Eco-profiles of the
European Plastics Industry

POLYVINYLCHLORIDE (PVC)
(SUSPENSION POLYMERISATION)

A report by

I Boustead

for

The European Council of Vinyl Manufacturers (ECVM) & Plastics*Europe*

Data last calculated

March 2005

IMPORTANT NOTE

Before using the data contained in this report, you are strongly recommended to look at the following documents:

1. Methodology

This provides information about the analysis technique used and gives advice on the meaning of the results.

2. Data sources

This gives information about the number of plants examined, the date when the data were collected and information about up-stream operations.

In addition, you can also download data sets for most of the upstream operations used in this report. All of these documents can be found at: www.plasticseurope.org.

ECVM & Plastics*Europe* may be contacted at

Ave E van Nieuwenhuyse 4
Box 3
B-1160 Brussels

Telephone: 32-2-672-8259
Fax: 32-2-675-3935

CONTENTS

POLYVINYL CHLORIDE **4**

STRUCTURE OF PVC **4**

PRODUCTION METHODS **5**

SUSPENSION POLYMERISATION 5
EMULSION POLYMERISATION 5
BULK OR MASS POLYMERISATION 6
USES OF PVC 6

SUSPENSION POLYMERISATION **7**

ECOPROFILE OF SUSPENSION PVC **7**

POLYVINYL CHLORIDE

Of all synthetic thermoplastics, polyvinyl chloride (PVC) is probably one of the polymers in modern use with the oldest pedigree. Regnault in France first produced vinyl chloride monomer in 1835 and Baumann first recorded its polymerisation in 1872 after exposing sealed tubes containing the monomer to sunlight. The earliest patents for PVC production were taken out in the USA in 1912 and pilot plants producing PVC began in Germany and the USA in the early 1930's.

Early PVC processing technology was based on established rubber moulding processes and the products that could be manufactured were limited to those using heavily plasticised polymer. The main problem was the inability to convert the polymer into usable products without severe thermal degradation because of the tendency of the polymer to de-hydrochlorinate at elevated temperatures. It was not until the discovery of suitable stabilisers that processing technology advanced to the point where the full potential of the polymer could be realised. Nowadays, by choosing suitable stabilisers and plasticisers, the polymer can be converted into a wide variety of different products as diverse as plastisols, which provide the seals in some closures, through coated fabrics used in architectural applications, films and sheets for use in packaging applications and extruded pipes and sections for use in building applications.

STRUCTURE OF PVC

PVC is a chlorinated hydrocarbon polymer. The structure is similar to that of polyethylene except that alternate carbon atoms in the main chain have one of their hydrogen atoms replaced by a chlorine atom to give the structure shown in Figure 1.

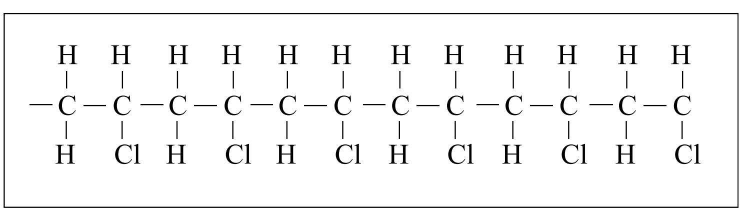

Figure 1. Structure of polyvinyl chloride

The polymer is produced from vinyl chloride by a process essentially similar to that used in the production of polyethylene, polypropylene and polystyrene; that is, the double bond in the vinyl chloride molecule is opened and neighbouring molecules combine with each other to produce a long chain molecule. Schematically the reaction is as shown in Figure 2.

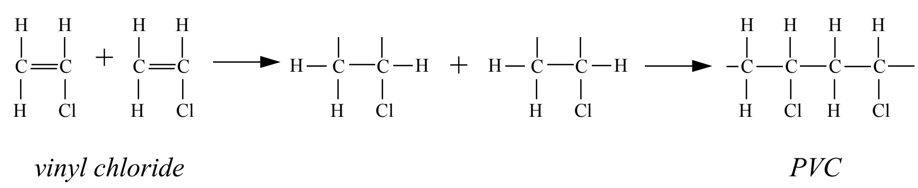

Figure 2. Schematic representation of the polymerisation of vinyl chloride.

