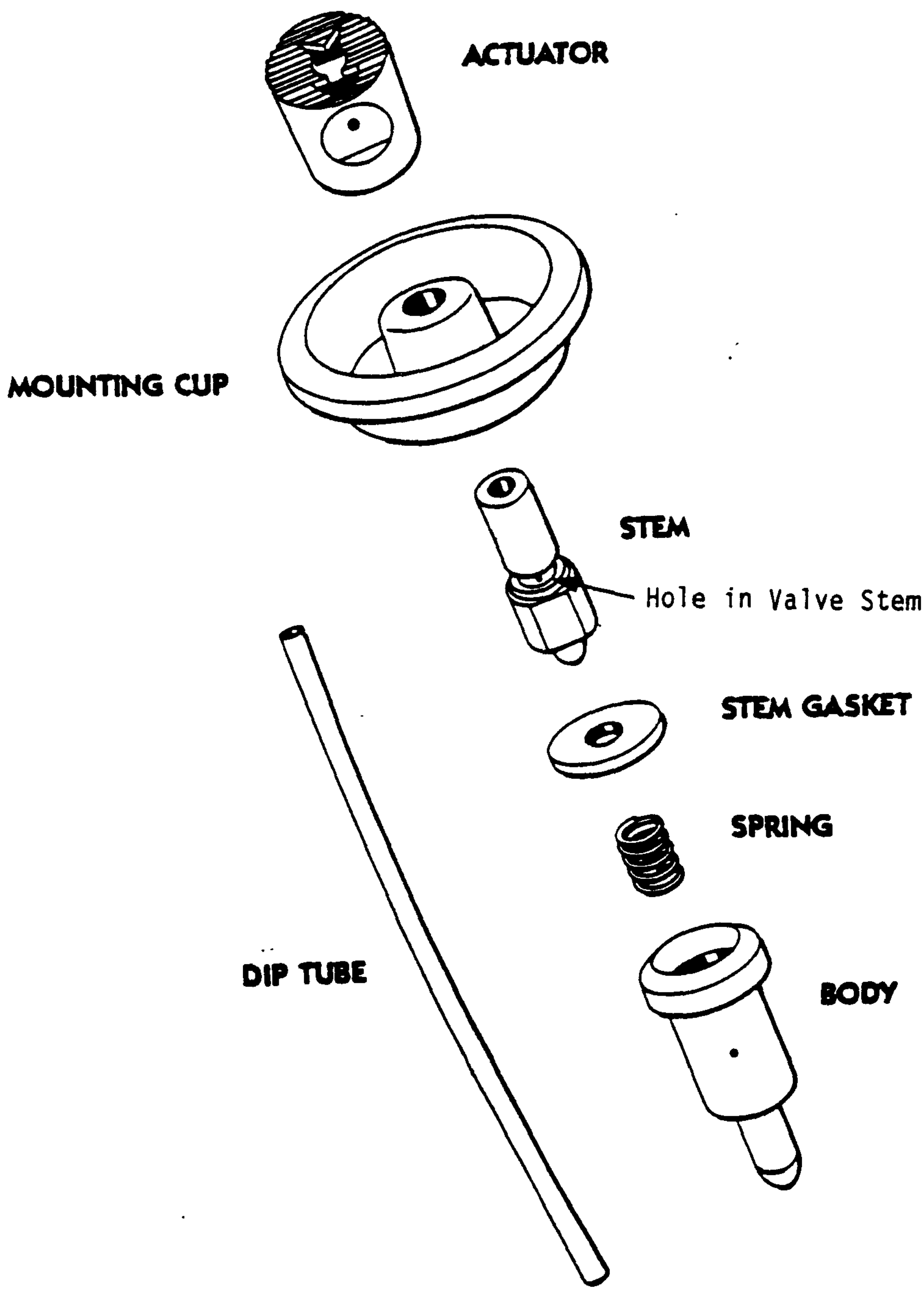

Figure 2-2 Components of the Precision Vertical Valve

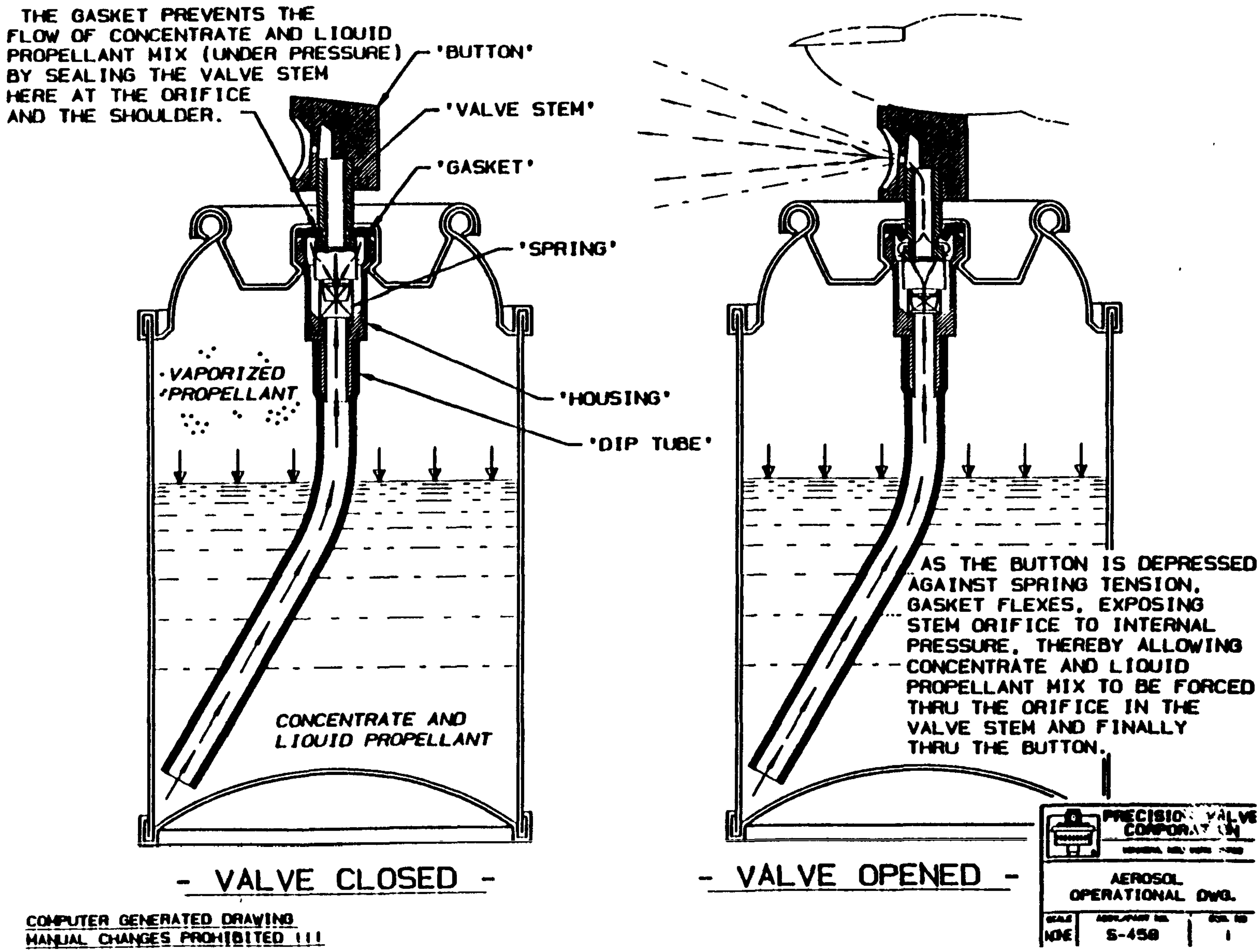

Figure 2-3 Operation of the Precision Vertical Valve

2.4.1.2 *Mounting Cup*

The outside edge of the stem gasket is clamped between the mounting cup and the valve body, keeping the stem gasket in one place. The mounting cup also serves as the hermetic seal to the 1-inch hole in the aerosol can. Mounting cups are available in conical and flat cup shapes (see Figure 2-4). The conical profile is used to elevate the actuator to allow a wide-angle spray to clear the edge of the mounting cup and to increase the strength of the mounting cup. The underside of the mounting cup may be lined to protect the metal from the product.

2.4.1.3 *Valve Stem*

The valve stem serves as the product flow regulator. The product passes through the orifice in the neck of the valve stem, through the large opening at the top of the stem, and then finally into the actuator. The orifice size can range from 0.01 to 0.05 inches. Smaller orifices are prone to plugging. Larger orifices weaken the valve stem, and the risk of breaking the stem increases. Stems are also marketed in different lengths so that the height of the actuator above the mounting cup can be regulated.

2.4.1.4 *Stem Gasket*

The stem gasket is designed to fit around the neck of the stem and seal the stem orifice so that the product is contained while the actuator is not depressed. The stem gasket is made of a flexible material so that, when the actuator is depressed, the gasket is bent and the orifice is exposed to the product. The manufacturer or marketer has to make sure that the material of the stem gasket is compatible with the product formulation. If the gasket deteriorates or swells, the product may leak out of the container.

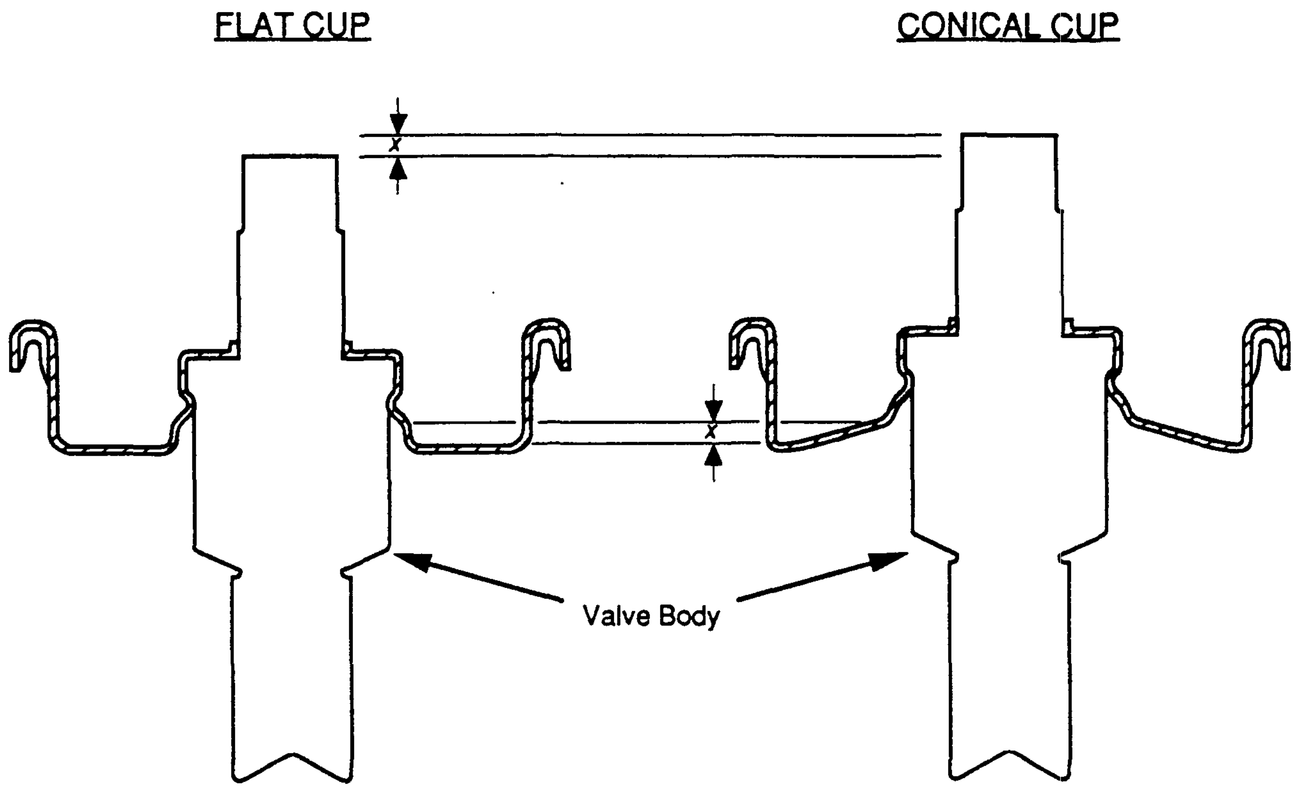

Figure 2-4 Cross Section of Typical Flat Cup and Conical Cup Valves

2.4.1.5 *Valve Body*

The primary purpose of the valve body, or housing, is to provide an enclosure for the spring to force the stem up against the stem gasket when the actuator is released. The bottom portion of the body has an extension that fits into the dip tube. Product flows from the dip tube into the reservoir, then is forced through the stem orifice when the actuator is depressed. Some valve bodies have a vapor tap, a hole that is exposed to the head space in the can (see Figure 2-2), to allow propellant vapor into the liquid stream to produce greater breakup and a lower delivery rate.

2.4.1.6 *Dip Tube*

The dip tube serves to transfer the product to the valve body and to act as a flow metering device. The larger the diameter of the dip tube, the more product is delivered to the valve body. Other factors affecting dip tube selection include can size, curvature, and tube material.

2.4.2 Tilt Valves

Tilt valves (Figure 2-5) differ from the vertical valve in that the consumer applies a lateral force to bend the stem gasket so that the orifice is opened and the product can flow. The force required to activate the flow of the product is generally less than the force needed to activate the vertical valve assembly. This type of valve is desirable where misdirection of the spray could be a problem. The spray will go in the direction that the valve is pushed. The main problem with this type of valve is that the gasket has more contact with the product than with a vertical valve; therefore, the gasket material must be compatible with the product formulation so that the gasket does not swell or deteriorate.

