

# FINAL REPORT

## VINYL CHLORIDE MONOMER EMISSIONS FROM THE POLYVINYL CHLORIDE PROCESSING INDUSTRIES

*prepared by*

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ENVIRONMENTAL PROTECTION AGENCY  
CONTROL SYSTEMS LABORATORY  
DURHAM, NORTH CAROLINA 27711

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The success of this program was totally dependent upon our being able to obtain data from resin manufacturers, compounders, and fabricators. Most manufacturers were extremely cooperative, both in allowing us to inspect their operations and in giving us their data. We would like to acknowledge this help and to thank these manufacturers for their time and effort.

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## SUMMARY

The recognition of the potential link between the exposure of workers to vinyl chloride monomer (VCM) and the development of angiosarcoma of the liver has resulted in the Occupational Safety and Health Administration setting standards to limit the exposure of plant workers to VCM. These standards are expected to result in controls which reduce the concentration of VCM in plant air to very low levels. However, the ventilation methods used as one major route to meeting the OSHA regulations in no way reduce the total amount of VCM emitted from the plants to the atmosphere. There is therefore still concern about the effects of VCM emissions on the non-worker population in communities surrounding PVC production and fabrication plants.

The purpose of this present study was to attempt to quantify the extent of VCM emissions from polyvinyl chloride processing plants, including both compounders and fabricators who process the compound--through the melt or solvent phase--into semi-finished products.

In this report, we discuss the structure of the PVC processing industry, and document the emissions from each segment of the processing industry. Emissions are categorized primarily by the type of fabrication process. Data on emissions were obtained from interviews with resin producers, compounders, and fabricators. The primary approach to the estimation of emissions was the classic material balance. The VCM content of resins entering each process step was estimated, and the amount of monomer in the product emerging from each process step was separately estimated. The difference in VCM concentration between the material entering and exiting from each process step was used to estimate the VCM losses. Total nationwide emissions, by process, were then obtained by multiplying the VCM lost per kilogram at each process step by the total amount of material processed each year by that process. Since the residual VCM levels in resin are constantly changing as manufacturers seek to minimize them in order to minimize worker exposure to the monomer in fabrication plants, we used late 1974 levels of residual monomer as the basis of these calculations.

Table S-1 shows the total U.S. emissions of VCM from polyvinyl chloride processing, categorized by process. As shown by this table, the predominant emissions arise from the compounding portions of the processing operations. VCM emissions from later processing operations are negligible. Table S-2 compares the annual VCM emission rates from PVC processing with the emissions from vinyl chloride monomer production and from polyvinyl chloride polymerization. Emissions from compounding and subsequent fabrication processes together account for less than one-half of one percent of the total U.S. emissions.

At present there is no external control equipment used to limit VCM emissions from compounding and fabricating facilities. Although such controls as carbon adsorption and scrubbing have been considered for VCM emissions from polymerization plants, their application to compounding and fabricating facilities appears economically impractical because of the low levels of VCM in exiting air from these facilities. Compounding is the only step in the fabrication process where some external controls may be warranted, specifically in the dry-blending portion of the operation. However, such controls as may be practical run counter to the current high-ventilation trend in operation used to limit in-plant emissions.

The most promising control technique to limit VCM emissions to the atmosphere from compounding and fabricating facilities appears to be further reduction of residual monomer levels in resin input to these operation. At present, resin manufacturers are modifying their processes to reduce these levels in order to aid their customers (compounders and fabricators) in complying with OSHA regulations. The effect on external emissions from compounding and fabricating facilities is expected to be substantial. Table S-3 shows the estimated average residual VCM levels which manufacturers expect to achieve by 1975 and by 1980; the total annual U.S. emissions of VCM expected from compounding and fabricating facilities using those resins is also shown.

TABLE S-1

TOTAL U.S. EMISSION RATE OF VCM FROM POLYVINYL CHLORIDE PROCESSING

<u>Process</u>	<u>Estimated VCM Emission Rate* kg/year</u>	<u>(lbs/yr)</u>
<u>A. Flexible PVC</u>		
1. Compounding	220,000	(480,000)
2. Extrusion	<3,000	(<6,000)
3. Calendering	<4,000	(<1,000)
4. Molding	<400	(<800)
<u>B. Rigid PVC</u>		
1. Compounding	300,000	(660,000)
2. Extrusion	<4,000	(<10,000)
3. Molding	<1,000	(<2,000)
<u>C. Plastisols, Organosols, Solution and Latex Fabrication</u>	2,000	(4,500)
<b>TOTAL</b>	<b>&lt;535,000</b>	<b>&lt;1,165,000</b>

\* Based on 1974 production rates and late 1974 VCM contents of resins.

TABLE S-2  
ANNUAL VINYL CHLORIDE EMISSIONS - 1974

<u>Process</u>	<u>Emissions</u> (kg/100 kg produced)	<u>Amount</u> <u>Produced</u> (millions of kg)	<u>Subtotal of U.S.</u> <u>Emissions by Process</u> (millions of kg)	<u>Total U.S.</u> <u>Emissions</u> (millions of kg)	<u>Percent of Total</u> <u>U.S. Emissions</u>
<u>A. Monomer Production</u>	0.25	2200	-	5.7	4.0
<u>B. Polymerization</u>	-	2400	-	130.0	95.4
Suspension Process	3.9	1900	76	-	-
Dispersion Process	6.0	280	17	-	-
Solution Process	1.8	59	10	-	-
Bulk Process	2.4	120	29	-	-
<u>C. Fabrication Processes</u>	-	2300	-	0.5-0.6	0.4

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Table S-3

ANTICIPATED FUTURE VCM LOSS RATES FROM COMPOUNDING AND FABRICATION

<u>Year</u>	<u>PVC Production Rates (millions of kg)</u>	<u>Avg. VCM Content of Raw Resin (ppm)</u>	<u>Total Annual U.S. VCM Release from Compounding and Fabricating (kg)</u>
1974	2000	300	600,000
1975	2100*	50	105,000
1980	2400 (est.)	20	48,000

\*Assumes 7% growth rate.

## I. INTRODUCTION

### A. BACKGROUND: THE VCM PROBLEM

In early 1974 the potential link between the exposure of polyvinyl chloride industry workers to high concentrations of vinyl chloride monomer (VCM) and their development of angiosarcoma of the liver began to achieve widespread recognition. The Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor acted rapidly to set temporary and then permanent safety standards to limit the exposure of plant workers to VCM. There is little doubt that the result of these standards will be to reduce to very low levels the VCM in the air which workers breathe.

Since the ventilation methods used as one major route to meeting the OSHA regulations in no way reduce the total amount of VCM emitted from the plants to the atmosphere, there is still concern about the effects of VCM emissions on the non-worker population in communities surrounding such plants. Although there is little data available at this time as to the actual levels at which VCM emissions to the atmosphere would be of danger to such populations, the Environmental Protection Agency believes it to be important to quantify the extent of these emissions.

### B. SCOPE OF STUDY

The purpose of this current program is to quantify the extent of VCM emissions from one segment of the polyvinyl chloride (PVC) industry: the processors of the resin. For the purposes of this study, these processors are defined as those manufacturers who work with polymerized polyvinyl chloride resins and, by suitable manipulations involving either a melt, latex or solvent phase, produce finished or semi-finished products. These processors include both compounders (who blend raw resin with additives prior to fabrication to produce a feed "compound" with the desired properties) and fabricators who process compound--through the melt or solvent phase--into semi-finished products. (Compounding may be done by the fabricators themselves, prior to "fabrication", or these fabricators may purchase compound from the resin manufacturers or from independent compounders.)

The PVC fabricating industry is highly diversified, fabricating over 4.5 billion pounds of resin per year into a myriad of product and end-use applications. Many of the twenty-one raw resin producers also compound some of their own resin, some even purchase resin from other resin producers, and many are also fabricators of finished or semi-finished products. In addition, several dozen independent compounders supply compound to fabricators. The fabricators themselves number several thousand, ranging from

small businesses to fabricators of several hundred million pounds per year of product.

In Sections II and III following, we describe the structure of the PVC processing industry, and the size of each segment. In those sections, the industry is described according to two major categorization schemes: the end products produced and the major type of process used to produce the product. In Sections IV and V, we describe the processes used to fabricate polyvinyl chloride, and document the major points of VCM emission from each process. Estimates of the amount of VCM emitted are also given in Section V. Section VI discusses control measures.

### C. METHODS

Our most important tool for estimating VCM emissions was the classic material balance. By knowledge of the VCM content of resins entering and exiting from each process step, we were able to estimate the amount of monomer lost at each step. "Total nationwide emissions" were then obtained by multiplying the VCM lost per kilogram, at each process step by the total amount of material processed each year by that method.

We should emphasize that no experimental work was done by us during this program. All data used to estimate VCM emissions were obtained by interviews with resin producers, compounders and fabricators. For some processes, data on VCM content of resins at each step were extremely sparse or inconsistent. Concern with monomer emissions in the PVC industry is of relatively recent origin, and manufacturers have not yet had the time to obtain complete data. An additional complication in these estimates arises from recent changes in raw resin manufacturing processes. Because of the OSHA regulations, resin manufacturers are devoting considerable efforts to reducing the monomer contents of their resins in order to reduce VCM emission in compounding and fabricating plants. Thus, "the VCM content" of a particular grade of resin is a changing quantity. In general, the residual VCM levels in most grades of resin were considerably lower in late 1974 than they were in early 1974; they are expected to be even lower in 1975 if resin producers' predictions are correct. For the purposes of this study, we have attempted to use the typical late 1974 VCM levels in resins for each process.

## II. POLYVINYL CHLORIDE MANUFACTURING: PROCESSES AND APPLICATIONS

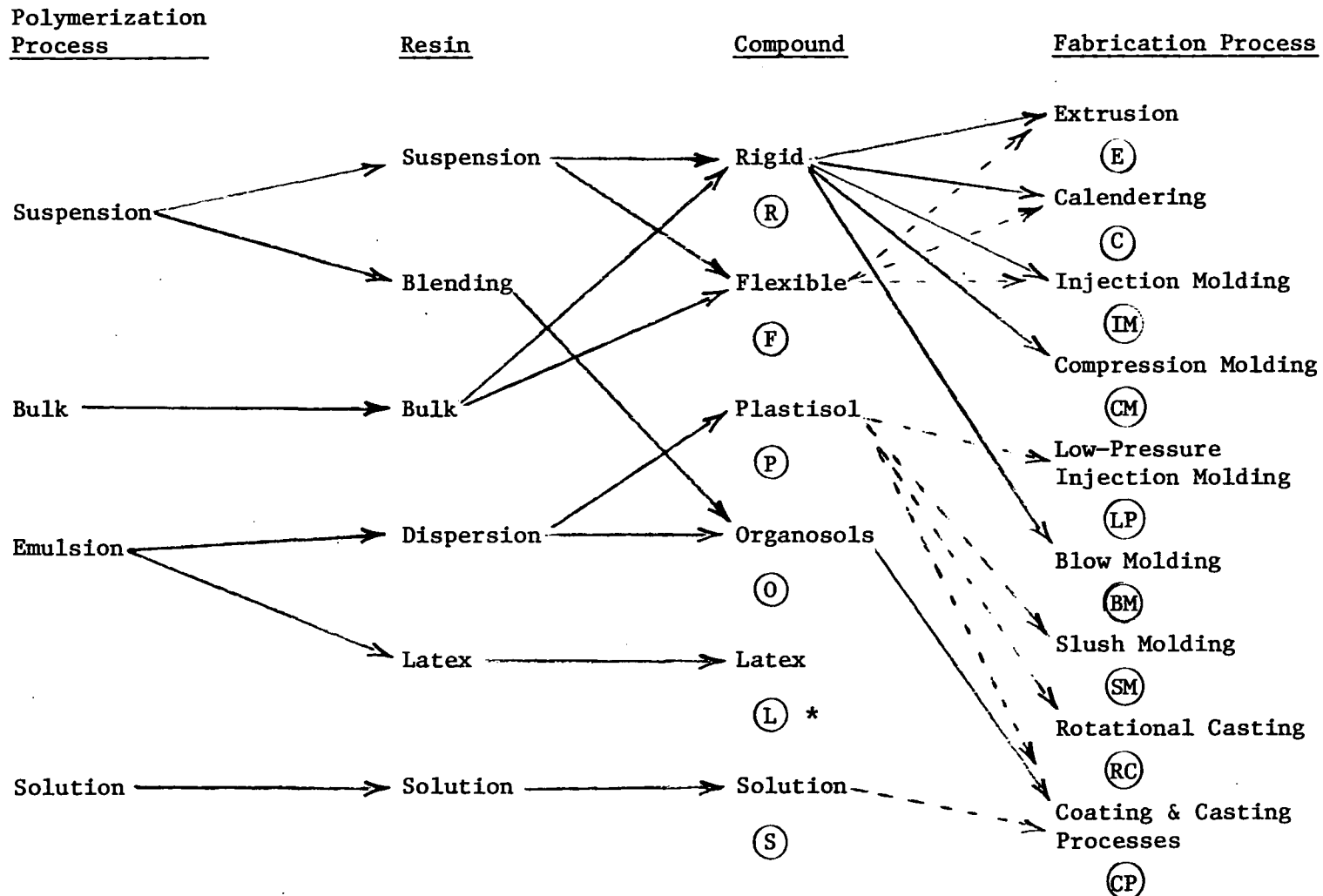
### A. GENERAL

Plastic products based on polyvinyl chloride (PVC) are among the oldest of the major plastic materials. The first commercial plant to make PVC resin was constructed in 1939, and consumption has now grown to over 4.5 billion pounds per year--the second largest plastic (after polyethylene) consumed in the United States. PVC is the most versatile type of synthetic resin produced and is used in more individual end products than any other type of plastic material. This versatility arises from the relatively low cost of PVC, its ease of fabrication, its solvent, weather and abrasion resistance, and the fact that its mechanical properties can be varied by proper adjustment of additives to yield products ranging from rigid, brittle materials to soft, rubbery ones.

There are three major processes in the conversion of vinyl chloride monomer to a finished polyvinyl chloride product: (1) polymerization of the monomer to the polymer; (2) compounding, or addition of additives to the polymer to yield the desired properties for handling the polymer and in the final product; and (3) fabricating, in which the compound is melted and then formed into the final shape required. Because of the wide variety of uses to which PVC is put, there is a considerable variety of polymerization processes, compounding operations and fabricating processes which must be used to arrive at the desired end properties. Figures II-1 a and b present a schematic of the types of polymerization processes used to produce each end product. These processes are discussed in some detail in the following subsections.

PVC resins vary in molecular weight and in chemical composition. The molecular weight of most commercial PVC resins lies between 50,000 and 120,000 and most PVC resins are homopolymers made from vinyl chloride alone. About 15% of the vinyl chloride polymers are copolymers containing vinyl chloride and other monomers, with vinyl acetate being the most common comonomer. The processing and performance characteristics of PVC depend upon the nature of the polymer itself and on the additives used in the compound.

Although it is the purpose of this present program to assess vinyl chloride monomer emissions only from the compounding and fabricating steps of this process, the details of the polymerization processes also impact on the monomer emitted. The different polymerization processes result in different amounts of residual monomer remaining in the raw resins, which may later be emitted during fabrication operations.



\*Latices are usually sold directly to the consumer rather than being used in later fabrication processes.

Figure II-1a. Polyvinyl Chloride Manufacturing Processes

<u>End Product</u>	<u>Fabrication Process</u>	<u>Compound</u>
Pipe & Conduit	E	R
Panel & Siding	E	R
Flooring	CP, C	P, F
Upholstery	CP, C	P, F
Pipe Fittings	IM	R
Lighting Fixtures	E	R
Film (Packaging)	E, CP, C	F, S, R
Sheet (Packaging)	C, E	R
Rainwater Systems	E	R
Bottles	BM	R
Weather Stripping	E	F
Wire & Cable	E	F
Baby Pants	C	F
Footwear	LP, IM, SM, CP, C	P, F
Outerwear	CP, C	P, F
Windows	E	R
Hose	E	F
Phonograph Records	CM	R
Toys	RC, IM, LP	P, F, R
Auto Mats	CP	P
Auto Tops	C, CP	P, F
Medical Tubing	E	F
Tool Handles	CP	P
Credit Cards	E	R
Wallcoverings	C	F
Can Coating	CP	S, O
Exterior Paint		L
Closure Gaskets	LP	P

Figure II-1b. Polyvinyl Chloride Manufacturing Processes

## B. POLYVINYL CHLORIDE POLYMERIZATION PROCESSES

### 1. Description of Processes

There are four commercial processes currently employed in the U.S. for the manufacture of PVC resin: suspension, emulsion, bulk, and solution polymerization. All four processes are based on free-radical polymerization of vinyl chloride monomer, using initiators such as organic peroxides. The choice of polymerization method depends on the ultimate application of the resin and the economics of the processes.

#### a. Suspension Polymerization

Suspension polymerization is the most commonly used process in the U.S. today, accounting for about 80% of PVC production. This process can be used to prepare both homopolymers and copolymers of a variety of molecular weights. In the suspension process vinyl chloride monomer is suspended in water with a small amount of a suspending agent. The molecular weight of the resulting polymer is generally controlled by the reaction temperature and by the addition of modifiers. After completion of the polymerization reaction, the solid polymer, which is in the form of fine beads, is recovered by centrifugation and drying. Depending upon the ultimate application, the product may be sold as (1) an unstabilized polymer, usually in the powder form as it is obtained from the reactor; (2) a dry powder blend with additives and/or colorants; or (3) a pelletized compound. Suspension resins are used for both rigid and flexible formulations; some (called blending resins) are also used in plastisol formulations (see below).

#### b. Emulsion Polymerization

About 11% of the PVC resin produced in the United States in 1974 was produced by emulsion polymerization, which is basically very similar to the suspension process, except that relatively large amounts of emulsifying agents are used. This process produces resins with a very small particle size and typically of higher molecular weight than the suspension resins. To maintain the small particle size, emulsion resins are usually dried using a spray drying technique. (Complete removal of the emulsifiers is never achieved in resins produced by this process so that products requiring high clarity, for example, packaging film or very low water adsorption, such as wire insulation, cannot be produced from emulsion resins. The resulting powders, which are called paste resins or dispersion resins are sold either to independent compounders or to fabricators. In the United States all plastisols are made from dispersion resins, primarily homopolymers. About 10% of the polymers made by the emulsion process--or a total of about 50 million pounds of PVC in 1974--were sold as latices for coating applications; all of these are copolymers. Latices are sold "as is", with a solids concentration varying from 45-60%.

#### c. Bulk Polymerization

Bulk polymerization is a relatively new process in the United States. It was developed in France (by Pechiney) and is used by Hooker Chemical Corporation,

the Goodyear Tire & Rubber Company, and the B.F. Goodrich Company. About 6% of the PVC resins produced in the U.S. in 1974 was made this way.

In this process the monomer is polymerized in the absence of solvent. The reactors are specially designed to handle bulk polyvinyl chloride at elevated temperatures.

These bulk polymers have several desirable features--high porosity (desirable in making flexible compound), clarity, and relatively uniform shape and size of the particles. They also have remarkably good heat stability and improved fusion properties, and can be processed with the ease of conventional vinyl chloride--vinyl acetate copolymers. Bulk-polymerized resins resemble the suspension resins and are used in many of the same applications.

#### d. Solution Polymerization

Although solution polymerization is over 40 years old, only about 3% of the PVC resins produced in the United States in 1974 were produced by this method. At present vinyl chloride solution polymerization is used only for the production of copolymers of vinyl chloride and vinyl acetate (usually containing 10-25% vinyl acetate). Union Carbide is currently the only U.S. producer of solution-polymerized resins.

In the solution process the monomers are dissolved in organic solvents such as n-butane or cyclohexane. The polymerization is carried out in an autoclave, and the polymer precipitates as the reaction proceeds. The resulting resins are usually dried and sold as powders or beads. Most solution process resins are sold to formulators who prepare solutions containing these resins for various coating applications.

## 2. Trends and Markets

Table II-1 shows the U.S. production of PVC resins in the last five years categorized by polymerization process. (Appendix Table A-I lists the major U.S. resin manufacturers.) As shown in Table II-1, in the period 1969-73, PVC production increased at an annual growth rate of about 11%. Production growth slowed to about 7% last year. Most of this growth has been in the production of suspension homopolymer resins. (Table II-1 resins made by the bulk process are included with the suspension resins.) Because of the improvement in the processability of suspension and bulk homopolymers, the need for easier-processing copolymers has diminished over the past few years.

## C. COMPOUNDING OF PVC RESINS

Pure polyvinyl chloride resin is usually unsatisfactory as a material for packaging, construction, upholstery, and many of the other applications for which it is used. Its brittleness, difficulty of processing, degradability, etc., require that the raw resin be "compounded" with a variety

TABLE II-1

U.S. PRODUCTION OF PVC RESINS

By Polymerization Process (MM Pounds)

	<u>Suspension Homopolymers</u> <sup>a</sup>	<u>Suspension Copolymers</u>	<u>Dispersion Resins and Latex</u> <sup>b</sup>	<u>Total</u>
1969	2052	592	388	3032
1970	2232	519	364	3115
1971	2475	504	458	3437
1972	3149	559	550	4258
1973	3433	540	589	4562
1974 <sup>c</sup>	3687	581	632 <sup>d</sup>	4900
<u>Annual Growth (%)</u>				
1969-1973	13.8	-2.5	11.0	10.7
1974	7.3	7.6	7.3	7.5

<sup>a</sup>Includes polymers made by bulk process.

<sup>b</sup>Includes polymers made by solution process.

<sup>c</sup>Estimated by Modern Plastics, January, 1975.

<sup>d</sup>We estimate the production of dispersion resins in 1974 amounted to 475 MM lbs.

Source: Society of Plastics Industries, Annual Statistical Reports, and Modern Plastics, January, 1975, and ADL.

of additives in order to achieve the required properties. The concentration of additives in these compounds can vary from 3% to over 100% (based on the weight of resin). Four major categories of compounding are considered: (1) rigid PVC compounding; (2) flexible compounding; (3) compounding (or formulating) of plastisols and organosols; and (4) formulating of PVC solutions.

#### (1) Rigid Compounds

Rigid compounds, which are supplied as powders or pellets, contain from 80 to 97% PVC depending upon the end application. Three to five percent of an elastomeric product is often added as an impact modifier to rigid compounds used for pipe applications. Rigid compounds often require pigments such as titanium oxide in addition to lubricants and stabilizers.

Although most rigid compounds are homopolymers, some copolymers are also sold. These are usually lower in molecular weight than the homopolymers, and contain vinyl acetate as the comonomer.

Dry blending is typically used to prepare rigid compounds of PVC in powder form. These powders are usually used to manufacture PVC pipe. Dry blend powders are economical, particularly if compounding is done directly in the polymerization vessel prior to discharging the resin. Robintech today manufactures a suspension resin which is compounded in the polymerization kettle and used to fabricate pipe, and which does not require further dry blend compounding.

#### (2) Flexible Compounds

Flexible PVC products require plasticizer to soften the hard resin; the types and concentration of plasticizers used are very varied. Flexible compounds are made by mixing the dry PVC resin with plasticizer and other additives, frequently followed by fusing and pelletizing of the compound. In these compounds, the dry resin accounts for 33-60% of the composition, with the plasticizers, fillers, antioxidants, lubricants, and other additives comprising the remainder. Resins used are primarily high-molecular-weight homopolymers; the molecular weight is usually higher than resins used in making rigid compounds. Resins for flexible compounds, like those for rigid compounds, are made by the suspension or bulk process.

#### (3) Plastisols and Organosols

Most flexible PVC coatings and a small fraction of flexible molded products are made from plastisols. These plastisols are dispersions of PVC resins in plasticizer with other compounding ingredients such as stabilizers, fillers, and pigments. Some plastisols are very thin liquids, and others are heavy, doughy pastes. The manufacture of plastisols requires PVC dispersion resins, which are made primarily by the emulsion process (although a very small percentage is produced by the solution process). Plastisols are made primarily from homopolymers.

Because the dispersion resins are more expensive than those made by the suspension process, small amounts of suspension resins are often added to lower the costs of a plastisol formulation. Suspension resins used for this application are called blending resins.

Organosols are similar in constitution to plastisols, except that they are thinned with solvents to control the viscosity for certain coating processes. Organosols are often used in coating processes, such as metal coating, where low viscosities are needed and where evaporation of the volatile thinner does not affect the appearance of the product.

Plastisols and organosols are not sold by the resin producers. They are sold either by an independent formulator or are prepared by the fabricator.

#### (4) Solutions

PVC solutions are also used for coating applications. Most PVC can coatings are formed from such solutions. Resins for this application are prepared primarily by solution polymerization although some are synthesized by the suspension polymerization process. Because the dispersing agents in suspension resins interfere with the properties of the solution, they must be removed after polymerization; otherwise, the coating resin will not possess maximum clarity and water resistance properties.

Most PVC solution coating resins are copolymers, typically containing 3 to 16% vinyl acetate as the comonomer; copolymers with vinylidene chloride or vinyl ethers are also available.

Because of the limited solubility of vinyl copolymers, strong solvents such as ketones and esters are used by the formulators, as the base of PVC coating solutions.

### D. FABRICATION PROCESSES

#### 1. Types of Processes

PVC compounds, both flexible and rigid, are converted to end products by a number of processing techniques including extrusion, calendering, injection molding, blow molding and compression molding. Flexible compounds are usually processed at lower temperatures than rigid ones, because the increased plasticizer compound lowers the softening point of the resins. Plastisol processing techniques include coating, casting, slush molding, rotational molding, and low-pressure injection molding.

##### a. Extrusion

The basic machine is the extruder, which consists of a metal barrel, a close-fitting internal screw(s) connected to a drive mechanism and a means for applying heat to the barrel in one or more zones. The process consists basically of mixing and melting a continuous stream of plastic and

pushing it through a specially designed orifice or die by the turning action of the screw(s). In general, the extruder is very versatile with respect to the type of materials it can process.

Extrusion is used for making continuous lengths of profiles. (A "profile" varies only in two dimensions, as opposed to molded products which vary in three.) Major profile products include: film and sheet, wire coating, pipe, rod, and siding. Both flexible and rigid PVC compounds in either powder or pellet form are used in this process; either suspension or bulk process resins may be used.

Wire and cable insulation accounts for a significant portion of the flexible compound that is extruded. In wire and cable coating, the compound is extruded around a continuous length of the wire or cable.

Typically, pelletized compound is used in this process. The concentration of plasticizer in the compound varies with the application. For example, communication wire contains about 60% PVC. Most fabricators in this segment of the industry do their own compounding, although a few purchase the compound.

Rigid pipe and tubing are formed as continuous extrusions through an annular die approximating the desired profile; cooling is usually effected by passing the extrudate through a water bath or trough. Pipe as large as one meter in diameter can be prepared this way.

Pipe extrusion requires the use of rigid compounds, containing 85 to 95% PVC. Most PVC resins used in pipe manufacture are compounded into powder blends by the pipe producer. However, Robintech sells pipe compound made by the in-kettle-compounding process.

Siding, Rain Gutters and Other Special Profiles are made in a similar way to rigid pipe. However, because these profiles are somewhat more difficult to extrude than pipe, manufacturers use rigid compound in pellet form for these processes. This segment of the industry typically uses single-screw extruders and purchases the compound.

Flexible Profiles are extruded from flexible compounds and include such items as medical tubing, garden hose, gaskets, weather stripping, water-stop, sheet, and cove base. Pelletized compound is used, typically containing about 60% PVC, with the remainder being plasticizers, pigments, and stabilizers. Major manufacturers of flexible profiles do their own compounding; smaller manufacturers usually purchase compound.

PVC film can be made either by extrusion or calendering. In the "blown-film" extrusion process, which is the preferred method for packaging films, pellets of homopolymer compound are melted and extruded through a die with a thin, annular opening to produce a thin-walled tube. This tube is expanded by air as it emerges from the die. The air is introduced internally under pressure through the center of the tube die. The bubble thus formed is cooled and the plastic is wound into rolls as tubing or, by slitting and trimmings, as single thickness film.