PRODUCTION METHODS

There are three commercial processes for the production of PVC:

1. Suspension polymerisation
2. Emulsion polymerisation
3. Bulk or mass polymerisation.

Suspension polymerisation

Liquid vinyl chloride is insoluble in water and disperses to fine droplets when mechanically agitated. The droplets remain in suspension as long as the agitation continues. Polymerisation is carried out in pressurised vessels under the influence of heat and initiators and/or catalysts, which are soluble in the water. A typical initiator is an organic peroxide.

The reaction is exothermic and the heat evolved is carried to the sides of the reaction vessel by the water. Suspension agents known as protective colloids are added to the reactor to prevent the monomer droplets coalescing and the polymer particles from agglomerating.

When the desired conversion is reached, the batch is transferred to a blow down vessel. Several batches may be transferred to this vessel for blending. Unreacted monomer is recovered and recycled back to the polymerisation reactor. The polymer particles are dried.

Emulsion polymerisation

In this process, surfactants (soaps) are used to disperse the vinyl chloride monomer in water. The monomer is trapped inside soap micelles are protected by the soap and polymerisation takes place using water soluble initiators.

The process can be either continuous or batch but both lead to a polymer latex which is a very fine suspension of polymer particles (~ 0.1µm diameter) in water. Excess monomer is recovered and recycled and the polymer particles are dried.

Bulk or mass polymerisation

Unlike suspension or emulsion polymerisation, bulk polymerisation is carried out in the complete absence of water, protective colloids or emulsifying agents. This process relies on the fact that the polymer is insoluble in the monomer and precipitates out to form grains that have no tendency to agglomerate. The main problem is the difficulty in heat removal and this problem is solved by carrying out the polymerisation in two stages.

In the first stage, vinyl chloride monomer is mechanically agitated ion a vertical autoclave with the appropriate initiators until a conversion of 7 – 10% is achieved. This first pre-polymerisation step determines the number of particles that will be formed. Heat is removed by continuously condensing the VCM vapour above the liquid reaction mixture.

The pre-polymer is then transferred to a horizontal autoclave equipped with a slow paddle. Here, the particles already formed grow by the formation of further polymer. The process is stopped when 70 – 90% of the monomer has been converted.

Uses of PVC

Suspension PVC is the general purpose grade and is used for most rigid PVC applications such as pipes, profiles, other building materials and hard foils. It is also plasticised and used for most flexible applications such as cable insulation, soft foils and medical products.

Emulsion PVC is primarily used for coating applications such as PVC coated fabrics.

Bulk PVC is used for specific types of hard sheets and bottles.

Suspension PVC accounts for more than 80% of the PVC market. The market share for emulsion PVC is approximately 10% and for bulk PVC, 5%.

Emissions of vinyl chloride monomer and ethylene dichloride are controlled by law in several European countries. These particular emissions are dealt with in the publications *On the environmental impact of the manufacture of polyvinyl* *chloride (PVC)* and *ECVM Industry Charter for the Production of VCM and PVC*.[1]

SUSPENSION POLYMERISATION

The report is concerned with suspension polymerisation and typical average process inputs are shown in Table 1.

Table 1
Average process requirements for the production of 1 kg of suspension PVC.

Input	Quantity	
Vinyl chloride monomer	1.008	kg
Other chemicals	0.001	kg
Nitrogen	0.001	kg
Compressed air	0.127	cu m
Process water	3.289	kg
Cooling water	13.992	kg
Electricity	0.853	MJ
Thermal fuels	0.732	MJ
Steam	0.969	kg

ECOPROFILE OF SUSPENSION PVC

Table 2 shows the gross or cumulative energy to produce 1 kg of suspension PVC and Table 3 gives this same data expressed in terms of primary fuels. Table 4 shows the energy data expressed as masses of fuels. Table 5 shows the raw materials requirements and Table 6 shows the demand for water. Table 7 shows the gross air emissions and Table 8 shows the corresponding carbon dioxide equivalents of these air emissions. Table 9 shows the emissions to water. Table 10 shows the solid waste generated and Table 11 gives the solid waste in EU format.