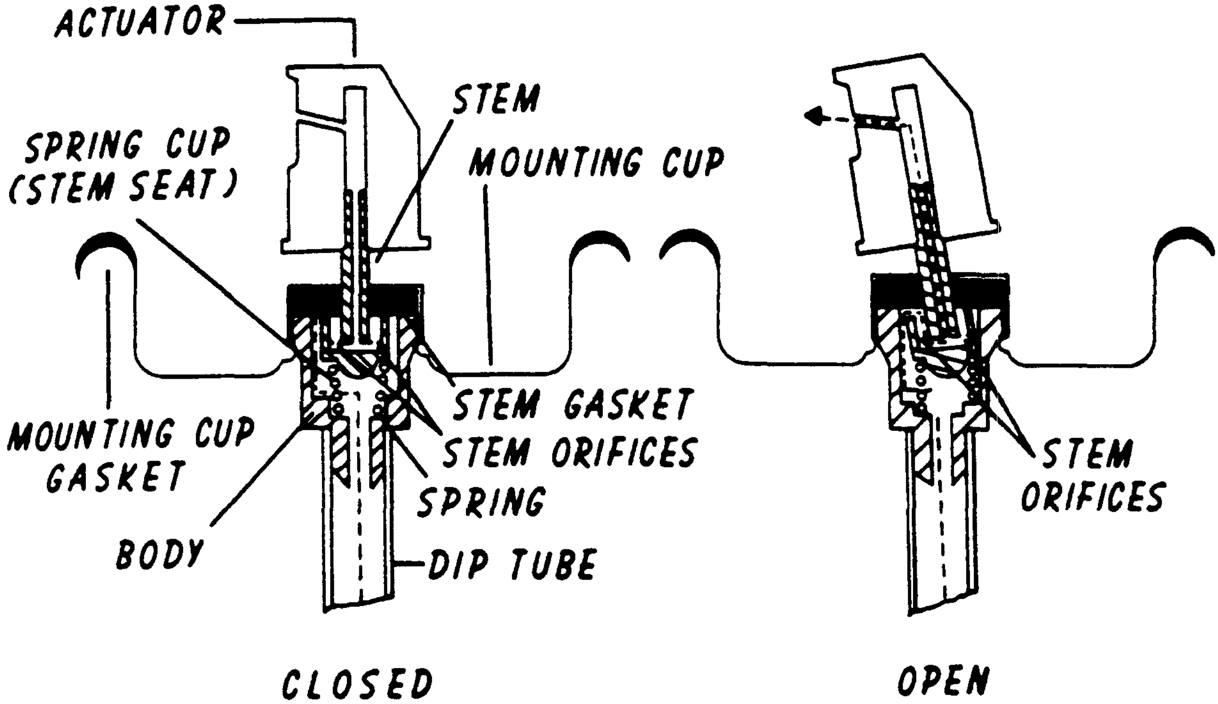

Figure 2-5 Cross Section of a Typical Tilt Valve

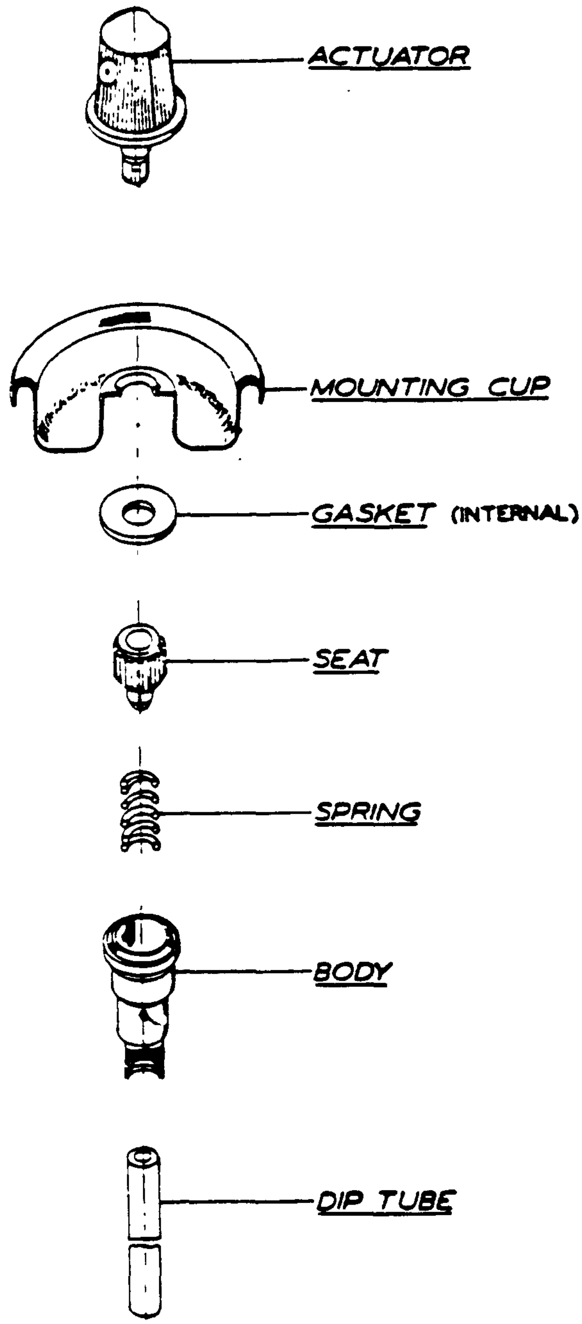

Figure 2-6 Typical Female Valve

2.4.3 Female Valves

Female valves (Figure 2-6) differ from the typical male valve in that the valve stem is part of the actuator. The actuator stem is inserted into the mounting cup hole. To activate the valve, the actuator is depressed vertically as in a normal male vertical valve. The primary use of the female valve is for products that will dry out or clog the orifice in the valve stem. The valve stem of a female valve is an integral part of the actuator and can be removed for cleaning. This is especially useful for aerosol paints and other coatings.

2.4.4 Total Release Valve Systems

A total release valve system is designed to stay open until the entire contents of the can are released. The actuator is fitted with a locking device that ensures that all of the product is expelled. The principal application for this type of valve is for insect foggers.

2.4.5 Summary of Valve Selection Considerations

Many different variables must be considered when deciding which valve is best suited for a specific application. The formulation must be tested to determine if it is compatible with the stem gasket, dip tube, valve body, and mounting cup. The manufacturer must also know what specific spray characteristics are desired so that a choice of MBU, orifice size, and dip tube diameter can be made. If the product is prone to clogging, a female valve may be the best choice for the product. There are hundreds of different permutations of valve components, and the marketer and manufacturer must select a combination that will ensure that the specific product performs optimally.

2.5 AEROSOL CONTAINERS

The container is a critical component of an aerosol consumer product because it must withstand the pressure of the product formulation and propellant without bursting or leaking. It is also the portion of the product that the consumer sees when making a decision to buy a particular product. Therefore, it must be attractive and cost effective. Aerosol product marketers must consider each of these aspects of can design in order to choose a can that will be best suited to a specific application.

2.5.1 Regulatory Concerns

The DOT is responsible for regulating the transportation of hazardous materials. Almost all aerosol products are classified as materials presenting a limited hazard during transport due to their form, quantity, or packaging. The Code of Federal Regulations, Title 49, Part 173.306 (49 CFR Part 173.306) governs the shipment of most aerosol products. These regulations dictate the type of packaging that can be used (transported) based on the pressure of the product.

The pressure rating for metal cans is based partly on the thickness of the ends of the can because these are the pieces most likely to fail. The 3 principal types of metal aerosol cans are "nonspecification" (2N), 2P, and 2Q. Table 2-4 presents the DOT requirements for metal thickness, pressure resistance without burst, and product pressure for each of these containers. The last column gives the maximum product pressure (at 130°F) allowed by DOT for each type of can. This upper limit is well below the minimum burst pressure. Each successive can type, 2N, 2P, and 2Q, respectively, can withstand higher product pressures before a failure occurs.

If the product has a pressure greater than 180 psig, the regulation allows for the use of a "specification 39" metal container. It does not have specific pressure or burst limitations. Instead, it is designed using a stress formula to determine the safe internal pressure for a given wall thickness. This allows for a wide range of product pressures

TABLE 2-4

D O T REQUIREMENTS FOR METAL AEROSOL CONTAINERS[5]

DOT Specification	Minimum Metal Thickness (inches)	(microns)	Minimum Pressure Resistance Without Burst (psig)	Maximum Product Pressure (psig at 130°F)
"Non-spec" (2N)	none	none	210	140
2P	0.007	178	240	160
2Q	0.008	203	270	180
39	variable	variable	*	*

* Burst pressure and maximum product pressure are determined by stress formula.

and diverse applications ranging from hair sprays to cruise missile containers. A general DOT exemption applies to containers of not more than 4 fluid ounces in overflow capacity. Bottles larger than this may be shipped interstate if pressures do not exceed 40 psia at 70°F, 104 psia at 130°F, or 40 psia at 100°F for flammable products. This regulation effectively eliminates from interstate shipment (without a special exemption) glass aerosols containing HC's and having more than a 4-ounce capacity. The DOT regulations also do not distinguish between coated and uncoated containers (see Section 2.5.3).

2.5.2 Metal Can Construction

Design considerations for aerosol containers must include strength of the material, compatibility with the product, cost effectiveness, and attractiveness to the consumer. To satisfy these criteria, the aerosol consumer product industry uses three-piece tinplate cans for most products. The three-piece can consists of a bottom endpiece, a top endpiece or dome, and the main body. Each of these components is designed to fulfill a specific purpose. The bottom endpiece is designed as a concave disk to withstand the internal pressure of the propellant. The purpose of the dome (shown in Figure 2-7) is threefold. It has a conical shape to withstand high pressures, a 1-inch hole in the top to hold the valve, and a vertical section to hold the cover cap in place. The main body is cylindrical in shape. The primary consideration when designing the main body is the desired package size and geometry. These characteristics should be consistent with the intended use of the product. For example, a small can (small main body) will hold less volume and, in turn, can be used for fewer product applications. A larger container can contain more of the formulation (i.e., more applications) but the larger size makes the aerosol can more difficult to handle.

The first step in manufacturing tinplate (or tin-free) containers is making the steel. The raw materials needed for the steel manufacturing are: iron ore, coke, and limestone. About 25 percent of the iron is obtained from recycled scrap material. These materials are combined in a basic oxygen furnace and molded into either continuous slabs or

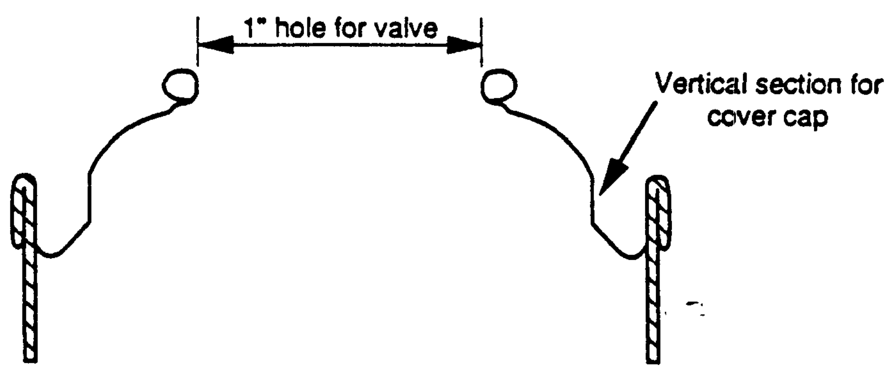

Figure 2-7 Cross Section of a Typical "Snap-Lock" Dome Top

ingots. The steel is then tempered for hardness and then annealed for stress reduction. The next step is to roll the steel to the desired thickness and to coat or line the steel. The steel has to meet specifications for strength, surface treatment (e.g., tinning, lubrication, etc.), and corrosion potential. Usually, surface characteristics and corrosion potential are adjusted by lining the tinplate or tin-free steel can. This protects the metal from damage by the product formulation. Linings include epoxy materials, vinyls, and vinyl organisols. There are at least 9 specific lining types used for aerosol cans. The type of lining used for a specific product depends on how the can material or the lining will react with the specific formulation. Products that have a high water content need a lining that retards rust. Products that are relatively inert may not need a can lining. The development of a lining includes laboratory testing of the material, plant trials to determine how the lining will act during the can manufacturing process, and, finally, commercialization of the lining. Lining development requires 18 months to 2 years from initial development to commercialization. This time delay can be important, especially since new formulation requirements, such as a water-based formulation, may require the development of a new lining to protect the can.

Can manufacturers receive sheets of tinplate or tin-free steel already lithographed with the can design and with a protective lining if required. After the metal sheets are received, they are cut into individual can sizes. In order to produce high quality cans at high speeds, the pieces must be cut within 1/1000 of an inch of the desired size. These individual rectangles are then fed into a machine that rolls the can into the cylindrical shape and welds the two endpieces together. The diameter of the main body is usually the critical dimension when designing a can manufacturing operation. Changing the diameter of a can requires either a separate machine or modification of existing equipment. Therefore, manufacturers have standardized the can sizes available for aerosol consumer products.

The can size is identified by both the diameter and the height of the can. The diameter is measured across the bottom of the can, and the height is measured from the base to the top of the top double seam where the dome cap meets the main body of the can. The dimensions are reported as a 3-digit number. The first digit is the number of inches and the last two digits are the number of sixteenths of an inch. A 211 x 908 is a can with a diameter of 2 11/16 inches and a height of 9 8/16 inches. Table 2-5 shows the dimensions of some of the cans marketed by United States Can Company.[18]

The next step after rolling and welding is to pass the can cylinders through a flanger. This device bends (or flanges) the top and bottom of the cylinder so that the endpieces can be fastened on in the crimping step. After the flanging step, the cans are top seamed and tested for leakage by pressurizing the cans with water.

Separate machines press the endpieces (tops and bottoms). Depending on the shape of the endpiece, the pressing is done in several stages. For bottom endpieces, the pressing is done in one or two stages. For dome tops that have a more complex shape, the pressing is done in six stages. This shape includes a 1-inch hole for insertion of the valve piece (see Figure 2-4). The next step in can manufacturing is to double seam the endpieces onto the can body. The seaming process presses the lips from the endpieces to the flange on the main body to form a tight seal. This step is important because an incorrect seam will cause a can to fail when it is filled. A loose seam may cause the end piece to separate from the can body due to the high internal pressure of the product. An excessively tight seam may cause the metal to fail, again resulting in separation of the endpiece from the body when pressurized.

Can manufacturers may conduct over 80 different checks on the cans during and after the manufacturing process to ensure that all specifications are met. The checks can be as simple as a visual inspection or as complicated as high-pressure tests in which water is forced into the cylinder of the main body which is then checked for leaks and/or buckling. Another check consists of a statistical sampling of cans from the manufacturing line to inspect the top and bottom crimps. The crimps are observed under high-powered microscopes to determine if they are too loose or too tight. If any of the numerous checks show that the cans being produced are inferior or will not meet specifications, the lines are shut down and the problem identified and corrected.

TABLE 2-5

CAN SIZES MARKETED BY UNITED STATES CAN COMPANY[18]

Size	Brim Full Capacity
202 x 214	5.0 oz
202 x 314	6.8 oz
202 x 406	7.8 oz
202 x 509	9.9 oz
202 x 700	12.5 oz
202 x 708	13.4 oz
207.5 x 605	15.3 oz
207.5 x 701	17.1 oz
207.5 x 708	18.2 oz
211 x 413	13.9 oz
211 x 604	18.0 oz
211 x 612	19.5 oz
211 x 713	22.6 oz
211 x 908	27.4 oz
300 x 709	26.9 oz

After all the final checks are done and it is determined that a can meets the required specifications, it is packaged and shipped to the product filler. The manufacturer/ marketer determined the size of can, the lining, and the lithography when the order was placed. The last step of filling the can and getting the final product to the marketplace is performed by either the marketer or a contract filler.

2.5.3 Glass Container Construction

Glass aerosol bottles are used primarily for fragrance products and pharmaceuticals. Glass containers account for only approximately 0.5 percent of aerosol consumer product production. The primary differences between aerosol and other types of glass packaging, such as pump sprays, is that the containers are restricted to smaller bottle sizes and less complicated shapes due to the high internal pressure of aerosols. A major concern in glass aerosol packaging is that of safety. Even though most glass bottles can withstand internal pressures well in excess of those needed for aerosol products, pressures are kept substantially lower, typically around 20 psig at $70^{O}F$. This reduces the risk of injury to the consumer. As added protection, more than 60 percent of all glass aerosols are plastic coated. This coating prevents personal injury from glass fragments if the bottle should rupture, and helps prevent injury due to ignition of the HC propellant by containing the bottle contents when ruptured.

The design of glass aerosol bottles must therefore consider geometries that have high impact resistance and pressure tolerances, and shapes that allow good glass distribution and strain elimination. For glass aerosol bottles produced in the United States, there is essentially one standard neck finish, tapered with a lip where the valve will be crimped into place. The neck has been standardized so that standard aerosol valves can be used. The bottle itself may have a flat wall surface or added surface features such as swirls or ribs.

The manufacture of glass aerosol bottles begins with blow-molding of molten glass into the desired shape of the container. The glass cools immediately, inducing stresses in the outer layers. These stresses must be alleviated to prevent the production of a defective bottle unable to withstand the internal pressures required. This is done through an annealing process.

The bottle might also be subjected to a surface toughening process known as "hot and cold end" treatment. This produces a skin of metallic dioxide that is substantially harder and tougher than the underlying glass. For best results, the oxide film is sprayed with a lubricant as the bottle leaves the cold end of the annealing lehr. The oxide/lubricant film helps prevent scratching and reduces environmental changes of the glass surface. One adverse effect of this treatment is that it may cause loss of adhesion between paper labels and siliconized glass bottles.

One purpose of the plastic coating is to provide protection from ultraviolet light. Coatings also protect the bottle from rough handling by increasing impact resistance. Plastic coatings also improve product aesthetics, provide special surface effects (high or low gloss, variegated colors, etc.), and allow safe utilization of pressures over 20 psig at 70°F and larger sizes up to 4 ounces for flammable compressed gases. The plastic coatings are applied by dipping the glass container into a bath of polyvinyl chloride. This dipping process is then repeated to form a soft covering high in tensile strength and with good impact absorption. The dipping and fusing cycles must be carefully controlled to produce optimum thicknesses and physical properties.

The finished bottles are then sent to the filling lines where the product is introduced into the bottles, and excess air is removed. As much air as possible must be removed to prevent an increase in the pressure and possible reactions with the product. The filled, purged bottles are then hand-fitted with a valve that is crimped onto the neck, creating a hermetic seal. Because coating thickness and bottle neck diameters vary, the optimum crimp diameter must be determined for each lot of glassware. This reduces the chance of obtaining a bad valve seal resulting in a leak. The bottles are then gassed and checked for leaks. Finally, glass aerosol bottles may be given a variety of finishes. They can be coated to provide a sheen, iridescence, and metallic or colored finish. They can be silk-screened, decorated by hot stamping, or paper or foil labels applied to the bottles. Composite containers, in which the glass bottle is inserted into an aluminum tube for example, can also be used.

The typical glass manufacturer follows a quality assurance program consisting of visual inspection, statistical inspection and attribute inspection. Visual inspections occur throughout the manufacturing process to detect defective or damaged bottles. There are 5 types of statistical inspections and 4 different attribute inspections performed throughout the process. As a result, glass aerosol containers have a safety record better than that of metal aerosol containers.

2.5.4 Plastic Container Construction

Plastic aerosol containers do not yet appear to be a viable alternative to the other two aerosol container types. There are many factors that must be considered when selecting the plastic to be used. These include high mechanical strength without brittleness; excellent chemical, creep, and permeation resistance; adaptability to production technology (injection molding, ultrasonic welding, etc.); design flexibility; and cost. It is difficult to find a single plastic that can meet all of these requirements. There are, however, 2 plastics being used on a much smaller scale than metal or glass aerosol packaging.

The design of plastic aerosol containers lends itself to a variety of shapes and sizes. For the most economical packages, the following attributes are recommended: cylindrical shapes, curved side walls, and embossed effects less than 0.010 inches deep. The most efficient shape would be a perfect sphere. Deviations from the sphere require more material to be used to compensate for increased stresses in the plastic.