Shrink film is made by stretching the film either as it is made or in a subsequent stretching operation. Stretching introduces orientation (the alignment of polymer chains).

A small amount of film is produced by flat die (slit-die) extrusion. This involves extruding molten resin from an extruder through a wide slit die with adjustable lips into a cooling system. These films typically have a lower degree of orientation than the blown film.

Sheet products (films greater than 10 mils in thickness) are manufactured by the slit-die extrusion technique. Most sheet extrusion processes use rigid compounds, although some may contain up to 10% plasticizer, depending upon the exact physical requirements of the end application. Sheet compounds usually are made from homopolymers; both pellets and powders can be used. Most fabricators purchase sheet compound, but a few of the larger fabricators do their own compounding.

A large portion of the sheet products are used in construction applications. such as transparent corrugated sheets. Sheet is corrugated by passing it through forming rolls after extrusion. Rigid sheet is also used in various packaging applications.

#### b. Calendering

Calendering is used primarily in the production of flexible sheet although a small fraction of rigid sheet is produced by this method. Calendering is capable of producing high-quality material at very high rates of output. In this process, the compound is passed between a series of three or four large heated revolving rollers which squeeze the material into sheet or film. The thickness of the finished material is controlled by the space between the final rolls. The resulting surface of the film or sheeting may be smooth, matted, or embossed, depending on the surface of the final rollers.

Calendering also can be used to coat PVC onto textiles or other supporting materials. In applying a coating, the compound is passed between two top horizontal rollers on a calender, while the uncoated material is passed between two bottom rollers. Finally, the substrate and film converge and are passed between a single set of rollers; the product emerges as a smooth film or sheet anchored to the substrate. The alternative process to calender coating is post-calender laminating. In this process, the vinyl coating is prepared in advance and then laminated onto fabric by passing the two materials through pressure rolls.

Although the cost of the calender together with the auxiliary equipment is very high (a typical calender train costs 2 to 3 million dollars), calendering is the most economical method for producing thick PVC film and sheeting. Film and sheeting of the middle-gauge range between 3 and 25 mils is almost entirely produced by calendering. Today's calender lines are designed with throughput capacities of from 2,000 to 10,000 pounds of compound

per hour, or 70 - 100 yards per minute. Widths of film and sheet usually run to 72 inches, with some as wide as 92 inches.

Because calender fabrication is economical only if the production volume is high, only a few end users can use the calendering process. The main products made on calender equipment are: vinyl sheeting, coated vinyls, and floor tile. Coated fabrics are widely used for upholstery. Unsupported vinyl film and sheet is used to manufacture inflatables, footwear, purses, handbags, wallets, raincoats, tablecloths, shower curtains, luggage, and other similar products. Over 90% of the PVC-coated fabrics used in furniture upholstery are produced by calendering. Only a relatively small quantity of high-style, "expanded vinyls" is cast from plastisol (see section below). In these products, the vinyl is foamed to give it a "hand" that is similar to leather. Expanded vinyl products can be made either by the casting or calendering process.

Most motor vehicles today use vinyl-coated fabrics as the primary upholstery material. The backing material is largely cotton. About 85% of these coated fabrics are made by the calendering process and the remainder by the casting or knife-coating process. Unsupported vinyl sheet also is used in a variety of automotive applications such as Landau tops and panel coverings. Crash pads are covered with a calendered sheet that is made from a blend of ABS and PVC. These products typically contain about 35% PVC, although some may contain as much as 70% PVC.

While the major application for vinyls in home furnishings is upholstery, the second largest application is wall covering. The wall covering product consists of PVC film laminated to paper, cotton, or other backing material. Window shades are frequently made from vinyl sheet. Light-gauge, clear, rigid, and semi-rigid PVC film is used in the manufacture of prefinished plywood and particle board. In this method, clear film is printed with a wood grain pattern and laminated to the board with the print on the inside. The prefinished product is used to manufacture such items as office furniture and stereo cabinets.

Rigid PVC films and sheet made by the calendering process are also used extensively as surface finishes for construction products. For example, large quantities of gypsum board are finished with printed, embossed, opaque sheet which is adhered to the surface to yield a decorative and abrasion-resistant finished panel.

For the most part, calender operators buy raw resin and carry out the compounding in their own facilities. Homopolymer made either by suspension or bulk polymerization process is used to make these compounds.

Vinyl asbestos flooring is another large outlet for calendered PVC. The resins used in this application are mostly vinyl chloride vinyl acetate copolymers with 8 to 18% vinyl acetate. These polymers can bind large amounts of the mineral fillers that are used in these products. Resin

and plasticizer account for about 17% of the formulation, with the resin alone accounting for only about 10% of the product.

Flexible tile is also made by the calendering process. In this case, a relatively low-molecular-weight homopolymer is used with calcium carbonate as the filler. Typically, the plasticizer content of the calendered compound is about 40%, and the resin is 30%. A third type of flooring is made by the coating process (see section below). The fabricator, who manufactures tile flooring by the calendering process, normally does his own compounding.

#### c. Injection Molding

In this process rigid or flexible compound is melted in a heating chamber, and the melt is forced through a nozzle under high pressure into a closed mold. The resins most frequently used in rigid PVC injection molding are medium-molecular-weight homopolymers; some lower molecular weight vinyl chloride-vinyl acetate copolymers are also used. These resins are derived from suspension or bulk polymerization processes. The feedstock may be in the form of pellets or powder, but most injection molding of PVC is done from pellets compounded by the resin manufacturer. In the future, large-scale manufacturers of pipe fittings may use powder compounded in their own plant.

Two major products made by injection molding are pipe fittings (from rigid compound) and shoe components, such as heels and soles (made from flexible compound). Other products include industrial parts, such as fan blades, handles, etc.

#### d. Blow Molding

Blow molding of rigid PVC is generally limited to the manufacture of bottles. This process is usually coupled with extrusion, using single-screw extruders.

Rigid compounds used in this process contain about 90 to 95% PVC. They are normally fed to the blow molding machine in pellet or cube form. Polymers used in this process are primarily homopolymers that are made by the suspension or bulk process. The bottle fabricator usually purchases his compound from the resin producer. Two compound grades are used: a food grade and a general-purpose grade, which differ primarily in the stabilizers used. Food-grade compound contains additives approved by the FDA, and is used to blow-mold bottles for products that may be ingested. The general-purpose grade compound is used to manufacture containers for such products as shampoo and liquid detergents.

#### e. Compression Molding

Compression molding of PVC is limited and is used primarily for processing rigid compounds into phonograph records. In conventional compression molding, the compound is fed directly into the open mold cavity either as bulk material or as a "biscuit". The mold is then closed, heat and pressure applied, and the compound caused to melt and flow throughout the mold. After taking on the shape of the mold, the pressure is released and the molded product is withdrawn. Record compounds use primarily copolymers

containing about 15% vinyl acetate; the compounds themselves contain about 3% additives.

Most record molders manufacture their own compound; however, a significant fraction of record compound is manufactured by one major independent compounder, who specifically manufactures for this industry. This compounder alone accounts for almost one-third of the PVC used by record molders. The manufacturer of phonograph records generally recycles returned records, and about 25% of the compound used by the industry is derived from this type of scrap.

#### f. Plastisol Processing

Most PVC emulsion polymers (dispersion resins) are used to manufacture plastisol compounds. These compounds typically contain about 50% PVC; most are made from homopolymer resins. Some plastisol compounds are formulated with blending resins made by the suspension process which are added to the compound primarily to lower the cost. Blending resins are also effective in reducing the viscosity of the plastisol systems. These resins are mostly homopolymers and are intermediate in particle size between dispersion and general-purpose suspension resins.

Plastisols are processed as fluids by a variety of processes including knife coating, roller coating, casting, rotational molding, dipping, and hot spraying.

Although the majority of PVC emulsion polymerization products are used to make dispersion resins, about 10%--50 million pounds in 1974--was used as latex rather than in the coagulated form. Most latex resins are copolymers of vinyl chloride with minor amounts of vinyl acetate. Others contain small amounts of acrylate monomers, or vinylidene chloride. Major applications of latices include: (1) outdoor house paint; (2) saturation and coating of paper and paperboard; (3) impregnation of non-wovens used in automotive trim such as door panels; and (4) vinyl wall coverings.

Coating. Most plastisol compounds are used to coat substrates such as textiles, paper, and sheet metal. Coating equipment generally consists of an adjustable doctor knife or spreading blade supported over a steel plate or roller. Rollers are sometimes used instead of doctor blades. Major fabricators of such products as coated fabrics and vinyl flooring usually do their own compounding.

Coated Flooring. The major plastisol product made by a coating process is flooring. In recent years, plastisol-coated felts have been used as an inexpensive floor covering, and have made inroads in the flooring market at the expense of calendered vinyl-asbestos tile.

Coated flooring is made in a number of ways. The base material can be felt, thick paper, or asbestos. In one method, the base is laminated with a printed PVC sheet and a coating of a clear (unfilled) plastisol

is applied as a protective top layer. PVC foam, made from a plastisol compound can be used in place of the vinyl sheet. The foam can be embossed or decorated and then top coated with a clear plastisol. In still another method, the base can be coated with a "filled" acrylic polymer and then finished with a top coat of the clear plastisol. Coatings are usually applied using a roll coater and then fused in an oven.

Dip and Slush Molding. Slush molding is a process for making thin-walled, flexible products. In this process, excess liquid plastisol is charged to a hollow mold of the desired contour. Heat, which is applied to the outside of the mold, fuses only the plastisol that is in contact with the hot mold surface; the unfused excess liquid plastisol is dumped out and used again. This process is used primarily to produce overshoes, rubbers, bathing caps, and similar products.

Dip molding is also used to produce skin-like products such as gloves, and handle-bar grips. In the dipping process, preheated products, particularly metal, are coated by dipping into a plastisol solution and then dried.

Rotational Casting or Molding. This is another major method of processing plastisols. In this case, a measured amount of liquid plastisol is charged into a rotating split mold. The speed of rotation is comparatively slow, so that the plastisol flows by the effect of gravity to form a layer of uniform thickness over the entire mold cavity. The plastisol layer is fused during rotation. The mold is then removed from the oven and cooled by water. The mold is opened and the molded article is removed.

Applications for rotational moldings include flexible toys, automobile arm rests and dash pads, beach balls, basketballs, etc.

Rotational molding is particularly suitable for the manufacture of hollow items. The process has the advantage that the equipment is relatively inexpensive, and the process is not very complex. Molds can be made from aluminum, and they are easy to produce. The process affords a high degree of flexibility and is economically attractive for short runs, frequent color changes, intricate designs and relatively thick walls.

Producers of products using slush molding and rotational casting typically purchase the plastisol compound from independent formulators.

Low Pressure Injection Molding. This technique, which resembles conventional injection molding, can be used for molding such items as shoe soles, and gaskets for glass containers and crown caps used as closures for glass beverage containers. Some companies also use liquid plastisols to manufacture the so-called "roll-on gaskets" which are used in aluminum "convenience" caps for beverage containers. Others form these compounds from PVC tape.

Typical formulations of liquid plastisols used for glass-container gaskets consist of 75 parts dispersion resin, 25 parts blending resin, and 100 parts of plasticizer and other additives. The major manufacturer who use plastisols for gasketing material used in packaging do their own compounding.

In general, low-pressure injection molding, just as other plastisol processing, uses relatively inexpensive equipment. The costs of the machines and molds are lower than for conventional injection molding.

#### g. Solution Systems

PVC-solution coatings or enamels are normally used as coatings for metal. PVC coating solutions are made from copolymers containing about 15% vinyl acetate, formed primarily by the "solution polymerization" process. Some suspension resins are also used.

The majority of PVC enamels are used as can and closure coatings, especially for interior top coatings for beer and soft drink cans. All aluminum ends for soft drink cans are coated with PVC, some of which is based on organosols rather than enamels. Beverage cans made from tinplate or tin-free steel are coated exclusively with PVC enamel. Approximately 25% of all food cans also are coated with the vinyl enamel.

PVC enamels are also used as coatings for the inside of metal closures such as jar lids. These coatings are usually modified with epoxy or phenolic resins. Minor amounts of PVC enamels are also used in combination with phenolics in exterior decorative coatings for some beverage cans.

In addition to their use as can coatings, PVC solution resins are used in a variety of other metal-coating applications, such as finishes for appliances, metal furniture, building panels and some non-electrical machinery. PVC enamels are also used in maintenance and marine-coating applications. In many of these latter applications, vinyls are used in combination with other resins.

Solution-based resin systems made from suspension resins are used to prepare cast film. Such cast film is of higher quality than film made by the blown-film extrusion process, with substantially improved clarity and brilliance and low gel content. Film thickness is also more easily controlled.

## 2. Trends and Markets

Table II-2 summarizes the reported domestic PVC resin consumption for the years 1969 to 1974, according to fabrication process. Note that extrusion and calendering consumed about 70% of all PVC resins.

In the four-year period, 1969-1973, consumption of all types of PVC resins grew an average of about 14% per year. During this same period, the use of PVC resins in the extrusion process increased at an average annual

TABLE II-2

DOMESTIC CONSUMPTION OF PVC RESINS

BY FABRICATION PROCESS

(MM Pounds)

	<u>EXTRUSION</u>	<u>CALENDERING</u>	<u>PASTE PROCESSES</u>	<sup>a</sup> <u>MOLDING</u>	<u>SOLUTIONS</u>	<u>OTHER USES</u>	<u>TOTAL</u>
1969	1000	793	279	248	84	350	2754
1970	1095	705	281	254	85	376	2796
1971	1295	835	415	309	90	281	3225
1972	2052	963	457	410	118	180	4180
1973	2298	913	496	511	142	224	4586
1974 <sup>b</sup>	2200	867	504	469	163	271	4474
Per Cent of PVC Production <sup>c</sup>	50	20	11	11	3	5	100
Annual Growth (%)							
1969-1973	23	3.5	15.2	20	14	-12	14
1974	-4	-5	2	-9	15	21	-3

Source: Society of Plastics Industries, Annual Statistical Reports,  
US Tariff Commission and Modern Plastics, Jan. 1975.

- a. Process uses dispersion resins manufactured by the emulsion process. Latices used in coating applications are included in this category.
- b. Estimate by Modern Plastics.
- c. As computed for the year 1973.

rate of 23%, with most of the growth occurring between 1971 and 1972. In contrast, the consumption of PVC resins in the calendering process showed little growth during this time period.

An analysis of the consumption of PVC resins by product within each fabrication category is shown in Table II-3. This table indicates that the rapid growth in the consumption of PVC by the extrusion process was due primarily to the increased use of rigid PVC pipe and conduit. Between 1971 and 1973, the consumption of PVC for this end use increased about 60% per year.

Film and sheet products accounted for the major growth in calendering. During the 1971-1973 period, the use of PVC resins in this application increased 8% per year. During this same period, the consumption of PVC resin in the blow molding process (the process used to make bottles) increased, on the average, 63% per year.

The use of PVC plastisol resins grew at a rate of approximately 14% per year. Textile and paper coating processes were the major factors responsible for the growth in plastisols.

TABLE II-3

## U.S. CONSUMPTION OF PVC RESINS

(MM POUNDS)

	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>1974</u>	<u>Annual Growth (%)</u> <u>1971 - 1973</u>
<u>Extrusion</u>					
Wire and Cable	343	439	414	354	10
Film and Sheet	179	220	204	216	7
Pipe and Conduit	497	1,008	1,254	1,259	60
Others	276	384	425	375	25
Total	1,295	2,052	2,298	2,204	35
<u>Calendering</u>					
Flooring	274	333	292	202	3.5
Textile	87	74	73	86	-9
Film and Sheet	474	556	548	579	8
Total	835	963	913	866	4.5
<u>Paste Processes</u> <sup>a</sup>					
Plastisol Formulating <sup>b</sup> and Molding	156	150	155	163	0
Textile and Paper Coating	142	173	190	200	15.5
Flooring	117	134	150	141	13
Total	415	457	495	504	9
<u>Molding</u>					
Bottles	36	77	87	75	63
Records	138	148	144	143	2
Pipe Fittings	75	86	90	97	9.5
Others	135	185	191	154	19
Total	309	410	511	469	29
<u>Solution</u>	90	118	142	163	26
<u>Other Processes</u>	281	180	224	271	-12

Source: Modern Plastics, January Issues, and Society of Plastics Industries, Annual Statistical Reports.

<sup>a</sup>Includes applications where PVC is used as a latex. About 9-10% of the total consumed in this category are coatings applied from a latex.

<sup>b</sup>The largest application under this category is rotational molding.

### III. END-USE MARKETS AND STRUCTURE OF THE FABRICATION INDUSTRY

#### A. AN OVERVIEW

PVC products are manufactured by some 8,000 fabricators. However, about two-thirds of the PVC resin produced annually is consumed by less than 100 large companies. Of the 22 major producers of PVC resin (listed in Appendix Table A-II), 19 have significant captive fabricating operations with Air Products, Keysor, and American Chemical being the only resin producers without captive fabricating operations. We estimate that captive consumption of PVC resin on the part of the resin producers is equal to about one-quarter of the total domestic consumption of PVC.

About a dozen large companies represent an additional 20% of the total consumption of PVC resin. These companies include Armstrong Cork, Western Electric (a subsidiary of AT&T), Ford Motor Company, Johns Manville, Certain-Teed Products, American Biltrite Rubber, W.R. Grace, and Kentile. These companies each purchase at least 25 million pounds of PVC resin per year, and most have more than one consuming location for PVC resins.

A list of the major fabricators appears in the Appendix (Table A-II). This list accounts for about 75% of the PVC sold to the fabricators in this country. In addition, there are thousands of small custom molders and extruders who process PVC (as well as a variety of other resins) into custom molded and extruded parts for numerous end users.

As noted throughout this report, PVC is one of the most versatile synthetic resins. Its myriad of applications fall into six major markets: building and construction, household furnishings, consumer goods, wire and cable, packaging, and transportation. This end-use breakdown for the PVC consumed in 1974 is shown in Table III-1. Table III-2 shows 1969-1974 trends. Note that the building and construction end-use market is responsible for almost half of all PVC consumed in the United States. Next in importance are household and consumer goods.

As Table III-2 indicates, the market for building and construction products has grown most rapidly. From 1969 to 1973, the average annual growth was 28%. In contrast, the consumption of PVC in wire and cable was essentially static during this same period.

#### B. STRUCTURE OF THE COMPOUNDING INDUSTRY

As indicated in the discussion above, compounding can be carried out by the resin producer, the fabricator, or by independent compounders who buy raw resin and prepare compounds for the fabricator. The location at which compounding is done depends upon the nature of the compound, the end product, and the size of the fabricator's operation.

TABLE III-1

DOMESTIC

END USE BREAKDOWN OF PVC RESIN - 1974

<u>END USE AND PRODUCT</u>	<u>% OF MARKET</u>	<u>MILLION LBS</u>
<u>Building and Construction</u>		
Pipe & Conduit		1259
Flooring		343
Fittings		97
Siding & Panels		97
Lighting		13
Foam Molding		48
Rainwater Systems		33
Weather Stripping		35
Windows, Other Profiles		53
Swimming Pool Liners		<u>42</u>
SUB TOTAL	45	2020
<u>Household Goods</u>		
Furniture Upholstery		317
Wall Covering & Wood Surface Films		128
Garden Hose		37
Appliance Parts (Hoses, Gaskets, etc.)		46
Others (Shower Curtains, Tablecloths, etc.)		<u>102</u>
SUB TOTAL	14	630
<u>Wire and Cable</u>	8	354
<u>Consumer Goods</u>		
Phonograph Records		143
Footwear		139
Toys		81
Outerwear		66
Sporting Goods		62
Baby Pants		<u>24</u>
SUB TOTAL	11	515
<u>Packaging</u>		
Film		125
Sheet		81
Bottles		75
{ Coatings		60
{ Bottle Cap Liners & Gaskets		<u>        </u>
SUB TOTAL	8	341

TABLE III-1 (Continued)

<u>END USE AND PRODUCT</u>	<u>% OF MARKET</u>	<u>MILLION LBS</u>
<u>Transportation</u>		
Upholstery & Seat Covers		185
Auto Tops		29
Auto Mats		42
	6	256
<u>Other Uses</u>		
Medical Tubing, Credit Cards, novelties, tools and hardware, etc.	8	358
GRAND TOTAL		4474

Source: Modern Plastics, Jan 1974, and A. D. Little estimates.

TABLE III-2

U.S. CONSUMPTION OF PVC RESINS BY END-USE

(MM Pounds)

<u>Year</u>	<u>Household Goods</u>	<u>Building and Construction</u>	<u>Electrical</u>	<u>Consumer Goods</u>	<u>Packaging</u>	<u>Transportation</u>	<u>Others</u>	<u>Total</u>
1969	513	817	405	374	228	224	151	2712
1970	513	1006	425	424	272	215	172	3027
1971	564	1165	385	437	286	240	209	3286
1972	630	1739	439	504	357	255	256	4180
1973	545	2134	414	550	375	255	313	4586
1974 <sup>a</sup>	630	2020	354	515	341	256	358	4474
Annual Growth (%)								
1969- 1973	2	28	0.5	10	13	3	20	14

Source: Modern Plastics, and SPI statistics<sup>a</sup> Arthur D. Little, Inc. estimates

III-4

Tables III-3 through III-5 show breakdowns of compounding operation locations by type of resin and end product. In total, approximately 75% of PVC compound is made in the fabricator's facilities, and about 5% is compounded by independent compounders or formulators. The remainder is compounded by the resin producer.

Approximately 64% of rigid compound is made on-site by the fabricators and 35% by the resin producers; little is compounded by the independent compounder. The only major exceptions are phonograph records and some profiles and injection molded products.

Flexible compound is also made primarily by the fabricators (83%) and by the resin producers (11%). Only 6% is compounded by the independent compounders. These "independents" supply compound to wire and cable extruders and molders who fabricate a variety of flexible products.

Paste resins are formulated either by the fabricator (80%) or by the independent formulator (20%). The resin producer provides only the resin.

Structure of the Independent Compounder Industry. This segment of the industry is divided into two separate groups: (1) compounders who prepare flexible and rigid compounds; and (2) formulators who prepare plastisol and organosol formulations.

Six companies dominate the independent compounders of flexible and rigid compounds. Teknor-Apex and Blane Chemical (a division of Reichhold Chemicals) are probably the largest ones. Both are located in New England. Others include Franklin Plastic (N.J.), Premier (Kentucky), MacIin (Los Angeles, CA), and Lyncore (MA). Blane also has plants in Kentucky and California, and Apex has another plant in Tennessee.

There are several dozen independent formulators of plastisols and organosols. By far the largest one is Chemical Products, followed by M & T Chemicals (American Can Co.). These formulators prepare drum quantities of the liquid plastisols for the numerous small fabricators who are involved in processing plastisols into specialty products.

Appendix Table A-III gives a list of suppliers of compound including both independent compounders and formulators and resin manufacturers who also supply compound. Fabricators who consume all their own compound are not included.

### C. STRUCTURE OF THE FABRICATING INDUSTRIES

#### 1. The Pipe, Conduit, and Pipe Fittings Industry

PVC pipe and fittings comprise by far the single largest use of PVC, accounting for 1.3 billion pounds (or 28% of the total U.S. output of PVC) in 1974. Although ABS, other styrene copolymers, and polyethylene compete with PVC in this market, PVC accounts for well over half of the total plastic pipe and conduit business.

TABLE III-3

ESTIMATED CONSUMPTION OF RESIN FOR RIGID COMPOUND IN 1974

(MM POUNDS)

<u>PROCESS/END-PRODUCT</u>	<u>COMPOUNDED BY</u>		<u>COMPOUNDER</u>	<u>TOTAL</u>
	<u>FABRICATOR</u>	<u>RESIN PRODUCER</u>		
Extrusion (Total)	<u>1150</u>	<u>416</u>	<u>5</u>	<u>1571</u>
Pipe & Conduit	1102	120		1222
Panels & Siding		97		97
Rainwater Systems		33		33
Sheet and Film*		81		81
Foam Moldings	48			48
Credit Cards		22		22
Windows, Other Profiles		63	5	68
Molding (Total)	<u>100</u>	<u>262</u>	<u>8</u>	<u>370</u>
Phonograph Records	100	40	3	143
Bottles		75		75
Pipe Fittings		92	5	97
Others		55		55
<u>GRAND TOTAL</u>	1250	678	13	1941
	% 64	35	1	100

Source: Arthur D. Little, Inc.

\*A small amount of rigid sheet is calendered rather than extruded.

TABLE III-4

ESTIMATED CONSUMPTION OF RESIN FOR FLEXIBLE COMPOUND IN 1974

(MM POUNDS)

<u>PROCESS/END PRODUCT</u>	<u>COMPOUNDED BY</u>		<u>COMPOUNDER</u>	<u>TOTAL</u>
	<u>FABRICATOR</u>	<u>RESIN PRODUCER</u>		
Calendering (Total)	<u>867</u>	-	-	<u>867</u>
Extrusion (Total)	<u>458</u>	<u>101</u>	<u>70</u>	<u>629</u>
Wire & Cable	284		70	354
Film	50	75		125
Garden Hose	37			37
Medical Tubing	25	26		51
Weather Stripping	35			35
Others	27			27
Molding (Total)		<u>75</u>	<u>25</u>	<u>100</u>
Footwear, etc.				
<u>GRAND TOTAL</u>	1325	176	95	1596
%	83	11	6	100

Source: Arthur D. Little, Inc.

TABLE III-5

ESTIMATED CONSUMPTION OF PASTE RESIN IN 1974

(MM POUNDS)

<u>END PRODUCT</u>	<u>PROCESS<sup>a</sup></u>	<u>COMPOUNDED BY</u>		<u>TOTAL</u>
		<u>FABRICATOR</u>	<u>FORMULATOR<sup>b</sup></u>	
Flooring	CP	150		150
Upholstery				
Auto	CP	28		28
Furniture	CP	32		32
Outerwear	CP	33		33
Sporting Goods	CP, RC	10	30	40
Footwear	SM, CP, LP	20	22	42
Toys	RC, LP		33	33
Closure Gaskets	LP	17	5	22
Other (Luggage, Wallets, etc.)	CP	<u>61</u>	<u>      </u>	<u>61</u>
	<u>TOTAL</u>	360	90	450
	%	80	20	100

Source: Arthur D. Little, Inc.

<sup>a</sup> CP = Coating and casting; SM = Slush molding; RC - Rotational casting;  
LP - Low-pressure injection molding.

<sup>b</sup> Paste resins are "formulated" rather than compounded, according  
to the terminology of the industry

Markets and Trends in the Pipe and Conduit Industry. A breakdown of uses of PVC pipe and conduit is shown in Table III-6. The major end-use application for PVC pipe is in potable and non-potable water distribution and supply, which requires pressure pipe. About 68% of PVC pipe goes into this end use. The use of PVC as sewer pipe is a new market, and one where PVC is expected to penetrate strongly. In DWV (drain, waste, and vent) pipe, PVC's market share is about 50%, and PVC is expected to gradually increase its share of this market at the expense of acrylonitrile-butadiene-styrene (ABS). According to industry observers, the use of low-pressure PVC pipe, particularly large diameter water pipe (12 inches and larger) and sewer pipe is expected to continue to expand. Other end uses also expected to grow include: telephone conduit, and residential hot-water pipe made from post-chlorinated PVC.

The use of PVC in pipe made the biggest jump in 1972, when consumption of PVC for this end use doubled from about 500 to 1,000 million pounds. In the two-year period, from 1971 to 1973, the average annual growth rate amounted to 60%; there was little growth in this market in 1974.

Structure of the Pipe and Conduit Industry. Several dozen companies manufacture PVC pipe and conduit. (A list appears in Appendix Table A-IV.) The three major producers in this industry, ranked in order of decreasing production are: Johns Manville, Robintech and Certain-Teed. These three companies account for 25 to 30 percent of all PVC pipe and conduit production. Johns Manville alone has 11 plants and one under construction in McNary, Oregon. Other important PVC pipe manufacturers are: Carlon, Amoco Chemicals, and Cresline. There is considerable integration within the plastic pipe industry; for example, Certain-Teed and Robintech have integrated backward toward resin production. Ethyl Corporation, a major resin producer, has integrated forward toward pipe production. Olin, another resin producer, also is a plastic pipe fabricator.