Table 2
Gross energy required to produce 1 kg of suspension PVC. (Totals may not agree because of rounding)

Fuel type	Fuel prod'n & delivery energy (MJ)	Energy content of delivered fuel (MJ)	Energy use in transport (MJ)	Feedstock energy (MJ)	Total energy (MJ)
Electricity	10.34	4.73	0.58	-	15.65
Oil fuels	0.32	5.93	0.12	14.09	20.46
Other fuels	0.65	13.83	0.06	9.69	24.23
Totals	11.31	24.50	0.75	23.78	60.34

[1] Both of these publications are available from ECVM, Ave E Van Nieuwenhuyse 4, Box 4, B-1160 Brussels, Belgium.

Table 3
Gross primary fuels required to produce 1 kg of suspension PVC. (Totals may not agree because of rounding)

Fuel type	Fuel prod'n & delivery energy (MJ)	Energy content of delivered fuel (MJ)	Fuel use in transport (MJ)	Feedstock energy (MJ)	Total energy (MJ)
Coal	2.68	3.24	0.17	0.24	6.33
Oil	1.02	6.30	0.29	14.09	21.70
Gas	2.81	12.88	0.16	9.44	25.28
Hydro	0.47	0.34	<0.01	-	0.81
Nuclear	4.04	1.88	0.12	-	6.04
Lignite	0.01	<0.01	<0.01	-	0.01
Wood	<0.01	<0.01	<0.01	0.02	0.02
Sulphur	<0.01	<0.01	<0.01	<0.01	<0.01
Biomass (solid)	0.04	0.02	<0.01	<0.01	0.06
Hydrogen	<0.01	0.53	<0.01	-	0.53
Recovered energy	<0.01	-0.82	<0.01	-	-0.82
Unspecified	<0.01	<0.01	<0.01	-	<0.01
Peat	<0.01	<0.01	<0.01	-	<0.01
Geothermal	0.03	0.02	<0.01	-	0.05
Solar	<0.01	<0.01	<0.01	-	<0.01
Wave/tidal	<0.01	<0.01	<0.01	-	<0.01
Biomass (liquid/gas)	0.04	0.01	0.01	-	0.07
Industrial waste	0.05	0.03	<0.01	-	0.07
Municipal Waste	0.10	0.05	<0.01	-	0.14
Wind	0.02	0.01	<0.01	-	0.03
Totals	11.31	24.50	0.75	23.78	60.34

Table 4
Gross primary fuels used to produce 1 kg of suspension PVC expressed as mass.

Fuel type	Input in mg
Crude oil	480000
Gas/condensate	490000
Coal	220000
Metallurgical coal	82
Lignite	590
Peat	270
Wood	2200

Table 5
Gross raw materials required to produce 1 kg of suspension PVC.

Raw material	Input in mg
Air	430000
Animal matter	<1
Barytes	210
Bauxite	4
Bentonite	25
Biomass (including water)	15000
Calcium sulphate (CaSO4)	3
Chalk (CaCO3)	<1
Clay	2
Cr	<1
Cu	96
Dolomite	2
Fe	200
Feldspar	<1
Ferromanganese	<1
Fluorspar	2
Granite	<1
Gravel	1
Hg	3
Limestone (CaCO3)	25000
Mg	<1
N2	76000
Ni	<1
O2	78000
Olivine	2
Pb	1
Phosphate as P2O5	2
Potassium chloride (KCl)	1000
Quartz (SiO2)	<1
Rutile	<1
S (bonded)	<1
S (elemental)	-420
Sand (SiO2)	560
Shale	7
Sodium chloride (NaCl)	1000000
Sodium nitrate (NaNO3)	<1
Talc	<1
Unspecified	<1
Zn	<1

Table 6
Gross water consumption required for the production of 1 kg of suspension PVC. (Totals may not agree because of rounding)

Source	Use for processing (mg)	Use for cooling (mg)	Totals (mg)
Public supply	2300000	-	2300000
River canal	830000	35000000	36000000
Sea	190000	5600000	5800000
Well	630000	220000	840000
Unspecified	5300000	15000000	20000000
Totals	9200000	56000000	65000000