Plastics also give added flexibility with respect to the type of neck opening. Any of the standard neck openings can be molded or post-machined on the containers. Valves are typically attached by ultrasonic welding that eliminates any contact between metal or rubber parts and the product.

The base design of the plastic container is the most critical because this area is the least resistant to impact. Recommended features include a wall tapered into the base, inverted truncated and conical-shaped base, and the use of extra material. Separate snap-on base sections can also be used to reduce the effect of impact. In general, the impact resistance of plastics far exceeds that of glass aerosols and most plastic-coated glass aerosols.

Safety concerns associated with plastic aerosols are minimal. Plastic does not shatter as does glass but usually breaks into two or three parts or develops a split. If the plastic does break, the pieces will fly outward due to the pressure release, but they do not present a large hazard because they are lightweight and are not sharply pointed. Plastics involved in a fire will melt and allow the pressurized product to be released gradually rather than explode. The low thermal conductivity of plastics prevents the build-up of extremely high internal pressure before softening can occur.

There are several problems with plastic aerosols not prevalent in metal or glass packaging. Many of the aerosol formulations contain darkly colored materials and will stain plastic containers. Internal linings or colored bottles can be used for these formulations. Storage of many scented products in unlined plastic containers results in odor stability problems. Another problem lies in the fact that all plastics can be permeated. Permeation is a function of the material, wall thickness, surface area, and temperature. Pressures involved in aerosol packaging have little effect. Many plastics are highly permeable to the HC's used as aerosol propellants. Finally, plastics are susceptible to adverse affects by organic solvents, and strong acids and bases. Plastics can be weakened or even dissolved by prolonged contact with many of these types of chemicals. Therefore, special compatibility tests on new formulations must be conducted for plastic aerosols. However, the time commitment for these studies is probably not any greater than similar development studies for the other packaging types.

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SECTION 3.0

CHARACTERIZATION OF THE AEROSOL PRODUCTS INDUSTRY

3.1 INDUSTRY HISTORY AND DEVELOPMENT

Aerosol products existed as early as the 1860's, with the first known aerosols being milk products and other beverages which were dispensed in aerated form through the use of carbon dioxide as a propellant. About 1910, cans and glass tubes of ethyl chloride were sold as topical anesthetics that chilled the skin prior to minor surgery. The most significant early work in aerosol product development was done in 1922, when Eric Rotheim of Norway developed an aerosol package comprised of a heavy brass shell and a primitive, threaded valve. Propellants for these early systems included isobutane, vinyl chloride, carbon dioxide, methyl chloride, and dimethyl ether. No further development of the aerosol packaging concept occurred until 1943, when U. S. Department of Agriculture researchers (Lyle Goodhue and William Sullivan) developed an insecticide "bomb" for use by U. S. troops in the South Pacific islands. Over 30 million of these units were produced from 1943 to 1947. These products utilized CFC propellants which were developed during the 1930's by Thomas Midgley of DuPont. Hydrocarbon propellants came into limited use in 1954, when Phillips Chemical Company introduced essentially odorless "Pure Grade" propane and butanes, and Risdon Manufacturing Company developed the first reliable mechanical breakup valve.[1]

The aerosol industry continued to use CFC's as the propellants of choice for most applications through the mid-1970's. With the advent of the Rowland and Molina ozone depletion theory which was published in 1974, the industry began converting to HC propellants. In 1975, approximately 50 percent of all aerosols were filled with HC propellants. By 1978, when CFC's were banned by the EPA and the FDA for use in most aerosol products, the conversion from CFC's to HC's was virtually complete. This conversion was costly to the aerosol industry because many existing plants were not designed to handle flammable propellants. To convert from CFC propellants to HC propellants, the aerosol industry incurred over $200 million in capital expenditures.[2] Furthermore, the growth of the aerosol industry was hindered because of consumers' perceptions about the adverse environmental effects of CFC's, even though nearly all post-ban aerosol products were propelled by HC's instead of CFC's. The number of aerosol units filled dropped from 2.9 billion units in 1973 to approximately 1.5 billion units annually between 1976 and 1980. The aerosol industry has gradually recovered and has reported growth in the number of units filled each year since 1982, with nearly 3 billion aerosol units being filled in the United States in 1989.[3] Currently, approximately 80 percent of all aerosols are HC-propelled. The few remaining CFC-propelled aerosols (approximately 2 percent of the market) are those permitted by exclusion or exemption (e.g., specific pharmaceutical, military, and aviation products) or those that are not regulated.[4] The overall growth of the industry is attributed to new product introduction in the household products area, as well as continued growth in the use of aerosol automotive and industrial products.[5]

A significant activity of today's aerosol industry is consumer education. Many consumers continue to believe that most aerosol products are propelled by CFC's and, therefore, contribute to stratospheric ozone depletion. One industry organization, the Consumer Aerosol Products Council (CAPCO), has produced an educational video, "The Aerosol Adventure -- How Tech Makes It Tick," that explains aerosol technology to a target audience of sixth to ninth grade students.[6]

3.2 STRUCTURE OF THE INDUSTRY

The aerosol industry cannot be defined by a single, uniform structure. Some companies perform multiple functions such as research and development, product formulation, can and valve design, propellant refining, container filling, and marketing. Other companies may perform only one or two of these functions. The aerosol consumer products industry presently employs approximately 20,000 persons directly, with an additional 80,000 persons being employed indirectly.[2] The following sections describe the primary elements of the aerosol industry: marketers, fillers, formulators, propellant and raw material vendors, container manufacturers, valve suppliers, and cover cap manufacturers.

3.2.1 Marketers

Aerosol product marketers promote and sell thousands of different products to consumers. Marketing strategies are affected by research, manufacturing development, packaging requirements, and economic factors. Marketers develop specifications for products based on consumer preferences, feasibility, and costs. Once a new product is developed, actual production can either be contracted out, performed in-house, or both. For instance, a marketer may produce formulations and perform the filling in-house, but contract out the container and valve manufacturing processes. When the work is contracted out, the filler, valve and container manufacturers, and propellant supplier provide the services required to produce each specific product. There are reportedly 500 marketers currently in the United States. Approximately half of these companies employ contractors to do their filling. About 25 percent of the marketers do their own filling, 5 percent fill their own cans as well as those of others, and 20 percent both fill their own and contract out the filling operation.[1,5] While most of the decisions concerning the valve, the container, and the formulation (propellant and product) are made by the marketer, these choices are ultimately influenced by the consumer. Consequently, most companies in the aerosol industry simply produce the products according to the marketer's specifications.[1,2]

Marketers have various perspectives on product introduction and improvement. Some are interested in marketing high-volume, routinely used products, while others hope to capture specialty markets. Other firms may command a small share of a major market such as hair sprays. These diverse goals require that fillers and valve and container manufacturers be prepared to deliver a wide range of goods and services tailored to individual marketers' unique specifications.

Most aerosols are sold in supermarkets, mass merchandiser outlets, drug stores, and hardware stores. The major market categories are personal care products, household products, automotive/ industrial products, paints and finishes, insect sprays, food products, and animal products.[7] In addition to traditional consumer products, a segment of the aerosol market is comprised of commercial and institutional products. This market sector represents a diverse spectrum of industries that rely on aerosol products to perform specific (and sometimes critical) functions. Consequently, these specialty aerosol products, which are typically not sold in normal consumer outlets, must be considered individually or as subsets of specific product categories.

3.2.2 Fillers

Aerosol fillers perform the task of injecting the product formulation (product and propellant) into the aerosol container and sealing the pressurized container. Aerosol containers are either filled in-house by the marketer of the product (captive filling), or the filling operation is contracted out to another company (contract filling). There are approximately 100 fillers in the United States (Table 3-1). About half these fillers are contract fillers that fill exclusively for the trade, while the other half fill for themselves as well as for marketers.[5,8] The product formulation is usually blended at the same facility as the filling. Therefore, most fillers are also formulation blenders.

Because some companies fill exclusively for the trade and others fill for themselves as well as for other companies, it is hard to define a clear relationship between the fillers and other members of the aerosol industry. It is known, however, that many contract fillers form one-on-one relationships with formulators and marketers. These relationships create a dependence on the formulator and marketer for business.[2,9]

TABLE 3-1

U.S. AEROSOL PRODUCT FILLERS[8]

F	Accra-Pac Incorporated
F	Accu-Pac
F	Advance Aerosol & Chemical Specialties
F	Aerofil Technology
F	Aerosol Research Laboratories Incorporated
F	Aerosol Services Company Incorporated
F	Aerosol Specialties Corporation
F	Aerosol Systems Incorporated
F	Aerosol West
F	Aerotech Industries
F,M	Aervoe Pacific Company Incorporated
F,M	Airsol Company Incorporated
F,M	Alberto-Culver Company
F,M	Altawood Incorporated
F,M	American Gas & Chemical
F,M	American Grease Stick
F	American Jet Way
F,M	Amrep Incorporated
F,M	Amway Corporation
F,M	Animal Repellents
F	Apollo Industries
F	Armstrong Laboratories Incorporated
F	Barr Company, Division of Pittway Corporation
F	Beatrice Cheese Incorporated
F,M	Berryman Products
F	Bissel Penn Champ Incorporated
F,M	Boyle-Midway, Division of American Home Products
F,M	Broughton Foods Company
F	Carroll Company
F,M	Carter-Wallace Incorporated
F	Case-Mason Filling Incorporated
F,M	Cello Corporation
F	Cessco Incorporated
F	Chase Products Company
F	Chem Force America Incorporated
F,M	Chem-Tech Incorporated
F	Chem-Tech Limited
F	Chemi-Coatings Incorporated
F	Chemical Packaging Corporation
F	Chemical Packaging Services Incorporated
F	Chemical Products
F	Chem-Pak Incorporated
F,M	Chemscope Corporation
F	Chemsico Incorporated
F	Chemspray Incorporated
F,M	Chesebrough-Pond's Incorporated
F,M	Claire Manufacturing Company

Continued

TABLE 3-1 (CONTINUED)

U.S. AEROSOL PRODUCT FILLERS[8]

F,M	Clairol Incorporated
F	J.L. Clark Company
F,M	Cline-Buckner Incorporated
F,M	Colgate-Palmolive Company
F	Contact Industries Incorporated
F,M	Cosmair Incorporated
F,M	CRC Chemicals
F,M	Creative Products Corporation
F,M	Crown Industrial Products Company
F	CSA Limited Incorporated
F	Custom-Pak Products Incorporated
F,M	Dana Parfums Corporation
F,M	DAP Incorporated
F,M	DeMert & Dougherty/Aeropak Division
F,M	DeSoto Incorporated, Chemical Coatings Division
F,M	Dow Brands
F,M	Dupli Color/Sprayon Products Company Incorporated
F,M	Dymon Incorporated
F	Dynamatch
F	E. Davis & Company
F,M	Enterprise Sales Company
F	Eveready Products Corporation
F	Fasse Paint Company Incorporated
F,M	Faultless Starch/Bon Ami Company
F	Fluid Packaging Company Incorporated
F,M	Follmer Development
F	Forrest Paint Company
F	Frank Orlandi Incorporated
F,M	Fre-Kote Incorporated
F,M	Fuller Brush Company
F,M	Fulton Chemical Company
F,M	Gabriel Manufacturing Company
F	Guardsman Products
F	G.C. Thorsen
F	Gainor Manufacturer Company
F	GEM Incorporated
F	Gemini Lacquers
F,M	General Paint
F,M	Gillette Company
F,M	Grow Group
F	Holt Lloyd Corporation
F,M	Huntington Laboratories
F,M	Hydrosol Incorporated
F	Hysan Corporation
F	IKI Manufacturing Company Incorporated

Continued

TABLE 3-1 (CONTINUED)

U. S. AEROSOL PRODUCT FILLERS[8]

F,M	Illinois Bronze Paint Company
F	Jerome Laboratories Incorporated
F	JL Manufacturers
F	J.M. Products
F,M	Knight Oil Corporation
F	Lighthouse for the Blind
F	Marcy Laboratories Incorporated
F	Major Paint, Aerosol Packaging Division
F,M	Midco Products Incorporated
F	Minnesota Mining and Manufacturing (3M)
F,M	Mobile Paint
F,M	Mohawk Finishing Products Incorporated
F,M	Mohawk Laboratories Incorporated
F,M	Morton Pharmaceuticals Incorporated
F,M	National Aerosol Products
F,M	New England Aerosol and Packaging Corporation
F,M	Noxell Corporation
F	Orb Industries Incorporated
F	Pel Associates Incorporated
F,M	Pennwalt Corporation
F,M	Petro Chemical Products
F,M	Percy Harms Corporation
F	Peterson/Puritan Incorporated
F	Pharmasol Corporation
F	Piedmont Laboratories Incorporated
F,M	Plasti-Kote Company
F,M	Plaze Incorporated
F	Precise Packaging
F	Premier Dye
F	Presto Foods
F,M	Pyroil Company
F	Quest Chemical
F,M	Raabe Corporation
F,M	Radiator Specialties Company
F	Randolph Products Company
F	Rawn Company Incorporated
F	Regency Chemical
F	Rempak Industries
F,M	Rite Off Incorporated
F	Riverside Metal Products Incorporated
F	RSI Incorporated
F	Rudd Paint & Varnish Company
F,M	Rustoleum Corporation
F	Safety Plus Incorporated
F,M	S.C. Johnson & Son Incorporated
F,M	Schering-Plough Incorporated
F,M	Scott's Liquid Gold

Continued

TABLE 3-1 (CONCLUDED)

U. S. AEROSOL PRODUCT FILLERS[8]

F	Security Equipment Corporation
F,M	Seymour of Sycamore Incorporated
F	Shaefer Paint Company
F	Shield Packaging Company
F	Shield Packaging of California Incorporated
F,M	Shirlo Incorporated
F,M	Shulton Incorporated
F	Southern Coatings & Chemical Company
F,M	Speer Products Incorporated
F	Spray Can Specialties Corporation
F,M	Spray-on Products/Division of Sherwin-Williams
F	Spray Products Corporation
F	Standard Management Incorporated
F	Stanhome Incorporated
F,M	Star Chemical Company Incorporated
F,M	Stoner Incorporated
F	Strobel Products Company Incorporated
F	Sun Laboratories Incorporated
F	Sun Laboratories of Atlanta
F	Sunrise Packaging
F,M	TDP Industries Incorporated
F,M	Tech Spray
F	Technical Chemical Company
F	Testor Corporation
F	Tradco
F	Ultramotive Corporation
F	Unipak Incorporated
F	Unsmoke International
F	U.S. Aviex Company
F,M	U.S. Packaging Corporation
F	Valvoline
F	Virbac
F	Warner Enterprises Incorporated
F,M	Whitmire Research Laboratories
F,M	Zep Manufacturing Company
F	Zoe Chemical Company

F Designates **contract fillers**. These companies fill aerosol containers for trade but do not market their own products.

F,M Designates **captive fillers**. These companies fill and market their own products.

3.2.2.1 *Aerosol Filling Lines*

The basic pieces of equipment that comprise the filling operation are can cleaners, can coders, powder or liquid fillers, valve inserters and crimpers, propellant gassers, and capping operations. The total cost of establishing a new filling line can exceed $2 million.[1] Two key considerations in filling line design are the type of products to be filled and the anticipated annual production volume. Many fillers have several lines, each one made as versatile as possible yet compatible with the others in order to maximize product adaptability. The diversity of aerosol formulations and packaging forms that must be handled by filling lines is illustrated by the wide array of aerosol products on the market. Some examples of specialized filling lines are aerosol pharmaceutical lines, aerosol food lines, paint and lacquer lines, compartmented can lines, and lines for highly viscous products. Aerosol lines are usually categorized according to speed ratings in terms of number of units filled per minute. They can be classified as slow, moderate, high, or very high, with production rates ranging from 10 to 500 units per minute.

3.2.3 Formulators

Aerosol formulations for individual products are specified by the marketer. Generally, the formulation is blended at the same facility where the can is filled (either a captive or contract filler). In a few cases, usually involving proprietary formulations, the formulation is blended at a separate facility and is shipped to the filler.[10]

3.2.4 Propellant Suppliers

The types of aerosol propellants currently in use and the domestic companies that supply them are presented in Table 3-2. Currently, about 81 percent of U. S. aerosol products are pressurized with HC propellants. Another 7 percent use CO_2, and the remaining 12 percent use N_2O, CFC's, DME, N_2, HFC-152a, and HCFC's (listed in approximately descending order).[4]

Hydrocarbon propellants are derived from petroleum raw materials generally referred to as liquified petroleum gas (LPG). In the United States, about 70 percent of the LPG produced is extracted from natural gas, and 30 percent is refined from crude oil. The initial refining is carried out by large petrochemical companies. Aerosol propellant companies further refine these materials to produce purified, aerosol-grade propane, n-butane, and isobutane. Isobutane accounts for 70 to 75 percent of the HC's used in aerosols. Propane accounts for 15 to 20 percent of the market share, and n-butane has around a 10 to 15 percent share. In 1989, approximately 65 million gallons of LPG were consumed to produce HC propellants used in approximately 3 billion aerosol units. This amount accounts for about 0.2 percent of total annual U. S. LPG production.[3]

Seven companies in the United States supply aerosol-grade HC's. Currently, 3 companies (Aeropres Corporation, Diversified CPC International, and Phillips 66 Company) produce over 80 percent of the HC propellants used in the United States.[10,11] For some of these companies, the production of aerosol propellants comprises virtually 100 percent of their business (i.e., aerosol products are the only use for the propellants they manufacture). For example, Aeropres Corporation is almost totally dependent on the aerosol industry, because their primary activity is the production of aerosol propellants. Although they market small quantities of highly purified gases for instrument calibration purposes and some unpurified fuel gases, these markets represent only a small fraction of Aeropres's overall business.[11] For more diversified companies such as Phillips 66 Company, the production of aerosol propellants may represent a much smaller segment of their overall business.