The economics of pipe shipment dictate that pipe extrusion plants be relatively small and located geographically convenient to the marketplace. Thus, this industry has a large number of plants.

A typical, modern, PVC-pipe plant produces 20 to 25 million pounds of pipe per year and has 4 to 5 extruders and a central compounding facility for blending the raw resin powder with additives.

Pipe Fittings. Pipe fittings, which are made by the injection molding process, are usually fabricated in relatively large single product operations. A list of the major injection molders of fittings is given in Appendix Table A-IV. Many fitting molders are also pipe producers, namely: Certain-Teed, Cantex, Charlotte Pipe, R & G Sloan Manufacturing Company, and Celanese Piping Systems. Robintech has recently broken ground on a new plant that will make molded fittings in Wetherford, Texas.

In 1974, about 97 million pounds of PVC were used in the manufacture of pipe fittings. In contrast to the pipe and conduit market, the pipe-fitting

TABLE III-6

ESTIMATED PVC CONSUMPTION IN PIPE AND CONDUIT

1973

<u>END-USE</u>	<u>%</u>
Communications Duct	10
Electrical Conduit	6
Pressure Pipe	68
Drain, Waste, and Vent Pipe	8
Sewer Pipe	5
Other	3

Source: Modern Plastics, March 1973, p. 59.

market has grown at a considerably slower rate. From 1971 to 1973, this segment of the PVC market has grown about 9 to 10 percent per year.

## 2. Other Extruded Construction Products

Siding. Among the construction products, vinyl siding, which is made by extrusion, is one of the more important products. In 1974, about 100 million pounds of PVC were used in this application (see Table III-7). Most PVC siding is sold in the replacement market and in mobile homes, where it competes with aluminum siding. Recently, PVC siding also has been used in new residential construction.

The PVC siding market continues to show good growth. From 1969 to 1973, the average annual growth rate of this market was about 16%. Even in 1974, this market continued to expand.

Because siding is compact, it can be shipped more economically than pipe. Siding manufacturers typically ship from single, strategically located plants, many of which are located in the Midwest.

This industry is dominated by five large manufacturers; none are integrated backward. The top three companies in the vinyl siding business--Bird and Son, Mastic, and Crane Plastics--probably account for 35 to 45 percent of the business.

Most siding manufacturers also manufacture other extruded profiles--both rigid and flexible. For example, Bird and Son, which is the number one company in siding, also sells PVC shutters and gutters. Crane plastics, which is third in the siding industry, extrudes siding as well as 3,000 profiles. About 97% of these are rigid profiles and the remainder are flexible.

Other Profiles. The use of PVC in rigid profiles includes rainwater systems, lighting fixtures, weather stripping, and vinyl-clad window frames. About 135 million pounds of PVC were used in these applications in 1974. In 1971, a new rigid profile was marketed--foamed molding. Whereas in 1971 only about 7 million pounds of PVC were used for this application, by 1973 the market had grown to 48 million pounds. About 50% of foamed PVC molding goes into mobile homes, where it has captured about 10% of the pre-finished wood molding market. B.F. Goodrich and Georgia Pacific are major producers of this product.

The use of PVC in window frames has been a fast-growing market and, from 1969 through 1973, this usage has grown at an annual rate of about 40%. Also, during this same period, the vinyl rain-gutter market grew at an annual rate of 60%. The consumption of PVC for weather stripping and lighting fixtures has shown modest growth during this period--approximately 5 - 6% annually.

TABLE III-7

END-USE MARKET FOR SIDING AND OTHER EXTRUDED PROFILES

(1974)

<u>END USE</u>	<u>MM POUNDS</u>	<u>%</u>
Siding and Panels	97	35
Lighting	13	5
Foam Moldings	48	17
Rainwater Systems	33	12
Weather Stripping	35	12
Windows, Other Profiles	<u>53</u>	<u>19</u>
TOTAL	279	100

Source: Mod. Plastics, Jan, 1975

Industry Structure. About 8 to 9 manufacturers dominate the profile extrusion industry, accounting for about 70% of the business. However, hundreds of small companies are involved in this same activity, particularly in the manufacture of profiles.

### 3. Flooring

There are at least three different vinyl flooring products, and both calendering and coating processes are used. Vinyl-asbestos tile and homogeneous tile are made by the calendering process and the so-called "heterogeneous tile" is made by the coating process. Although prior to 1970 this market was dominated by vinyl-asbestos flooring, in recent years coated vinyl has made deep inroads into this market.

Market Trends. In 1974, about 140 million pounds of PVC were consumed in the manufacture of vinyl flooring made by the coating process, and about 200 million pounds of PVC were calendered into vinyl flooring. In the last few years, the growth rate for calendered flooring has slowed to about 3% per year; in contrast, flooring made by the coating process has been growing at a rate of about 13% per year.

In 1974, the vinyl flooring market remained essentially constant. Because of the persisting trend toward the use of carpeting, the market for PVC flooring as a percentage of the total floor covering market has been declining since 1961. In 1961, PVC flooring accounted for about 50% of all basic floor coverings, whereas in 1971 it was only 30%. Growth in this market is also dependent upon the construction market.

Structure of the Industry. Vinyl flooring is produced by about 25 companies. Of these, Armstrong Cork and Kentile dominate the industry, accounting for approximately 40% of the market. (Estimates for the market shares for the major suppliers of PVC floor covering are shown in Table III-8.) With the exception of a few of the smaller companies, these companies produce a number of products other than PVC flooring, and most of the larger companies produce vinyl flooring by all three processes. With the exception of Goodyear, few of these manufacturers of vinyl floor covering are integrated backward toward resin production.

### 4. Wire and Cable

The major market for PVC in the wire and cable industry is construction or building wire, comprising over 50% of all PVC used in wire and cable coating. PVC is the dominant coating for this application.

Power cable carries voltages greater than 600V, and PVC is used to a minimum extent in this end application, because it lacks the required high-temperature resistance. Only about 15% of the wire and cable compound is used in this application.

TABLE III-8

MARKET SHARES FOR MAJOR SUPPLIERS OF PVC FLOOR COVERING

<u>Company</u>	<u>Share of Total (%)</u>
Armstrong Cork	30
Kentile	12
Congoleum-Nairn	8
Ruberoid (GAF)	8
Flintkote	7
American Biltrite	6
Johns-Manville	4
Goodyear	3
Mannington Mills	3
Robbins	3
Uvalde Rock Asphalt	2
Others	<u>12</u>
TOTAL	100

Source: Arthur D. Little, Inc., estimates.

Other PVC wire and cable products include flexible cord, appliances, automotive, communication and miscellaneous wire. A breakdown of usage of wire and cable products is shown in Table III-9.

Market Trends. During the past few years the consumption of PVC compounds for wire and cable applications has shown an average annual growth of about 10%. However, with the drop in the construction market last year, consumption decreased from 400 million pounds in 1973 to 350 million pounds in 1974; little growth is expected in 1975.

Industry Structure. Approximately 75 companies manufacture insulated wire and cable, all of them using PVC to some extent. The major producers of PVC-insulated wire and cable are: Western Electric, General Cable, Essex Wire and Cable, Phelps Dodge, and General Electric.

Three companies dominate the construction wire market, Phelps Dodge, Anaconda, and Essex. Phelps Dodge also dominates the power-cable market, and Essex is the largest non-captive manufacturer of automotive wire. The other major manufacturer of automotive wire is Packard Electric, a division of General Motors.

Western Electric is, by far, the major producer of communication wire, accounting for about 80% of this market. Beldon Manufacturing is an important factor in the flexible cord market, and probably accounts for 20% of this market.

No wire and cable producer is integrated backward toward resin production. On the other hand, many of these wire and cable manufacturers are subsidiaries of larger end-user companies such as General Electric, ITT, AT&T, and General Motors. In these instances, the major portion of the wire and cable products are used by the parent company, although the subsidiaries usually sell also to jobbers or to other major users of wire and cable.

## 5. Film and Sheet

### a. Coated Fabrics and Unsupported Film and Sheet

Market Trends. The major application for coated fabrics is upholstery. About 500 million pounds of PVC were used in this application in 1974. Of this volume, about 60% was used in furniture and 40% for automotive upholstery and seat covers. (About 30% of all furniture upholstery is vinyl.) The vinyl upholstery market (both automotive and furniture) has grown slowly--about 4 to 5% per year.

Today, about 80% of the interior trim in the average automobile is vinyl. The average automobile uses about 7 pounds of PVC (on a dry basis) in the form of unsupported sheet or film and as coated fabrics. Table III-10 shows a breakdown of PVC soft trim in automobiles.

TABLE III-9  
PVC WIRE AND CABLE USAGE  
(1973)

<u>WIRE TYPE</u>	<u>%</u>
Building and Construction	54
Communications	16
Flexible Cord and Appliances	14
Automotive and Miscellaneous	11
Power	5

Source: A. D. Little, estimates.

TABLE III-10

PVC USAGE IN SOFT TRIM FOR AVERAGE AUTOMOBILE

<u>ITEM</u>	<u>WT. DRY RESIN, LBS.</u>	<u>%</u>
Seats	3.08	44
Vinyl Roofs	1.82	26
Door Panel	1.26	18
Head Lining	0.56	8
Crash Pad <sup>a</sup>	0.28	4
<u>TOTAL</u>	7.00	100.0

<sup>a</sup> ABS/PVC Blend. Contains 35% PVC

Source: Arthur D. Little estimates

Wall coverings are another major end-use for coated-PVC fabrics. About 86% of all wall covering uses PVC and about 60% of the wall covering market uses PVC coated fabrics. Strippable vinyl "paper", which is made from vinyl film or sheet, represents about 3% of all wall coverings.

Wood surfacing films are also made from PVC. These are usually made by the calendering process, and account for about 65% of the cabinet surfaces for television, stereo, and high fidelity sets. In 1974, approximately 130 million pounds of PVC were used for wall coverings and wood surface films.

Coated fabrics are also sold to industries that construct footwear, handbags, apparel, and luggage. (PVC accounts for about 60% of all luggage.) About 50 million pounds of PVC-coated fabrics were used in 1974 for slipover rainwear, especially women's and children's overshoes and boots, and some 40 million pounds of PVC were used in shoe uppers last year. This represents about 40% of all shoe upper production.

Outerwear apparel consumed another 66 million pounds of PVC in 1974; another 24 million pounds were used to make vinyl sheet for baby pants. During the period of 1969 to 1973, consumption of PVC for outerwear grew at an average annual rate of 14%.

Structure of the Industry. Coated fabrics and unsupported sheet can be manufactured either by the calendering or casting process. Because calendering is a very capital intensive operation, manufacturers using this process generally are very substantial companies. Only about 150 calenders are currently in operation in the United States. (Appendix Table A-VI gives a list of calendering operation in the United States.) The degree of backward integration in this end-use application is very extensive, with approximately 14 of the 22 PVC resin producers also operating calendering facilities. Most calender plants also have plastisol casting lines for short runs of specialty products.

The dominating companies in the coated fabrics industry are General Tire and Uniroyal. These two top companies are followed by Union Carbide and Grace. Following this major group is one that consists of Borden, B.F. Goodrich, Hooker, Bemis, Tenneco, Stauffer, Pantasote, and Plymouth Rubber. Borden and General Tire are major factors in the wall covering market, and Borden is the major supplier of coated fabrics to the luggage market. Note that most of these major manufacturers are also resin producers. These companies are among the 40 or so companies that manufacture coated fabrics by the calendering process.

Ford Motor Company and Chrysler are examples of end-users who have integrated backward toward fabrication. Ford fabricates about 80% of its needs, and Chrysler fabricates a smaller portion. Their calender operations service only the automotive industry.

Companies using the casting process alone for coated fabrics are more numerous. These companies are generally considerably smaller than those who have calender lines.

#### b. Packaging Film and Sheet

Market Trends. About 125 to 135 million pounds of PVC were used in 1973 in the fabrication of highly plasticized film for packaging applications; about 80 million pounds were used in rigid sheet. Rigid sheet is manufactured primarily by the calendering process and the remainder by extrusion. Most rigid packaging film is made by blown-film extrusion, with a small amount made by the solvent casting process. Rigid sheet is used in a variety of packaging applications. About 70% of the calendered rigid sheet is used in "blister packaging", with the remainder used in such packaging applications as lids, which are thermoformed from rigid sheet.

Flexible PVC film is used primarily for meat and produce wrapping. About 90 million pounds of PVC were used in 1973 in the manufacture of self-service meat wrap and about 25 million pounds for fresh produce wrap. The remainder was used for a variety of food wraps--for the householder and institutions.

From 1969 to 1973, the market for flexible PVC packaging film grew at an average annual rate of 5%. Rigid PVC sheet in packaging applications grew at an average annual rate of 11%.

Structure of the Industry. Goodyear, Filmco (a division of RJR), and Borden are the major companies manufacturing PVC film by the blown-film process. These three companies account for 70 to 80% of this market. Ethyl Corporation and Union Carbide also manufacture film by this process. Note that most of these fabricators are also resin producers.

Three manufacturers produce PVC film by the solvent cast system. These manufacturers include: Reynolds Metals, Goodyear, and Cast Vinyl Film, Inc. A list of manufacturers of flexible and rigid film and sheet appears in Appendix Tables A-VII, VIII, and IX. Manufacturers of cast PVC film are listed in Appendix Table A-X.

#### 6. Bottles

Markets. In 1966, only 11 million pounds of PVC were consumed in blow molding bottles. By 1973, consumption rose to 87 million pounds. From 1971 to 1973, the average annual growth rate was about 60%. This growth was arrested in 1974, when consumption dropped to about 75 million pounds because of restrictions placed on the industry by OSHA. The FDA is currently examining the health risks of vinyl chloride monomer, because the monomer may contaminate products packaged in PVC bottles. To date, these tests have not been completed.

Because of these uncertainties, some PVC bottle fabricators have decided to delay expansion plans. We know of at least two companies that were planning to construct new plants in 1974, and because of these uncertainties, their plans have been postponed. At this time, most PVC bottle fabricators are also examining substitute materials, such as the nitrile polymers.

Structure of the Industry. The number one company in this industry is Imco (Ethyl Corporation); the other major bottle fabricators are Continental Can, Anchor Hocking, Aim Packaging, National Can, Johnson and Johnson and perhaps 20 smaller companies. The top five companies account for 60% of the business. Ethyl Corporation is the one example of a fabricator that is integrated backward. Johnson and Johnson and Breck are examples of fabricators who are integrated forward to the end user.

A typical small company in this sector operates one plant with 4 to 6 blow-molding machines. The larger companies operate at least two plants with a total of 15 to 25 blow-molding machines. Only two resin producers supply this segment--Ethyl Corporation and Hooker Chemical (Division of Occidental Petroleum).

## 7. Phonograph Records

Market. Phonograph record manufacturers produce both 12" and 7" records. All 12" records are made from vinyl chloride-vinyl acetate copolymers sometimes combined a small amount of low-molecular-weight homopolymer.

In contrast, only about half of 7" records are based on vinyl chloride copolymers. Lower quality records are made from polystyrene.

The PVC record fabrication industry has shown little growth over the years. Estimates for the domestic consumption of PVC for this end-use vary. Although Modern Plastics indicates that about 140 million pounds of PVC were consumed in record fabrication in 1974, our contacts with the industry have indicated that the real figure is between 100 and 125 million pounds. From 1971 to 1973, the average annual growth of this market was only about 2%.

Structure of the Industry. The three major record companies in the U. S. are: Columbia, RCA and Capitol, accounting for about 40% of U. S. production. Columbia is the number one company in this segment. The chief supplier of resins to the record industry is Tenneco. Keyser-Century Corporation, which sells compounds mostly on the West Coast, also is a major supplier. Relatively small suppliers to this industry are Borden and Air Products. In the near future, Firestone may also supply this market. None of these manufacturers are integrated backward; most are end-users who also sell to jobbers.

## 8. Closures

Glass-Container Closures. Essentially all vacuum closures use a plastisol liner or gasket; only about 6% continue to use rubber latex for this application. Plastisol liners are also used in many non-vacuum closures. About 30% of the non-vacuum metal caps used for glass food containers are made with plastisol liners and about 60% of the closures used in non-food applications are based on plastisol. Furthermore, about 40% of the glass containers used for home canning use plastisol-lined closures. In total, about 17 million pounds of dry resin were used in this application in 1974.

Continental Can (White Cap Division) is by far the major company in this segment, accounting for about 70% of this business. Others are Duraglass, Anchor Hocking, Owens-Illinois, Kerr, and Ball Corporation. There are few companies in this sector because the capital investment is high and the demand is relatively modest. Anchor Hocking, Owens-Illinois, and Continental Can combined account for about 90% of this business activity. With the exception of Continental Can Company, all of the manufacturers of plastisol liners are integrated with glass container manufacturing.

Beverage Crown Caps. About 80% to 90% of all metal beverage crown caps use PVC compound, the remainder using cork. This end-use market consumes about 8 to 10 million pounds of dry resin or 15 to 20 million pounds of plastisol.

No more than six manufacturers supply this market. The number one company is Crown, Cork and Seal; the other major companies are Zapata, Kerr, and National Can. These top four probably account for about 95% of the business. Zapata uses flexible compound rather than plastisol to manufacture the gaskets.

Roll-on Gaskets. All roll-on or "convenience" closures for beverage containers use PVC cut either from sheet or tape. About 5 million pounds of PVC resin are used in this application. Most manufacturers cut the gaskets from the tape, insert them into the closure, and form the gasket in place. Only about 10% of the industry uses a plastisol compound. Alcoa is the major manufacturer in this segment, second is Owens-Illinois, followed by Zapata and National Can. Crown, Cork and Seal also manufacture roll-on gaskets using plastisol.

## 9. Vinyl Enamels

Market Trends. About 30 million pounds of PVC, on a dry-resin basis, are consumed in can and closure coating applications. This corresponds to about 18 million gallons of PVC solution.

Another 15 million pounds of PVC, or 9 million gallons, are used in the solution form for a variety of metal coating applications. Typical applications include finishes for appliances, collapsible tubes, electrical wire and apparatus, non-electrical machinery, metal furniture, pre-finished metal sheet, strip or coil which is subsequently formed into appliance parts, automobile dashboard panels, caps for bottles, metal building panels, and other metal parts.

Still another application for PVC enamels is in maintenance and marine-coating systems. This application includes primers and top coats for pipes, tanks, structural metal used in chemical plants, oil refineries, etc. Vinyl maintenance coatings are also used on bridges, dams, and locks. Marine applications include the coating of both the hull and super-structure of merchant and military ships. This application consumes about 10 million pounds of PVC on a dry-resin basis, which corresponds to about 6 million gallons of solution.

Another 10 million pounds of PVC (about 7 million gallons of enamels) were consumed in miscellaneous coatings. Included in this category are coatings for concrete and masonry, film and foil, leather, magnetic tape, paper, plastics and wood products. In many of these applications vinyls are used in combination with other resin systems.

Structure of the Industry. Among the major producers of PVC enamel solution coatings for cans and closures are American Can Company (M & T Chemicals Division), Glidden, Mobil, DeSoto, the Dexter Corporation (Midland Division), Inmont, and PPG Industries. The major supplier of the dry resins used in the formulation of enamels is Union Carbide Corporation. UCC sells primarily solution-polymerized resins for these coating applications.

These coatings are applied primarily by can manufacturers, who either coat coil or sheet for endstock, or spray coat the can bodies. Alcoa also coats a small portion of the can sheet stock with a modified vinyl enamel.

Many paint companies supply vinyl coatings for maintenance and marine applications. Among the 12 largest industrial coating companies, the following are major suppliers of these vinyl coating enamels: Celanese, DuPont, Glidden, Mobil, PPG Industries, Reliance Universal, and Sherwin-Williams.

#### D. FUTURE TRENDS

Domestic PVC sales dropped last year for the first time, dropping about 3% between 1973 and 1974, with the biggest declines coming in automotive construction-related markets. Prediction of sales for the next five years is extremely risky at this time. The PVC industry, like others is presently suffering from a drop in demand due to the present recession. Little growth in the market for PVC products is expected for 1975.

Further complicating any forecast is the impact of the new OSHA requirements on the PVC resin producers and fabricators. For example, last year Goodyear closed one of their plants on the grounds that it would be economically unfeasible to bring the plant into compliance with OSHA exposure standards. We expect that additional plant closings, especially old plants, will be announced in the coming year. In January 1975, the nameplate capacity for PVC resins in this country was slightly less than 6 billion pounds. Closing of these plants will reduce this capacity and restrict supply. Furthermore, resin producers will have to meet the OSHA standards and possibly new standards developed by EPA and the FDA. All of these factors will tend to increase the cost of manufacturing PVC resins. Consequently, in the future, PVC may no longer hold its number two position among the plastic resins in this country.

Published forecasts for the year 1980 vary widely. Some suggest that the PVC resin production could increase to as much as 8.5 billion pounds (Peter Sherwood Associates, 1974) or as low as 6.8 billion pounds (Foster D. Snell Report to OSHA, 1974). We believe that even the low forecast is somewhat optimistic.

#### E. SUBSTITUTION OF OTHER RAW MATERIALS FOR PVC RESIN

Because of the versatility of PVC resin, it would be difficult to duplicate the exact properties of vinyl plastic products by using substitute raw materials. Even if it were possible to make an "equivalent or acceptable" substitute product, the costs of production and the resulting selling prices of the final products would in most instances be greater than those products made from PVC. In many cases, such costs and prices would likely be prohibitive and would essentially price the substitute product out of the market. Some of the more useful substitute materials are now made only in small quantities relative to PVC and thus would be in very short supply.

Assuming, however, that substitute raw materials will be available in sufficient quantity when needed, and that the physical capacity to produce the additional non-vinyl chloride based end products would be operating when required (which is most unlikely), considerable research and development would still be needed to effect the required changes in product, process, and equipment design. In addition, time would be required for delivery and installation of new equipment to make the vinyl substitute products on a commercial scale. This latter stage could in itself take up to two years. Based solely on technological factors, we believe that substitute products which would take the longest lead time to develop are those products required by the construction and motor vehicle industries. Such products include: insulated wire and cable for communication, building and automotive uses, pipe, flooring, automotive upholstery, and related soft trim materials.

A discussion of substitution for PVC is presented below according to the major PVC product lines.

##### 1. Pipe, Conduit, and Fittings

PVC pipe has established itself in the marketplace because it has good chemical and corrosion resistance, is non-flammable, rigid, and is easy to install. The price is also relatively low. In some pressure pipe markets (e.g., gas distribution) polyethylene could be used. ABS resin, which has a higher price and lacks chemical and flame resistance, is another substitute material, especially for DWV (drain, waste, and vent) pipe for home construction. ABS could also be used in place of PVC in electrical and communication conduit and sewer pipe. Technically, it may be possible that ABS could substitute for 20-25% of the PVC pipe market; however, this would increase the total ABS resin market by roughly one-third, and the resin would not be available in this quantity for this market for at least 2-3 years. Again, from a technical point of view, some of the PVC pipe markets could conceivably be satisfied by metal pipe. However, the metal pipe industry is itself operating at capacity and likewise could not supply the replaced PVC pipe market in less than two years.

Automotive. In the absence of PVC, the preferred approach for substitution of vinyl coated fabric for automotive upholstery would probably be to use another synthetic resin such as polyurethane. (Another possible substitute, of course, would be conventional uncoated textile upholstery fabrics such as those based on nylon and polyester blends, which today represent only a small percentage of the automotive market. However, even assuming that the nylon and polyester fibers were available in ample supply, the textile products industry would still need at least two years to install the necessary equipment to manufacture the quantities of such upholstery fabrics which would be required by the auto producers.)

Polyurethane-based coated fabrics are not as easily calendered as are the PVC based products. Coated polyurethane fabrics made by the casting process are now used in the apparel and furniture upholstery markets, where they are considered "deluxe" products. Polyurethane coated fabrics are now being used selectively in the automotive industry in Europe, and are presently being tested by the U.S. auto makers. Because the price of urethane compounds is about four times that of PVC compound, the price of urethane-based coated fabrics are substantially higher than PVC-coated fabrics. Nonetheless, this approach might be preferred because, as mentioned above, most present fabricators of PVC-coated fabrics use calendering equipment.

According to our industry contacts, polyurethane-coated fabrics should have adequate properties to meet the performance required of them in this application. Polyurethanes, in general, lack good UV stability, but some materials are now available that can meet this requirement. Some properties of polyurethanes are superior to those of PVC. For example, polyurethanes have better abrasion than PVC; consequently, thinner coatings can be used to produce equivalent properties. Alva-Tech, Inc., has developed a non-solvent polyurethane coating, which can be run on a conventional plastisol casting line and which they claim is competitive with vinyl coatings, if a thinner coating is used. Goodrich also has developed a new thermoplastic elastomer, called "Telcar", which perhaps could be used as a fabric coating.

The use of polyurethane-coated fabrics made by the casting process as a substitute for PVC-coated fabrics would require a research and design period of about one year to meet the needs of the motor vehicle industry. Since casting is not the process used by most of the coated fabrics industry, several new facilities using different equipment would also have to be constructed. For example, the conventional urethane casting process would require special drying ovens because the polyurethanes are applied as a solution from which the solvent must be removed. (This is not the case with PVC plastisol casting or the new material from Alva-Tech.) Disregarding polyurethane material shortages which are significant, 18-24 months would be needed to install the necessary casting facilities to handle this market. Moreover, because the production rate for the casting process is considerably slower than the calendering process, larger casting facilities would be

needed in place of the existing PVC calendering facilities to meet demand. Thus, from a technology viewpoint alone, the casting process approach could require at least 2-3 years to meet demand.

On the other hand, if the polyurethanes were processed by the calendering process, at least two years of research and design period would be required. While a few polyurethanes are available today that can be calendered, more research will be needed to develop the specific polyurethanes needed by the motor vehicle industry. We estimate, therefore, that if the calendering process were selected as the preferred approach, the polyurethane substitute coated fabric could be at least four years away from commercialization. Most industry respondents also agree that polyurethanes designed for calendering would process at a slower production rate than PVC. Nonetheless, this approach might be preferred because, as mentioned above, most present fabricators of PVC-coated fabrics use calendering equipment.

Rohm and Haas has recently developed a new product, based on foamed acrylate which could also compete with high-priced coated vinyls, although at this time it is only in the developmental stage. Rohm and Haas is currently seeking potential licensees who would manufacture this product called "Ayracryl".

Chlorinated polyethylene (CPE) is another possible substitute material, although its present output and availability is very limited. This product has the advantage that it can be calendered in much the same manner as the present calender-grade PVC. In the opinion of fabricators who have worked with this resin, the product is close to meeting most existing PVC specifications for automotive upholstery. However, CPE does not have the necessary low-temperature flexibility needed by the motor vehicle manufacturers. Furthermore, it is more difficult to calender PVC and some have estimated that the production rate would be slowed by as much as 20%. Still another possible substitute for PVC in this application is ethylene-vinyl acetate copolymer (EVA). This product also can be calendered but, again, it lacks the necessary low-temperature flexibility. Because EVA, in contrast to PVC and CPE, lacks inherent flame resistance, it has to be especially formulated to meet this requirement. Thus, substituting EVA or CPE for PVC would mean some sacrificing of performance. Furthermore, these substitute products would still require about three years to reach commercialization, again assuming the raw materials were available.

Fabricators and motor vehicle manufacturers are also developing new methods for manufacturing motor vehicle seats--methods which would not require coated fabrics. For example, one promising approach is the manufacture of one-piece molded seats using foam polyurethanes with an external skin; the boating industry is currently using products of this type. However, this approach will require considerably more research and development time than the approaches described above in order to replace PVC-based automotive upholstery fabrics.