Table 7
Gross air emissions associated with the production of 1 kg of suspension PVC.
(Totals may not agree because of rounding)

Emission	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	From biomass (mg)	From fugitive (mg)	Totals (mg)
dust (PM10)	560	190	5	460	-	-	1200
CO	1500	820	47	220	-	-	2600
CO2	720000	1300000	12000	97000	-2000	-	2100000
SOX as SO2	4100	3100	150	320	-	-	7600
H2S	<1	-	<1	<1	-	-	<1
mercaptan	<1	<1	<1	<1	-	-	<1
NOX as NO2	2100	2400	88	210	-	-	4800
NH3	<1	-	<1	12	-	-	12
Cl2	<1	<1	<1	120	-	-	120
HCl	74	21	<1	57	-	-	150
F2	<1	<1	<1	<1	-	-	<1
HF	3	1	<1	<1	-	-	4
hydrocarbons not specified	900	200	26	640	-	<1	1800
aldehyde (-CHO)	<1	-	<1	<1	-	-	<1
organics	<1	<1	<1	68	-	-	68
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Hg+compounds as Hg	<1	-	<1	<1	-	-	<1
metals not specified elsewhere	1	1	<1	<1	-	-	3
H2SO4	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	<1	-	-	<1
H2	65	12	<1	4300	-	-	4400
dichloroethane (DCE) C2H4Cl2	<1	-	<1	44	-	4	48
vinyl chloride monomer (VCM)	<1	-	<1	70	-	8	78
CFC/HCFC/HFC not specified	<1	-	<1	15	-	-	15
organo-chlorine not specified	<1	-	<1	10	-	-	10
HCN	<1	-	<1	<1	-	-	<1
CH4	21000	410	<1	1700	-	<1	23000
aromatic HC not specified	<1	-	<1	19	-	<1	19
polycyclic hydrocarbons (PAH)	<1	<1	<1	<1	-	-	<1
NMVOC	<1	-	<1	39	-	-	39
CS2	<1	-	<1	<1	-	-	<1
methylene chloride CH2Cl2	<1	-	<1	<1	-	-	<1
Cu+compounds as Cu	<1	<1	<1	<1	-	-	<1
As+compounds as As	-	-	-	<1	-	-	<1
Cd+compounds as Cd	<1	-	<1	<1	-	-	<1
Ag+compounds as Ag	-	-	-	<1	-	-	<1
Zn+compounds as Zn	<1	-	<1	<1	-	-	<1
Cr+compounds as Cr	<1	<1	<1	<1	-	-	<1
Se+compounds as Se	-	-	-	<1	-	-	<1
Ni+compounds as Ni	<1	<1	<1	<1	-	-	<1
Sb+compounds as Sb	-	-	<1	<1	-	-	<1
ethylene C2H4	-	-	<1	14	-	-	14
oxygen	-	-	-	1	-	-	1
asbestos	-	-	-	<1	-	-	<1
dioxin/furan as Teq	-	-	-	<1	-	-	<1
benzene C6H6	-	-	-	<1	-	<1	<1
toluene C7H8	-	-	-	<1	-	<1	<1
xylenes C8H10	-	-	-	<1	-	<1	<1
ethylbenzene C8H10	-	-	-	<1	-	<1	<1
styrene	-	-	-	<1	-	<1	<1
propylene	-	-	-	1	-	-	1

Table 8
Carbon dioxide equivalents corresponding to the gross air emissions for the production of 1 kg of suspension PVC. (Totals may not agree because of rounding)

Type	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	From biomass (mg)	From fugitive (mg)	Totals (mg)
20 year equiv	2000000	1300000	12000	200000	-2000	<1	3600000
100 year equiv	1200000	1300000	12000	140000	-2000	<1	2700000
500 year equiv	880000	1300000	12000	110000	-2000	<1	2300000

Table 9
Gross emissions to water arising from the production of 1 kg of suspension PVC. (Totals may not agree because of rounding).