3.2.5 Raw Material Vendors

Within the major categories of consumer aerosol products are thousands of specific products with formulations containing a vast number of chemicals. Table 3-3 lists the major types of raw materials used to produce aerosol formulations. The various raw materials are supplied by hundreds of different companies in the United States.

TABLE 3-2

U. S. AEROSOL PROPELLANT SUPPLIERS[5,11,12]

Hydrocarbons

- Aeropres Corporation[a]
- Copia Associates Incorporated
- Demert & Dougherty/Aeropak Division
- Diversified Chemicals and Propellants[a]
- Petrolane Transport
- Phillips 66[a]
- Technical Propellants

Carbon Dioxide

- Liquid Carbonic Corporation

Nitrogen and Nitrous Oxide

- Puritan-Bennett Corporation

Fluorocarbons

- Aeropres Corporation
- Copia Associates Incorporated
- Diversified Chemicals and Propellants
- DuPont
- Atochem Corporation
- Technical Propellants
- Kaiser LaRoche
- Allied Signal Incorporated

Dimethyl Ether

- Aeropres Corporation
- Copia Associates Incorporated
- Diversified Chemicals and Propellants
- DuPont
- Technical Propellants

Hydrofluorocarbons and Hydrochlorofluorocarbons

- Allied Signal Incorporated
- DuPont
- ICI

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[a] These three companies account for over 80 percent of U. S. hydrocarbon propellant production.

TABLE 3-3

RAW MATERIALS USED IN AEROSOL FORMULATIONS[8]

Alcohol
Antioxidants, Bacteriostats
Antiperspirant Raw Materials
Antistatics
Deodorants
Emollients
Emulsifiers
Gellants
Hair Spray Resins
Insect Repellents
Lanolin & Derivatives
Odor Neutralizers
Paint, Concentrates & Pigments
Perfuming Materials
Pesticide Materials-Toxicants & Synergists
Preservatives
Quaternary Ammonium Compounds
Silicones
Solvents
Stabilizers
Sunscreens
Surfactants
Vapor & Flame Suppressors

3.2.6 Container Manufacturers

Approximately 25 container manufacturers supply tinplate, aluminum, glass, and plastic cans for the aerosol industry. Table 3-4 presents a list of container manufacturers in the United States. Although many of these companies also produce nonaerosol containers or other products, some depend on the aerosol industry for most of their business.[2,14] When making a decision about what type of can to use for a specific product, the marketer must consider the size of the can, whether the formulation may react with the can, what the pressure rating of the can should be, the aesthetics of the can, and product safety. The following sections provide brief discussions of the primary types of aerosol containers and the part they play in the market.

3.2.6.1 *Tinplate Cans*

In the United States, the 3-piece tinplate aerosol can is the predominant packaging medium for most aerosol products, with over 87 percent of all aerosol products being packaged in tinplate cans. Tinplate cans are generally the least expensive of the various types of aerosol cans. The cost varies with can size and pressure rating. An average tinplate aerosol can costs about $0.25, although cans with higher pressure ratings may cost up to about $0.85.[12] Although tinplate cans are relatively versatile, they are often not used with formulations of high water or saline content because of corrosion problems. They also may not be desirable for products that require aesthetic appeal, such as perfume.

Four companies (United States Can Company, American National Can Company, Heekin Can Incorporated, and Crown Cork and Seal Company) produce over 95 percent of the tinplate aerosol cans used in the United States today.[15,16] One of these companies, United States Can Company, is very dependent on the aerosol industry. While it also makes some nonaerosol paint cans, this company has over 70 percent of its business dedicated to aerosol can sales. Conversely, the other 3 major aerosol can suppliers are less dependent on the aerosol industry, because their principal products are

TABLE 3-4

U. S. AEROSOL CONTAINER MANUFACTURERS[5,8,13,14]

Tinplate Containers

American National Can Company[a]	Heekin Can Incorporated[a]
CMB Enterprises Incorporated	Ring Can Company
Crown, Cork and Seal Company Incorporated[a]	Sexton Can Company
Davies Can Company	Specialty Packaging Products, Inc.
Garrett-Hewitt International	United States Can Company[a]

Jumbo Size Metal Containers

Advanced Monobloc	Complete Cosmetic Service
CMB Enterprises Incorporated	United States Can Company

Aluminum Containers

Advanced Monobloc[b]	Lako Associates Inc.
American National Can Company	Lechner U.S.A
Anomatic Corporation	3M Company
Complete Cosmetic Service	Parker-Hannifin Corporation
Connecticut Metal	Peerless Tube Company[b]
Emson Research Incorporated	Riverside Metal Products
Lablabo/BLM Associates	Specialty Packaging Products Inc.

Coated Glass Containers

3M Company	Wheaton Aerosol Company

Uncoated Glass Containers

Garrett-Hewitt International	T.J. Holmes Company
Riverside Metal Products	Wheaton Glass Company

Plastic Containers

Wheaton Aerosol Company

Barrier Pack Containers

Advanced Monobloc	Exxel Container L.P.
CMB Enterprises Incorporated	Lechner U.S.A.
Confor	United States Can Company
Crown Cork and Seal Company	

[a] These 4 companies supply over 95 percent of the tinplate aerosol containers in the U. S.

[b] These 2 companies supply over 80 percent of the aluminum aerosol containers in the U. S.

food and beverage containers. An estimated 4,000 to 6,000 persons are directly dependent on the tinplate aerosol can industry in the United States.[14]

3.2.6.2 *Aluminum Cans*

Aluminum aerosol cans comprise about 12 percent of the aerosol container market in the United States.[15,17] Aluminum cans generally cost 15 to 30 percent more to produce than equivalent tinplate cans because raw material and manufacturing costs are higher for aluminum, even though approximately 30 percent of the aluminum cans are made from recycled material. Because aluminum aerosol cans are produced by impact extrusion, they have no welded side-seam (as used in the 3-piece tinplate can). Accordingly, they appear smooth and sleek, and for that reason may be desirable for use with some personal care products. Aluminum cans are also often used instead of tinplate cans to contain formulations corrosive to tinplate (such as those high in water content).[13,14]

Two companies (Peerless Tube Company and Advanced Monobloc) produce over 80 percent of the aluminum aerosol cans in the United States. These two companies are almost totally dependent on the aerosol industry. While they both make other types of aluminum tubes, these companies primarily produce aerosol cans.[10,14,18] Aluminum aerosol can production is a small percentage (less than 0.1 percent) of the overall aluminum container market.

3.2.6.3 *Glass Containers*

The use of glass containers for formulated aerosol products began about 1950, although one product, a topical anesthetic spray consisting of ethyl chloride, was marketed about 1910. The glass aerosol market, which consists primarily of fragrance products and pharmaceuticals, grew steadily until the mid-1970's when the switch from CFC's to HC propellants caused a sharp decline. As marketers became less reluctant to utilize HC propellants in fragrance products, the market recovered to some degree over the years. Today, glass aerosols account for approximately 0.5 percent of the aerosol container market.[1]

3.2.6.4 *Plastic Containers*

Plastic aerosol containers currently account for a negligible share of the aerosol market. Many types of plastic containers have been examined by the industry, but none has proved favorable enough to capture a significant market share. Only one company (Wheaton Plastics Company) currently produces plastic aerosol containers, and these comprise a very small segment of Wheaton's business. The few plastic aerosol containers manufactured are typically made of polyethylene terephthalate (PET).[19]

3.2.7 Valve Suppliers

The valve is an essential element of every aerosol dispenser. When actuated, it releases the product from the container and produces a spray pattern appropriate for the specific application. In the United States, 9 firms supply virtually all aerosol valves. Table 3-5 presents a list of these valve producers. Three companies (Precision Valve Corporation, Seaquist Valve Company, and Summit Packaging Systems) supply over 90 percent of the aerosol valves used in the United States.[10] Each of these companies, while also involved to varying degrees in the production of pump spray valves, depends on the production of aerosol valves for pressurized containers as a major portion of their business.[20]

Although some valve manufacturers list suggested specific valve combinations for various standard aerosol products, the companies usually manufacture valves to the marketers' specifications. One U. S. valve manufacturer reportedly has over 10,000 specific aerosol valve designs from which to choose.[10] While many marketers have their own unique ideas concerning what constitutes an acceptable spray pattern, a large degree of supplier interchangeability can be obtained by maintaining the same orifices, gaskets,

TABLE 3-5

U. S. AEROSOL VALVE MANUFACTURERS[5,8,10]

General Purpose Valves

- Bespak Incorporated
- Emson Research Incorporated
- Newman-Green Incorporated
- Precision Valve Corporation[a]
- Seaquist Valve Company[a]
- Summit Packaging Systems[a]

Valves for Use with Foam, Food, and Viscous Products

- Bespak Incorporated
- Clayton Corporation
- Precision Valve Corporation
- Risdon Corporation
- Seaquist Valve Company
- Summit Packaging Systems

Valves for Use with Paint Products

- Newman-Green Incorporated
- Precision Valve Corporation
- Seaquist Valve Company
- Summit Packaging Systems
- Sprayon Products

Valves for Use with Glass/Plastic Bottles

- Bespak Incorporated
- Precision Valve Corporation
- Risdon Corporation

Valves for Use with Carbon Dioxide Propellants

- Bespak Incorporated
- Newman-Green Incorporated
- Precision Valve Corporation
- Seaquist Valve Company
- Summit Packaging Systems

Metered Valves

- 3M Company
- Bespak Incorporated
- Emson Research Incorporated
- Risdon Corporation
- Minnesota Mining and Manufacturing (3M)

[a] These three companies produce over 90 percent of the aerosol valves used in the United States.

and other attributes during the development of alternative or secondary source valve specifications.[1]

Research conducted by valve manufacturers includes development of new valves that reduce flammability and provide better spray characteristics. Innovations in valve design have also allowed greater use of CO_2-propelled products, thereby reducing the use of CFC and HC propellants.

3.2.8 Cover Cap Manufacturers

Aerosol cover caps are necessary to protect the spray head from damage, prevent the actuator from discharging the contents during storage, prevent accumulation of dust or dirt on the valve, and enhance the general appearance of the container. Table 3-6 lists the 11 cover cap manufacturers in the United States. Two of these companies (Berry Plastics and Knight Plastics) produce over 90 percent of the aerosol caps used in the United States.[10]

3.3 REFERENCES

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TABLE 3-6

AEROSOL CONTAINER COVER CAP MANUFACTURERS[1,6,19]

Anomatic Corporation
Berry Plastics [a]
Clayton Corporation
Knight Plastics [a]
Pacific States Plastics
Paragon Plastics Incorporated
Precision Valve Corporation
Risdon Corporation
Shellvick Industries Incorporated
Trans Container Corporation
West Penn Manufacturing & Supply

a These 2 companies produce over 90 percent of the cover caps used in the U. S.

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10. Teleconference between B. Broberg, Radian Corporation, and M. Johnsen, Montford Johnsen Associates. September 10, 1990.

11. Teleconference between L. Davis, Radian Corporation, and H. McCain, Aeropres Corporation. September 11, 1990.

12. Draft Trip Report - Site Visit: Claire Manufacturing Company. Submitted to EPA by B. Broberg, Radian Corporation. July 24, 1990.

13. Teleconference between L. Davis, Radian Corporation, and T. Maloney, American National Can Company. September 11, 1990.

14. Teleconference between L. Davis, Radian Corporation, and R. Jacobsen, U. S. Can Company, September 13, 1990.

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19. Teleconference between L. Davis, Radian Corporation, and W. Hoyle, Wheaton Plastics, Inc. Sept. 10, 1990.

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SECTION 4.0

ALTERNATIVE DISPENSING TECHNOLOGIES

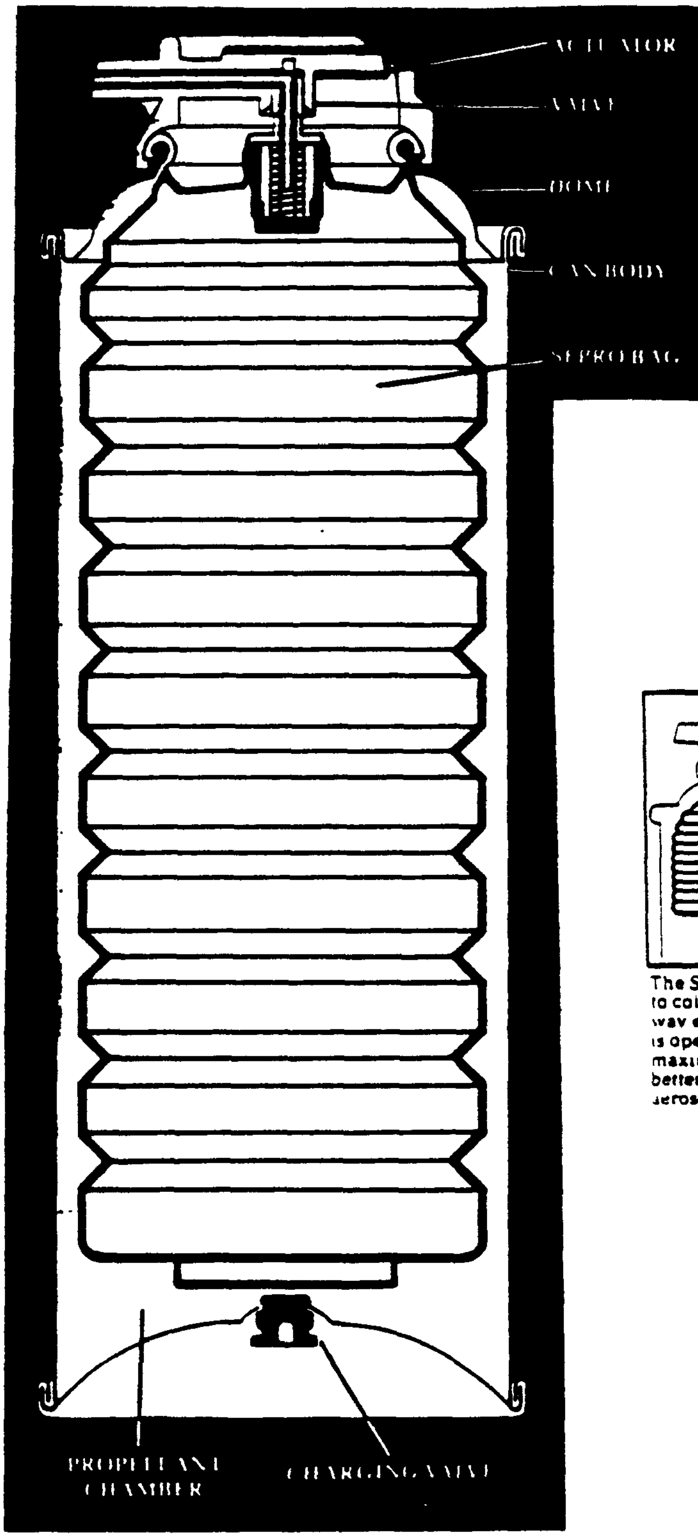
4.1 INTRODUCTION

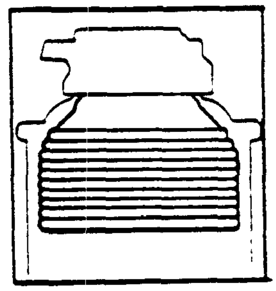
One option that has been suggested as a means of reducing VOC emissions from aerosol consumer products is to switch from conventional aerosol packaging systems to alternative technologies that reduce the amount of HC propellant required to expel the product. While this is a reasonable and effective approach for many applications, each individual conversion must be considered carefully with regard to the net environmental benefit that will be achieved. This section describes the advantages and limitations of several alternative packaging technologies that have been or may be used for consumer products.

4.2 THE "BAG-IN-CAN" SYSTEM

One alternative dispensing system for aerosol products is the bag-in-can system. This container (aluminum or tinplate) houses an inner bag containing the product concentrate and the exo-space propellant. The bag can be made of one of several different materials to ensure that the product and the propellant are kept separate. Under normal use, the system is designed to permit gas-free dispensing; however, upon disposal, the propellant would likely be released to the environment. The top of the can is fitted with a valve and an actuator. As the actuator is depressed, the inner bag begins to collapse due to the pressure of the exo-space propellant, and the product is dispensed. Figure 4-1 shows the Sepro Can®, which was the first bag-in-can unit introduced for aerosol products.