Furniture. The preferred substitute for PVC in coated fabrics for furniture again appears to be the polyurethane. Polyurethane-coated fabrics are used commercially today as furniture upholstery material. However, it is still only a small part of the market compared to PVC-coated fabrics. At the present time, most of these urethane-coated fabrics are made by the solution casting process. As discussed above, a series of relatively new urethane polymers have become available that can be calendered, and cast in much the same way as plastisols. The product design period for the changeover from PVC to polyurethane in this market should be no more than one year. Following that, modification of the existing equipment and the installation of some new equipment should be able to take place within one additional year. Thus, the time lag for PVC substitution in this application would be about two years, assuming that the polyurethane resins were then available.

Manufacturers of PVC-based furniture upholstery, like the automotive upholstery industry, have also considered other substitute materials. Ethylene-vinyl acetate polymer is one other candidate material. Though it can be calendered and formulated to meet most property requirements, it lacks low-temperature flexibility. Chlorinated polyethylene has been used, but it would have similar deficiencies. "Ayracryl" is another potential substitute.

Flooring. Because of the unusual ability of PVC resin to be made into a variety of colors (including pastels), surface finishes ("shiny" or dull), degrees of hardness, and the fact that PVC possesses excellent chemical and flame resistance, it would essentially be impossible to duplicate the same line of vinyl flooring products now on the market by using other synthetic or natural polymers. New facilities would have to be built to produce much larger quantities of linoleum and asphalt tile if the consumer would indeed go back to using these inferior products. It is more likely that most of the hard surface plastic flooring market would be replaced by soft carpeting rather than with these "outmoded" resilient flooring materials.

## 2. Wire and Cable

Building Wire. PVC was originally selected as the preferred material for the application because of its low cost (which derives in part from its "easy" processability), excellent flame resistance, good low-temperature flexibility and colorability (e.g., for coding), in addition to desirable electrical insulation properties. If PVC were no longer available, a major constraint that would inhibit the introduction of a substitute material would be the existing building codes. Although most of the codes involve performance specifications, they essentially restrict the material to PVC, because they specify performance requirements, such as flame resistance and flammability, that only PVC can meet.

The easiest substitute approach would be to use polyethylene plastics. Although this material lacks the inherent flame resistance of PVC, the industry believes that, given sufficient time, polyethylene could be formulated to meet this requirement. However, even "flame resistant" polyethylene does not satisfy the operating temperatures required in many

building-wire applications. Although "flame-resistant" polyethylene could be used in most homes, it would probably be unsatisfactory in many industrial, commercial, and institutional applications where relatively high service temperatures are required. Polyethylene is also less flexible than PVC, a major disadvantage in household wiring. One approach might be to use thinner coatings to get improved flexibility; however, this might result in unsatisfactory insulation value.

Another possible PVC substitute would be EPR (ethylene-propylene-rubber) with an outer coating of chlorosulfonated polyethylene or neoprene. By itself, EPR is too soft for many applications and does not have the required resistance; therefore the Hypalon or neoprene coating would be required. These materials would impart the necessary flame resistance. Although Hypalon or neoprene alone would fulfill many of the property requirements, these materials are much more expensive and are not available in the quantities required. Neoprene would be satisfactory in many building-wire applications, but it lacks the necessary abrasion resistance required in several non-building construction applications. Another potential substitute material is cross-linked polyethylene (XPE), a thermosetting material. Again, XPE would have to be formulated to meet the flame resistance requirements; otherwise, it would have most of the other necessary properties, including the relatively high-service-temperature property. However, a rigid material, which would limit its use significantly in this market.

Assuming that the constraints of the building codes were removed and that sufficient amount of the substitute materials were available (again essentially impossible today from a physical capacity viewpoint), the redesigning of the substitute product would take up to two years, depending upon which substitute materials were selected. Even if the "easiest" approach were taken, such as using polyethylene, the existing extruding equipment would have to be modified (e.g., new and different screws would be needed). If a thermoset material, such as Hypalon, were selected, then considerably new auxiliary equipment and facilities also would be required. Therefore, depending upon which material was selected, the total time needed to commercialize substitute building wire products would be from two to four years. Achieving the needed raw material capacity would take much longer.

Automotive Wire and Cable. The average passenger car uses about ten pounds of PVC compound as insulating material for wire and cable; although small in terms of weight percent, this is a very necessary product. According to the industry, the best substitute material would be polyethylene. Ordinary polyethylene has an operating temperature somewhat lower than PVC. In most instances, therefore, the auto industry would require crosslinked polyethylene (XPE), which is used in some automotive wire applications today. The crosslinked variety of polyethylene has an operating temperature of 150°C (compared with a rated operating temperature of 105°C). Polyethylene itself will not meet the existing flame-resistance requirements, but can be satisfactorily formulated to meet these requirements. However, substituting polyethylene would mean giving up other performance requirements such as flexibility.

Because crosslinked polyethylene wire is a commercial product today, the redesign period would be relatively short--perhaps about six months--if crosslinked polyethylene were used as a substitute. However, this material is processed differently from PVC, and the need for additional equipment and space would introduce an additional time lag of 12-24 months. While the existing PVC extruders could be used in the fabricating operation, the processors would have to change the extruder screw and, more significantly, would have to add new curing lines. Curing of crosslinking polyethylene requires heat and, therefore more space and, obviously, more steam would be needed than is the case with PVC products. Furthermore, substituting crosslinked polyethylene would also reduce productivity--perhaps by as much as one-third. Consequently, additional extruding equipment also would be needed. In summary, it is estimated that substituting XPE for PVC in automotive wire applications would require about two years.

Communication Wire. Flexible PVC compound is widely used as the wire insulation is primarily used inside buildings--commercial, industrial, and residential--and consequently must meet local building codes. PVC is the preferred material in this application because of its overall cost/performance characteristics, its relatively high-temperature resistance, and its good flexibility and colorability. Perhaps most important, because it is used inside buildings, PVC is preferred because it meets the necessary flame-resistance requirements. Neoprene and Hypalon could substitute for PVC in many of the existing applications. Neoprene could probably meet all of the existing requirements met by PVC insulation today, even though its electrical properties are slightly inferior to those of PVC. Hypalon also can be considered a good substitute material. But Hypalon and neoprene rubbers are thermoset materials that would require new processing equipment. A thermoplastic material would be preferred.

Polyethylene could be used in many applications if it were formulated to meet the flame-resistant requirements. (Chlorinated polyethylene might also be used, if it were available in the quantities needed to satisfy this large market.) The best approach would be to substitute appropriately formulated polyethylene for many of the current applications that use PVC and use neoprene as the substitute material for those applications that cannot be served by polyethylene alone.

Again, disregarding the constraint introduced by the need to change the existing building code requirements, extensive research and development would be needed to develop the substitute insulation material for communication wire. The specifications for materials used in this application are very stringent. Thus, research and development required to develop a neoprene substitute product would probably involve at least a two-year period. Neoprene would also require different processing equipment. Therefore, another two years would be needed to install the new facilities and build the additional space to manufacture the neoprene-insulated wire. The design and development period for the polyethylene substitute material would be somewhat shorter. The total time lag for substituting PVC in this application is estimated to be from three to four years.

#### 4. Packaging

Meat Wrapping. At the present time, flexible PVC is essentially the only wrapping film used for fresh meat. In the past, cellophane was used, and can therefore be considered a potential substitute material. However, the manufacturing process required to make cellophane film is completely different from that used to fabricate PVC film. New facilities might be needed to manufacture the additional cellophane film, because at the present time most cellophane manufacturing facilities are relatively antiquated. Two to three years would be needed to construct these facilities.

Cellophane would meet most of the existing performance requirements; however, it is not as flexible as PVC. Other substitutes for PVC in this application might be polyethylene and ethylene-vinyl acetate resins. However, these alternatives are not very acceptable, because they are inferior to PVC with respect to clarity and oxygen-transmission properties.

Can Coatings. Most metal cans have an internal coating to protect the contents of the can from metal contamination, and, in some instances, to protect the metal from corrosion. In food canning applications, a variety of coatings are used, including vinyl chloride-based copolymers. Other coating materials used for these purposes include olefin resins, phenolics, and epoxy resins; some polybutadiene resins are also used in beverage cans.

Polyvinyl chloride-based resins have been used primarily because of their flexibility--a property that is important in the manufacture of two-piece metal cans that are "deep drawn". The industry could use epoxy resins as a substitute product in this application because it would require a minimum of new equipment. However, the use of epoxy resins, will slow production somewhat for it is more difficult to spray; most two-piece cans are sprayed while three-piece cans are coated by a roll coating process. Although epoxy resins are generally acceptable in beverage and food cans, these resins may sometimes introduce a flavor problem. From this point of view, polybutadiene coatings would likely be preferred for beverage containers because they impart little or no taste. Assuming that epoxy resins were commercially available, the time required for the changeover would be minimal--less than one year.

Recently PPG Industries introduced a new can-coating product based on acrylics that can potentially replace the vinyl enamel system. The new product called "Environ-1776", is now under test in beer cans.

PVC coatings are also used in the manufacture of some composite (paper-foil) cans used for foods. Here, it is typically used as a slip coating on aluminum foil, and provides heat sealability. In this case, the industry has substitute products under development and, if PVC were not available, these products could be introduced within 6-12 months.

Crowns and Closures. Most beverage crowns use a PVC plastisol compound as a gasket to provide the necessary seal to keep the content of the bottle fresh for long periods of time. Cork can be used, but it is imported, and is expensive and difficult to obtain. The new convenience "roll-on" closures for beverage bottles also use a plastisol compound as a liner material. Although cork is a possible substitute material for this application, realistically, it is not preferred. The use of a cork liner requires very different equipment than that which is used to apply the plastisol liners. At the present time, substitute products are under development, and one manufacturer has developed a new ethylene-based elastomer material which is currently in use in Europe. However, to utilize this new material new equipment would be required and installation of this equipment would introduce a time lag of about one year.

Plastisol materials are also widely used as liners for the wide-mouth jar closures. In this case, the best substitute product would be a rubber latex material, such as a natural or an SBR rubber. Some rubber latices are presently used in this application, and therefore a changeover to this substitute material could be carried out with a minimum of research and development time. (Sealing products in these applications, of course, must meet FDA requirements.) The equipment required to manufacture closure liners based on rubber latex is different from that required for the manufacture of plastisol liners. Consequently, about one to two years would be required to obtain the necessary equipment in-place. Furthermore, the process that uses rubber latex is considerably slower than that used for plastisol. Therefore, the production rate would be cut substantially. However, for the most part, these products would not meet the existing performance requirements. Although rubber does have adequate sealing capabilities in many applications, there are some applications where it does not. Also, in some of the high-temperature processes required during the bottling of food, rubber is not as good as plastisol. In addition rubber often has "cut through" problems and can introduce taste changes.

In the case of non-vacuum closures, substitution will be much easier. Here, plastisol is not used as widely, and rubber or coated paper inserts can provide satisfactory performance.

Table III-11 presents a summary of the primary substitution materials for PVC resin and the time required to substitute them in the different major end uses.

TABLE III-11

SUBSTITUTION ASPECTS OF FABRICATED VINYL PRODUCTS

<u>PVC Based Product</u>	<u>Primary Substitute Raw Material Candidates</u>	<u>Total Time Required for Substitution (a)</u> (years)
Pipe	ABS, Polyethylene Metal	1-2
Conduit	ABS, Polyethylene Metal	1-2
Flooring		
Tile	Coumarone-indene resin, SBR	2-3
Yard Goods	Linseed oil (for linoleum)	3-4
Upholstery Material		
(Coated fabrics)	{ Polyurethane, CPE, "Ayracryl"	2-3
Automotive		1-2
Furniture		
Wire Insulation	Polyethylene, Neoprene, HYPALON, EPR	2-4
Phonograph Records	Polystyrene	3-4
Siding	Wood, metal (steel, aluminum)	1-2
Packaging Materials		
Flexible Film	Cellophane	1-2
Rigid Film	Cellulosic resin, polystyrene, nitrile resin	1-2
Bottles	Nitrile resin, glass	1-2
Cap liners	Cork, rubber	1-2
Can linings	Epoxy resin, acrylic coating	1-2
Medical Tubing	Rubber (e.g., thermoplastic elastomer)	1-2

- (a) Assumes that (1) sufficient quantities of substitute raw materials would be available when required by market demand;  
(2) production facilities are in place and operating at the time required.

Source: Arthur D. Little, Inc., estimates

#### IV. DESCRIPTION OF PROCESSES AND EMISSION POINTS

In this section we describe the details of the various compounding and fabricating operations used in the manufacture of polyvinyl chloride products. For each process we have identified the major sources of vinyl chloride monomer loss where such information was available, or have attempted to estimate the loss based on known losses from similar processes.

In all cases, VCM content or loss is reported in "ppm"--that is, parts by weight of vinyl chloride monomer per million parts of polymer. (This is in contrast to units used to report concentration of VCM in air, where "ppm" is used to denote parts per million by volume).

At the end of each process description, the amount of VCM emitted per weight of polymer is multiplied by the known amount of polymer processed by this method in the United States each year to arrive at the "total nationwide emissions" from each process. These totals are then summarized in Section V.

##### A. COMPOUNDING

The physical and chemical properties of polyvinyl chloride are such that it can be used in only a very few applications in its pure (unmodified) form. In most of its applications, PVC requires the addition of a number of additives to increase its flexibility, ease of processing, resistance to degradation, etc. These additives (which may total as much as 100% of the weight of the raw PVC resin) include:

Plasticizers (such as the phthalates) to increase the flexibility of the finished product.

Heat stabilizers (such as metallic salts, etc.) to prevent degradation and discoloration of the PVC at the elevated temperatures required for processing.

Lubricants to improve the flow of the molten PVC and to prevent its sticking to metal processing surfaces.

Fillers to increase the bulk and lower the cost of the final material.

Pigments and dyes to produce the desired color.

Successful compounding of these ingredients to achieve satisfactory properties in the final product depends on the ability to blend all of the additives sufficiently well that a homogeneous material results. The compounding process has been divided into the following separate processes, all or some of which may take place in any given operation:

1. Simple mixing of all the ingredients.
2. Adsorption of liquid ingredients onto the surface layer of resin particles.
3. Complete plasticization of the solvated resin particles.
4. Cohesion between plasticized resin particles.
5. Loss of identity of the individual particles by fusion.
6. Chemical interaction of the polymer with some of the ingredients (e.g., stabilizers).

## 1. Flexible PVC Compounds

### a. Process Description

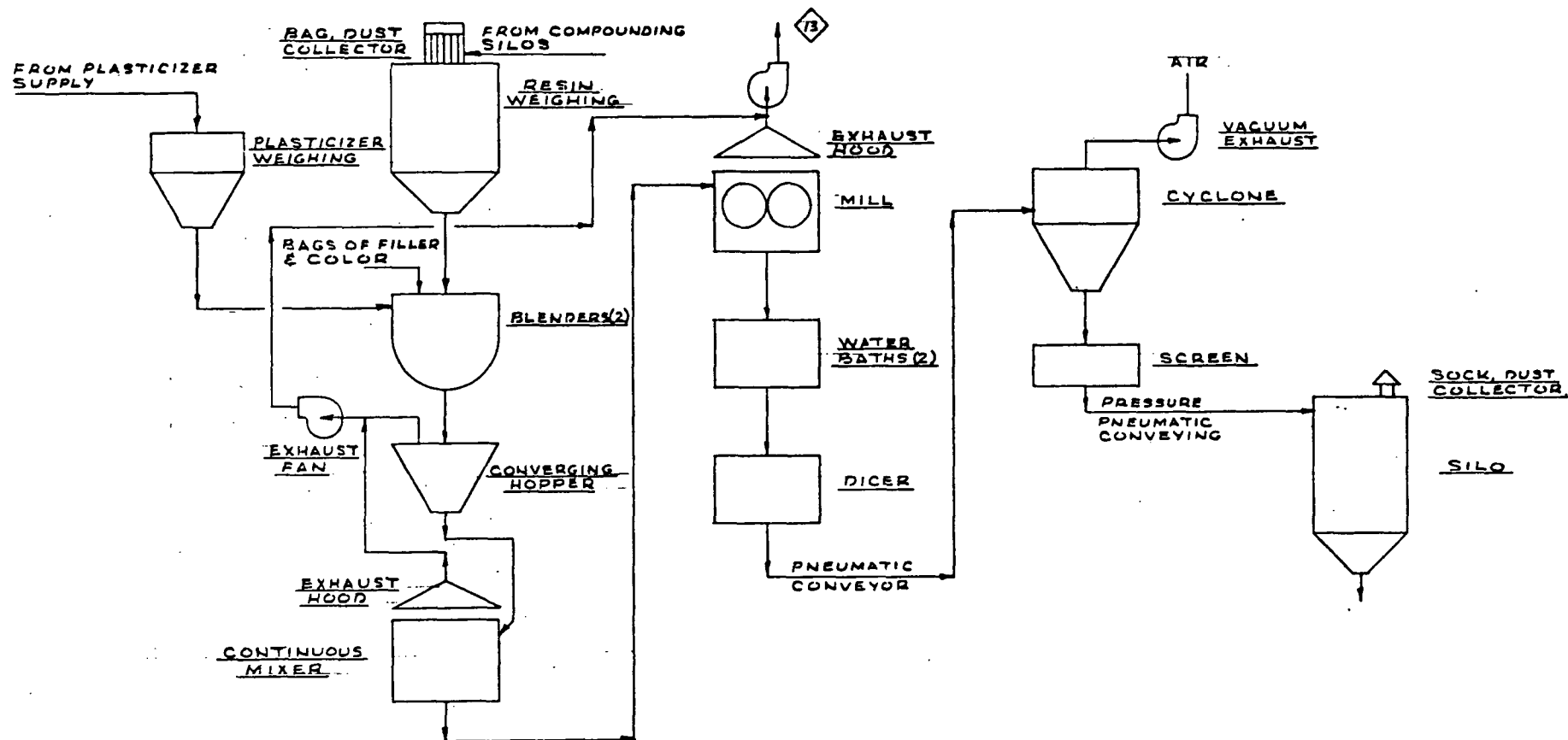
There are two major methods for the preparation of plasticized PVC: dry blending and hot compounding. In the dry blending operation, the liquid additives are simply mixed with the resins and stirred rapidly below the fusion temperature at 93-107°C (200-225°F). The resin particles "soak up" (or adsorb) the liquid and the result is a dry powder barely distinguishable in appearance from the original resin. Although the resulting mixture is technically not yet "fully compounded", it may be stored and then fed directly to fabricating equipment where the resulting high temperatures melt the dry powder and produce a fused compound in the process of fabrication.

Hot compounding is frequently used when larger amounts of plasticizer are to be added to the polymer. In this operation the ingredients are first mixed together (in an operation roughly identical to "dry blending"). The resulting blend is then kneaded and fused to produce a homogeneous melt. The melt is then cooled and diced into pellets or granules.

Figures IV-1 and IV-2 show typical process flow diagrams for the hot compounding processes: a continuous process using a Farrel continuous mixer and a batch process using a Banbury mixer. Figure IV-3 is a cross sectional view of a typical Banbury mixer installation showing the ventilation system.

As shown in these flow diagrams, the process consists of several major steps:

1. Blending of raw resin and additives in a blender, where heat is usually generated by the process. (In some operations, additional heat may be added to promote mixing.) A dry powder results.
2. Heat mixing (Farrel Mixer or Banbury) to knead and fuse the powder to produce a homogeneous mass.



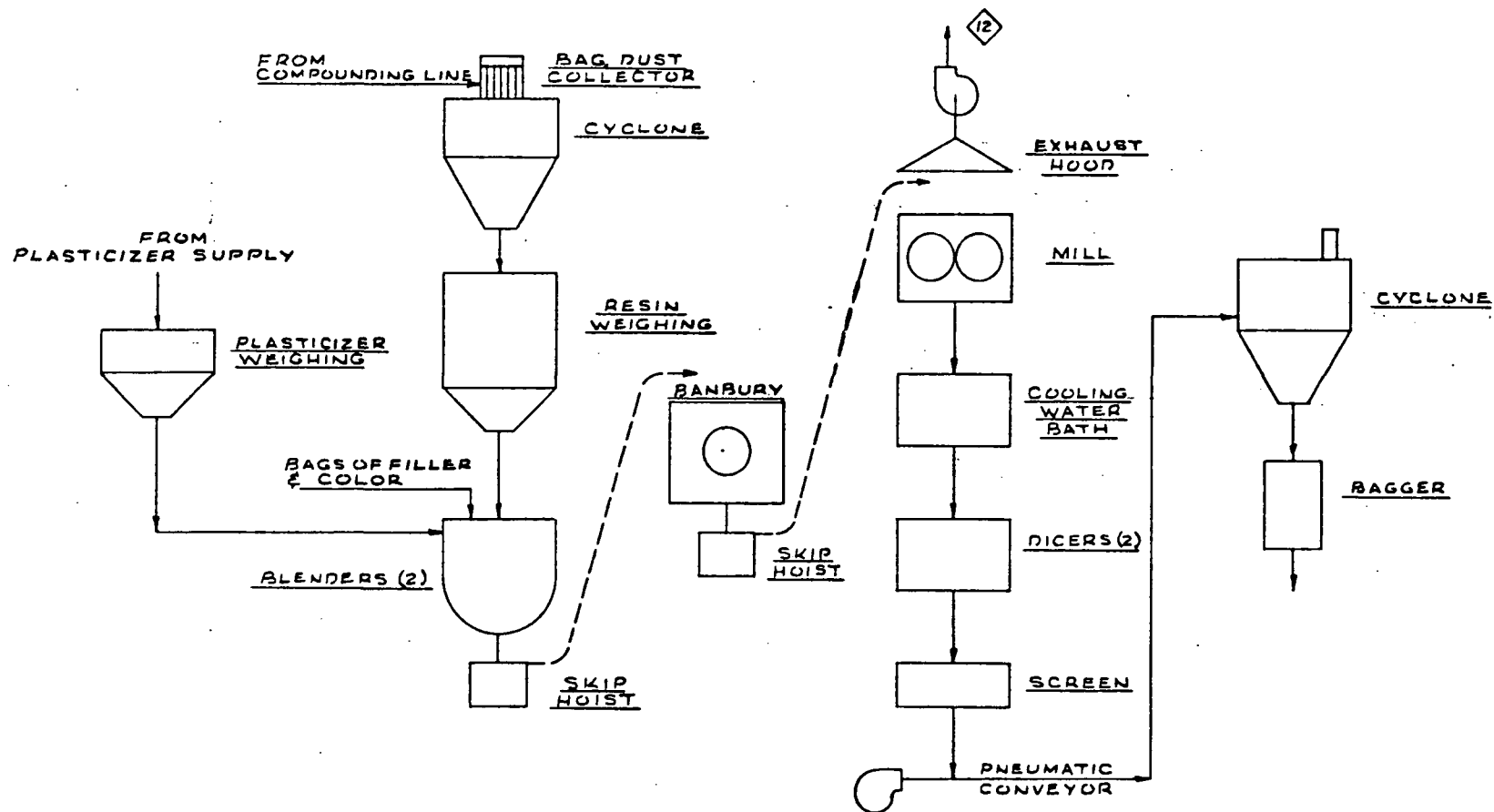
NOTES:

TOTAL COMPOUND PRODUCTION  
160,000 LBS/DAY LINE 3

◇ EMISSION STREAM NUMBER

NUMBER IN ( ) INDICATES NUMBER  
OF EQUIPMENT ITEMS IN SERVICE

Figure IV-1. Continuous Hot Compounding Line.



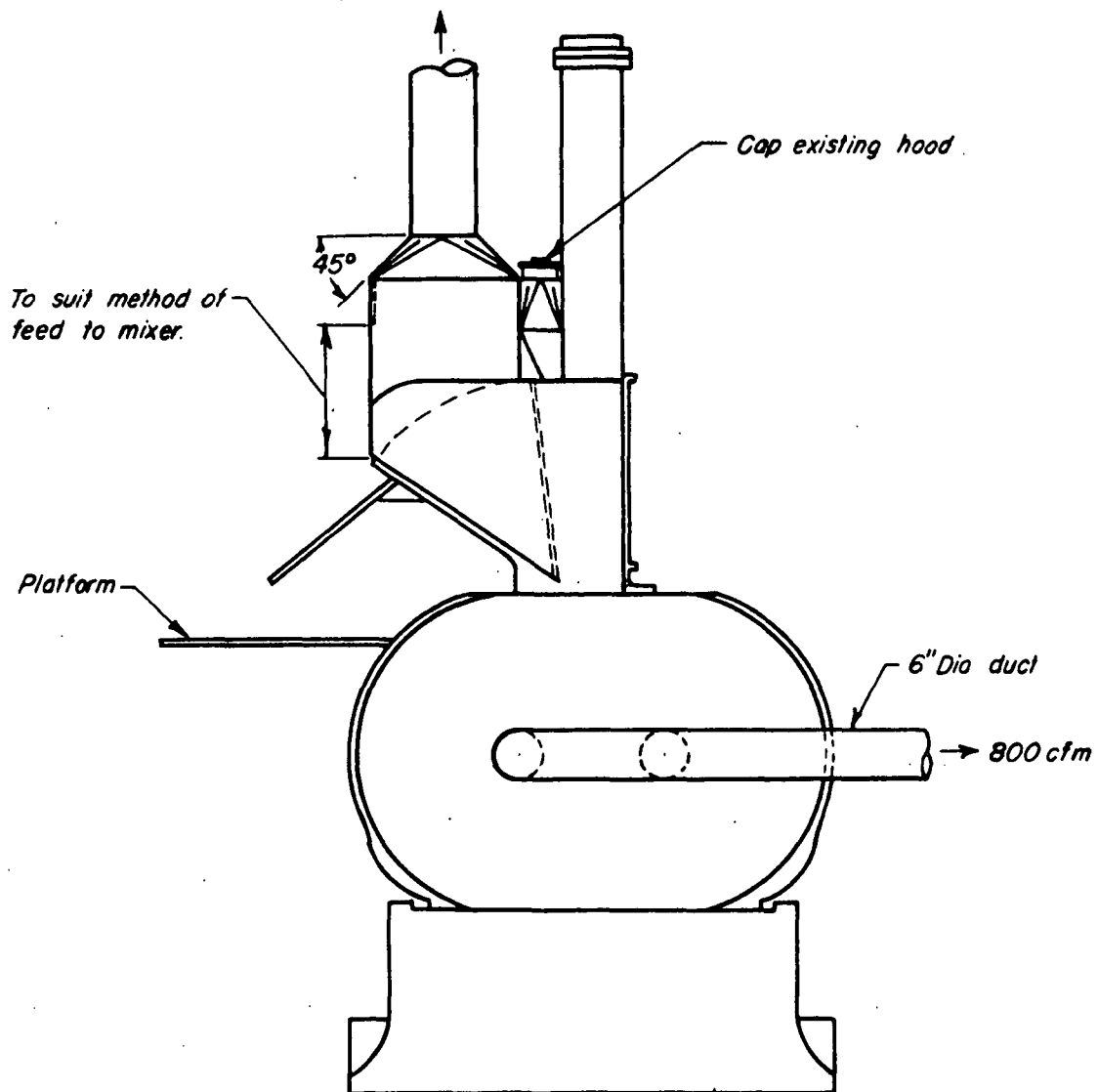
NOTES:

TOTAL COMPOUND PRODUCTION  
10,000 LBS/DAY LINE 1

◆ EMISSION STREAM NUMBER

NUMBER IN ( ) INDICATES NUMBER OF  
EQUIPMENT ITEMS IN SERVICE

Figure IV-2. Batch Hot Compounding Operation.