Emission	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	Totals (mg)
COD	3	-	<1	13000	13000
BOD	<1	-	<1	130	130
Pb+compounds as Pb	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	<1	<1
Na+compounds as Na	<1	-	<1	27000	27000
acid as H+	4	-	<1	10	14
NO3-	<1	-	<1	6	6
Hg+compounds as Hg	<1	-	<1	<1	<1
metals not specified elsewhere	1	-	<1	39	40
ammonium compounds as NH4+	3	-	<1	14	17
Cl-	<1	-	<1	46000	46000
CN-	<1	-	<1	<1	<1
F-	<1	-	<1	<1	<1
S+sulphides as S	<1	-	<1	<1	<1
dissolved organics (non-	<1	-	<1	19	19
suspended solids	58	-	5	6400	6400
detergent/oil	<1	-	<1	8	8
hydrocarbons not specified	3	<1	<1	<1	3
organo-chlorine not specified	<1	-	<1	1	1
dissolved chlorine	<1	-	<1	3	3
phenols	<1	-	<1	1	1
dissolved solids not specified	<1	-	<1	20000	20000
P+compounds as P	<1	-	<1	32	32
other nitrogen as N	1	-	<1	13	14
other organics not specified	<1	-	<1	160	160
SO4--	<1	-	<1	3300	3300
dichloroethane (DCE)	<1	-	<1	2	2
vinyl chloride monomer (VCM)	<1	-	<1	10	10
K+compounds as K	<1	-	<1	33	33
Ca+compounds as Ca	<1	-	<1	350	350
Mg+compounds as Mg	<1	-	<1	1	1
Cr+compounds as Cr	<1	-	<1	<1	<1
ClO3--	<1	-	<1	240	240
BrO3--	<1	-	<1	<1	<1
TOC	<1	-	<1	11	11
AOX	<1	-	<1	1	1
Al+compounds as Al	<1	-	<1	<1	<1
Zn+compounds as Zn	<1	-	<1	<1	<1
Cu+compounds as Cu	<1	-	<1	2	2
Ni+compounds as Ni	<1	-	<1	1	1
CO3--	-	-	<1	770	770
As+compounds as As	-	-	<1	<1	<1
Cd+compounds as Cd	-	-	<1	<1	<1
Mn+compounds as Mn	-	-	<1	<1	<1
organo-tin as Sn	-	-	<1	<1	<1
Sr+compounds as Sr	-	-	<1	<1	<1
organo-silicon	-	-	-	<1	<1
benzene	-	-	-	<1	<1
dioxin/furan as Teq	-	-	<1	<1	<1

Table 10
Gross solid waste associated with the production of 1 kg of suspension PVC. (Totals may not agree because of rounding)

Emission	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	Totals (mg)
Plastic containers	<1	-	<1	<1	<1
Paper	<1	-	<1	<1	<1
Plastics	<1	-	<1	630	630
Metals	<1	-	<1	<1	<1
Putrescibles	<1	-	<1	<1	<1
Unspecified refuse	1100	-	<1	<1	1100
Mineral waste	190	-	54	7700	8000
Slags & ash	16000	2100	21	4300	22000
Mixed industrial	-2600	-	2	1600	-1000
Regulated chemicals	1400	-	<1	1900	3300
Unregulated chemicals	1000	-	<1	3200	4200
Construction waste	<1	-	<1	90	90
Waste to incinerator	<1	-	<1	4100	4100
Inert chemical	72	-	<1	4800	4900
Wood waste	<1	-	<1	43	43
Wooden pallets	<1	-	<1	<1	<1
Waste to recycling	<1	-	<1	650	650
Waste returned to mine	43000	-	2	7800	51000
Tailings	1	-	2	3800	3800
Municipal solid waste	-13000	-	-	<1	-13000
Note: Negative values correspond to consumption of waste e.g. recycling or use in electricity generation.					