The bag-in-can technology can be used to dispense viscous products with a positive yield point, i.e., the product retains its shape. The primary use is for post-foaming, gel-type shave creams (although these are now marketed in piston cans). Other





The Sepro bag is designed to collapse in a specific way each time the valve is opened. This action maximizes product usage better than any other aerosol can.

Figure 4-1 The Sepro Can®.

products include toothpaste, depilatories, caulking compounds, catsup, mustard, insulating gel, honey, jelly, vegetable oils, artist's pigments, petrolatum, cake icing, cleaners, disinfectants, medicines, dental gels, gum cements, and hair coloring pastes. Some bag-in-can systems have been used as the power units for nail dispensers.

There are many limitations to this type of packaging system, some of which are listed below:

- Products with high viscosities - result in slow transport through valve
- Products that are highly lubricating - result in a loss of seal for rubber components
- Products that are acidic - tend to attack certain types of bag materials
- Products with long shelf lives before use - the propellant permeates the bag and enters the product
- Products containing strong solvents - result in bag degradation or dissolution
- Products that must be hot-filled - results in flammability hazard and/or bag distortion

Most bag-in-can systems use HC propellants such as n-butane, isobutane, propane, and their blends. The use of compressed gases is severely limited because there is no reserve against slow leakage, and the propellant may be unable to dispense the entire contents of the can. It should be noted that the Alucompack and Micro-Compack systems can use compressed gases because the exo-space is greater than that of the inner tube or bag. Therefore, the pressure will not decrease substantially during tube collapse. The HC-propelled bag-in-can requires a propellant content of about 0.5 percent by weight. The post-foaming gel-type shave creams contain approximately 2 percent by weight VOC's in the product to cause the gel to foam when the product comes in contact with the skin. This can be compared with 3 percent VOC content that is typical of regular

TABLE 4-1

BAG-IN-CAN DISPENSING SYSTEMS

Bag-In-Can System	Supplier	Filling Method	Bag Material	Bag Design
Sepro Can®	Continental Can Division of U.S. Can Company	Base gassing	Conalloy plastic Nylon Lamicon	Horizontal "V" shaped pleats
Bi-Can	CMB Packaging, Ltd.	Base gassing	Nylon	Fits can body with longitudinal bulge
Alucompack	ASM, S.A.	Under-the-Cup (U-t-C) injection	Aluminum	Tube with flat base and flanged top
Micro-Compack	ASM, S.A.	U-t-C injection	Aluminum	Tube with flat base and flanged top (10 to 15 ml)
Lechner I	Lechner GmbH	Base gassing or injection	Low density PE High density PE	Vertically pleated
Lechner II	Lechner GmbH	Base gassing or injection	Aluminum	Fitted to can
Lechner III	Lechner GmbH	Base gassing	Polyolefin lining	Fitted to can
Lechner IV	Lechner GmbH	Base gassing or injection	Aluminum	Fitted to can

aerosol shaving creams. Hair sprays, which typically uses 20 to 35 percent HC propellant, require only about 2 percent propellant if packaged in a Sepro Can®. However, the spray characteristics of the hair spray deteriorates, and the total quantity of VOC's emitted may actually increase due to increased solvent requirements.

Several different versions of the bag-in-can dispenser are currently used in the marketplace. Table 4-1 lists the various suppliers of these systems as well as the various bag types and filling methods. The Sepro Can® dispenses between 94 and 97 percent of the product. Most of the other systems dispense closer to 98 percent of the product.

4.3 PISTON CANS

A second type of alternative aerosol dispensing system is the piston can. This unit consists of an aluminum or tinplate can and a free-floating polyethylene piston that separates the propellant from the formulation. Figure 4-2 presents a cross section of a piston can. The propellant is injected through the base of the can below the piston. Hydrocarbons are the most common propellant type for the piston cans. Compressed gases cannot be used because they do not maintain a constant pressure as the contents are expelled.

These systems can be used for creams, gels, pastes, lotions, and other low to medium viscosity products such as shave creams, chocolate syrups, margarine, air fresheners, cheeses, cake toppings, and silicone-based tub and tile sealants. Piston cans typically dispense 95 to 98 percent of their contents. Limitations of piston cans include:

- Products with low viscosity will distort the piston
- Piston bypass and permeation will result in propellant reduction and foam generation in the product
- Incompatibility of the product with the can or piston

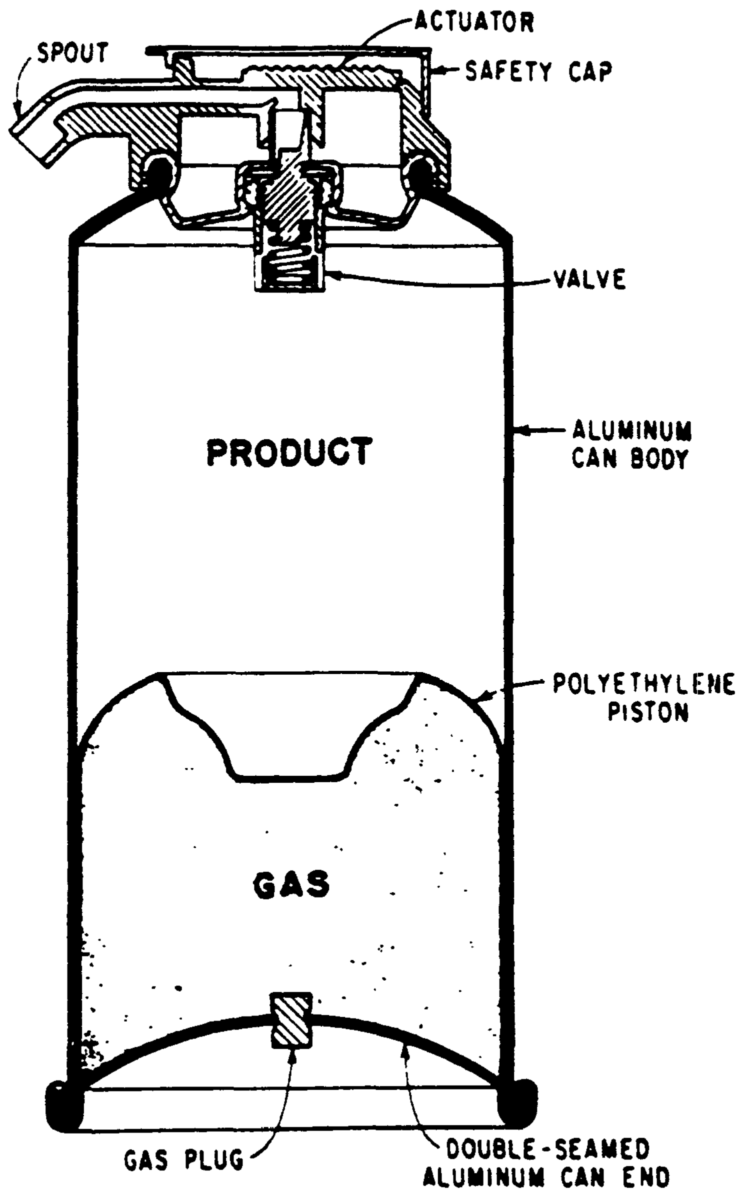


Figure 4-2 American National Can Company's Mira-Flo® Piston Can

Suppliers of piston can dispensing systems include American National Can Company, Advanced Monobloc, Ltd., United States Can Company, Boxal/Alusuisse, and Rocep® Pressure Packs, Ltd. Most of the units marketed by these companies are standard piston systems, except for the Rocep® cans and the Boxal® pump dispenser. The principal difference in the Rocep® can is that it uses a double piston to prevent contamination of the product by the propellant. It should be noted that currently the Rocep® can employs an HCFC propellant primarily because Rocep® does not possess a suitable facility for the safe handling of flammable gases. The Boxal® pump dispenser is a propellantless version of the piston can that operates on a vacuum suction principle. This unit consists of an aluminum can with an inner piston, perforated bottom, and an actuating spout that meters product flow. Depression of the actuator creates a low vacuum and causes the piston to move upwards, causing expulsion of the product. This package dispenses approximately 95 to 97 percent of the material.

Piston cans are similar to the bag-in-can systems in that only a small amount of propellant is needed to dispense the contents. Typically, the piston can requires about 0.5 percent propellant. This can be compared to 3 percent used with traditional viscous aerosol products.

4.4 ENVIRO-SPRAY® SYSTEM

The Enviro-Spray® system is the opposite of the bag-in-can system in that the product occupies the exo-space, and the propellant is inside the bag. The propellant bag consists of a large pouch containing a 50-percent citric acid solution in water, and four smaller pouches containing sodium bicarbonate. The smaller pouches are ruptured as the contents are expelled and thebag expands, pressurizing the container. Mixing of the citric acid and sodium bicarbonate produces sodium citrate salts and CO_2 gas that maintains the pressure in

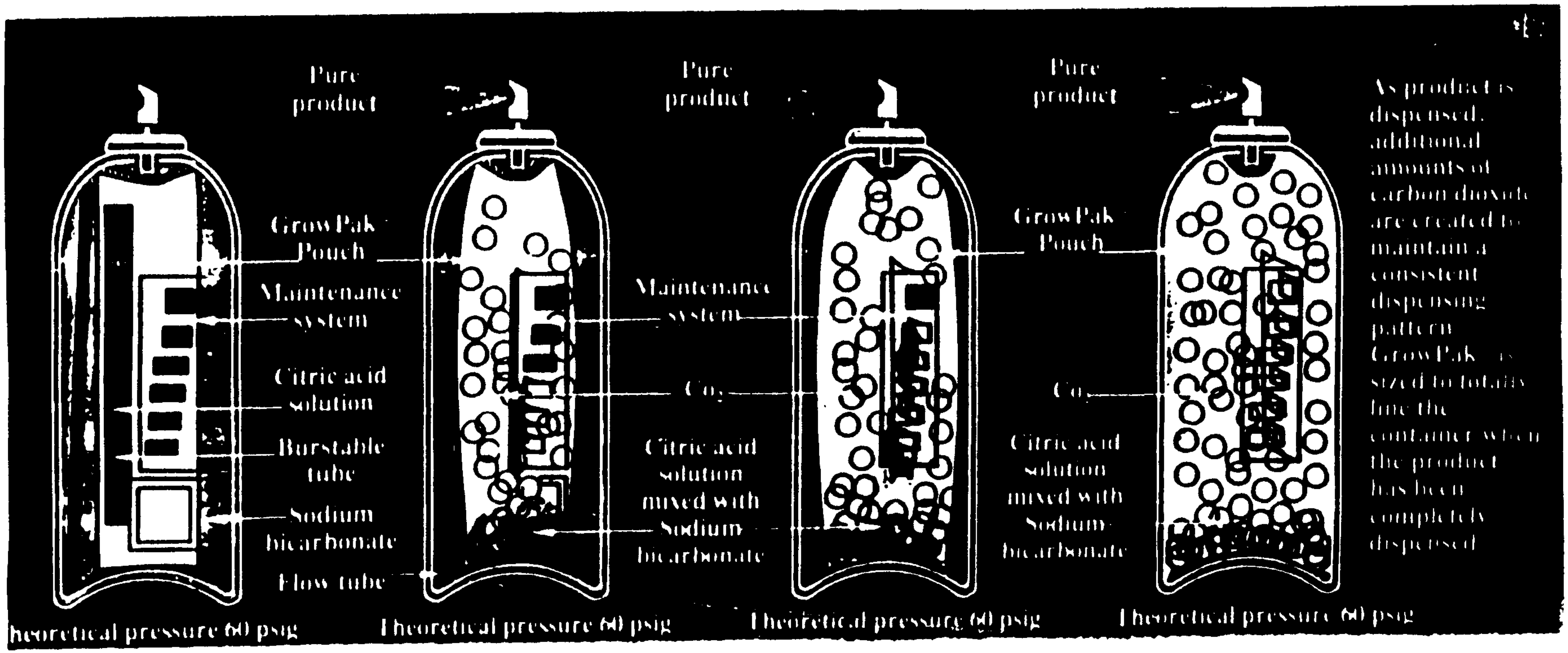


Figure 4-3 Various Stages in the Operation of an Enviro-Spray® Product

the unit at the original level. The product can be dispensed as acoarse spray, gel, paste, or post-foaming gel. The citric acid pouches in this unit are laminates that have a core layer of aluminum or polyester. The reservoir of sodium bicarbonate for the first pressurization step is contained in a special water-soluble polyvinyl alcohol bag. This system does not require any VOC propellants. Figure 4-3 shows the various stages in the operation of an Enviro-Spray® dispensing system.

Enviro-Spray® dispensers are used for various insecticides, leaf shines, shave creams, colognes, rubefacient creams, catsup, mustard, and plant nutrient sprays. This dispensing system is currently marketed in the United States and Europe by ECOM (a division of CCL Industries, Ltd.) Toronto, Canada. Some limitations of this dispensing system include:

- Product incompatibility with the can
- Product incompatibility/permeation of the pouch
- Variations in delivery rate due to pressure fluctuations

4.5 PUMP SPRAYS

There are two basic types of pump dispensers, the aspirator type and the standard mechanical type. The aspirator type consists of a jar containing a dip tube, which aspirates the product into an orifice and out of the dispenser as a spray. Aspirator pumps have been used primarily for space spray insecticides; however, smaller versions of this type have been used for perfumes and colognes. The primary limitation of these units is that the product must have low viscosity so that it can be dispensed as a spray.

Several aspirator-type sprayers are currently available. The "Pre-Val" unit (made by Precision Valve Corporation) consists of a glass or plastic jar (product reservoir) and a dip tube extending through a bag holding liquid propellant. When the valve button is depressed, propellant is discharged, creating a vacuum that causes the concentrate to be

TABLE 4-2

PUMP SPRAYER SYSTEMS AND SUPPLIERS

Product	Type	Supplier
Pre-Val® Unit	Aspirator	Precision Valve Corporation
"FLIT" Gun	Aspirator	Penola Oil & Chemical Corp. Esso Oil Company Humble Oil & Refining Co. Exxon, Inc.
Finger-Pump Sprayer	(Standard) Finger-pump	Calmar Corporation Bakan Products Co. Risdon Manufacturing Co. Emson Research Company Seaquist Closures, Division of Pittway, Inc. Kingswood Laboratories, Inc. United Industries Corporation
Trigger Sprayer	(Standard) Trigger-pump	Afa Corporation

entrained and discharged. Because the propellant does not reside in the same container as the formulation, any liquid propellant can be used. A compressed gas cannot be used because the entire contents of the propellant container would be discharged soon after the valve is opened (unless a gas cylinder with very high pressures is used).

The aspirator-type pump sprayer consists of a cylinder and piston arrangement connected to a reservoir from which the product is aspirated through the dip tube, through a jet orifice, and propelled by a stream of air. An example of this type dispenser is the old "FLIT" gun. These have been used mainly for insecticides and were sold by companies such as Exxon and Gulf. Today, only a very limited number of these units are sold. These units do not use any kind of propellant.

The standard-type pump sprayers commonly in use today exist in two forms, the finger-pump sprayer and the trigger-action sprayer. The operating principles of the two systems are the same. The actuator/valve assembly usually has a threaded connection that fits into a glass or plastic container. As the actuator is depressed, the valve stem is forced downward into the body chamber that is normally filled with product. The product forces the chamber to expand outward, allowing product to flow past the piston into the orifices of the stem. The liquid then moves up the stem, through the adapter and button, and out the actuator as a stream or spray. When the button is released a partial vacuum is created in the chamber allowing product to refill the body chamber. The principal differences between the finger- and trigger-pump sprayers are the amount of product dispensed per actuation and the mechanical advantage of the pinioned trigger that provides higher internal pressure in the chamber.

The standard pump sprayers are best suited for surface applications and are used to dispense hair sprays and moisturizers, residual insecticides, herbicides, pet sprays, colognes and perfumes, curl activators, lens cleaners, spot cleaners, window cleaners, cookware lubricants, topical sprays, chrome polishes, stainless steel cleaners, and etc. Pump sprayers can be modified into extruders by replacing the actuator with a spout. These extruder systems can be used to dispense pharmaceuticals, skin dewrinklers, perfumed lotions, dishwashing detergents, fabric softeners, and other lotions and gels. The valves in these pump systems make them sensitive to a number of product types, including:

- Volatile flammables
- Viscous liquids - results in coarse spray or stream
- Strong solvents
- Sterile liquids - sterility is lost at first actuation
- Acidic liquids - acetal valve components dissolve at low pH
- Moisture-sensitive liquids - moisture enters by return air and permeation
- Suspensoid fluids - results in valve plugging
- Foam-type emulsions
- Polyethylene-warping liquids;
- Staining liquids - because of dribble;
- Air- or light-sensitive liquids;
- Two-phase liquids - phases can separate in the valve chamber and be resistant to reconstitution by shaking;
- High-odor liquids - permeates plastic bottles; and
- Thixotropic viscous products.