$Q = 200-300 \text{ cfm/sq ft open face area.}$   
 $500 \text{ cfm/ft of belt width if belt feeder used.}$   
 $\text{Duct velocity} = 3500 \text{ fpm minimum.}$   
 $\text{Entry loss} = 0.25 \text{ VP at hood}$   
 $1.0 \text{ VP at trunnion}$

Figure IV-3. Banbury Mixer

3. Milling to produce a ribbon of compound.
4. Cooling of the compound ribbon.
5. Dicing of the ribbon to make pellets.
6. Packaging or storing.

b. Vinyl Chloride Monomer Emission Points in Flexible Compounding Operations

The major point of VCM emission in the compounding of flexible resin is in the addition of plasticizer during the dry blending operation. (This conclusion holds whether or not the dry blended powder is later subjected to fusion.) Experiments by resin and compound manufacturers appear to show that little or no VCM is released during the simple process of stirring and heating in the dry blender (if no aspiration is used), but that upon addition of the plasticizer, most of the residual monomer is released. Our limited data appear to indicate that with the initial VCM contents of the input resin in the range of 20 to over 1,000 ppm, the VCM content of the dry powder after plasticizer addition is usually reduced to less than 20 ppm. Minor amounts of VCM are emitted at later points of the compounding operation, notably in the additional blending of the dry powder, and in the processing of the melt after the melt mixers. (Although it had originally been hypothesized that the major points of VCM emission would be at the points at which the resin was melted, this is apparently not so for two reasons: (1) very little VCM is left by the time the compound reaches the melt mixer and (2) the surface area of polymer exposed to the atmosphere during the melt is very small compared to the large surface area exposed by the fine particles in the dry blender.)

Table IV-1 shows VCM levels measured by a major manufacturer at various points along his compounding operation. As shown by these data, the major point of VCM loss is at the addition of the plasticizer in the dry blending part of the operation. The dry blending alone, even with the addition of considerable heat did not result in significant release of VCM. Finally, after the dry blending operation is complete, a small amount of residual VCM remains; much of this is then lost in the subsequent "melt" phases of the operation.

These data are confirmed by the data of Tables IV-2 and IV-3, gathered by major manufacturers. Although less detailed, they confirm that essentially all of the residual VCM in the input raw resin to a flexible resin compounding operation is lost after the dry blending operation.

Finally, it is important to note that the residual VCM level in fully compounded flexible resins is very low; hence, any further processing of these resins into fabricated products can result in only a very small total amount of VCM emission from the fabrication process.

TABLE IV-1

VCM Levels in Resin at Points along Compounding Process (ppm by weight)

<u>Processing Step</u>	<u>Flex</u> (1)	<u>Flex</u> (2)	<u>Flex</u> (3)	<u>Flex</u> (4)	<u>Flex</u> (5)	<u>Flex</u> (6)	<u>Semi-Rigid</u> (7)	<u>Rigid (co polymer/ polymer mix)</u> (8)
(a) Resin as charged	24*	18*	33*	58*	134**	374**	356	218***
(a-1) dry blend after heating but before plasticizer added	[essentially unchanged]							
(b) dry blend after additives in.	4	6.4	10	7.6	7.3	3.2	65	190
(c) dry blend after completion of blending cycle	N.D. <sup>†</sup>	4	5.1	N.D.	0.3	0.7	34	180
(d) belt feeder to continuous mixer (after holding hopper)	"	3.2	5.6	"	0.3	0.6	26	184
(e) Out of continuous mixer (melt)	"	2.1	5.4	"	N.D.	0.6	11	211
(f) Mill slab	"	2.7	4.7	"	"	0.4	13	218
(g) Pelletized	N.D.	1.8	2.7	N.D.	N.D.	0.3	13	229

\* Bagged suspension resin stored over two months.

\*\* Suspension resin bought in bulk rather than in bags.

\*\*\* Relatively non-porous particles

† Non-Detectable (&lt;0.1 ppm).

TABLE IV-2Vinyl Chloride Concentrations in Film Processing

<u>Date</u>	<u>Resin</u>	<u>VCM Concentration - ppm</u>		
		<u>Dry Blend</u>	<u>Pellets</u>	<u>Film</u>
3/6/74	1400	2	21	2
8/22	360	4	7	ND
9/23	240	ND	ND	ND
9/23	300	5	7	ND
9/23	350	7	4	ND
10/14	210	3	8	ND
3/7	2400	48	23	2
3/7	2600	74	80	8
2/21	590	2	6	2
3/8	800	10	2	-
3/12	38	2	ND	ND
3/12	1000	90	7	-
3/25	470	20	ND	ND
3/25	560	13	1	ND
3/25	340	4	1	ND
7/9	12	1	ND	-
7/25	200	2	ND	-
7/26	170	ND	ND	-
7/26	90	ND	ND	-
7/26	55	ND	ND	-
7/26	120	3	ND	-
8/13	91	1	4	-
8/13	86	1	-	-
10/1	210	4	2	-
10/1	135	1	5	-
10/24	730	ND	2	-

TABLE IV-3  
Flexible VCM Compound Production

<u>Process</u>	<u>Input VCM Level (ppm)</u>	<u>Output VCM Level (ppm)</u>
Dryblending	72	15
	12(?)	12
	157	10
	411	2
	629	<1
	72	6
Pelletizing	15	1
	12	<1
	10	<1

c. Total Amounts of VCM Emitted from Flexible PVC Compounding Processes

The amount of vinyl chloride monomer emitted from flexible resin compounding processes is almost directly proportional to the amount of residual VCM in the input resin to the operation, since practically all of the residual VCM in the resin is released upon compounding. The amount of residual VCM in the incoming resin is highly variable, and dependent upon a number of factors, notably the details of the polymerization and post-stripping process, and the storage and shipping history of the resin prior to compounding. Storage time of the resin before use strongly affects the residual VCM levels: it has been estimated that approximately 25 to 50% of the original VCM content of raw resin is lost during the first 30 days of shipping and storage under ordinary conditions. This loss may be accentuated under conditions of high ventilation. Because of this effect of storage, VCM losses will, in general, be higher from compounding operations which take place at the same location at which the raw resin is manufactured, and lower from these operations which purchase or ship input resins from other locations.

In studies of suspension resins, residual VCM levels ranged from less than 50 ppm to as high as 2600 ppm vinyl chloride monomer by weight. Tables IV-4 and IV-5 show a tabulation of VCM contents of resins received in consecutive shipments from suppliers by one major fabricator in late 1974. Suspension resin VCM contents are shown to vary from a low of 30 to a high of 3500 ppm.

Complete statistics on VCM levels in input resins are not available. On the basis of our plant visits we estimate that the majority of flexible resin compounding operations had an input resin VCM content of 200 to 1000 ppm. in 1974. In the latter part of 1974, raw resin manufacturers were beginning to devote considerable effort to lowering the VCM levels in their resins, so that the input resin to many of the operations probably fell in the 200-500 ppm range. It has been estimated by manufacturers that by the end of 1975 most suspension resins will have residual VCM levels below 50 ppm. The technology to achieve these low levels appears to be a practical and important "control" measure for reducing VCM release to the atmosphere from flexible resin compounding operations.

For the purposes of estimating the total VCM release rate to the atmosphere from a compounding operation, the following formula may be used:

$$\frac{100,000 \times 300}{10^6} = 30 \text{ lbs/day} = 13.6 \text{ kg/day}$$

Assuming as a very rough estimate a nationwide average of 300 ppm in the input resins to flexible resin compounding operations in 1975, the nationwide release of VCM last year can be estimated as:

TABLE IV-4  
Percent\* Vinyl Chloride Monomer in PVC Homopolymer

<u>Identification</u>	<u>Type Resin</u>	<u>% Vinyl Chloride Monomer*</u>
105-1	Suspension	.086
244	Emulsion	.003
283	Suspension	.082
283	Suspension	.081
283	Suspension	.14
283	Suspension	.13
283	Suspension	.031
294	Emulsion	.005
309	Suspension	.016
309	Suspension	.01
311	Suspension	.064
311	Suspension	.073
311	Suspension	.068
311	Suspension	.029
311	Suspension	.053
311	Suspension	.049
311	Suspension	.033
311	Suspension	.037
312	Suspension	.030
312	Suspension	.064
312	Suspension	.047
312	Suspension	.091
312	Suspension	.033
312	Suspension	.041
313	Suspension	.28
313	Suspension	.28
313	Suspension	.19
313	Suspension	.06
313	Suspension	.14
321	Suspension	.087
321	Suspension	.063
321	Suspension	.084
321	Suspension	.045
321	Suspension	.046
321	Suspension	.087
321	Suspension	.045
321	Suspension	.030
321	Suspension	.022
321	Suspension	.025
323	Suspension	.014
323	Suspension	.099
903	Suspension	.004

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\* 1% = 10,000 ppm

TABLE IV-5Percent\* Vinyl Chloride Monomer in PVC-PVA Copolymer

<u>Identification</u>	<u>Type Resin</u>	<u>*% Vinyl Chloride Monomer</u>
163	Suspension	.071
163	Suspension	.050
163	Suspension	.077
163	Suspension	.2500
163	Suspension	.2600
163	Suspension	.2100
297	Suspension	.041
430	Solution	.009
430	Solution	.007
440	Suspension	.054
440	Suspension	.041
440	Suspension	.100
450	Suspension	.058
450	Suspension	.079
450	Suspension	.097
450	Suspension	.039
450	Suspension	.034
451	Suspension	.078
451	Suspension	.074
458	Suspension	.062
458	Suspension	.14
458	Suspension	.080
458	Suspension	.080
458	Suspension	.054
459	Suspension	.10
459	Suspension	.082
459	Suspension	.083
459	Suspension	.136
459	Suspension	.16
459	Suspension	.15
459	Suspension	.12
459	Suspension	.118
459	Suspension	.17
479	Solution	.055
479	Solution	.01
480	Solution	.003
532	Suspension	.35

---

\* 1% = 10,000 ppm.

Nationwide Release of VCM in 1974  
 from Flexible Resin Compounding Operations  $= \frac{300}{10^6} \times 1.6 \times 10^9$  lbs/yr of flexible resins produced

$= 480,000$  kg/yr of VCM released

(  $= 218,000$  lbs/yr of VCM )

By the end of 1975, assuming the goal of 50 ppm is reached, the annual rate of VCM release from flexible resin compounding operations may be estimated (assuming the same rate of production):

Annual Rate of VCM Release  $= \frac{50 \text{ ppm}}{10^6} \times 1.6 \times 10^9 = 80,000$  lbs/yr  
 $= 36,000$  kg/yr

As discussed in Section III (Table III-4) approximately 83% of flexible PVC compound is produced by the fabricators of semi-finished products, about 11% is produced by the raw resin producers, and about 6% by independent compounders. Table III-4 of Section III further subdivides the compounding operations by type of final product.

## 2. Compounding of Rigid Formulations

### a. Process Description

In rigid dry blend formulations, the resin, filler, lubricant and stabilizers are mixed in an intensive (high speed) mixer where considerable heat is generated. It is then cooled in a ribbon blender or in a lower speed cooling mixer similar in design to the hot, high intensity mixer, and transferred for packaging or storage. In this operation, the compound does not go through the melt phase. Figure IV-4 shows a schematic of a dry blend process.

A minor amount of rigid compounds is also produced by a process involving fusing of the powder and dicing to produce rigid pellets.

By far the largest application for rigid PVC resins is in the production of PVC pipe. The great majority of PVC pipe producers do their own compounding on the same site as the pipe production. Mixing the additives with the raw resin takes place in a high intensity "hot" mixer through the use of an air sweep or a vacuum, considerably increasing the amount of VCM given off. Older installations do not have this feature, but the pressures of the OSHA regulations and the hazards of exceeding the lower explosive limit for VCM will probably result in more and more facilities providing for VCM removal in the "hot" mixer.

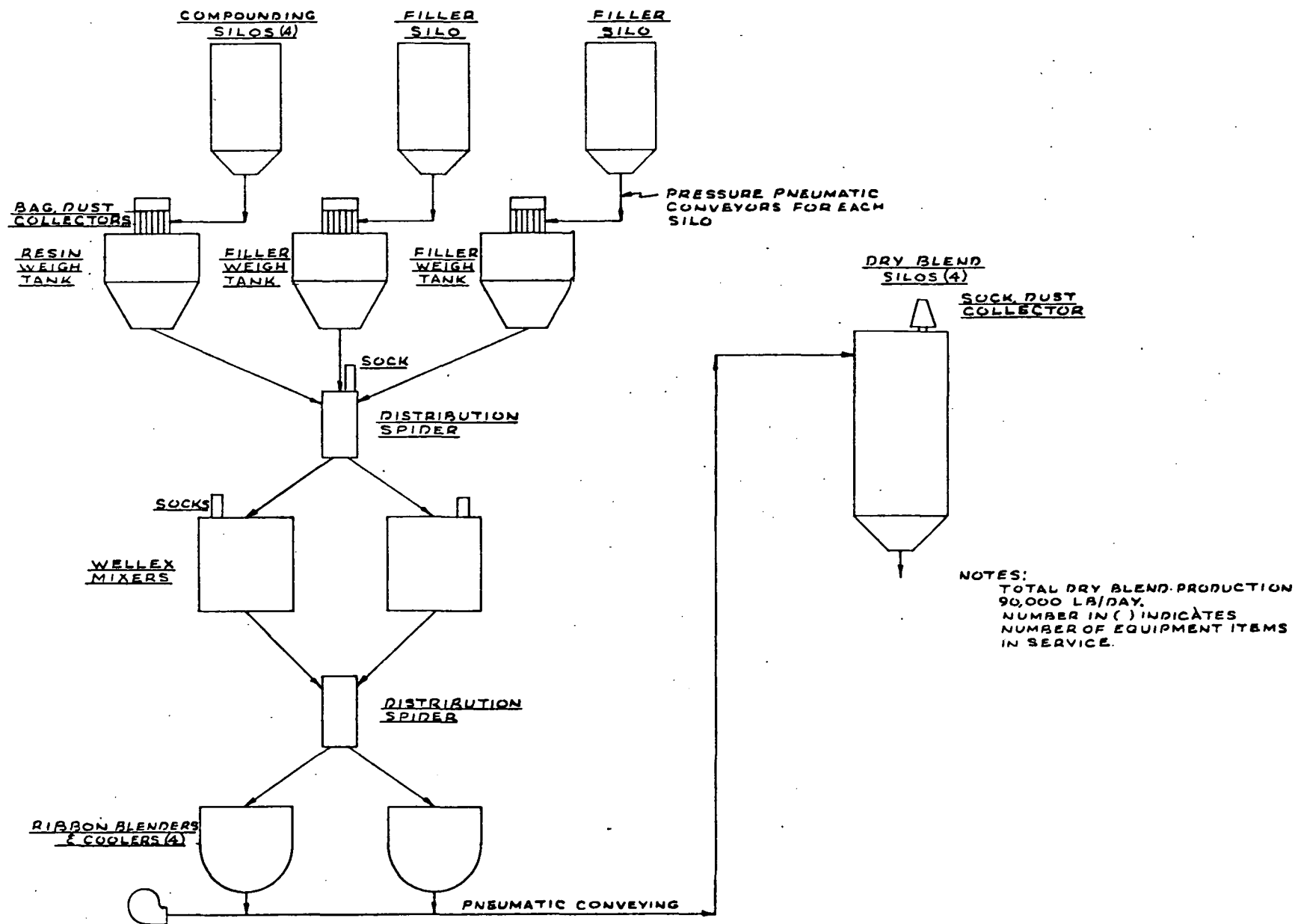


Figure IV-4. Dry Blend Compounding

From the "hot" mixer, the blended powder is sent to a cooler, which may be a high intensity mixer with a cooling jacket, or a ribbon blender from which it is transferred to a storage silo.

A variation of this process is the "double batching" method of compounding in which only a portion (usually 50%) of the batch of raw resin is mixed with additives in the hot mixer. The remaining portion of raw resin is sent directly to the cold mixer where it is blended with the material from the hot mixer. A typical double batching compounding set-up is shown in Figure IV-5. Double batching is efficient in that energy savings are possible and the heat exposure of the resin is minimized. Single batching which is much more widely practiced in the pipe industry, removes a considerably large quantity of VCM since the major point of VCM emission appears to be the hot mixing stage.

b. Points of VCM Loss and Amounts of Loss from Compounding of Rigid PVC Formulations

Data on VCM loss in rigid formulation compounding is scarce. Almost all of the data which do exist come from the compounding of pipe compound, which is by far the largest application of rigid PVC.

It appears that under some circumstances, very high removal rates for VCM are possible in the dry blending operation due to the relatively high temperatures in the hot mixer (as high as 138°C (280°F)) and the large surface area of the resin powder. The amount of VCM given off in the compounding operation appears to be highly variable, and dependent upon mixing temperature and time, mixing intensity, resin particle size and porosity, and aspiration within the hot mixer. Some manufacturers show negligible amounts of VCM lost in the compounding operation, while one manufacturer reported 94 to 98% removal of VCM during rigid compounding. Data from a manufacturer of an internal aspiration system for hot blenders indicate that the loss is highly dependent upon the amount of aspiration, ranging from 84% removal of VCM without aspiration to 99% removal with aspiration and air stripping. These data are all summarized in Table IV-6.

Raw resins to pipe compounding operations in late 1974 (which are presumed to be typical of PVC resins for other rigid formulations) typically contained 300 to 500 ppm VCM, with VCM levels in compounded resins about 50 ppm. As a very rough estimate therefore, the total loss of VCM from PVC compounding manufacturing operations is estimated to be about 250-450 lbs per million lbs of pipe produced. At an estimated 1.9 billion lbs of rigid PVC produced in 1974, this corresponds to a total VCM loss of 216,000-388,000 kg (475,000-855,000 lbs) of VCM lost/year from rigid PVC compounding.

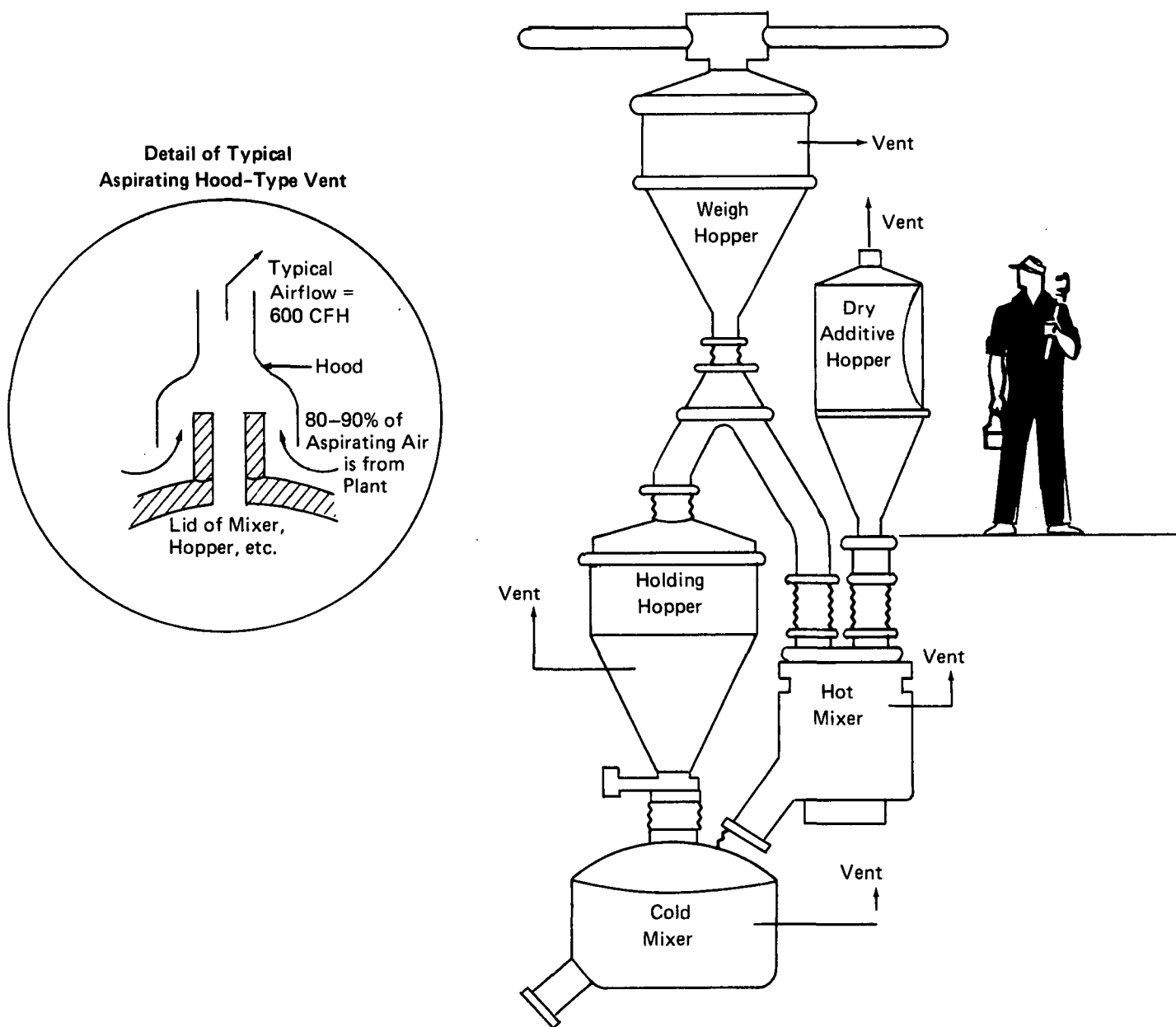


FIGURE IV-5 TYPICAL DOUBLE BATCH COMPOUNDING OF PIPE RESIN

TABLE IV-6

VCM Loss During Dry Blend  
Compounding of Rigid PVC Formulations

	VCM Content (After Stripping)			
	<u>Input Resin (ppm)</u>	<u>Blend from Mixer (ppm)</u>	<u>Blend from Cooler (ppm)</u>	<u>% VCM Removal After Cooler</u>
Manufacturer A	218	190	180	17
Manufacturer B				
Batch 1	1014	33	30	98
Batch 2	413	-	26	94
Manufacturer C	550	-	74	87
Manufacturer D				
Batch 1	300	-	80	73
Batch 2	530	-	92	83
Batch 3	390	-	200	49
Werner-Pfluderer "Exorsta" Data				
Mixing @ 120°C (237°F)				
No Aspiration	1000	565	160	84
Aspiration	1000	205	36	96
Aspiration & Air Stripping	1000	68	11	99

### 3. Plastisol and Organosol Compounding

Plastisols and organosols are liquid systems consisting of dispersions of PVC resins in additives. Plastisols typically contain 30 to 50% plasticizer plus other additives such as stabilizers and fillers. Organosols differ from plastisols in that the former are thinned with solvents to control the viscosity. The VCM emissions from plastisol and organosol compounding appear to be negligible because the VCM content of the input resin is extremely low. Most organosols and plastisols are made from emulsion resins. Data from manufacturers indicate that raw emulsion resins typically have VCM content of less than 10 ppm. Thus, the total amount of VCM which could be emitted could not exceed 10 pounds of VCM per million pounds of emulsion resins used to produce plastisols or organosols, or a total of 2,000 kg (4,400 lb) per year.

### B. EXTRUSION

Extruded products account for a large fraction of the consumption of PVC resins, and include both flexible and rigid formulations. Approximately 80% of rigid PVC is processed by extrusion; major products include pipe and conduit, panels and siding, windows and other profiles and rigid sheet. Extrusion also accounts for almost 40% of flexible PVC fabrication with major products being wire and cable sheathing, weather stripping, medical tubing, garden hose and film. (A breakdown of the type and quantity of products made by extrusion of PVC is given in Table II-3.) Extrusion takes place at temperatures ranging from 120 to 190°C (Table IV-7). In general, extruders processing powder blends will operate at the upper temperatures, and those processing granulated compounds at the lower end. Unplasticized PVC is processed at a somewhat higher temperature than plasticized PVC.

#### 1. Extrusion of Flexible PVC

Extruders of flexible PVC operate in either of two modes: they may purchase compounded flexible PVC to be fed directly into their extruders, or they may purchase raw resin and do their own compounding in-house. The VCM emissions from the plants of extruders of flexible PVC is totally dependent upon which of these choices is made. As discussed under "Flexible PVC Compounding" above, almost all the residual vinyl chloride monomer in raw resin compounded into flexible formulations is lost during the hot blending portion of the compounding operation, when plasticizer is added. The amount of VCM remaining after completion of compounding is usually less than 10 ppm. Thus, the extruder of flexible PVC resin will have VCM emissions of a maximum of only ten parts of VCM per million parts of resin processed if he starts with compound. His counterpart who purchases and compounds from raw resin will have emissions as high as 200-500 parts per million.

TABLE IV-7

Typical Extruder Temperatures for PVC

	<u>Temp, °C</u>
<u>Plasticized Compounds</u>	
feed end of screw	120-140
front end of screw	140-160
head	150-170
die	160-180
<u>Unplasticized (rigid) Compounds</u>	
feed end of screw	140-150
front end of screw	155-165
head	165-175
die	170-190

We estimate that approximately 70 to 75% of manufacturers of extruded flexible PVC products do their own compounding. (A breakdown of this is shown in more detail in Table III-4 of Section III.) The only major purchasers of ready-made flexible compound for extrusion are makers of film and medical tubing, who buy their compound from the resin producers; wire and cable coating extruders also buy a minor fraction of their feed as compound, from independent compounders.

Wire and cable coating and film extrusion are good examples of products made by extrusion of flexible PVC. Wire and cable coating is the single largest extrusion process for flexible PVC and accounts for approximately 354 million lbs per year, or about 22% of the 1.6 billion lbs of flexible PVC consumed in the United States each year. The major resin used is a homopolymer of medium to high molecular weight, with an additive content of 40 to 60 percent based on the final compound. About 125-135 million pounds of PVC were used in 1973 for the fabrication of flexible film for packaging applications.

- Wire and Cable Coating

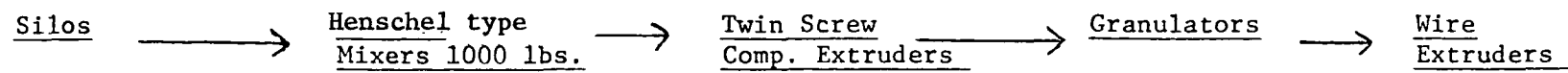
The producers of PVC-insulated wire and cable generally purchase raw resin and produce granulated compound themselves. (About 70 million lbs--or 20%--is bought from independent compounders who prepare special formulations for the wire and cable industry.) The total process is shown schematically in Figure IV-6.

In the extrusion process for wire coating, high rates of output are of primary importance. Figure IV-7 is an illustration of the crosshead type die used for wire coating. The wire to be coated passes straight through a crosshead die at right angles to the length of the extruder. The polymer melt (melted granules) enters the crosshead from the extruder and is directed around the wire and merges through the die. After emerging, the wire may be preheated electrically or flamed to remove lubricants and to improve adhesion.

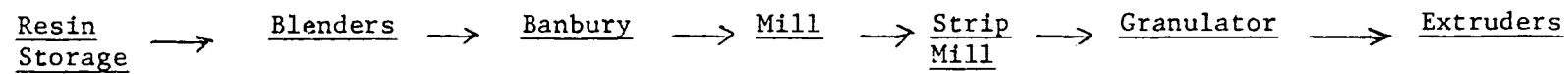
- VCM Emissions from Wire and Cable Coatings

As discussed above, the primary emissions of VCM from wire and cable coating operations will occur in the compounding steps. The primary point of this emission would be in the addition of the plasticizers and additives to the raw resin during the hot mixing portion of the compounding operation (discussed above). Emission of VCM at later points in the process is negligible. Taking as a very rough average a net emission from the entire coating operation of 300 parts of VCM per part of resin processed in 1974, the emissions from a 1,000 lb per hour extrusion line would be 0.3 lbs per hour of VCM, or 3.3 kg/day (7.2 lb/day). The total nationwide emissions from the process (assuming 354 million lbs of PVC used per year) would be approximately 48,000 kg VCM per year (106,000 lb/year).

Method 1



Method 2



IV-21

Figure IV-6. Schematic of Wire and Cable Coating Process.