Table 11
Gross solid waste in EU format associated with the production of 1 kg of suspension PVC. Entries marked with an asterisk (*) are considered hazardous as defined by EU Directive 91/689/EEC

Emission	Totals (mg)
010101 metallic min'l excav'n waste	640
010102 non-metal min'l excav'n waste	45000
010306 non 010304/010305 tailings	4
010308 non-010307 powdery wastes	3
010399 unspecified met. min'l wastes	170
010408 non-010407 gravel/crushed rock	55
010410 non-010407 powdery wastes	<1
010411 non-010407 potash/rock salt	5200
010499 unsp'd non-met. waste	2
010505*oil-bearing drilling mud/waste	1300
010508 non-010504/010505 chloride mud	1000
010599 unspecified drilling mud/waste	1100
020107 wastes from forestry	43
050106*oil ind. oily maint'e sludges	2
050107*oil industry acid tars	97
050199 unspecified oil industry waste	120
050699 coal pyrolysis unsp'd waste	82
060101*H2SO4/H2SO3 MFSU waste	6
060102*HCl MFSU waste	14
060106*other acidic MFSU waste	<1
060199 unsp'd acid MFSU waste	<1
060204*NaOH/KOH MFSU waste	<1
060299 unsp'd base MFSU waste	<1
060313*h. metal salt/sol'n MFSU waste	3200
060314 other salt/sol'n MFSU waste	140
060399 unsp'd salt/sol'n MFSU waste	480
060404*Hg MSFU waste	56
060405*other h. metal MFSU waste	780
060499 unsp'd metallic MFSU waste	400
060602*dangerous sulphide MFSU waste	<1
060603 non-060602 sulphide MFSU waste	-1
060701*halogen electrol. asbestos waste	170
060702*Cl pr. activated C waste	<1
060703*BaSO4 sludge with Hg	12
060704*halogen pr. acids and sol'ns	190
060799 unsp'd halogen pr. waste	640
061002*N ind. dangerous sub. waste	<1
061099 unsp'd N industry waste	<1
070101*organic chem. aqueous washes	<1
070103*org. halogenated solv'ts/washes	<1
070107*hal'd still bottoms/residues	1700
070108*other still bottoms/residues	5
070111*org. chem. dan. eff. sludge	11
070112 non-070111 effluent sludge	<1
070199 unsp'd organic chem. waste	400
070204*polymer ind. other washes	<1
070207*polymer ind. hal'd still waste	3000
070208*polymer ind. other still waste	430
070209*polymer ind. hal'd fil. cakes	<1

continued over …..

Table 11 - continued

Gross solid waste in EU format associated with the production of 1 kg of suspension PVC. Entries marked with an asterisk (*) are considered hazardous as defined by EU Directive 91/689/EEC

070213 polymer ind. waste plastic	510
070214*polymer ind. dan. additives	170
070216 polymer ind. silicone wastes	<1
070299 unsp'd polymer ind. waste	1400
080199 unspecified paint/varnish waste	<1
100101 non-100104 ash, slag & dust	18000
100102 coal fly ash	280
100104*oil fly ash and boiler dust	1
100105 FGD Ca-based reac. solid waste	72
100113*emulsified hyrdocarbon fly ash	<1
100114*dangerous co-incin'n ash/slag	820
100115 non-100115 co-incin'n ash/slag	250
100116*dangerous co-incin'n fly ash	28
100199 unsp'd themal process waste	220
100202 unprocessed iron/steel slag	59
100210 iron/steel mill scales	4
100399 unspecified aluminium waste	<1
100501 primary/secondary zinc slags	<1
100504 zinc pr. other dust	<1
100511 non-100511 Zn pr. skimmings	<1
101304 lime calcin'n/hydration waste	4
110199 unspecified surf. t waste	<1
130208*other engine/gear/lub. oil	<1
150101 paper and cardboard packaging	<1
150102 plastic packaging	<1
150103 wooden packaging	<1
150106 mixed packaging	<1
170107 non-170106 con'e/brick/tile mix	<1
170904 non-170901/2/3 con./dem'n waste	<1
190199 unspecified incin'n/pyro waste	<1
190905 sat./spent ion exchange resins	4800
200101 paper and cardboard	<1
200108 biodeg. kitchen/canteen waste	<1
200138 non-200137 wood	<1
200139 plastics	410
200140 metals	<1
200199 other separately coll. frac'ns	-3700
200301 mixed municipal waste	1
200399 unspecified municipal wastes	-12000
Note: Negative values correspond to consumption of waste e.g. recycling or use in electricity generation.	