Despite all these limitations, finger-pump sprayers are the major competitor to aerosols in certain product categories. Table 4-2 lists the types and suppliers of the various pump sprayer dispensing systems.

4.6 DISPENSING CLOSURES (SQUEEZE BOTTLES)

Another aerosol alternative is the screw-threaded closure or cap with a dispensing hole which is plugged shut by various cap features when the product is not in use. Three of these designs are shown in Figure 4-4. A metal can or flexible plastic container is

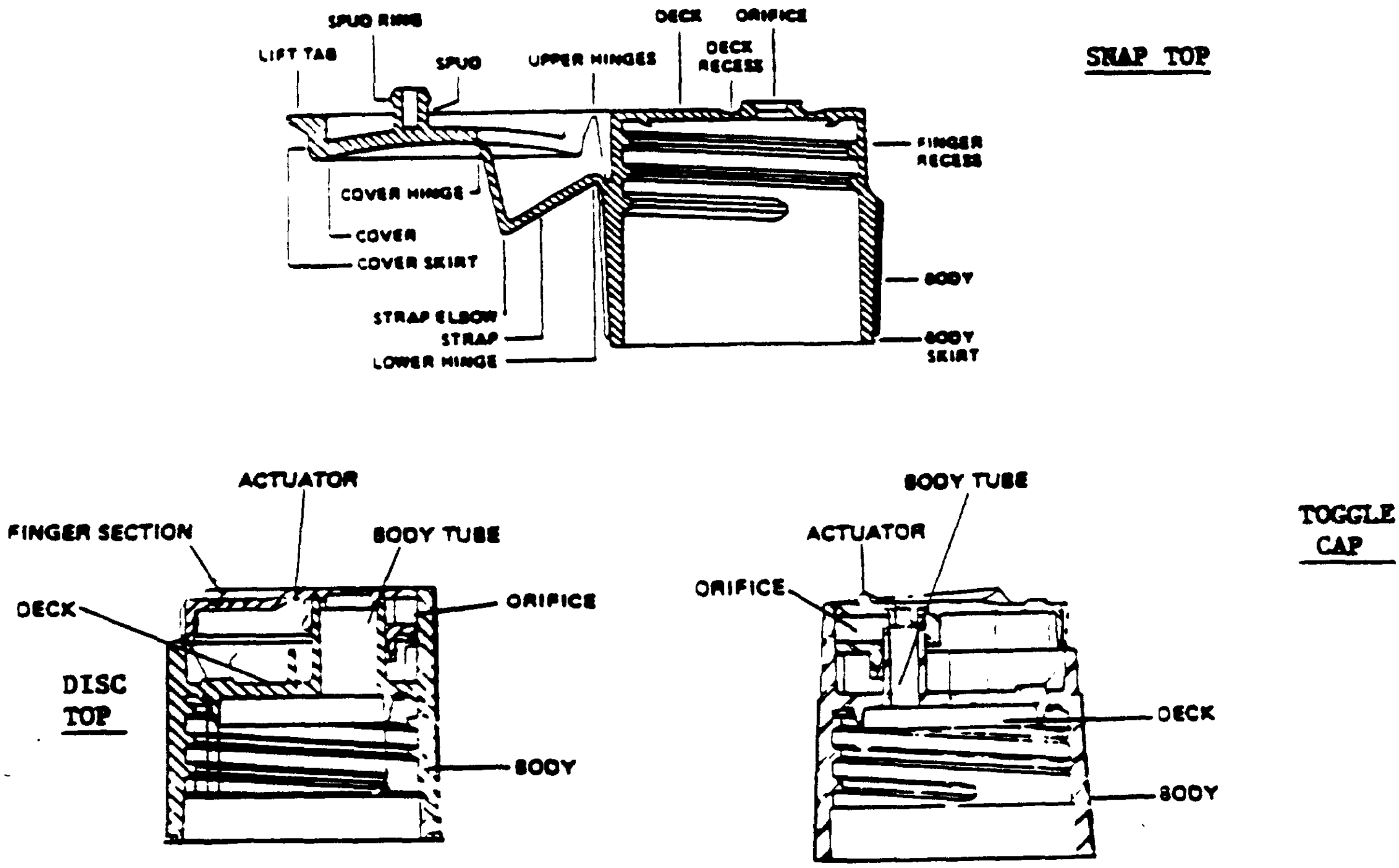


Figure 4-4 Dispensing Closures Made by Seaquist Closures Division

inverted and squeezed to dispense the product. This type dispenser is very efficient, because only the amount of product that adheres to the inside walls of the container will not be dispensed. These units are used for liquids, thin gels, soft creams, and lotions. Some examples are charcoal lighters, cosmetics, toiletries, other personal care products, paint thinners and strippers, furniture polishes, margarine, catsup, mustard, lubricants, carburetor and choke cleaners, silicone shoe and boot dressings, etc. The primary limitation is that the product dispensed in these units must be able to flow freely. Consequently, many of these products may require addition of solvent in order to achieve acceptable performance.

4.7 TWIST-N-MIST II®

The Twist-N-Mist II® (shown in Figure 4-5) is a pressurized packaging system that dispenses the product using energy supplied by manually rotating the full-diameter screwcap and integral piston. This is a propellantless dispenser. Accordingly, the only VOC's will be those associated with the product itself. By twisting the threaded cap several revolutions, the piston is raised, creating a vacuum in the reservoir below. This causes the product to rise through the dip tube, past the stainless steel ball check valve, and into the cavity. The cap is then twisted an equal number of turns in the opposite direction, moving the piston downward, pressurizing the reservoir, and forcing the product into a Buna-N rubber bladder. The "memory" of the elastomer causes the bladder to return to its original shape as the product is dispensed through an aerosol-type valve. This unit dispenses about 95 percent of the product.

This system is currently used for some hair spray products, and the supplier recommends that it be used for personal care, household, industrial, and automotive products. The Twist-N-Mist® was developed and patented by CIDCO Group, Inc. Molds for the hair spray products were produced by Avedon Engineering.

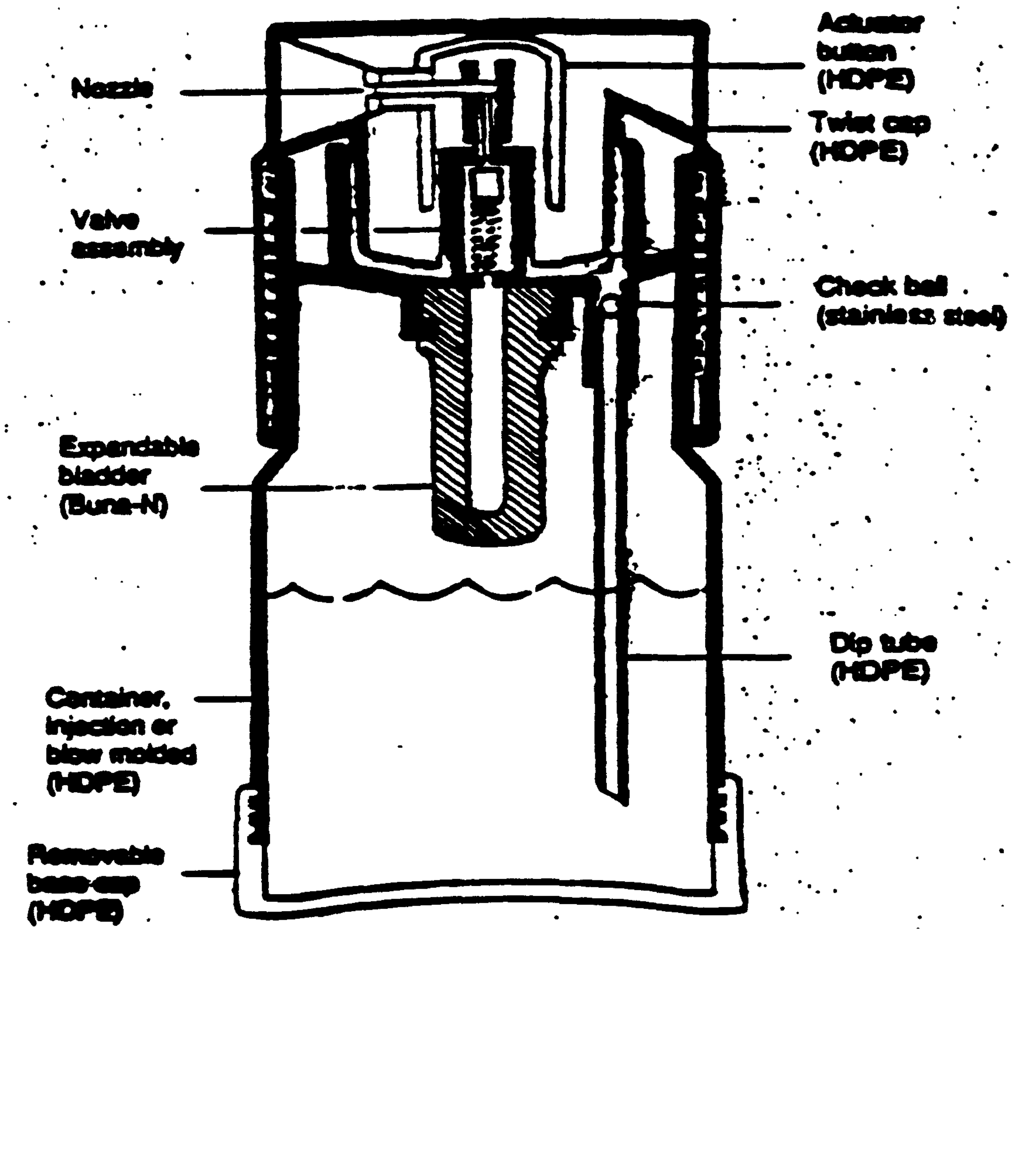


Figure 4-5 Twist-N-Mist II® by CIDCO Group, Inc.

Currently existing drawbacks and limitations of this system include:

- Persistent stress cracking problem
- Inconvenience in that it can require many turns to expel the product
- Products cannot include foams
- Products cannot contain solvents incompatible with the Buna-N bladder
- Product incompatibility with the bladder results in product discoloration or odors.

4.8 THE EXXEL® SYSTEM

Another alternative dispenser is the Exxel® system by Exxel Company, which consists of a thick, elastomeric rubber sleeve whose open end is fitted with a valve and actuator. The product is compressed into an inner PET sleeve and, because of the elasticity of the outer sleeve, is under pressure. Products currently dispensed in the Exxel® unit include welding flux spray, sun oil spray, muscle relaxant, sterile food products, Betadine® topical antiseptic solution, fragrances, hair gel, shampoo and conditioner, and hand and body cream. Skin care, hair care, and pharmaceutical products of the post-foaming gel type are in the developmental stages. The limitations of the Exxel® system include the following product types and/or conditions:

- Solvents such as terpenes and ketones
- Products with pH values over 10.0
- Products containing more than 5 percent isopropanol
- Products containing more than 60 percent ethanol
- Prolonged exposures to temperatures over 113^{o}F
- High surface tension products
- Resins capable of drying and clogging actuators
- Products that require in-package mixing

These product incompatibilities come into play when the product contacts various parts of the unit, including the PET bottle, Nylon 66 valve housing, natural polypropylene/high density polyethylene (HDPE) button, and 302-SS or 316-SS spring. This system also experiences loss of pressure due to loss of elasticity of the sleeve. The pressure loss is smaller for the smaller units (4 fluid ounces) that dispense 92 to 95 percent of the product. The larger units (7 fluid ounces) dispense 92 to 94.7 percent of the product. However, these ranges may be reduced to 90 to 93 percent for viscous products with positive yield points.

4.9 THE MISTLON ECO-LOGICAL® SYSTEM

The Mistlon Eco-Logical® Spray Bottle is a propellantless system in which the product is poured into a bottle fitted with a screw-threaded closure with an aerosol valve and actuator and a polypropylene cap. The base section of the unit contains a hollow cylinder with a one-way compound valve, which functions as a piston within a cylinder protruding into the container, also ending in a one-way valve. To pressurize the air in the container, the base section is pumped a number of times. The maximum pressure achieved is about 100 psig. By pressing a soft diaphragm in the center of the base, excess air pressure within the hollow cylinder is removed. The spray is very coarse. However, the unit can be equipped with a MBU unit to produce a more acceptable spray.

The Mistlon Eco-Logical® system cannot be used for all products. It should not be used for highly flammable formulations or formulations that deform polypropylene or attack polyvinyl acetate. Additionally, its applications are limited in that it cannot be used for direct foam products or highly viscous fluids. This unit is supplied by the MONDEX Trade & Development Corporation in Toronto, Canada.

4.10 AIRSPRAY® SYSTEM

This propellantless system is similar to the Mistlon Eco-Logical® system in that it uses a pumping action to compress air into a pressure-resistant container. This unit is distributed with a refillable screw top or with a disposable crimp-on. The containers can be made of plastic, metal, or glass. When pressurized to the maximum pressure of 55 psig, this unit will dispense up to 100 ml of product before it requires repumping.

The limitations of the Airspray® system are similar to those of the Mistlon Eco-Logical® system. It is not compatible with highly flammable formulations and formulations that deform polypropylene or attack polyvinyl acetate. It should not be used for products that are highly viscous or are direct foams. This unit is marketed by the American National Can Company and Airspray International, Inc. in the United States and by W. Braun & Company in Canada.

4.11 THE SELVAC® SYSTEM

The Selvac® system is a self-pressurized dispensing system. It consists of an aerosol valve, an inner membrane made of butyl rubber to hold the product, and an outer energy storage structure. The outer structure expands when the unit is filled under pressure with the product. When the actuator is depressed, the outer energy structure exerts pressure on the inner membrane and causes the product to be dispensed through the actuator. This system can be used for liquids, pastes, gels, lotions, and creams. Typical products include bath gels, body lotions, deodorants, hair products, shampoo, toothpastes, air fresheners, disinfectants, insect sprays, plant sprays, stain removers, antiseptic sprays, nasal sprays, dental products, topical creams, and flea and tick sprays. The Selvac® system is marketed by the Selvac Corporation.

4.12 THE WERDING NATURE SPRAY® SYSTEM

The Werding system consists of various actuators and nozzles, depending on the product to be dispensed. The Werding 'R' Actuator can be designed to provide a constant delivery rate, regardless of the internal pressure of the unit, thereby making it most useful for products pressurized with compressed gases. The thrust regulator controls flow into the nozzle, where the multistaged, interconnected venturi system results in a higher mechanical breakup effect than conventional actuators. The system also includes two stainless steel accelerator discs, a plastic expansion chamber, and a regulation disc. The design of the regulation disc and the nozzle are responsible for the regulation of the product flow. Under high pressures, the metal disc compresses, and the orifice size increases. This causes an increase in turbulence and a resistance to product flow through the thrust regulator. This ability to accommodate pressure fluctuations results in a constant dispensing rate of the product.

4.13 VAPORIZERS

Vaporizers provide mists or condensation nuclei of the product in the air. Electrically operated vaporizers consist of a wafer containing the concentrate and a small heater that is connected to an electrical wall outlet. As the wafer is warmed, the product is vaporized and released into the air. These units are used primarily for insecticides and air fresheners and are limited to products with appreciable vapor pressures. The wafers are marketed by S. C. Johnson & Son, Inc.; Refinacoes de Milho, Brasil, Ltd.; Bayer, GmbH; and Reckett & Coleman, Ltd.

4.14 STICK AND ROLL-ON APPLICATORS

The stick-in-canister units consist of an outer canister of polyethylene and polypropylene, with a bottom-entering plastic screw that is used to elevate the product in solid form. Roll-on applicators are comprised of a container, a ball, and a screw-on cap. When the cap is in place, the ball fits against a ring seal and depresses a perforated diaphragm beneath it. When the cap is removed, the diaphragm is released, lifting the ball from the sealing ring, and allowing the ball to turn freely. Product is dispensed when the ball is rolled against the skin.

These products include antiperspirants and deodorants, insect repellents, spot cleaners, and analgesics. Sticks and roll-ons are very popular in certain product categories. For instance, in the underarm products area, sticks and roll-ons command a market share of approximately 74 percent, whereas aerosols account for only 23 percent.[1]

4.15 ADDITIONAL CONSIDERATIONS OF DELIVERY SYSTEM SELECTION

This chapter has presented a number of alternative dispensing technologies that could potentially reduce VOC emissions by reducing propellant usage. However, it must be noted that the removal of propellant, which functions as a co-solvent in many products, may require the addition of other solvents to dilute the product concentrate. This may offset any VOC emission reductions achieved through the removal of the propellant. Therefore, each product type must be evaluated to determine whether one or more of these alternative technologies would be suitable for that specific application.