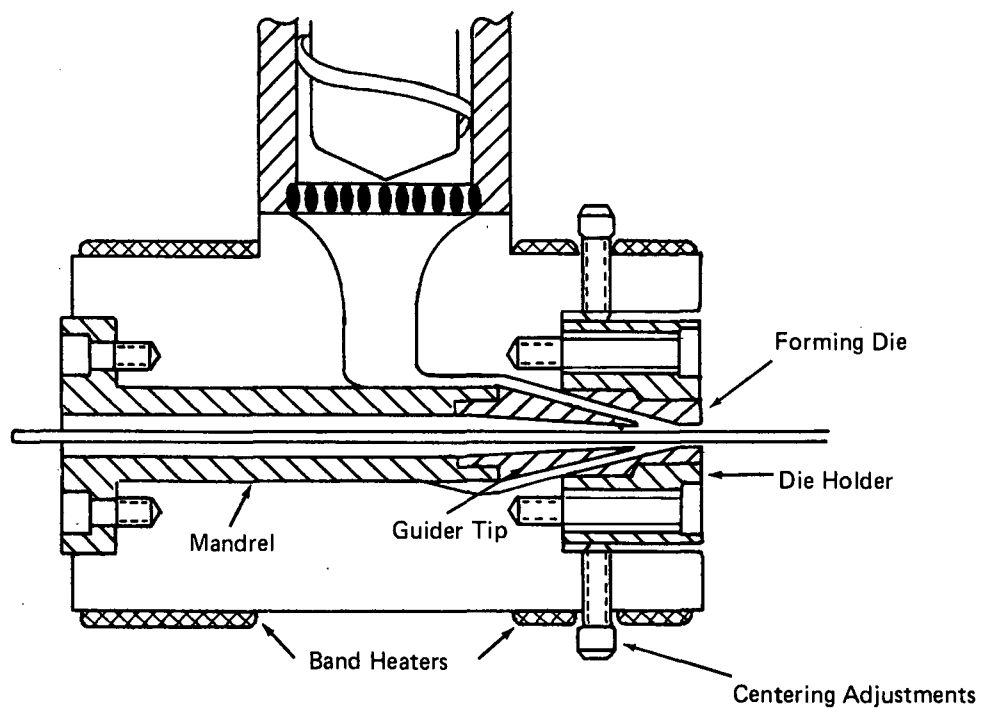


FIGURE IV- 7 CROSSHEAD DIE FOR WIRE COATING

- Film Extrusion

Most flexible PVC packaging film is made by blown film extrusion. These products are used for a variety of consumer and industrial applications. Consumer applications include meat and produce wrap; industrial applications include wrapping for small parts or loose paper type products. A particular advantage of the PVC films for these applications is their ability to be oriented and then shrunk during subsequent exposure to heat to produce a so-called shrink wrap film.

It is possible to extrude film from either compounded powder or pellets. Most flexible PVC extruded film is formed from pellets (which are made using conventional powder blending techniques described earlier), followed by extrusion of a strand which is cooled and pelletized. Film is made from either purchased pellets or via in-house compounding at the fabrication plant. Flexible film is also made from powder which is compounded on-site using standard techniques.

Both of these methods are indicated in the flow chart of a typical flexible film extrusion plant, shown in Figure IV-8. (Figure IV-8 also indicates the sources of VCM emission.) The major source of emission will be from the hot stage of the compounding operation. Other emission points of less importance are from:

- unloading,
- venting to the atmosphere from raw powder and pellet storage silos,
- the vacuum port of the pelletizing extruder, and
- the fume collector which surrounds the film bubble.

We have obtained data on residual VCM content of extrusion-blown film from two major manufacturers. In one case the manufacturer reported that during a six month period VCM concentrations in film leaving the plant never exceeded 0.02 ppm. The second manufacturer indicated that with rare exception the concentrations were below the levels detectable by gas chromatographic methods.

Thus, emissions from this portion of the industry can be estimated by assuming all of the VCM entering as raw resin leaves the film operation. One major manufacturer's sampling of incoming (uncompounded) resin between June and November of 1974 measured VCM concentrations ranging from 2 to 325 ppm, with typical readings of 65 ppm.

Assuming this figure is typical and that 130 MM lbs of flexible PVC packaging film are processed annually, the emissions from this sector of the industry are  $65 \times 130 = 8450$  lbs/yr (3840 kg/year). It should be noted that approximately 90% of this arises from the compounding portion of the operation, and less than 10% arises from the actual extrusion process.

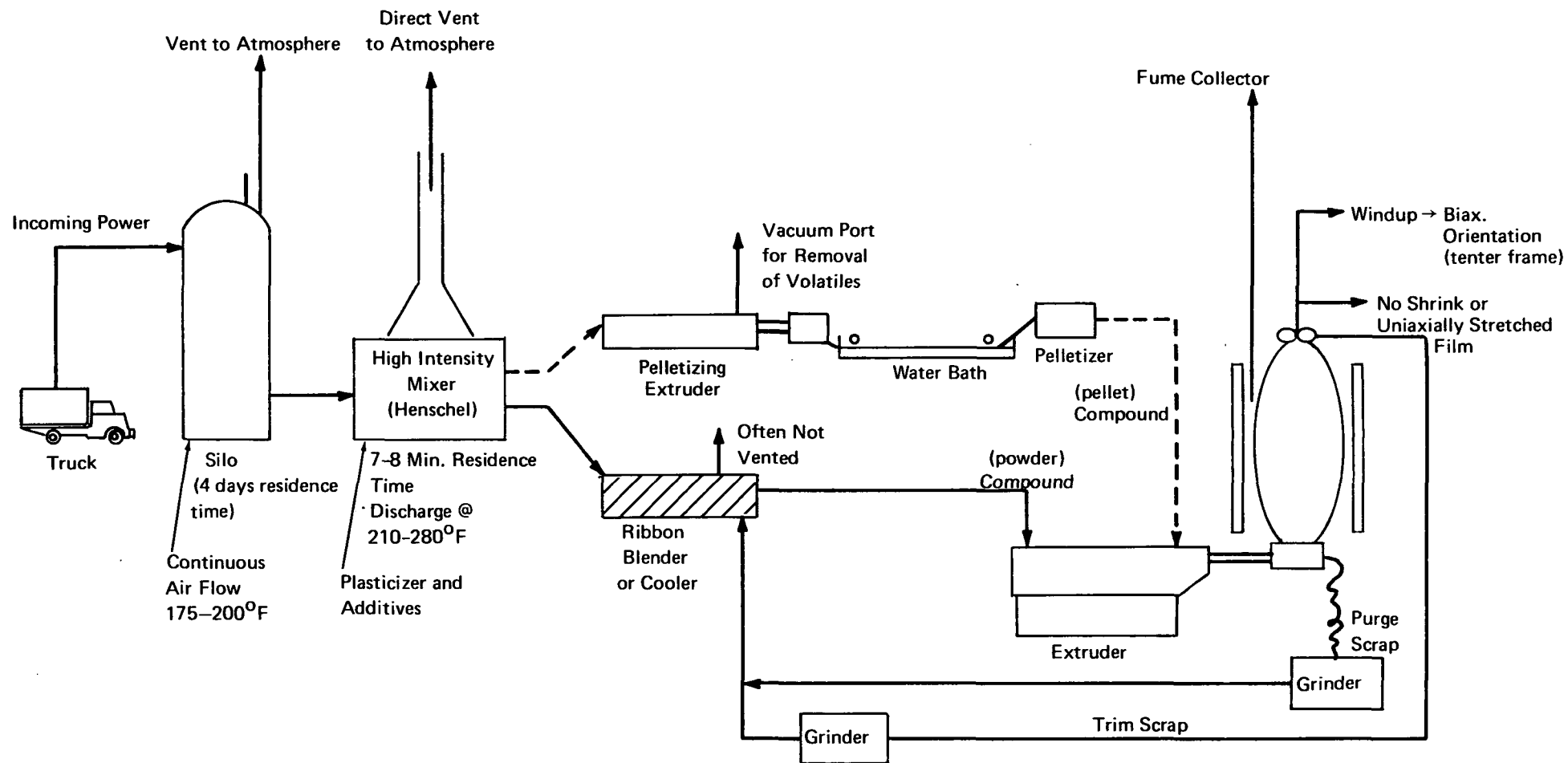


FIGURE IV-8 FLEXIBLE PVC FILM EXTRUSION WITH IN-PLANT COMPOUNDING

## 2. Extrusion of Rigid PVC Resins

### a. General

As in the case of processors of flexible PVC resins by extruders, manufacturers of rigid PVC resins by extrusion may purchase ready-made compound from the resin producers, or may compound their resins themselves. (The independent compounder of rigid PVC resins for extrusion is virtually nonexistent.) Manufacturers of pipe and conduit--which account for 78% of the total consumption of rigid PVC for extrusion--compound about 99% of their resin themselves. Most other manufacturers of extruded rigid PVC products purchase all of their compound from the resin producers. (An exception to this rule are the producers of foam molding, many of whom formulate their own compounds.)

### b. Major Examples of Extruded Rigid PVC Products

#### (1) Pipe

Production of PVC pipe represents about 55% of the total extrusion of PVC in this country (or about 78% of extrusion of rigid PVC). Most PVC pipe manufacturers compound raw material at the same site, and the majority of the VCM loss is from the hot mixing step of the compounding operation.

A typical PVC pipe manufacturing facility produces 20-25 million pounds of extruded pipe per year using 4805 extruders. A schematic of a typical plant's operations is shown in Figure IV-9. (Note that in Figure IV-9 compounding via both simple and double batching is indicated.)

The economics of PVC pipe extrusion dictate that individual processors purchase raw PVC resin powder and add stabilizers, lubricants, and processing aids and pigments in a central compounding operation at the plant. The powder blend to feed the extruders is typically prepared in 400-1,000 lb (180-455 kg) batches.

The capacity of the extruders is typically 600-700 lbs/hr (270-320 kg/hr) although some plants, particularly those manufacturing larger diameter pipe, use extruders with capacities as high as 1,300 lbs/hr (590 kg/hr). Simple twin-screw machines typically consist of two twin-screw machines operating in series. In this mode of operation, the first extruder's function is to melt and mix the powder and extrude it into the hopper of the second extruder via an intermediate evacuated pelletizing stage (in which the molten strands of resin are cut into pellets using a hot face cutter.) Evacuation occurs from this intermediate "pelletizing" stage.

After emerging from the second extruder, the melt passes through the annular orifice of the die, and then is cooled in a water bath, cut into lengths and stored. Some types of pipe require a secondary finishing or shaping operation prior to storage.

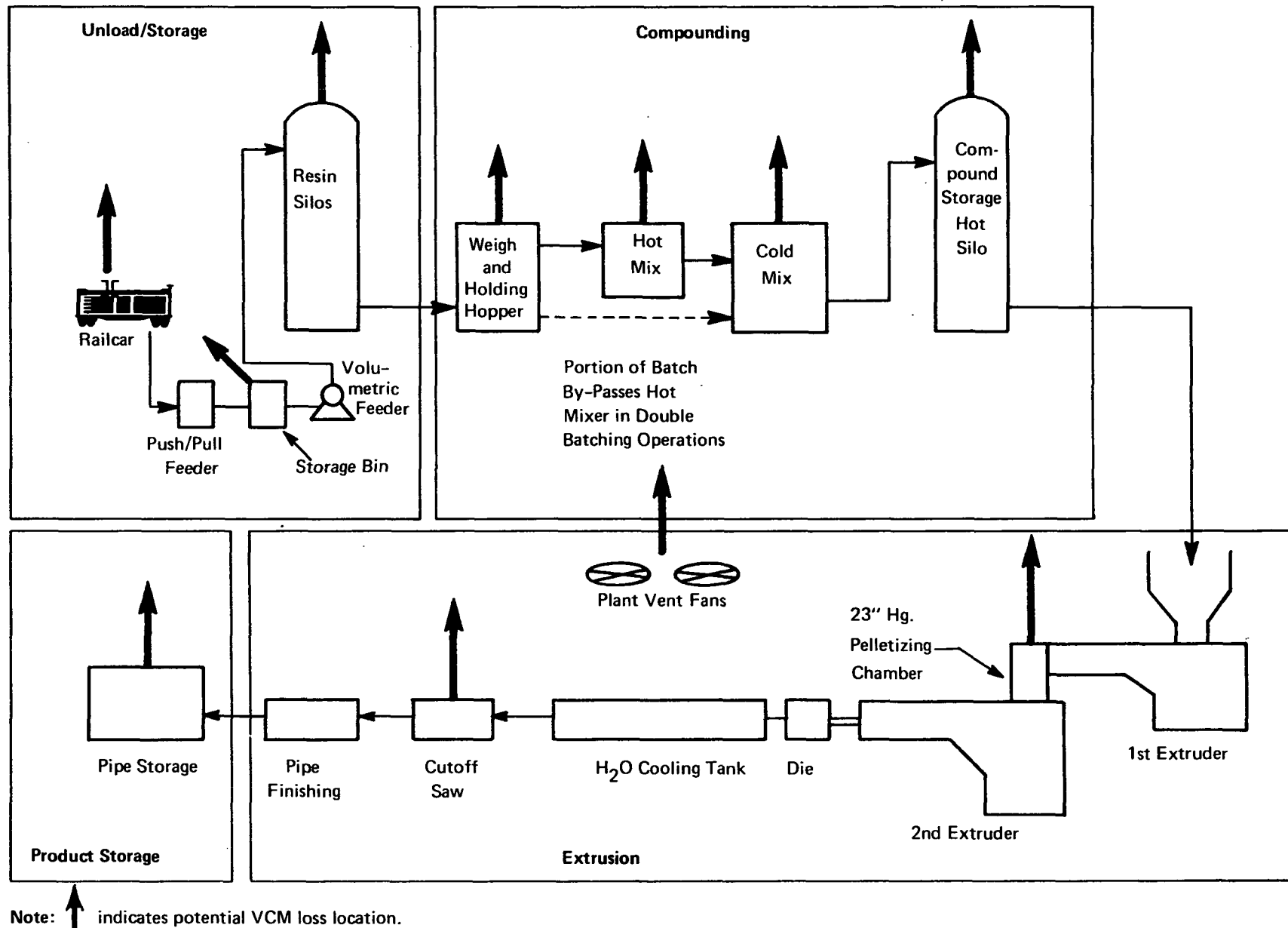


FIGURE IV-9 TYPICAL PVC PIPE EXTRUSION OPERATION

### c. Sources of VCM Loss in Pipe Extrusion

In practice, resin is transferred from the storage silo to the hot mixer via an intermediate weighing station in which additives are mixed. The batch is processed using either the single or double-batch method which have been described previously. From the processor's viewpoint, double-batching is efficient in that energy savings are possible and the heat exposure of the resin is minimized. Single batching, however, removes a considerably larger quantity of VCM. In estimating the quantity of VCM discharged by a particular plant, it is therefore essential to determine which practice is used.

Sources of VCM losses from pipe extrusion facilities are from vents in the following four areas:

#### 1. Resin Handling

- Hopper car, transfer devices, and raw resin storage silos
- In-plant conveying systems
- Weighing station
- Extruder hopper
- Hot mixer

#### 2. Compounding

- Cold mixer
- Compound storage

#### 3. Extrusion

- Extruder vent pump
- Extruder die

#### 4. Pipe Handling/Storage

- Pipe cutting station
- Pipe storage facility

The major locations of VCM removal and discharge to the atmosphere are (in decreasing order of importance): hot mixer, cold mixer, extruder vent, resin unloading and transfer.

Hot mixer. As discussed previously, considerable quantities of VCM can be removed during the hot blending stage. Modern installations remove VCM directly from the bowl of the hot mixer through the use of an air sweep or a vacuum. Although there are still a considerable number of installations which do not follow this practice, it appears that the pressures of OSHA regulations and the hazards of exceeding the lower explosive limit for VCM will result in provision for VCM removal from the bowl of the intensive mixer.

Cold mixer. After hot mixing the powder compound is transferred to the cooling stage. Removal of VCM at this stage is comparable to that achieved in the hot mixer.

Extruder vent. Elimination of volatiles from the molten pipe extrudate is crucial to the production of quality pipe. This removal occurs from an evacuated port at a stage in the extruder at which the resin is molten. Typically, the molten resin is exposed to a vacuum of 12-14" Hg., although vacuums as high as 23" Hg. have been observed during our field visits. In the case of pipe production using a single extruder (either single screw or twin screw), the volatiles are removed from a vacuum port located along the barrel.

Ventilation. In modern pipe production plants the ventilation systems from the storage/transfer and compounding stages are collected at a central location - often this is a rooftop collector containing a bag for filtering powder particles. This is known as the bag house and is important for economical operation since considerable quantities of PVC powder can be recovered. The bag house is also the major concentrated location of VCM in a typical pipe processing plant.

Robintech, Inc., has the capability of blending additives in the polymerization kettle. These resins are referred to as in-house compounded (IHC) resins and they do not require compounding at the pipe extrusion facility. The VCM discharge from such plants should be considerably less since the compounding steps are eliminated.

VCM Loss in Pipe Extrusion. Although data on VCM levels in pipe from extruders are not available, an estimate of the amount of VCM lost may be made from the measured VCM levels in the air exiting from the extrusion process. Typical concentrations of VCM between 23.5 and 430 ppm (in air) were reported at a flow rate of 3.5 SCFM of air, corresponding to a total loss of  $4.2 \times 10^{-4}$  -  $77.4 \times 10^{-4}$  lbs/hr ( $1.9 \times 10^{-4}$  -  $35 \times 10^{-4}$  kg/hr) of VCM at an extrusion rate of 1,000 lbs/hr (454 kg/hr) of pipe. This corresponds to a VCM loss of 0.4 - 7 lbs VCM per million lbs of PVC pipe extruded--a negligible quantity.

The total nationwide emissions of VCM from PVC pipe extrusion (accounting for 1.26 billion lbs/year of PVC resin) are estimated to be:

VCM loss from compounding: (250-450 ppm lost)	142,000-257,000 kg/yr (315,000-567,000 lbs/year)
VCM loss from extrusion:	218-3,800 kg/year (negligible) (480-8,400 lbs/year)

## (2) Profiles and Siding

Profiles and siding account for almost 100 million lbs of rigid PVC extrusion per year. Manufacturers typically buy pelletized compounds from the resin manufacturers who supply custom formulations to the large fabricators.

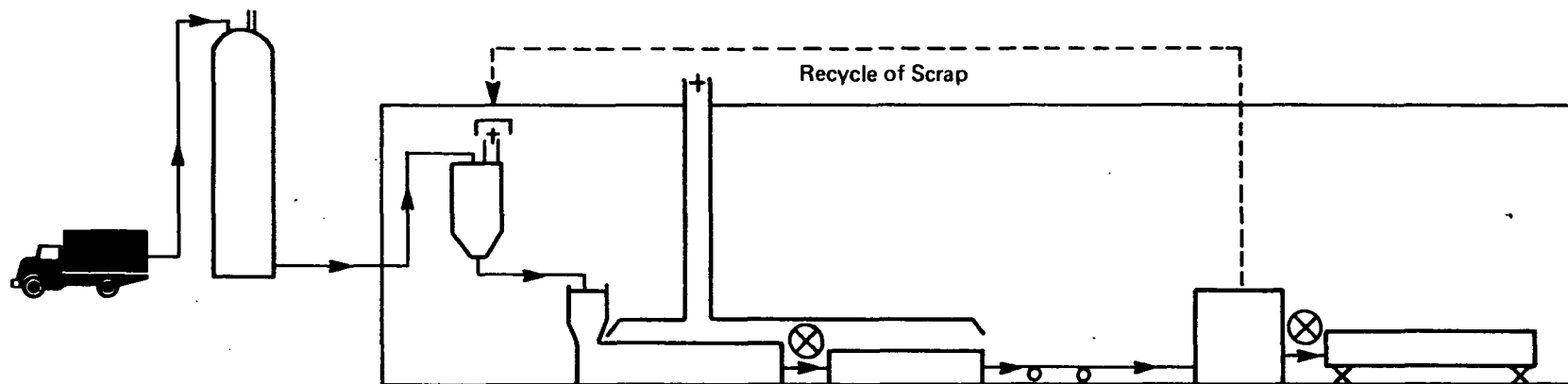
Compound arrives to the fabricator in trucks and is stored in vented silos. The residence time of the compound in the silo can vary from three days to two months. From the silos, the resin is conveyed into vented surge hoppers where it is warmed slightly [to 380°C (100°F)], and then into the extruder. From the extruder, the profile is conveyed through a cooling system--either water or air-cooled--and thence to a cutter. Scrap from the cutting operation (averaging about 15% of the product) is sent to the grinding room for recycling. (Figure IV-10 shows a schematic of the operation.)

Essentially no data are available on the VCM emission from these operations. One manufacturer quoted an input compound level of 100 ppm VCM as received from the resin manufacturer. The amount of further loss during the extrusion step is not known. One source of loss to the atmosphere is from the storage silo. This loss may be relatively small since the resin is in pellet form rather than in powder form. Some loss probably occurs over the heated extrusion section. However, this appears to be quite small, since the measured levels of VCM in the air exhaust over the extrusion is very small --less than 0.1 ppm (volume of VCM vapor per volume of air).

## C. CALENDERING

Calendering is used for the production of both plasticized and rigid PVC sheet as well as coated fabrics and unsupported flexible films. It is capable of producing high quality material at very high rates of output. The resin formulations typically contain 20-30% plasticizer. Its major application is in the production of flexible PVC sheet and film, and accounts for the consumption of approximately 867 million pounds per year of flexible resin--or about 54% of the total U.S. consumption of flexible compound.

Essentially all calendering compound is produced by the fabricator rather than the resin producer. Typically, the raw (suspension or bulk process) resin and additives are fed to a hot blender, thence to a Banbury mixer where it is melted; it is then milled and discharged directly into the calender. Often a screening extruder is used before the calender. After the calender, the sheet is cooled and finished.



Delivery      Silo      Surge Hopper      Extruder      Cooling Air or Water      Conveyor      Cutter      Packing

**Emission Sources:**

Intermittent

Continuous

Continuous

Continuous

Continuous

VCM (in air)  
(volume VCM  
per volume  
of air)

0.03

N.D.—0.03

Stack  
Height (ft)

32

20

—

—

—

—

Fan (CFM)

None

244

1875

—

—

—

—

Temp °F

R.T.

110

350

R.T.

R.T.

R.T.

R.T.

**Code:**

+ Fan Location

⊗ Location of VCM Measurement

FIGURE IV-10 RIGID PROFILE EXTRUSION

Calendering can also be used for coating fabric and paper with plasticized PVC sheet; the substrate is fed into the calender nip of the last roll to carry out the lamination.

In calendering, the PVC is subjected to fairly high temperature because of the high shear; molecular weight polymers can therefore be used. In rigid sheet production, extreme pressures and high roll temperatures--approaching 200°C for homopolymers--must be used.

Figure IV-11 shows a schematic of a typical calendering operation which could be used for manufacturing flexible unsupported films or coated fabrics. These products are used for shower curtains, baby pants, wall coverings, swimming pool lining, tape, surgical drapes and book covers.

As in all processing of flexible PVC resins, the majority of the residual vinyl chloride monomer loss in PVC calendering plants occurs during the compounding portion of the operation. In the past, raw resin arrived with a residual VCM level typically between 100 and 500 ppm. Even at these input levels it is possible to reduce VCM in outgoing film to below 1 ppm. Table IV-8 shows data obtained from a manufacturer of unsupported film which shows the reduction in VCM at different stages in the process. This data was obtained on a process which has two mills following the Banbury. Unfortunately data were not obtained directly after the Banbury. The data does indicate however that the major portion of VCM is removed either by the Banbury alone or in combination with the first run. The fact that very little reduction in VCM content is measured between the first and second mill supports the conclusion that the major portion of the VCM is eliminated by the Banbury. This loss is not surprising, since the polymer during this operation is hot, molten, plasticized, and has a high surface-to-volume ratio--all optimum conditions for the release of monomer.

Based on these data, the nationwide emissions from calendering of flexible PVC can be estimated to be:

Compounding portion: (100-500 ppm)	39,000-195,000 kg/year (86,700-430,000 lbs/year)
Calendering portion: (10-20 ppm)	3,900-7,900 kg/year (8,670-17,340 lbs/year)

#### D. BLOW MOLDING

Rigid PVC bottles are produced by the blow molding process. All blow molded PVC bottles are made from compounded pellets purchased by the blow molder from the resin supplier. These pellets are stored after delivery and then vacuum-conveyed to a hopper which feeds a single-screw extruder. The compound is melted in the extruder, reaching a temperature of 380°F. From the extruder, the molten compound passes through a die to a mold where it is blown and cooled. After cooling the flashings are cut from the bottle and recycled into a grinder and thence to the extruder hopper. About 30% of the feed is recycled as ground flashings.

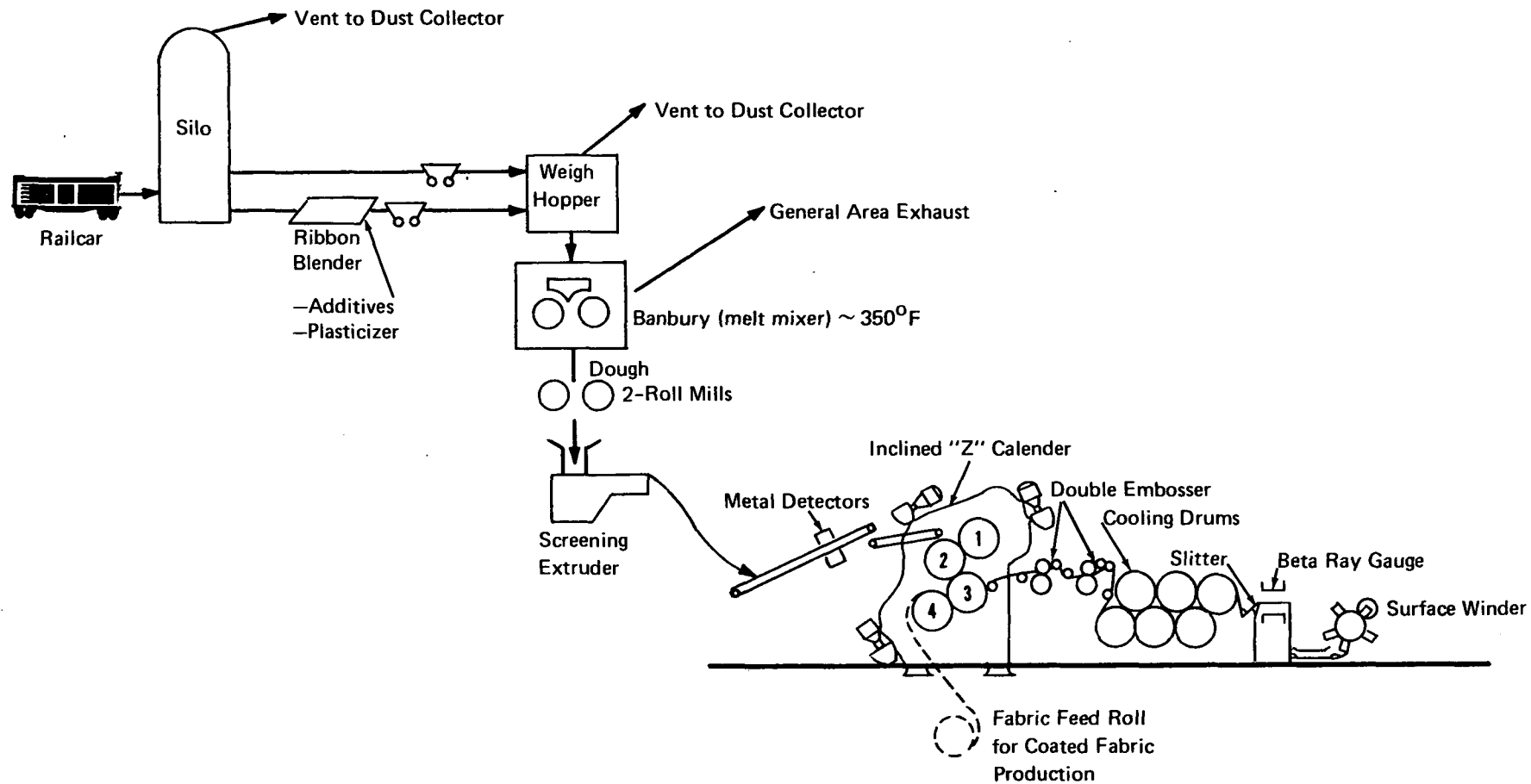


FIGURE IV-11 TYPICAL CALENDERING OPERATION

TABLE IV-8

VCM Losses from Flexible PVC Calendering

	<u>VCM Concentration (ppm)</u>
PVC resin to Banbury	400
PVC compound from Banbury	- (No value was measured)
PVC compound from first mill	32
PVC compound from second mill	26
Film from calender	ND (<1 ppm)

Resin manufacturers typically control the VCM levels in compound for bottles to extremely low values. Ethyl Corporation, who is a major supplier of blow molding resins for example, currently produces to a specification of less than 1 ppm VCM for their food grade bottles and to a specification of less than 10 ppm in its general purpose bottle compound. They estimate and we agree, that less than 15% of the VCM in the compounded pellets is removed during blow molding.

These figures indicate that the total loss of VCM from blow molding is very small (probably less than 1 lb VCM loss per million lbs of PVC processed by this route). The major source of this loss may be at the point at which the bottles are blown. Prior to this, the process is essentially totally enclosed. Little, if any, VCM can escape from the extruder, and the residence time at the die (where the molten compound is first exposed to the atmosphere) is too low--typically about 4 seconds--to allow much escape of VCM.

#### E. INJECTION MOLDING

Injection molding is an intermittent, cyclic process in which particles of compound are heated until they become molten. The melt is then forced into a closed mold where it cools, solidifies and is ejected as a finished or semi-finished part.

Both flexible and rigid PVC compounds are injection molded. Both homopolymers and copolymer resins are used, with homopolymers predominating. Although it is possible to mold powder blends, most injection molders use compounded pellets. Shoe components account for the majority of the injection molding of flexible compound and pipe fittings account for the majority of rigid compound which is injection molded.

VCM Loss. VCM loss during the injection molding of flexible PVC pellets is slight or negligible. Little monomer remains in the compound granules which are put into the injection molding process since most has been removed during compounding. In addition, the injection molding process is essentially close to the atmosphere allowing little or no monomer to escape.

We have no data on the VCM losses during injection molding of rigid PVC compound. In contrast to flexible compound, the VCM content of rigid compound is sometimes substantial (possibly ranging as high as 100 ppm in late 1974 compound). However, the opportunity for VCM loss is relatively slight. We would estimate that the major source of loss in the injection molding process would be at the point at which the pellets are melted.

#### F. COMPRESSION MOLDING

Phonograph records are the major PVC product fabricated by compression molding. In the record molding process either compounded resin or dry blend is fed to a small extruder where it is melted. A measured amount of material is then extruded between the labels that go onto the record. The operator picks this up from the extruder and places the sandwich in a press. The press closes and the finished record is removed some 15 to 30 seconds later.

VCM Loss. Records are made from a polyvinyl chloride/polyvinyl acetate copolymer which in early 1974 had a relatively high monomer content (greater than 500 ppm). However, manufacturers of records tell us that in late 1974 the monomer content in raw resin was reduced to 50 to 100 ppm. Compounding of semi-rigid compound for records may take place either at the resin producers or at the record manufacturing site. It appears that approximately half of the input resin monomer content is lost in the compounding process. (This is a very rough estimate, based on a minimal amount of data.) We cannot estimate the additional VCM loss during the compression molding process since no data are available.

#### G. SOLVENT CAST FILM

The solvent casting process is used to produce packaging films of higher quality than those made by blown film extrusion. The solvent cast product has better gauge control and improved clarity.

The solvent cast processing consists of dissolving powdered resin and casting the solution onto a belt. The casting belt is totally enclosed thereby permitting complete recovery of solvent. The wet film is then passed to a drying oven. A high percentage of solvent recovery is essential to the economics of the process. The details of the solvent recovery system are considered proprietary by the film manufacturers.

A generalized flow chart for solvent cast film production showing potential emission points for VCM is shown in Figure IV-12. The sources of VCM loss are primarily from the solvent recovery operation with minor quantities during resin transfer and storage. We have not been able to obtain quantitative data on VCM concentrations in streams leaving the processes.

One manufacturer reported the results of several months monitoring of incoming resin at solvent casting operations, indicating an average VCM concentration of 20 ppm. Typically they found no detectable concentration of VCM in film leaving the process, but they have not been able to isolate the specific source of VCM loss from the process.

We estimate that 50 million lbs of solvent cast PVC film are manufactured in the U.S. Assuming that an average concentration of 20 ppm enters the process in the raw PVC powder, and that it is completely lost in the

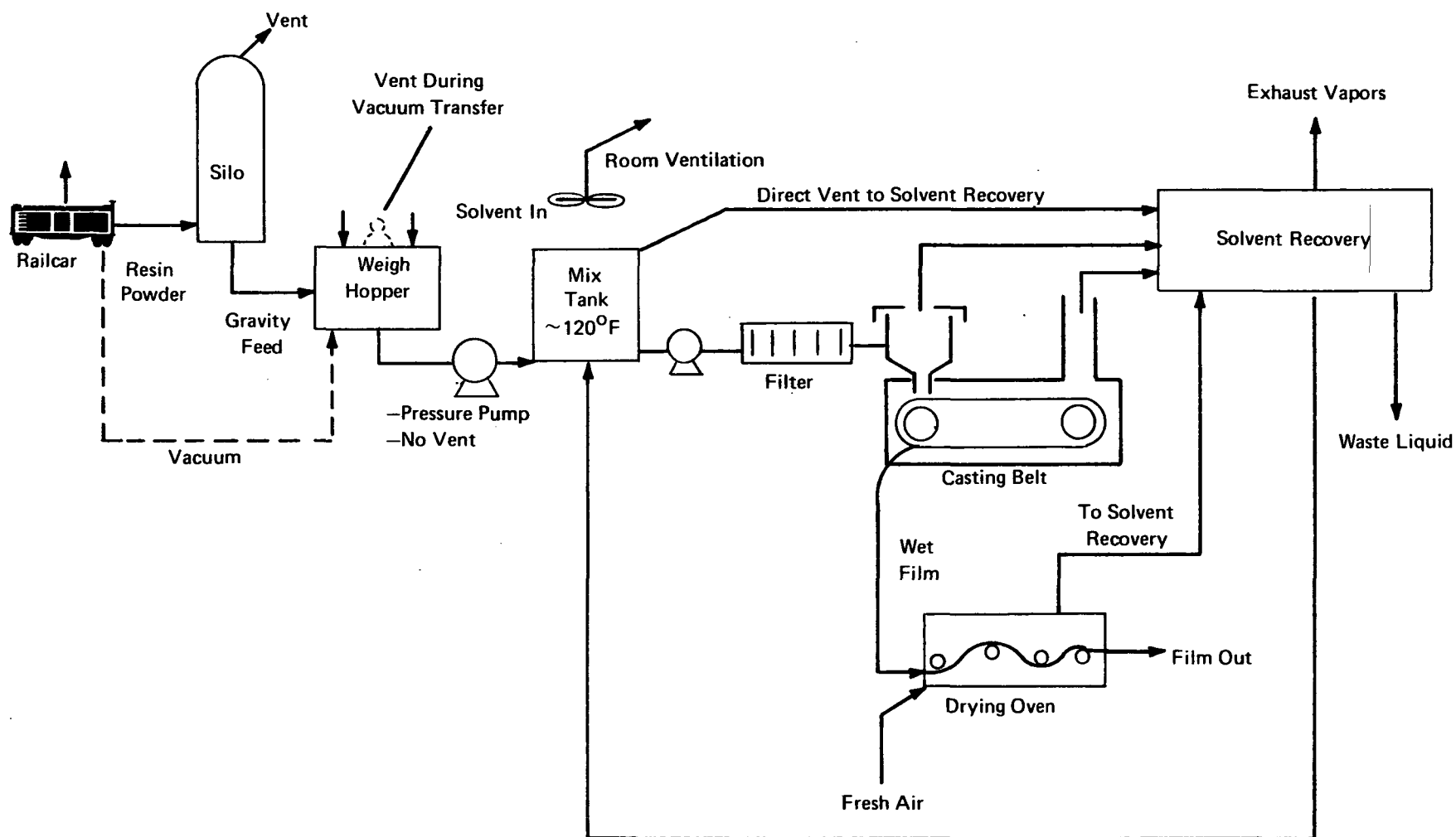


FIGURE IV-12 SOLVENT CAST PVC FILM PRODUCTION

production process, the loss of VCM from this segment of the industry is estimated to be:

$$\frac{20 \text{ lbs}}{\text{million lbs}} \times 50 \text{ million lbs} = 1,000 \text{ lbs/year} \\ (450 \text{ kg/year})$$

V. TOTAL U.S. EMISSIONS OF VINYL CHLORIDE MONOMER  
FROM POLYVINYL CHLORIDE COMPOUNDING AND FABRICATING

Table V-1 lists estimates of the total U.S. emission rate of VCM from PVC compounding and fabricating processes. These totals are based on 1974 production rates of PVC products and on representative VCM levels in the various types of resins in late 1974. Bases for the various estimates are discussed in some detail in Section IV above.

Table V-2 shows the estimated annual VCM emissions from all stages of PVC product manufacture, starting with the monomer production and proceeding to PVC polymerization and thence to fabrication. As shown in this table PVC fabrication processes, including compounding, account for less than one-half of one percent of the total VCM emissions in the U.S. Fabrication excluding compounding amounts to about one one-hundredth of one percent of total U.S. emissions.

TABLE V-1

TOTAL U.S. EMISSION RATE OF VCM FROM POLYVINYL CHLORIDE PROCESSING

<u>Process</u>	<u>Estimated VCM Emission Rate* kg/year</u>	<u>(lbs/yr)</u>
<u>A. Flexible PVC</u>		
1. Compounding	220,000	(480,000)
2. Extrusion	<3,000	(<6,000)
3. Calendering	<4,000	(<1,000)
4. Molding	<400	(<800)
<u>B. Rigid PVC</u>		
1. Compounding	300,000	(660,000)
2. Extrusion	<4,000	(<10,000)
3. Molding	<1,000	(<2,000)
<u>C. Plastisols, Organosols, Solution and Latex Fabrication</u>	2,000	(4,500)

\* Based on 1974 production rates and late 1974 VCM contents of resins.

**TABLE V-2**  
**ANNUAL VINYL CHLORIDE EMISSIONS - 1974**

<u>Process</u>	<u>Emissions</u> (kg/100 kg produced)	<u>Amount Produced</u> (millions of kg)	<u>Subtotal of U.S. Emissions by Process</u> (millions of kg)	<u>Total U.S. Emissions</u> (millions of kg)	<u>Percent of Total U.S. Emissions</u>
<u>A. Monomer Production</u>	0.25	2200	-	5.7	4.0
<u>B. Polymerization</u>	-	2400	-	130.0	95.4
Suspension Process	3.9	1900	76	-	-
Dispersion Process	6.0	280	17	-	-
Solution Process	1.8	59	10	-	-
Bulk Process	2.4	120	29	-	-
<u>C. Fabrication Processes</u>	-	2300	-	0.5-0.6	0.4

V-3

Arthur D. Little, Inc.

VI. CURRENT STATUS OF CONTROLS TO LIMIT VCM EMISSIONS  
FROM THE PVC FABRICATION INDUSTRIES

A. CURRENT CONTROL TECHNIQUES

In 1974, the major emphasis on limitation of VCM emissions was, perforce, concentrated on reduction of VCM content in plant air, in order to minimize risk to the plant workers. These control measures took two forms:

1. Massive ventilation and hooding at the points of the process where large amounts of VCM could be expected to be emitted; and
2. Reduction of the residual VCM levels in input resins so that the total amount of monomer available to be released would be minimized.

In none of the 25 to 30 facilities we visited or interviewed by telephone and letter was there any control equipment used to limit the VCM emission from the fabricating plants into the surrounding atmosphere (aside from the usual stacks).<sup>\*</sup> Manufacturers believed that the most practical way to limit emissions both inside and outside the plant was to reduce the monomer content in the incoming resin. Both resin manufacturers and users of the resins were confident that, by the end of 1975, the residual monomer in resin coming into compounding and fabricating facilities would be sufficiently low that additional control measures to limit external emissions would not be required. (Thus, the OSHA regulations to limit internal plant emissions were expected to result in solving of the "external" emission problem also.)

Compounders and fabricators did not believe that, at present, there were any economically practical ways to control emissions from compounding and fabricating externally without seriously hindering their ability to control internal plant emissions. Not even the more sophisticated and advanced facilities (notably those compounding operations operated by the more research-minded resin-producing firms) had any method for removing VCM from vented air from the plant.

The reason for the lack of control methods available appears to be in the very low level of VCM in the vented air (typically less than 1.0 and

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<sup>\*</sup>It should be noted that VCM emissions from oven-dried PVC coatings (such as coatings on sheet metal and fused plastisol resins on cast sheet and coated fabrics) are inadvertently controlled. The air in the drying ovens is recirculated through the gas burners; both the solvent and the VCM are thereby consumed. The VCM released in coatings, however, is negligible--totalling less than a few thousand lbs/year nationwide.

almost always less than 10 ppm even in the air vented directly from the dry blenders and Banbury machines in the compounding facilities) and in the large volumes of air to be processed. These factors make scrubbers, after-burners and adsorbers (such as carbon columns) largely impractical.

We should note at this point that activated carbon adsorption of VCM has been suggested as a practical method for removing and recovering VCM from stack gas. Although this method offers some promise for the reduction of VCM emissions from PVC polymerization facilities, its utility appears to be limited to recovery of VCM from low volume, high concentration streams. In the Tenneco pilot plant in which it is currently under investigation, the VCM concentration in the stream is between 10 and 30% (100,000 to 300,000) ppm. The maximum concentrations of VCM in fabricating plant vents is usually 50,000 to 100,000 times lower than this. In addition, much of the emissions from compounding and fabricating plants will also contain larger amounts of volatile plasticizers and other additives--frequently in much larger concentrations than the VCM--which would be expected to compete with VCM for the carbon adsorption sites, and significantly limit the utility of the carbon.

At present, therefore, it does not appear practical to suggest carbon adsorption for limiting emissions from fabricating and compounding facilities, unless significant and unanticipated breakthroughs in VCM concentrating and adsorption techniques occur.

Similar difficulties arise in attempting to apply other emission control techniques such as condensation, compression and scrubbing which have been suggested for application to PVC polymerization facilities. The levels of VCM are simply too low to be practical.

## B. FUTURE CONTROL TECHNIQUES

### 1. Reduction of VCM in Input Resins

The major control technique for the future appears to be reduction of residual VCM content in incoming resins. Since polyvinyl chloride does not generate VCM (decomposition of PVC generally produces HCl instead), the only VCM which can be emitted from compounding and fabricating facilities will be that in the incoming resins. We are told by resin manufacturers that they anticipate reducing residual VCM levels in resins to less than 50 ppm. Should this be achieved, the total nationwide emissions from all PVC compounding and fabricating facilities will be less than 110,000 kg/year (230,000 lbs/year) nationwide.

A few resin producers have predicted that a 10 ppm residual monomer content can be achieved by 1976 to 1977. Should this be achieved, the total nationwide emissions should be less than 23,000 kg/year (50,000 lbs/year) by 1977--a negligible quantity. These estimates are summarized in Table VI-1.

Table VI-1

ANTICIPATED FUTURE VCM LOSS RATES FROM COMPOUNDING AND FABRICATION

<u>Year</u>	<u>PVC Production Rates (millions of kg)</u>	<u>Avg. VCM Content of Raw Resin (ppm)</u>	<u>Total Annual U.S. VCM Release from Compounding and Fabricating (kg)</u>
1974	2000	300	600,000
1975	2100*	50	105,000
1980	2400 (est.)	20	48,000

\*Assumes 7% growth rate.

Finally, it appears that reduction of VCM emissions at later stages of fabricating (after compounding) is best accomplished by reducing the VCM levels either in the input raw resin or in the final compound. Techniques exist for both reductions, and it would appear wasteful to attempt to design and build equipment for removing VCM further downstream if it could be removed before it even entered the fabricating operations.

The major difficulty in achieving these low VCM levels appears to be the quality of resin produced. Current techniques for reducing monomer content--many of them proprietary at this time--appear to result in diminished adsorbability of the raw resin for plasticizer and in reduced insulation properties and altered color.

The additional cost of producing resins of lower VCM levels cannot be estimated at this time since techniques are still in the developmental stage and information is proprietary. However, it appears that the pressures from OSHA to reduce in-plant emissions (and the high cost of providing respirators and other controls if emissions cannot be reduced), will place a very high premium on reducing the VCM content in resins. The industry is quite competitive, and it appears that fabricators will favor those manufacturers' resins which have the lowest VCM levels, thus increasing the incentives for the resin manufacturers to reduce these levels.

## 2. Auxiliary "External" Control Techniques

For completeness one should consider other techniques which might be applicable for controlling VCM emitted from compounding and fabricating operations. It should be stressed, however, that these techniques are purely speculative at this time, and have not been considered by any manufacturers we interviewed.

The most promising control techniques which we can envision are those which might operate at points of high VCM emissions--notably at the dryblending points of compounding operations. As we have noted, up to 90% of the residual VCM in resins used in flexible formulations is emitted at the dryblending stage. A sizable fraction of the VCM in rigid compounds is also emitted at this stage. At least in theory, it should be possible to totally enclose the dryblending equipment, and vent it with only small volumes of air, which could then be used as feed air to gas burners or incinerators. The purpose of the small volume of venting air would be to increase the VCM levels in the air and to reduce the volume of air to be processed to amounts which could be usefully employed in the burners. VCM is highly combustible and decomposes readily at normal burner temperatures.

There are several disadvantages to this technique which must be considered. At present, it runs totally counter to current "improvements" in processing equipment designed to sweep away any VCM emissions which might go into the workspace. Thus, equipment would have to be totally redesigned for low flows. Secondly, the dryblend powder would probably need a longer residence time in order to ensure that enough VCM is stripped out under the low-air-flow conditions. Finally, of course, the burners would have to be built of materials that would withstand the HCl emitted when vinyl chloride monomer is burned.

It is not possible at this stage to estimate the cost of equipment redesign for VCM burning since such a system is simply at the speculation stage.

APPENDIX TABLE A-I

Major U.S. Producers of Raw PVC Resin

	<u>Annual Capacity (million lbs) by December 1975</u>
Goodrich	950
Borden	545
Tenneco	480
Robintech	470
Continental Oil	430
Firestone Tire & Rubber	400
Diamond Shamrock	360
Union Carbide	350
Goodyear	200
Georgia Pacific*	220
Others (Air Products, American Chemical, Certain-teed, Ethyl, General Tire, Olin, Pantasote, Shintech, Occidental Petroleum, Stauffer Chemical, Uniroyal, Keysor)	<u>1,895</u>
TOTAL	6,400

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\*Not currently a producer; plant opening in late 1975.

APPENDIX TABLE A-II

MAJOR MERCHANT PVC RESIN CONSUMERS

<u>COMPANY</u>	<u>MAJOR PLANT LOCATION</u>
<u>Wire and Cable</u>	
Anaconda Wire & Cable	Hastings, New York
American Enka	Willimantic, Connecticut
Belden Manufacturing	Chicago, Illinois
Essex Wire & Cable	Marion, Indiana
General Cable	Bayonne, New Jersey
General Electric	Bridgeport, Connecticut
Hatfield (Div. Continental Cooper & Steel)	Hillside, New Jersey
Kaiser Aluminum & Chemical	Bristol, Rhode Island
Okonite (LTV)	Passaic, New Jersey
Packard Electric (General Motors)	Warren, Ohio
Phelps Dodge	Yonkers, New York
Simplex Wire & Cable	Cambridge, Massachusetts
Triangle Conduit & Cable	New Brunswick, New Jersey
Western Electric	Baltimore, Maryland
<u>Flooring</u>	
American Biltrite Rubber	Trenton, New Jersey
Armstrong Cork	Lancaster, Pennsylvania
Congoleum	Kearny, New Jersey
Flintkote	Chicago, Illinois
Johns-Manville	Manville, New Jersey
Kentile	New York, New York
Robbins Floor Products	Tuscumbia, Alabama
Ruberoid (GAF)	Newburgh, New York
Uvalde Rock Asphalt	Houston, Texas
Vinyl Plastics (U.I.P.)	Sheboygan, Wisconsin
<u>Film, Sheet and Coated Fabrics</u>	
Athol Mfg.	Butner, North Carolina
Bemis	Stratford and Plainfield, Connecticut
Burlington Industries	Reading, Massachusetts
Chrysler	Sandusky, Ohio
Dart Industries (Fabrovin)	Paterson, New Jersey
Dayco (L.E. Carpenter)	Wharton, New Jersey

APPENDIX TABLE A-II (continued)

MAJOR MERCHANT PVC RESIN CONSUMERS

<u>COMPANY</u>	<u>MAJOR PLANT LOCATION</u>
<u>Film, Sheet and Coated Fabrics (Continued)</u>	
Fields Plastics and Chemicals	Lodi, New Jersey
Ford Motor	Mt. Clemens, Michigan
W.R. Grace (Southbridge, Elm Coated Fabric, Elay Rubber)	Clifton, New Jersey; Brooklyn, New York; Corinth, Mississippi Los Angeles, California
Haartz-Mason	Watertown, Massachusetts
Interchemical	Toledo, Ohio
Lyntex	Conshohocken, Pennsylvania
3M	Hastings, Michigan
O'Sullivan Rubber	Winchester, West Virginia
Plastic Calendering	Farmingdale, New York
Plymouth Rubber	Canton, Massachusetts
Weymouth Art Leather	Braintree, Massachusetts
Whittaker (Am. Finishing)	Memphis, Tennessee
<u>Phonograph Records</u>	
Capital	Scranton, Pennsylvania
CBS	Pitman, New Jersey
Decca	Gloversville, New Jersey
MGM	Bloomfield, New Jersey
RCA	Indianapolis, Indiana
<u>Slush Molding (Dolls, Toys)</u>	
Doughbough Industries	Richmond, Virginia
Dublon	Newark, New Jersey
Ideal Toy	Hollis, New York
Kaysam	Paterson, New Jersey
Mattel	Hawthorne, California
<u>Miscellaneous Extrusions</u>	
Abbott Labs	Ashland, Ohio
American Biltrite Rubber	Trenton, New Jersey
American Vinyl	Hialeah, Florida
Backstay Welt (Division of Essex International)	Union City, Indiana

APPENDIX TABLE A-II (continued)

MAJOR MERCHANT PVC RESIN CONSUMERS

<u>COMPANY</u>	<u>MAJOR PLANT LOCATION</u>
<u>Miscellaneous Extrusions (Continued)</u>	
Dart Industries (Colorite)	Paterson, New Jersey
Geauga Industries	Middlefield, Ohio
Globe	Philadelphia, Pennsylvania
Hoover	Canton, Ohio
Johnson Plastics	Chagrin Falls, Ohio
Kraco	Los Angeles, California
3M	St. Paul, Minnesota
Norton	Akron, Ohio
Premoid	Holyoke, Massachusetts
Rubbermaid	Wooster, Ohio
Swan Rubber (Div. Amerace)	Bucyrus, Ohio
Whittaker (Suval)	New York
<u>Industrial Tape</u>	
Anchor Continental Tape	Columbia, South Carolina
Arno Adhesives	Michigan City, Indiana
Behr-Manning (Norton)	Troy, New York
3M	Minneapolis, Minnesota
Permacel Tape (Johnson & Johnson)	New Brunswick, New Jersey
Technical Tape	New Rochelle, New York
<u>Packaging Film</u>	
Clopay	Cincinnati, Ohio
Filmco (R.J. Reynolds)	Aurora, Ohio
FMC (American Viscose)	Marcus Hook, Pennsylvania
W.R. Grace (Cryovac)	Cedar Rapids, Iowa
Reynolds Metal	Grottoes, Virginia
<u>Rigid Products (Pipe, Sliding, Other)</u>	
Alpha Plastics	Livingston, New Jersey
Amos Molded Plastics (National Lead)	Edinburg, Indiana
Andersen	Bayport, Minnesota
Bird & Son	Bardstown, Kentucky
Borg-Warner	Los Angeles, California
Cabot	Louisville, Kentucky
Certain-teed Products	McPherson, Kansas

APPENDIX TABLE A-II (continued)

MAJOR MERCHANT PVC RESIN CONSUMERS

<u>COMPANY</u>	<u>MAJOR PLANT LOCATION</u>
Rigid Products(Pipe,Sliding,Other) (Continued)	
Colonial Plastics Mfg.(Van Dorn)	Cleveland, Ohio
Consolidated Pipe	Stow, Ohio
Crane Plastics	Columbus, Ohio
Flintkote	Whippany, New Jersey
Glamorgan Pipe & Foundry	Lynchburg, Virginia
Harsco	Mineral Wells, Texas
Johns-Manville	Manville, New Jersey
Kraloy (Div. of Dart Industries)	Santa Ana, California
Mastic Asphalt	South Bend, Indiana
Skyline Plastics (Phillips Petroleum)	Titusville, Pennsylvania
Sloane Mfg. (Susquehanna)	Sun Valley, California
Standard Oil (Ohio)	Columbus, Ohio
Whittaker (Thermoplastics)	Charlotte, North Carolina
Yardley (Div. of Celanese)	Columbus, Ohio
<u>Containers</u>	
American Can	Chicago, Illinois
Creative Packaging (Div. of Eli Lilly)	Roanoke, Virginia
Owens-Illinois	Toledo, Ohio
<u>Footwear</u>	
American Biltrite Rubber	Chelsea, Massachusetts
Avon Sole	Avon, Massachusetts
Bata Shoe	Belcamp, Maryland
Brown Shoe	St. Louis, Missouri
Genesco	Nashville, Tennessee
International Shoe	St. Louis, Missouri
New Jersey Rubber	Taunton, Massachusetts
O'Sullivan Rubber	Winchester, Virginia
USM	Kenton, Tennessee
<u>Coatings</u>	
American Cyanamid	Buchanan, New York
Baldwin Montrose	St. Louis, Missouri
Bradley & Vrooman (Whittaker)	Chicago, Illinois

APPENDIX TABLE A-II (continued)

MAJOR MERCHANT PVC RESIN CONSUMERS

<u>COMPANY</u>	<u>MAJOR PLANT LOCATION</u>
<u>Coatings (Continued)</u>	
Chemical Products	East Providence, Rhode Island
Continental Can	New York, New York
Dennis Chemical	St. Louis, Missouri
DeSoto	Chicago, Illinois
Dewey and Almy (Div. W.R. Grace)	Cambridge, Massachusetts
General Electric	Louisville, Kentucky
Glidden (Div. SCM)	Cleveland, Ohio
Interchemical	Newark, New Jersey
Michigan Chrome & Chemical	Detroit, Michigan
3M	St. Paul, Minnesota
Permalastic	Detroit, Michigan
Stoner-Mudge (Div. Mobil Oil)	Cleveland, Ohio
<u>Compounding</u>	
Bamberger	Carlstadt, New Jersey
Reichhold Chemicals	Mansfield, Massachusetts
A. Shulman	Akron, Ohio
Vinyl Industrial Products	Grand Rapids, Michigan
Machlin	
Premier	
Chemical Products	

APPENDIX TABLE A-III  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Abbey Plastics Corp. Hudson, Mass.		X			B
Acro Chemical Prod. Corp. Longualley, N.J.				X	AA
Albis Corp. Houston, Texas	X	X	X		
Alpha Chemical & Plastics Corp. Newark, N.J.		X			B
American Chemical Corp. <u>Subs.:</u> Atlantic Richfield Co. Stauffer Chemical Co. Long Beach, California	X				
Americhem, Inc. Cuyahoga Falls, Ohio				X	

AAAA	Over	\$1,000,000/Year in Sales
AAA	Over	500,000/Year in Sales
AA	Over	300,000/Year in Sales
A	Over	100,000/Year in Sales
B - D	<	50,000/Year in Sales

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Atlas Coatings Corp. Long Island, N.Y.		X	X	X	A
Axel Plastics Research Labs, Inc. Long Island City, N.Y.			X	X	A
Ball Chemical Co. Glenshaw, Pa.			X		AAAA
Blane Chemical Division Reichhold Chemo, Inc. Mansfield, Mass.		X			AA
Borden Chemical Div. of Borden, Inc. Columbus, Ohio	X	X	X	X	AAAA
Bostik Chemical Group USM Corp. Middleton, Mass.				X	AAAA