Another factor that needs to be considered when determining the feasibility of various alternative technologies is the potential for emissions or other waste problems from the manufacture or disposal of the containers themselves. Table 4-3 shows the types of materials associated with each system. Materials such as glass and metal are easily recyclable, which reduces the amount of waste generated. Other products such as butyl rubber and plastics are more difficult to recycle. These issues should be considered when evaluating the suitability of the alternative technologies.

TABLE 4-3

MATERIALS USED IN ALTERNATIVE DISPENSING SYSTEMS

Dispensing System	Valve Material	Can Material	Other Components
Sepro Can®	Rubber plug	Aluminum Tinplate	Bag: Conalloy plastic alloy Lamicon
Rocep®	Not available	Tinplate base Aluminum top and wall extension	Plastic piston
Boxal® Pump Dispenser	Not available	Aluminum	HDPE piston
Enviro-Spray Systems®	Not available	Aerosol can	Bag: Laminated aluminum foil, Mylar
Finger Pump	Polypropylene Polyethylene Nickel or SS ball	Clear plastic Plain glass	
Trigger Pump	Polypropylene Polyethylene Nickel or SS ball	Clear plastic Plain glass	
Dispensing Closures	Polyethylene	Metal Plastic	

Table 4-3 (CONCLUDED)

MATERIALS USED IN ALTERNATIVE DISPENSING SYSTEMS

Dispensing System	Valve Material	Can Material	Other Components
Twist-N-Mist II®	SS ball & spring	HDPE	Buna-N rubber bladder
Exxel System®	Nylon Polypropylene HDPE SS spring	Glass Plastic Metal Paper Composites	PET bottle Rubber sleeve
The Mistlon System®		Polypropylene	
Airspray®	Plastic	Plastic Metal Glass	
Selvac®	Not available		Butyl rubber membrane
Werding Nature Spray-Systems®	Not available		SS accelerator discs Plastic expansion chamber
Vaporizers	None		Paper wafer Aluminum foil or PET-laminate
Sticks	None	Polyethylene Polypropylene	

TABLE 4-4 ALTERNATIVE DISPENSING SYSTEMS AND THEIR APPLICATIONS

Delivery System	# of Units Sold (1989)	Insect Sprays	Household Products	Personal Products	Animal Products	Auto/Industrial Misc. Household	Paints & Finishes	Food Products	Misc.
Sepro Can®	52,000,000*		X	X		?		X	X
Rocep®	3,500,000 (projected)		X	X		?		X	X
Boxal® Pump Dispenser	ND		X	X		?		X	X
Enviro-Spray Systems®	ND	X	?	X	X	?		X	X
Finger Pump	>1,000,000,000	X	X	X	X	X		X	X
Trigger Pump	800,000,000	X	X	X	X	X		X	X
Dispensing Closures	ND		X	X		X		X	X
Twist-N-Mist II®	13,200,000 (projected)	?	X	X	?	X			?
Exxel System®	ND	?	?	X	X	X		X	X
The Mistlon System®	ND	X	X	X	?	?			X
Airspray®	ND	X	X	X					X
Werding Nature Spray-Systems®	ND	X	X	X	?	?			X
Vaporizers	ND	X	X			X			
Sticks	310,000,000*	X	X	X					X

* Considerable decrease in sales is expected
ND No data available
? Potential application

In general, most alternative dispensing technologies currently do not enjoy a large market share. This is primarily because of high cost, lack of consumer acceptance, or narrow product applications. Without changing consumer market demands, these technologies are likely to continue to represent only a small portion of the consumer product industry.[2] Table 4-4 lists the various alternative technologies, identifies the product share for each, and indicates which consumer products could reasonably utilize the technology.

4.16 REFERENCES

1. Radian Corporation. *Report to Congress - Volatile Organic Compound Emissions from Consumer and Commercial Products - Underarm Deodorants and Antiperspirants*. Draft Report, December 1991.

2. Meeting of the National Aerosol Association and U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Durham, North Carolina. May 7, 1991.

SECTION 5.0

CHARACTERISTICS OF SELECTED AEROSOL PRODUCTS

5.1 INTRODUCTION

Many different consumer products are dispensed via aerosol delivery systems. Each product is packaged in an aerosol form for a specific reason. This chapter summarizes the attributes of the aerosol packaging form for selected consumer products. The feasibility of using alternative dispensing technologies and non-HC propellants is also discussed.

5.2 PERSONAL CARE PRODUCTS

5.2.1 Hair Sprays

Aerosol hair spray formulations are single-phase (the propellant is in solution with the product). The solvent content (typically ethanol) of hair sprays is 60 to 70 percent. The ethanol is used to solubilize the film-former resin and allows the spray to dry rapidly.

Hair sprays are available in mechanical pumps and in other propellantless containers such as the Exxel® container. Only one comparison has been made of the effect on emissions of switching from aerosol hair sprays to mechanical pumps or Exxel® containers (a California Air Resources Board [CARB] report by American Research and Testing).[1] For adult users, more emissions resulted from aerosol products than for the mechanical pumps. However, this was not true of teenage users. Teenagers using the pump sprays tended to use more product per application, resulting in more emissions than the aerosol package. The mechanical pumps are also less popular because of wet spray, finger fatigue during use, and occasional plugging of the meter spray valve. Hair sprays have been converted to water-based formulations using DME, thus decreasing the amount of ethanol required. In general, compressed gases cannot be used because the propellant also serves as a solvent in the product.

5.2.2 Shaving Creams

Aerosols are the packaging of choice for shaving cream. Aerosol products make up about 90 percent of the shaving cream market. These products are valued for their performance. Simply pushing a button generates a foam lather that improves the razor shave and reduces the number of nicks and cuts. The newer gels also use a HC propellant, but the propellant is injected under a piston in the container and does not come in contact with the product. Shaving creams are water-based formulations; therefore the VOC content of the product is very low. Dimethyl ether is not used as a propellant because it does not produce a foam.

Alternatives include tubes and mugs. These products are mixed with water and applied to the skin with a brush. These products require more preparation than the aerosol products. Compressed gases are not used because they produce a very satiny foam that has not proven to be marketable.

5.2.3 Underarm Antiperspirants

Aerosol antiperspirants are popular with consumers because they produce a dry spray and household members can hygienically share the dispenser. The aerosol antiperspirant accounts for approximately 18 percent of the underarm product market share.

Antiperspirants are also available in semisolid stick, liquid roll-ons, and saturated pads. All of these alternative forms have lower VOC contents than the aerosol form. Compressed gases cannot be used in these products because the HC propellants are critical to the distribution of the product on the skin surface. If compressed gases were used, the formulas would drip and run down the body.

5.2.4 Underarm Deodorants

Aerosol deodorants are popular with the consumer because the spray has a dry feel and the user can share the dispenser with other household members. Aerosol deodorants account for approximately 4 percent of all underarm products. Deodorants are also available in both semisolid stick and liquid roll-ons. Both of these products have fewer VOC's than the aerosol alternative. Compressed gases cannot be used for this product for the same reasons identified for underarm antiperspirant. Some products are available as water-based formulations that use DME as a propellant.

5.2.5 Medicinal Products

This category consists of a wide variety of products and makes up only 1.1 percent of the aerosol market. Examples of pharmaceutical products include metered dose inhalants, such as steroids and adrenergic bronchodilators, hair restorers, skin chillers, and medical solvents. Because of the variety of products, it is difficult to make general statements about why these products are packaged in aerosol sprays. Some medicinal products can use CFC propellants because they are exempt from the 1978 ban on CFC's for aerosol products. These products are often ingested or inhaled, therefore toxicity of the propellant is very important. Another option may be the use of compressed gases, such as CO_2 or compressed air. Nitrous oxide, also known as "laughing gas," cannot be used because of the physiological effects of the N_2O.

5.2.6 Hair Lusterizers

Hair lusterizers are used especially by persons with very curly hair. These products do not contain the film-forming resin found in hair spray, but they contain silicone fluid or mineral spirits to convey a sheen or a look of healthy hair. No data are available on alternative dispensing technologies or on the possible use of compressed gases. These products are also available as water-based products using DME as a propellant.

5.2.7 Hair Mousse

Hair mousse is a relatively new product designed to provide both hair setting and conditioning qualities. Hair mousse (French word for "foam") is a water-based formulation that employs a specialty polymer to achieve this goal. An aerosol dispenser is needed to generate the foam structure. No data are available on alternative dispensing technologies. Compressed gases cannot be used because they will not produce a quality foam.

5.2.8 Colognes and Perfumes

Aerosol colognes and perfumes are used for convenience. The aerosol dispenser can produce a consistently fine spray pattern, with good directional control. Alternatives to aerosol colognes and perfumes include air-aspirated sprays and dab-on liquid concentrates. Compressed gases could be used as an alternate propellant. However, spray patterns would be adversely affected and higher pressures may preclude the use of glass containers which are generally preferred by consumers.

5.2.9 Other Personal Products

This is another category that also contains a wide variety of products and represents only 0.1 percent of the aerosol market. Some examples include suntan lotions, body mousses, and depilatories. Because of the variety of products, it is difficult to make general statements about why these products are packaged in aerosol sprays or about alternative dispensing technologies. These products can be propelled with HC's, DME, or compressed gases. Alternative packaging forms, such as lotion, liquids, etc., could also be used. However, these decisions must be made for each specific product.

5.3 HOUSEHOLD PRODUCTS

5.3.1. Room Deodorants and Disinfectants

Room deodorants and air fresheners are packaged in an aerosol form because the aerosol spray results in small particles, which remain airborne longer. The aerosol product can be dispersed in a large room very quickly with rapid results. In the case of disinfectants, the aerosol spray allows the consumer to apply the product in concentrated form into wastebaskets, trash cans, and other surfaces.

Room deodorizers could be marketed in containers such as Exxel® and mechanical pumps. The primary consideration is whether the dispenser can produce small particles that will stay suspended. Solid room deodorizers are also very popular products, second only to the aerosol form in market share. There are also liquid deodorizers, such as "Air-wick®." No comparisons have been made to quantify the difference in VOC emissions from these alternate technologies.

Disinfectants are also available in liquid form, usually as part of a cleaning solution. The effectiveness of a disinfectant product depends on the amount of active disinfectant in the formulation. The purpose of the aerosol package is to make the product more effective, efficient, and easy to use. Therefore, whether to use the product as an aerosol or in the liquid form is a matter of application requirements. However, the aerosol packaging form may result in less product waste, thereby decreasing the total VOC's emitted.

Most current deodorizing and disinfectant sprays are propelled by compressed gas. However, formulation data shows that the HC-propelled products have lower VOC contents for the same product weight.[2] Additionally, the spray from the compressed gas products may not be as uniform as the two-phase HC propellant products. Another alternative for reducing VOC emissions from these products is reformulating them as water-based formulations. One of the more popular air fresheners is already using a water-based formulation.

5.3.2 Window Cleaners

Window cleaners are typically water-based formulations with 5 to 15 percent VOC (alcohol) and a small amount of detergent. Aerosol window cleaners are convenient products for those who do not want to use a trigger pump or finger pump dispenser. Aerosol glass cleaners usually dispense a foam that does not drip or run as quickly as the mechanical pump products, thereby making the product more efficient. Window cleaners that use the finger or trigger pump dispenser are more popular than the aerosol product, because they are usually less expensive than the aerosol versions.

No comparisons have been made to evaluate the effect on VOC emissions of switching from mechanical pumps to aerosol sprays. These products could be propelled with compressed gases. However, the compressed gases will not produce a foam, which is a major selling point for the HC-propelled product. Dimethyl ether propellants are not used because the formulation is already a water-based formulation.

5.3.3 Oven Cleaners

Aerosol oven cleaners are convenient products for cleaning a dirty oven. Cleaning an oven with an aerosol product takes less time than with liquid abrasive compounds. Furthermore, many of the newer oven surfaces are not made to withstand cleaning with abrasives. Oven cleaners are often formulated with very caustic, anhydrous chemicals. Therefore, the aerosol product has the further advantage of minimizing the contact of the consumer with the chemicals. Most aerosol oven cleaners do not contain large concentrations of VOC's (only 5 to 6 percent HC propellant) because of the flammability potential when exposed to an oven pilot light.

The most popular alternative to the aerosol oven cleaner is the self-cleaning oven. This does not require the use of chemicals. Baked-on grease and food on the inside of the oven is baked off at high temperatures. One possible drawback of this alternative is that VOC's are be emitted when the grease and food is volatilized. Other alternatives include oven cleaner pads and brush-on oven cleaners. However, unlike these alternatives, the aerosol oven cleaner allows the consumer to apply a uniform coating of foam to the entire interior of the oven. There are no data to determine the applicability of alternate dispensing technologies.

5.3.4 Hard-Surface Cleaners

The aerosol hard-surface cleaner is used in various cleaning duties, such as bathroom and kitchen cleaning. Often the aerosol product is dispensed as a foam. These products are convenient to use because they require no mixing or dilution and can be used immediately. The aerosol package allows the consumer to apply a uniform coating of cleaner to the entire surface. Also, the aerosol-generated foam does not drip or run as fast as the liquid products. Hard-surface cleaners are all water-based formulations and contain 10 to 25 percent of VOC's.

Alternative dispensing technologies include liquids, powders, and mechanical pump sprays. Aerosol products have a mid-level market share compared with these other dispensing technologies. These alternative package forms may be more difficult to use because it is more difficult to apply a uniform coating of the cleaner. However, no specific comparisons have been made to evaluate the different level of emissions resulting from using the aerosol products versus the other packaging forms.

5.3.5 Carpet and Rug Cleaners

Aerosol carpet and rug cleaner is used for both small and large carpet cleaning. For example, some consumers may use these products to clean a spill on a small area of carpet, and some may use them to clean the entire carpet. These products are convenient to use since the cleaning materials are already premixed in the correct proportions. When the products are used according to directions, they are capable of providing results better than vacuuming alone, but probably not as good as professional cleaners. Another advantage is that the aerosol package allows the consumer to apply the cleaner at any time. Immediate treatment may prevent the stain from setting, which might otherwise require professional cleaning. These products are already water-based formulations and contain only 5 to 10 percent HC propellants.

Alternatives include mechanical pump sprayers, liquid and dry spot removers, rented cleaning equipment, and professional rug and cleaning services. The mechanical pumps will not produce a foam, which is an important feature of the aerosol package. The latter options are typically more expensive than using aerosol products. No comparisons have been made to evaluate the effect on emissions from switching from the aerosol package to the mechanical pump. Compressed gases are not used because the can must be inverted when applying the product to the carpet.

5.3.6 Spray Starch Laundry Products

Spray starch is applied to clothes before they are ironed to keep clothes neat and crisp. The aerosol spray starch is the most popular form of starch application, mainly because it is always ready to use. Another advantage of the aerosol package is that it is better suited to maintain sterile conditions that are needed to prevent the growth of microorganisms. The starches are water-based formulations, therefore, the only VOC emissions are associated with the propellant (some products contain 5 to 9 percent HC propellant). Other spray starches use compressed gas as a propellant.

Alternatives to the aerosol form include mechanical pumps, bulk starches, and professional laundering services. The mechanical pump technology is easy to use but it does not produce as fine a spray as the aerosol product. The bulk or powder starches require extensive preparation. Laundering services are more expensive than self application. None of these alternatives will result in VOC emissions.

One evaluation of aerosol versus nonaerosol starch products has been made for the CARB. This study showed that the aerosol products were the easiest to use. Nonaerosol pumps were the next easiest. The bulk starches were found to be the most efficacious per unit cost, but consumer acceptance was very low because of the inconvenience.

5.3.7 Fabric Finish Laundry Products

Aerosol fabric finish is used to obtain the same crisp feel of starch with less stiffness. These products were originally developed especially for synthetic (polyester) blends, but they can also be used with straight cotton or high-cotton blends. No data are available on alternatives to the aerosol fabric finish. However, these products could possibly be adapted to mechanical pump dispensers.

5.3.8 Pre-Wash Laundry Products

Aerosol pre-wash products are used to remove stains or to pretreat excess dirt. These products contain a mild detergent or a solvent (paraffinic HC) for stain removal. An aerosol pre-wash may contain up to 30 percent water in the formulation.

Alternative dispensers include mechanical pumps sprays and semisolids (sticks). Only one comparison has been made of the efficacy of aerosol, pump, and direct-delivery laundry pre-wash products. Again, American Research and Testing performed the study for CARB. The study showed that stain-removal efficacy was dependent on the stain and the fabric. The aerosol formulation had improved performance on oily stains.

Nonaerosol products were more effective in removing tea and grass stains. There are no data to evaluate the use of compressed gas.

5.3.9 Furniture Waxes and Polishes

Aerosol furniture wax and polish are the most popular forms of these products. They are convenient, allowing the user to spray a uniform amount of wax over the entire surface. The furniture polishes are water-based formulations that contain silicone emulsions.

Alternatives include mechanical pumps and semisolids (paste wax). No comparisons have been made of the effect on emissions from the aerosol form versus emissions from the mechanical pumps. The primary drawback to paste wax is the difficulty of application and removal. Compressed gases may be an option, but there may be problems because the containers need to be used at all angles.