AAAA	Over	\$1,000,000/Year in Sales
AAA	Over	500,000/Year in Sales
AA	Over	300,000/Year in Sales
A	Over	100,000/Year in Sales
B - D	<	50,000/Year in Sales

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Cary Page Chems., Inc. Edison, N.J.		X			
*Chemetron Corp. Pigments Division Holland, Michigan				X	AAAA
Chemical Coating & Engineering Co., Inc. Media, Pa.			X	X	A
Chemical & Engineering Assoc., Inc. Elkton, Md.			X	X	
Chemical Industries Pasadena, California			X		
Chemical Prod. Co. E. Providence, R.I.				X	AAAA

AAAA	Over	\$1,000,000/Year in Sales
AAA	Over	500,000/Year in Sales
AA	Over	300,000/Year in Sales
A	Over	100,000/Year in Sales
B - D	<	50,000/Year in Sales

\*Chemetron Corp., 111 E. Wacker Drive, Chicago, Ill. 60601

APPENDIX TABLE A-III (Continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Colorite Plastics Co. Div. Dart Industries, Inc. Ridgefield, N.J.		X			AAA
Conoco Chemicals Div. Continental Oil Co. Saddlebrook, N.J.		X			AAAA
Custom Chemicals Co. Patterson, N.J.		X	X	X	
Diamond Shamrock Chemical Company Plastics Div. Cleveland, Ohio	X	X			AAAA
Dynamit Nobel of America, Inc. Northvale, N.J.		X			

AAAA	Over	\$1,000,000/Year in Sales
AAA	Over	500,000/Year in Sales
AA	Over	300,000/Year in Sales
A	Over	100,000/Year in Sales
B - D	<	50,000/Year in Sales

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Eronel Industries Hawthorne, California				X	B
*Ethyl Corp. Polymer Division Baton Rouge, La.	X	X			AAAA (All plants and division)
*Ferro Corp. Composite Div. Norwalk, Conn.			X		AAAA (All divisions of Ferro)
Firestone Plastics Co. Div. Firestone Tire & Rubber Co. Pottstown, Pa.	X	X			AAAA
Flexcraft Industries Newark, N.J.			X	X	
George, P.D. Co. St. Louis, Mo.			X	X	AAAA
AAAA	Over			\$1,000,000/Year in Sales	
AAA	Over			500,000/Year in Sales	
AA	Over			300,000/Year in Sales	
A	Over			100,000/Year in Sales	
B - D	<			50,000/Year in Sales	
* Ethyl Corp., 330 S. 4th St., Richmond, Va. 23219					
Ferro Corp., 1 Erie View Plaza, Cleveland, Ohio 44144					

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
B.F. Goodrich Chemical Div. of B.F. Goodrich Co. Cleveland, Ohio	X	X		X	AAAA
W.R. Grace & Co. Elm Coated Fabrics Div. New York, N.Y.		X			AAAA (All of Grace & Co)
Great American Chemical Corp. Fitchburg, Mass.	X	X			
Guardsman Chemical Coatings, Inc. Grand Rapids, Mich.				X	AAAA
C.L. Hawthaway & Sons, Corp. Lynn, Mass.				X	
AAAA	Over				\$1,000,000/Year in Sales
AAA	Over				500,000/Year in Sales
AA	Over				300,000/Year in Sales
A	Over				100,000/Year in Sales
B - D	<				50,000/Year in Sales

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Howell Industries Paterson, N.J.		X	X	X	B
Jedco Chemical Corp. Mt. Vernon, N.Y.					
Key Polymer Corp. Lawrence, Mass.				X	
Leon Chem. & Plastics, Inc. Div. of U.S. Industries, Inc. Grand Rapids, Mich.		X	X	X	AAA
Loes Enterprises		X	X	X	A
M.R. Plastics & Coating, Inc. Maryland Heights, Mo.	X	X	X	X	AAAA

AAAA	Over	\$1,000,000/Year in Sales
AAA	Over	500,000/Year in Sales
AA	Over	300,000/Year in Sales
A	Over	100,000/Year in Sales
B - D	<	50,000/Year in Sales

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
M-R-S Chemo, Inc. Hazelwood, Mo.		X			AAAA
*M & T Chems., Inc. Subs.American Can Co. Rahway, N.J.		X			AAAA
Machlin Co. Industry, California		X			
Michigan Chrome & Chemical Co. Detroit, Michigan			X		AAAA
			X		AAAA
Monsanto Co. St. Louis, Mo.	X	X	X	X	AAAA

AAAA	Over	\$1,000,000/Year in Sales
AAA	Over	500,000/Year in Sales
AA	Over	300,000/Year in Sales
A	Over	100,000/Year in Sales
B - D	<	50,000/Year in Sales

\*M & T Chem., Inc., Subs. American Can Co., American Lane,  
Greenwich, Conn. 06830

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Moore Chemical Corp. Div. Moore Plastics Ind., Inc. Burlingame, Calif.		X		X	
H. Muchlstein & Co. Greenwich, Conn.	X	X			AAAA
Nat'l Adhesives Div. Nat'l Starch & Chemical Corp. New York, N.Y.				X	AAAA
P.F.D., Penn. Color, Inc. Subs. Bonn Ind., Inc. Doylestown, Pa.				X	AAAA
Parcloid Chemical Co. Ridgewood, N.J.			X	X	
AAAA	Over			\$1,000,000/Year in Sales	
AAA	Over			500,000/Year in Sales	
AA	Over			300,000/Year in Sales	
A	Over			100,000/Year in Sales	
B - D	<			50,000/Year in Sales	

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Perma-Flex Mold Co. Columbus, Ohio		X			B
Piper Plastics Corp. Copiague, N.Y.			X		
Poly Resins Sun Valley, Calif.		X	X	X	AA
The Polymer Corp. Reading, Pa.					AAAA
Premier Thermo-Plastics Co. Subs. Plastic Bldg. Products Co. Jeffersontown, Ky.		X			AAAA
R.A. Chemical Corp. Brooklyn, N.Y.				X	
AAAA	Over			\$1,000,000/Year in Sales	
AAA	Over			500,000/Year in Sales	
AA	Over			300,000/Year in Sales	
A	Over			100,000/Year in Sales	
B - D	<			50,000/Year in Sales	

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding of Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Reichhold Chemical, Inc. White Plains, N.Y.		X			AAAA
Research Sales, Inc.			X	X	AAAA
Reynolds Chemical Prod. Division Hoover Ball & Bearing Co Ann Arbor, Michigan			X	X	AAAA
Ruco Division Hooker Chemical Corp. Hicksville, N.Y.	X	X	X	X	AAAA
A. Schulman, Inc. Akron, Ohio					AAAA
Soc-Co Plastic Coating Co. Paramount, Calif.			X	X	AAA
AAAA	Over			\$1,000,000/Year in Sales	
AAA	Over			500,000/Year in Sales	
AA	Over			300,000/Year in Sales	
A	Over			100,000/Year in Sales	
B - D	<			50,000/Year in Sales	

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Solar Compounds Corp. Linden, N.J.				X	AAA
Special Products Div. Sun Steel Co. Chicago Hghts., Ill.			X		AAAA
Stanchem, Inc. E. Berlin, Conn.			X		AAAA
Stauffer Chemical Co. Plastics Div. Westport, Conn.	X				AAAA
Tamite Industries Div. Watsco, Inc. Hialeah, Fla.		X	X	X	AAAA (Watsco, Inc.)
Tenneco Chemicals, Inc. Tenneco Intermediate Div. Piscataway, N.J.	X	X	X	X	AAAA
AAAA	Over			\$1,000,000/Year in Sales	
AAA	Over			500,000/Year in Sales	
AA	Over			300,000/Year in Sales	
A	Over			100,000/Year in Sales	
B - D	<			50,000/Year in Sales	

APPENDIX TABLE A-III (continued)  
LIST OF SUPPLIERS OF PVC COMPOUND

CORPORATION	TYPE OF COMPOUND				SALES CATEGORY (Of Parent Corporation)
	Basic Resins	Molding or Extrusion Compounds	Organosols & Plastisols	Solutions, Emulsions or Dispersions	
Union Carbide Corp. Chemicals & Plastics New York, N.Y.	X	X			AAAA
*Uniroyal, Inc. Adhesives & Coatings Dept. Mishawaka, Ind.			X		AAAA
The Vorac Co. Carlstadt, N.J.			X		AAA
Watson Standard Co. Harwick, Pa.			X	X	AAAA
George Woloch Co., Inc. Allentown, Pa.		X			AAAA
Youngstown Vinyl Comp., Inc. Youngstown, Pa.		X			

AAAA	Over	\$1,000,000/Year in Sales
AAA	Over	500,000/Year in Sales
AA	Over	300,000/Year in Sales
A	Over	100,000/Year in Sales
B - D	<	50,000/Year in Sales

\*Uniroyal, Inc., Uniroyal Products Information Center  
1230 Avenue of the Americas, New York, N.Y. 10020

APPENDIX TABLE A-IV

PRODUCERS OF PVC PIPE AND FITTINGS

<u>CORPORATION</u>	<u>PIPE</u>	<u>FITTINGS</u>
Adams Brothers Co., Inc. Eads, Tennessee	X	X
Amoco Chemicals Corp. Industrial Products Division Stow, Ohio	X	X
ASC Industries, Inc. Plastics Division Spokane, Washington	X	
Can-Tex Industries A Division of Harsco Corp.	X	X
Celanese Piping Systems Hilliard, Ohio	X	X
Certain-Teed Products Corp. McPherson, Kansas	X	X
Charlotte Pipe & Foundry Co. Plastic Division Monroe, North Carolina	X	X
Clin Plastics	X	X
Continental Plastics Industries, Inc. Denver, Colorado	X	X
Cresline Plastic Pipe Co., Inc. Evansville, Indiana	X	X
Cupples Coiled Pipe, Inc. Austin, Texas	X	X
Dixie Plastics Mfg. Co. New Orleans, Louisiana	X	X

APPENDIX TABLE A-IV (continued)

PRODUCERS OF PVC PIPE AND FITTINGS

<u>CORPORATION</u>	<u>PIPE</u>	<u>FITTINGS</u>
Graspo, Inc. Honolulu, Hawaii	X	X
Harvel Plastics, Inc. Easton, Pennsylvania	X	
Jet Stream Plastics (Ralph Jones Co.) Div. of Winrock Enterprises Siloam Springs, Arkansas	X	
Mid-American Industries, Inc. Memphis, Tennessee	X	X
Plastiline, Inc. Pompano Beach, Florida		X
Portco Corp. Vancouver, Washington	X	
Shamrock Industries, Inc. Minneapolis, Minnesota		X
Simpson Extruded Plastics Co. Eugene, Oregon	X	
R & G Sloane Mfg. Co., Inc. Sun Valley, California	X	X
U-Brand Corp. Plastic Division Ashland, Ohio		X
Western Plastics Corp. Hastings, Nebraska	X	
Western Plastics Corp. Tacoma, Washington	X	

APPENDIX TABLE A-V

SUPPLIERS OF RESIN OR COMPOUND TO PVC PIPE FABRICATORS

Allied Chemical Corp., Plastics Division  
Morristown, New Jersey

American Chemical Corp.  
Long Beach, California

Argus Chemical Corp.,  
Subsidiary of Witco Chemical Corp.  
Brooklyn, New York

Borden Chemical, Division of Borden, Inc.  
Leominster, Massachusetts

Celanese Piping Systems  
Newark, New Jersey

Cincinnati Milacron Chemicals, Inc.  
Reading, Ohio

Conoco Chemicals  
Saddle Brook, New Jersey

Diamond Shamrock Chemical Co.  
Cleveland, Ohio

E.I. duPont de Nemours & Co., Inc.  
Pencader Plant, Pipe Division  
Wilmington, Delaware

Eastman Chemical Products, Inc.  
Kingsport, Tennessee

Ethyl Corp., Polymer Division  
Baton Rouge, Louisiana

General Electric Co., Plastics Dept.  
Pittsfield, Massachusetts

B.F. Goodrich Chemical Co.  
Cleveland, Ohio

APPENDIX TABLE A-V (continued)

SUPPLIERS OF RESIN OR COMPOUND TO PVC PIPE FABRICATORS

Goodyear Tire & Rubber Co., Chemical Division  
Niagara Falls, New York

Gulf Oil Co.,  
Houston, Texas

Hooker Chemical Corp., Ruco Division  
Burlington, New Jersey

M & T Chemicals, Inc.  
Rahway, New Jersey

Mallinckrodt Chemical Works  
St. Louis, Missouri

Marbon Division, Borg-Warner Corp.  
Washington, West Virginia

Mobil Chemical Co.  
New York, New York

Monsanto Polymers & Petrochemicals Co.  
St. Louis, Missouri

Permatex Co., Inc.  
West Palm Beach, Florida

Rohm & Haas  
Philadelphia, Pennsylvania

A. Schulman, Inc.  
Akron, Ohio

Sinclair-Koppers Co.  
Pittsburgh, Pennsylvania

Synthetic Products Co.  
Cleveland, Ohio

Tenneco Chemicals, Inc., Tenneco Intermediates Division  
Piscataway, New Jersey

APPENDIX TABLE A-V (continued)

SUPPLIERS OF RESIN OR COMPOUND TO PVC PIPE FABRICATORS

Union Carbide Corp., Plastics Products Division  
New York, New York

Uniroyal Chemical Division, Uniroyal, Inc.  
Naugatuck, Connecticut

Witco Chemical Corp..  
New York, New York

APPENDIX TABLE A-VI

FILM AND SHEETING CALENDERS IN OPERATION IN THE U.S.A. \*

(Includes coating but not flooring calenders)

<u>COMPANY</u>	<u>LOCATION</u>	<u>TOTAL NO. OF CALENDERS</u>
Associated Rubber	Bronx, New York	2
Bemis Bag	Stratford, Connecticut	4
** Borden Co.	Columbus, Ohio (4) San Francisco, Calif.(1)	5
** Burlington Industries	Reading, Massachusetts	4
** Chrysler Corp.	Sandusky, Ohio	4
Continental Plastics	Avenel, New Jersey	2
C.S. Fields	Lodi, New Jersey	4
Diamond Shamrock (Harte & Co.)	Brooklyn, New York (5) Mountaintop, Pa.(1)	6
** Firestone Tire & Rubber Co.	Pottstown, Pennsylvania	3
** Ford Motor Co.	Mt. Clemens, Michigan	3
** General Tire & Rubber Co.	Columbus, Mississippi (4) Jeanette, Pa. (3) Lawrence, Mass. (6) Newcomerstown, Ohio (2) Toledo, Ohio (3)	18
** B.F. Goodrich & Co.	Marietta, Ohio	2
Goodyear Tire & Rubber Co.	Akron, Ohio	5

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\*SOURCE: Monsanto Company  
\*\*MAJOR PRODUCT: Coated Fabrics

APPENDIX TABLE A-VI (continued)

FILM AND SHEETING CALENDERS IN OPERATION IN THE U.S.A. \*

(Includes coating but not flooring calenders)

<u>COMPANY</u>	<u>LOCATION</u>	<u>TOTAL NO. OF CALENDERS</u>
W.R. Grace	Los Angeles, Calif. (2) Brooklyn, N.H. (7) Corinth, Miss. (3)	12
** Hooker Chemical Corp.	Carteret, New Jersey	3
Imperial Chemical (Atlantic Tubing)	Cranston, R.I.	5
** Inmont	Toledo, Ohio	1
Lamcal	Hickory, North Carolina	2
Lynn Vinyl Plastics Co.	Lynn, Massachusetts	1
Lyntex Corp.	Conshohocken, Pennsylvania	2
Macklin Co.	Los Angeles, Calif.	1
Middletown Rubber Co.	Middletown, Connecticut	1
MMM	St. Paul, Minnesota	2
Monsanto Co.	Springfield, Massachusetts	2
** O'Sullivan Rubber Corp.	Winchester, Virginia	3
Pantasote Co.	Passaic, New Jersey	5
Parker, Strearns & Co.	Brooklyn, New York	1
Phillips Petroleum	Auburn, Pennsylvania	2

APPENDIX TABLE A-VI (continued)

FILM AND SHEETING CALENDERS IN OPERATION IN THE U.S.A. \*

(Includes coating but not flooring calenders)

<u>COMPANY</u>	<u>LOCATION</u>	<u>TOTAL NO. OF CALENDERS</u>
Plastic Calendering	Farmingdale, L.I., N.Y.	2
Plicoflex, Inc.	Houston, Texas	1
** Plymouth Rubber	Canton, Massachusetts	5
Rand Rubber Co.	Brooklyn, New York	1
Rudd Plastics	Brooklyn, New York	2
** Stauffer Chemical Co.	Newburgh, New York (2) Delaware City, Del. (2) Yardville, N.J. (3)	7
Swartz-Dondero	Yonkers, New York	2
** Tenneco Chemicals, Inc.	Newton Upper Falls, Mass. (1) Nixon, N.J. (6) Chicago, Ill. (1)	8
Union Carbide Corp.	Bound Brook, New Jersey (4) Ottawa, Ill. (4)	8
** Uniroyal, Inc.	Chicago, Illinois (2) Mishawaka, Ind. (2) Philadelphia, Pa. (3) Port Clinton, Ohio (2)	9
Vernon Plastics Corp.	Haverhill, Massachusetts	1
Vinyl Masters	Brooklyn, New York	2
TOTAL		153

APPENDIX TABLE A-VII  
MANUFACTURERS OF FLEXIBLE (PLASTICIZED) PVC SHEET

<u>CORPORATION</u>	<u>NUMBER OF EMPLOYEES</u>	<u>CALENDERED</u>	<u>EXTRUDED</u>
Ace-Tex Vinyls, Inc. New York, New York	1 - 9	X	
American Renolit Corp. Whippany, New Jersey		X	
Ameron Corrosion Control Division Brea, California			X
Bakelite Xylonite Ltd London, England		X	X
Cadillac Plastic & Chemical Co. Detroit, Michigan	800	X	X
Commercial Plastics & Supply Corp. Cornwells Heights, Pennsylvania		X	X
Dynamit Nobel of America, Inc. Northvale, New Jersey		X	X
Ellay Rubber Division W.R. Grace Co. Los Angeles, California	100 - 499	X	
Ethyl Corp. Baton Rouge, Louisiana	13,743		X
Firestone Plastics Co. Div. of Firestone Tire & Rubber Co. Pottstown, Pennsylvania	675	X	
Ford Motor Co. Mount Clemens, Michigan	442,607	X	X

APPENDIX TABLE A-VII (continued)

MANUFACTURERS OF FLEXIBLE (PLASTICIZED) PVC SHEET

<u>CORPORATION</u>	<u>NUMBER OF EMPLOYEES</u>	<u>CALENDERED</u>	<u>EXTRUDED</u>
Franklin Fibre-Lamstex Wilmington, Delaware	50 - 99	X	X
Gelman, Herman A. Co. Brooklyn, New York		X	X
General Tire & Rubber Co. Akron, Ohio	37,000	X	X
Goodyear Tire & Rubber Co. Akron, Ohio	145,000	X	
Goss Plastic Corp. Los Angeles, California		X	
Harte & Co. New York, New York	100 - 499	X	
Hydrawlik Co. Roselle, New York			X
Industrial Vinyls, Inc. Miami, Florida	60		
Jodee Plastics, Inc. Brooklyn, New York	20 - 49	X	X
Kessler Products Co. Youngstown, Ohio	200		X
Lavorazione Materse Plastiche, S.P.D. Torino, Italy			X
Leathertone, Inc. Chelsea, Massachusetts	20 - 49	X	
Maclin Co. Industry, California	50 - 99	X	

APPENDIX TABLE A-VII (continued)

MANUFACTURERS OF FLEXIBLE (PLASTICIZED) PVC SHEET

<u>CORPORATION</u>	<u>NUMBER OF EMPLOYEES</u>	<u>CALENDERED</u>	<u>EXTRUDED</u>
Masland Duraleather Co. Philadelphia, Pennsylvania	450	X	
Monsanto Co. St. Louis, Missouri	57,833	X	X
New England Plastic Corp. Woburn, Massachusetts	20 - 49		X
Norton Co. Akron, Ohio	100 - 499		X
O'Sullivan Corp. Winchester, Virginia	700	X	
Pervel Industries, Inc. Plainfield, Connecticut	1,300	X	
Plastic Mfg., Inc. Philadelphia, Pennsylvania		X	X
Polyval Corp. New York, New York		X	
Rowland Products, Inc. Kensington, Connecticut	200	X	
Ross & Roberts, Inc. Stratford, Connecticut	250	X	
Rotuba Extruders, Inc. Linden, New Jersey	100 - 499		X
Ruco Division, Hooker Chemical Corp. Burlington, New Jersey	700	X	

APPENDIX TABLE A-VII (continued)

MANUFACTURERS OF FLEXIBLE (PLASTICIZED) PVC SHEET

<u>CORPORATION</u>	<u>NUMBER OF EMPLOYEES</u>	<u>CALENDERED</u>	<u>EXTRUDED</u>
S.G.L. Haddonfield, New Jersey	940		X
Scranton Plastic Laminating, Inc. Scranton, Pennsylvania	75	X	
Stauffer Chemical Co. Westport, Connecticut	10,000	X	
Strauss, H.B. Corp. Bronx, New York	20 - 49	X	
Tenneco Chemical Co. New York, New York		X	X
Union Carbide Corp. New York, New York	67,942	X	X
Uniroyal, Inc. Chicago, Illinois	100 - 499	X	X
Vanguard Extruders, Inc. Farmingdale, New York	50 - 99		X
Vernon Plastics Corp. Haverhill, Massachusetts	40	X	

APPENDIX TABLE A-VIII  
MANUFACTURERS OF RIGID PVC SHEET

<u>CORPORATION</u>	<u>NO. OF EMPLOYEES</u>	<u>CALENDERED</u>	<u>EXTRUDED</u>
Ain Plastics Co. Mt. Vernon, New York		X	
Ameron Corrosion Control Div. Brea, Calif.	650	X	
Atlas Plastics Corp. Cape Guardeaw, Mo.	300		X
Bakelite Xylonite Ltd. London, England			X
Brimai Fair Lawn, N.J.			X
Canadian Industries Ltd. Montreal, Que, Canada	9,000	X	
Ellay Rubber Division W.R. Grace & Co. Los Angeles, Calif.	100-499	X	
Ethyl Corp. Baton Rouge, Louisiana	13,743	X	X
Extrudyne, Inc. Amityville, New York	20-49		X
Hydrawlik Co. Roselle, New York			X
Industrial Vinyls, Inc. Miami, Florida	60	X	
Keller Products, Inc. Manchester, N.H.	110		X
Kessler Products Co. Youngstown, Ohio	200	X	

APPENDIX TABLE A- VIII (Continued)  
MANUFACTURERS OF RIGID PVC SHEET

<u>CORPORATION</u>	<u>NO. OF EMPLOYEES</u>	<u>CALENDERED</u>	<u>EXTRUDED</u>
Lavorazione Materse Plastiche, S.P.D. Torino, Italy			X
Leathertone, Inc. Chelsea, Mass.	20-49		X
Lustro Corp. of California Valencia, California	100	X	X
Masland Duraleather Co. Philadelphia, Pa.	450	X	
Monsanto Co. St. Louis, Missouri	57,833	X	X
New England Plastic Corp. Woburn, Mass.	20-49		X
Polyval Corp. New York, New York		X	
Rohm & Haas Co. Philadelphia, Pa.	16,026		X
Rotuba Extruders, Inc. Linden, New Jersey	100-499	X	
Scranton Plastic Laminating, Inc. Scranton, Pennsylvania	75	X	
S.G.L. Industries, Inc. Haddonfield, New Jersey	940	X	X
Sheffield Plastics, Inc. Sheffield, Mass.	100-499		X
Technical Plastic Extruders, Inc. Kearny, New Jersey	50-99	X	X

APPENDIX TABLE A-VIII (Continued)  
MANUFACTURERS OF RIGID PVC SHEET

<u>CORPORATION</u>	<u>NO. OF EMPLOYEES</u>	<u>CALENDERED</u>	<u>EXTRUDED</u>
Union Carbide Corp. New York, New York	67,942	X	X
Uniroyal, Inc. Chicago, Ill.	100-499	X	X
Vanguard Extruders, Inc. Farmingdale, New York	50-99	X	X

APPENDIX TABLE A-IX  
U.S. PRODUCERS OF PVC FILM  
(Calendered and Extruded)

<u>CORPORATION</u>	<u>NUMBER OF EMPLOYEES</u>
Ace-Tex Vinyls, Inc. New York, New York	1 - 9
Allied Chemical Corp. Morristown, New Jersey	33,000
Alusuisse Metals, Inc. Fort Lee, New Jersey	
American Hoechst Corp. Delaware City, Delaware	2,500
American Renolit Corp. Whippany, New Jersey	
American Soplaril Co. Atlanta, Georgia	
Columbus Coated Fabrics Columbus, Ohio	500 - 999
Continental Plastic Co. Chicago, Illinois	50 - 99
Dynamit Nobel of America, Inc. Northvale, New Jersey	
Fabric Leather Corp. Glen Cove, New York	250
Firestone Plastics Co., Division of Firestone Fire & Rubber Co. Pottstown, Pennsylvania	675
Flex-O-Glass, Inc. Chicago, Illinois	325
Ford Motor Co. Mount Clemens, Michigan	442,607

APPENDIX TABLE A-IX (continued)

U.S. PRODUCERS OF PVC FILM  
(Calendered and Extruded)

<u>CORPORATION</u>	<u>NUMBER OF EMPLOYEES</u>
Franklin Fibre-Lamstex Corp. Wilmington, Delaware	50 - 99
General Binding Corp. Northbrook, Ill.	1,800
General Plastics Corp. Marion, Indiana	50
General Tire & Rubber Co. Akron, Ohio	37,000
Gelman, Herman A. Co. Brooklyn, New York	
Goodrich, B.F. Chemical Co. Cleveland, Ohio	
Goodyear Tire & Rubber Co. Akron, Ohio	145,000
Goss Plastic Corp. Los Angeles, California	
Grace, W.R. & Co. New York, New York	66,400
Harte & Co. New York, New York	100 - 499
Jodee Plastics, Inc. Brooklyn, New York	20 - 49
Maclin Co. Industry, California	50 - 99
Norton Co. Akron, Ohio	100 - 499

APPENDIX TABLE A-IX (continued)

U.S. PRODUCERS OF PVC FILM  
(Calendered and Extruded)

<u>CORPORATION</u>	<u>NUMBER OF EMPLOYEES</u>
O'Sullivan Corp. Winchester, Virginia	700
Pervel Industries, Inc. Plainfield, Connecticut	1,300
Reynolds Metals Co. Richmond, Virginia	35,200
Ross & Roberts, Inc. Stratford, Connecticut	250
Rowland Products, Inc. Kensington, Connecticut	200
Ruco Division, Hooker Chemical Corp. Burlington, New Jersey	700
Stauffer Chemical Co. Westport, Connecticut	10,000
Strauss, H.B. Corp. Bronx, New York	20 - 49
Vernon Plastics Corp. Haverhill, Massachusetts	40

APPENDIX TABLE A-X

U.S. PRODUCERS OF CAST PVC FILM AND SHEET

Borden Chemical Division,  
Borden, Inc.  
Columbus, Ohio

Cadillac Plastic & Chemical Co.  
Detroit, Michigan

Clopay Corp., Plastic Film Division  
Cincinnati, Ohio

Commercial Plastics & Supply Corp.  
Cornwells Heights, Pennsylvania

Crystal-X Corp.  
Darby, Pennsylvania

Dura Plastics of New York, Inc.  
Westport, Connecticut

Fassler, M.J. & Co.  
Bayshore, New York

King Plastic Corp.  
Venice, Florida

Newage Industries, Inc.  
Jenkintown, Pennsylvania

Plastic Mfg., Inc.  
Philadelphia, Pennsylvania

Reynolds Metals Co.  
Richmond, Virginia

Rhodia, Inc.  
New York, New York

Tenneco Chemical, Foam & Plastic Division  
New York, New York