5.3.10 Furniture Cleaners

Aerosol furniture cleaners are used for cleaning cabinets, paneling, and other surfaces that have relatively thin varnished or lacquered surfaces. These products are anhydrous because the water can penetrate the wood and deteriorate the finish. Alternatives to HC-propelled cleaners include mechanical pumps, liquid forms, and compressed gas propellants. Because all of these alternatives probably consist of similar formulations, possibly little or no reduction in VOC emissions would occur.

5.3.11 Other Household Products

Other household products include shoe polishes, dyes, leather dressings, antistatic sprays, and caulking and sealing compounds. These products are so diverse that no general statements can be made as to what specific alternatives would be applicable.

There may be some alternate dispensing technologies that are applicable, such as mechanical pumps for antistatic sprays and dyes. Almost all of these products are also available in other package forms such as creams and lotions. There are no data to determine whether compressed gases could be used, nor is there any information concerning water-based formulations.

5.4 AUTOMOTIVE/INDUSTRIAL PRODUCTS AND HOUSEHOLD LUBRICANTS

A segment of the aerosol industry supplies products to the industrial sector. These products are consumed during the manufacture of other products and are not sold in ordinary consumer outlets. While generally priced higher than normal aerosol products, these aerosols provide a safe, effective solution to many industrial needs. The alternative to these aerosols would be products of equal or similar VOC content which may not be as safe or efficient as aerosols.

5.4.1 Lubricants and Silicones

This category includes penetrating oils, demoisturizers, rust proofing, and mold releases. Penetrating oils are a major product category. These products (such as WD-40®) contain mineral or silicone oils, additives, and a small amount of propellant. One of the features of the aerosol package form is that an extension tube can be attached to the actuator to direct the spray into otherwise inaccessible areas. The other products in this category have uses outside the consumer product area.

The oil can is the most common alternate dispensing technology for the heavier and more-viscous products. However, the lighter and less-viscous oils cannot be dispensed with an oil can. No data are available to determine if non-HC propellants can be used with these products.

5.4.2 Carburetor and Choke Cleaners

Carburetor and choke cleaners consist of approximately 60 percent toluene or xylene, 30 percent acetone or alcohol, and 10 percent HC propellant. The active ingredients are flammable solvents, so the aerosol package can provide desirable safety qualities. The performance and efficiency of the aerosol package is good, because the valve can be fitted with an extension tube to allow the consumer to spray otherwise inaccessible areas, with little overspray.

These products are also marketed as liquids and gas tank additives. The liquids are essentially the same solvents as the aerosol version. However, because it must be brushed on, more waste may result from spillage during application. The gas tank additives cannot replace the aerosol product because it will only clean the internal parts of the carburetor. They will not free sticking linkages on the outside. Professional carburetor cleaning is also an option. It often involves complete disassembly and replacement of gaskets and seals. Also, auto mechanics generally use a solvent degreaser (cold cleaner) for parts cleaning. This alternative is more expensive than the aerosol product and may emit VOC's as well. The carburetor cleaners could not be reformulated as water-based products because the efficacy of the product depends on how well the formulation dissolves grease and shellac buildup. Water will not act as a solvent for these compounds. Additionally, it is undesirable to contaminate a carburetor with water. These products may be able to be propelled with compressed gases.

5.4.3 Engine Starting Fluid

Aerosol engine starting fluid consists of diethyl ether (90 percent), plus CO_2 propellant. This product is used to help start gasoline and diesel engines, especially in cold weather. The aerosol package is an essential part of the safety of the product, because the ether is highly flammable. In a liquid form there is a danger of spillage or using too much liquid, which could cause an explosion or a fire in the carburetor. In addition, much of the liquid product would be lost to evaporation, resulting in VOC emissions.

5.4.4 Tire Inflator and Sealants

A tire inflator consists of a water dispersion of resin, ethylene glycol, a trace of surfactant, and approximately 25 percent propellant. These products allow the consumer to seal and reinflate a flat tire, thus avoiding a costly and time-consuming tow truck call. The tire can then be removed from the car at a later, more convenient, time. This product is only available as an aerosol. The only alternative to HC propellants is a fluorocarbon propellant. Some of the higher-pressure HCFC's could be used.

5.4.5 Cleaners

This category consists of automotive upholstery cleaner, leather and vinyl cleaner, whitewall tire cleaner, and tire dressing. These aerosol cleaning products may dispense in the form of a foam or a mist. The foaming action (upholstery cleaner) is intended to improve the product efficacy by decreasing the tendency for the product to run or drip on vertical surfaces. The foam is then scrubbed into the surface and rinsed away. The whitewall tire cleaner may contain deodorized kerosene, so the aerosol package allows a safe method for handling the flammable material. The tire cleaners may also contain dangerous ingredients (caustic material), which make the aerosol dispenser an ideal package because it will limit the contact a consumer has with the dangerous chemicals.

Most of these products are also sold in mechanical pump packages. Some leather cleaners are sold in cream or lotion forms. No information is available for determining the effect on emissions of switching from HC-propelled products to mechanical pumps, creams, or lotions. Some whitewall tire cleaners may be propelled by CO_2.

5.4.6 Brake Cleaners

Aerosol brake cleaner consists of either alcohol (methanol or ethanol) or chlorinated solvents and an HC or compressed gas propellant. It is used to clean parts on hydraulic brake systems. The aerosol package is an essential part of the product efficacy, since the solvent is sprayed quickly and forcefully from the can. The aerosol also has safety advantages, since the solvents may be toxic. An alternative is to brush on a solvent. Because the solvent content of the aerosol and liquid product is similar, differences in VOC emissions would depend on possible spillage and waste during cleanup.

5.4.7 Engine Degreasers

These products consist mostly of deodorized kerosene, xylenes, and a small amount of surfactant. The aerosol form allows the consumer to uniformly spray the degreaser over the engine. After the solvents have had time to dissolve the deposits, the consumer simply hoses off the engine with running water.

Alternatives to the aerosol form of degreasers are steam cleaning and self-service cleaners (coin-operated car washes). Both of these options are less convenient, because the consumer has to either pay for the engine to be cleaned professionally, or has to drive to an establishment that offers self-service cleaning facilities. An alternative to HC-propelled degreasers are CO_2-propelled products, which may be preferred over HC propellants in that flammability may be reduced. The formulation of the engine degreaser is designed to act as a surfactant that will allow grease to be soluble when washed. Therefore, a water-based formulation may not work as effectively.

5.4.8 Spray Undercoating

Spray undercoating is used by consumers to add a sound-deadening or corrosion-resistant layer to the automobile underside. This aerosol product is a substitute for professional undercoating and costs much less. The undercoating consists of approximately 50 percent pigments and solids and 50 percent solvent/propellant.

Alternatives to the aerosol product include brush-applied and commercially applied undercoatings. The brush-applied alternative would reduce product efficacy because of the difficulty in reaching all areas underneath the automobile. Because the undercoating is only effective if it covers all exposed surfaces, brush application might allow corrosion to occur. Also, the brush-applied method may require a substantial amount of solvent to be used for cleanup. Professionally applied undercoatings are more expensive than the consumer-oriented aerosol product. No data are available on non-HC (compressed gas or DME) propellants used with the products currently on the market.

5.4.9 Windshield and Lock De-icers

De-icers typically contain methanol as the primary active ingredient. The aerosol package allows the consumer to safely use the toxic material. Also, the sealed can ensures that the volatile methanol does not evaporate. At least one windshield de-icer formulation is propelled with CO_2. Compressed-gas propellants are well suited for use in cold conditions because the inside can pressure is not as affected by low temperatures. The vapor pressure of liquified gas propellants is suppressed by low temperatures. As with all products that use compressed gas propellants, the consumer must be careful to always operate the can in the upright position. Because the product is used in cold weather, water-based formulation would have problems, such as freezing.

5.4.10 Other Automotive and Industrial Products

This category consists of a wide variety of products that make up a very small portion of the aerosol market. Because of the variety of products, it is difficult to make general statements about why they are packaged in aerosol sprays or about alternative dispensing technologies.

5.5 PAINTS, PRIMERS, AND VARNISHES

Aerosol spray paints are marketed as being more convenient, less messy, and faster to use than brush-on paint. For many applications, aerosol paints result in a higher-quality finish than brush application. Also, aerosols do not require an expensive air compressor and spray gun to apply a high-quality paint finish. Aerosol spray paint is especially useful when painting irregular surfaces.

Brush-on paint is available for many types of finishes. Conventional spray equipment (air compressors and spray guns) are used by professionals. Preliminary tests by the aerosol paint industry show that despite the high VOC content of aerosol spray paints, VOC emissions may be less than with other methods of application if emissions from cleanup solvent emissions are considered.

The formulation of an aerosol paint is single-phased and contains a HC propellant. That is, the propellant is dissolved in the formulation and acts as a solvent. Therefore, compressed gas is not an alternative. An alternative may be to use DME, which may allow reformulation to lower-solvent-content paints.

5.6 INSECT SPRAYS

All insecticides, such as total release foggers, crack and crevice residual insecticides, and wasp and hornet sprays, etc., are registered with the federal government. Any change in content will require testing and extensive administrative time and effort to accomplish the new registration. Toxicity and efficacy studies require EPA registration and approval under the Federal Insecticide, Fungicide, and Rodenticide Act. Any changes would be very costly (>$100,000), and this cost would be passed on to the consumer.

5.6.1 Space Insecticides

Space insecticides include flying insect killer, house and garden spray, total release room fogger, patio fogger, and wasp and hornet spray. These products are packaged in aerosol form because of the unique spray characteristics. In the case of a flying insect killer or a house and garden spray, a fine particle size and good dispersion is needed so that the chemical remains airborne long enough to come into contact with the insects. Foggers are only possible because of the aerosol package because a very fine particle size is needed to penetrate all areas of a room. Wasp and hornet sprays must have a powerful, consistent propellant to produce a stream of insecticide that will contact the insect up to 20 feet away. A further advantage of the aerosol package is that the sealed, premixed aerosol package eliminates the need for the consumer to handle the toxic ingredients.

Before the development of aerosol insecticides, the hand-operated "FLIT" gun was used to disperse the insecticide. A more recent product was the "No-pest" strip that is essentially a controlled release package. Both of these technologies have been abandoned in favor of the aerosol package because of the efficiency and ease of use of the aerosol product. Another alternative available to the consumer is a professional exterminator. The exterminator is much more expensive than an aerosol product, and is usually only used for severe insect problems.

In the past, space insecticides were propelled by CFC's. Currently, with few exceptions, they are propelled by HC propellants. Some of the wasp and hornet sprays are pressurized with compressed gases. Expanded use of compressed gases is hampered by the problem of the degrading spray pattern resulting from the decreased pressure as the product is used up. This could be especially critical with wasp and hornet spray, since it is important that the product deliver a full force all the time.

Historically, insect sprays have employed solvent-based formulations. Recently, with the increased use of DME as a propellant, manufacturers have started marketing more water-based products. In some instances, however, safety concerns regarding electrical applications may need to be addressed (e.g., the use of wasp and hornet sprays in proximity to high voltage electrical apparatus). This trend should help reduce the amount of VOC's emitted from space insecticides. Dispensing technologies that could be used include "FLIT" guns and insecticide strips. However, presently no data are available to evaluate the effect of these alternative dispensers on reducing VOC emissions.

5.6.2 Residual Insecticides

Residual insecticides include ant and roach killer and premise sprays (carpet, bedding, furniture, etc.), and wasp and hornet sprays. Ant and roach killers require a fine spray to penetrate cracks and crevices where the insects live. Dispensing technologies other than aerosol sprays are available. Ant and roach killers are available in dry poisons and bait traps. These residual insecticide products are a also available in mechanical pump dispensing containers. Other dispensing technologies that could be used include Airspray® and Werding Nature Spray®.

With few exceptions, residual insecticides are propelled by HC propellants. Dimethyl ether could possibly be used so that the products could be reformulated as water-based products. Compressed gases are not used because of limitations on operation at some angles or inverted positions. Also, a consistent and fine spray pattern is needed throughout the life of the product, and compressed gas propellants are characterized by degrading spray pattern as the product expended.

5.6.2 Insect Repellents

Insect repellents are products that are sprayed on the body. Some of these products are packaged in the aerosol form, mainly because of convenience. Personal insect repellents require a fine spray to apply the action chemical uniformly to the desired surface. Personal repellents are available in sticks and lotions, which can be an attractive option because the transfer efficiency of a lotion is virtually 100 percent, whereas the transfer efficiency of sprays is only about 65 percent. No data are available to determine the effect of these alternative dispensing technologies on reducing VOC emissions.

5.7 FOOD PRODUCTS

These products include pan sprays, whipped cream, cheese topping, and cake decoration. They are packaged in the aerosol container mainly for convenience. The major product in this category is pan and flavoring sprays that consist of corn oil, alcohol, lecithin, and HC propellant. The HC propellant is essential to the product because it lowers the viscosity of the mixture. The pan spray is valued for its health benefits (low fat, no cholesterol) and is a popular substitute for butter or margarine. Whipped cream is the next most popular aerosol food product.

Conventional bottled vegetable oil is a substitute for the pan sprays. Synthetic whipped toppings are available in plastic tubs. Cheese toppings and cake icing are also available in pre-prepared nonaerosol packaging. Besides these pre-prepared products, all of these products can be made in the kitchen.

Whipped cream is propelled by N_2O. The minor products (cheese topping and cake icing) are packaged in piston cans that may be adaptable to compressed gas propellants. It may not be feasible to replace HC propellants in the pan and flavoring sprays with compressed gases because these alternative propellants will expel the products in a solid stream unusable by the consumer.

5.8 ANIMAL PRODUCTS

This category includes flea and tick killer, veterinary products, and shampoos. Flea and tick killer sprays are similar to other insect sprays. These products are desirable for their ease of use and ability to uniformly cover the pet's entire body. No data are available on veterinary products.

Flea and tick killers are available in liquid form, mechanical pumps, powders, and treated collars. The powders are less desirable from a consumer's point of view because uniform coverage of the pet is difficult to achieve. The mechanical pumps can be difficult to use on larger animals because of finger fatigue. No data are available to estimate the effect on emissions of switching from aerosol flea and tick spray to a mechanical pump spray. Also, because the container may have to be inverted to spray some areas of the pet, a compressed gas propellant is not an attractive option.

5.9 MISCELLANEOUS PRODUCTS

This category covers products that do not fit into other categories. Examples include skin chillers and cleaners, boat/air horns, computer tape developer, electronic diagnostic chillers, herbicides, and fungicides. Propellants for these products include CFC's (exempted for these applications) and VOC's. This category is so diverse it is difficult to make general statements concerning alternatives. Options might include compressed gases, water-based formulations, mechanical pumps and alternate packages.

5.10 REFERENCES

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SECTION 6.0
CONCLUSIONS

This study of aerosol products and packaging systems was undertaken in order to present information on (1) the functions, attributes, and applications of aerosol consumer and commercial products; (2) the technology associated with aerosol delivery systems and the functions and interactions of the system components; and (3) possible opportunities for reduction of emissions of VOC's from these products, primarily through reduction in their VOC content. Based on the information available at the time of the study, the following conclusions were reached:

1. Consumer products are dispensed in aerosol form for specific reasons that relate to each product. Some of the reasons include controlled application, consumer health and safety, and consumer convenience.

2. Aerosol products function as systems comprised of the product, the propellant, the valve, and the container. The product and propellant comprise the formulation. As in any system of interrelated components, modification of one or more system components must be carried out judiciously in order to preserve the functionality of the system. Consequently, seemingly expeditious measures to reduce the VOC content of aerosol products (e.g., changing from an aerosol to a mechanical pump spray, switching to non-VOC compressed gas propellants, changing to water-based formulations, etc.) may not achieve the desired results in many cases.

3. Alternative dispensing technologies are available to reduce the VOC content (and emissions) of various products while allowing the products to be delivered as a spray or mist. However, each of these technologies has limitations, sometimes including increased VOC levels, and none of these technologies can be applied to all products.

4. A widely held misconception is that most aerosol products employ CFC's as propellants and contribute to stratospheric ozone depletion. While a very small number of aerosol products are propelled by CFC's (e.g., pharmaceuticals, military specification products, aviation products, etc.), these uses are exempt from the 1978 ban on the use of CFC's in aerosol products. The vast majority of aerosol products currently employ hydrocarbons (propane, n-butane, and isobutane) and dimethyl ether as propellants.

5. Considering the complexity of the interactions among the components of aerosol packaging systems, the variety of specific functions that aerosol products fulfill in individual product categories, and the difficulty in achieving across-the-board VOC reductions from aerosol products, it may be inappropriate to consider aerosol products a discrete category of products for regulatory purposes. The most realistic and manageable approach may be to consider the aerosol delivery system as one of several packaging forms available in each separate category of consumer and commercial products regulated. Using this approach, opportunities for VOC reductions through reformulation, change in delivery method, use of alternative technologies, etc. could be evaluated on a product by product basis.