A Brief Discussion

Environmental Sensitivity of Clay Pipe versus PVC Pipe

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Executive Summary

Buzzwords and phrases such as Environmental awareness, sensitivity, sustainability and friendliness have been thrown around by political and corporate leaders for the past decade. The public has now begun to ask if there is more talk going on than action. One area that does not seem to have been considered for action is in the selection of environmentally sensitive materials.

The purpose of this paper is to take a brief initial look at the environmental sensitivity of Polyvinyl Chloride (PVC) pipe and Clay pipe. It is not intended to be a definitive statement on which pipe material is best. Several other factors go into the decision about the pipe material to be chosen for each specific use. This paper only looks at the environmental impacts, but considers the global impacts not just the local ones. The main thrust of the study is on the manufacturing processes. Many of the harmful by products of the manufacture of PVC have their primary impact overseas.

The primary method of comparison is an analysis of two 30 metre lengths of 300 mm diameter sewer pipe. PVC pipe is about one sixth as light as Clay pipe at 300 mm, so comparing tonnages does not give an accurate picture of the impacts.

In every way that they have been compared, PVC pipe is causing more damage to the environment. A simple way to think of environmental effects is air, water, land and toxics. Table El below gives a summary,

Table E. 1- Summary of Comparison of the Environmental Impacts from the Production of Clay and PVC pipe

	PVC produces	Waste generation from one years Australian PVC pipe production
Greenhouse Gases. Air Pollutants	2 x Clay 12 x Clay	 2100 tonnes
Waste Water.	1400 L versus nil by Clay	320 million Litres
Solid Waste to Municipal disposal	21,5 kg versus nil by Clay	4900 tonnes
Chlorinated Organics Mercury	74,5 g versus nil by Clay 0.3 g versus nil by Clay	17 tonnes 27 kgs

Air - PVC produces about twice the greenhouse gases that Clay does. PVC produces about 12 times the total air pollutants (particulates, Hydrocarbons, NO SO N CO, 503, Total Fluorine compounds) that clay produces. Many of these are important Acid Rain gases. One years PVC use in Australia, 92,800 tonnes (Greenpeace 1995), produces about 2100 tonnes of these air pollutants. Most are generated overseas in petroleum refining and Vinyl Chloride Monomer (VCM) manufacture.

Water - PVC produces about 1400 Litres of wastewater for each 30 metre section of 300 mm pipe, or about 320,000,000 Litres for all the PVC pipe used in Australia, No wastewater is produced in the manufacturing of Clay Pipe. About 12 times as much water is needed in the manufacture of PVC as in Clay pipe making for 30 m of 300mm pipe.

Land -21.5 kg of PVC go to landfill for each 30 m length of 300mm pipe. This amounts to about 4900 tonnes per year of solid waste going to Municipal Solid Waste disposal due to the production of PVC pipe for the Australian market. It is likely that most of this is disposed o Australia because the majority of the waste comes from the PVC manufacturing process not the preliminary stages. No materials, clay, PVC or otherwise need disposal from clay pipe manufacturing. Due to the extra bedding requirements of PVC, about 50% more clay and sand mining is needed for equal lengths of 300mm PVC than for 300mm Clay.

Toxics - Toxic materials such as chlorinated organics, mercury, heavy metals and phenol are produced in the manufacture of PVC pipe. None of these materials are generated in the production of Clay pipe. PVC manufacturing generates about 75 grams of chlorinated organics pollution for each 30 metre section of 300 mm pipe, or about 17 tonnes for all the PVC pipe used in Australia. Mercury is 0.3 grams and 27 kg.

It is hoped that this initial study will promote further discussion on other materials and on the general principle that there is a balance we, as a society, must seek between the materials we use and the environmental impacts that those materials cause.

1.0 Introduction

Concern for the environment is receiving more public attention each year. One of Sydney's strongest selling points in winning the Olympics was that it was to be the environmental games, Sustainable development has become a goal of many governments and governmental authorities in the past few years. The World Commission on Environment and Development defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Many politicians, from local to federal level, have tried to tie themselves to "green" causes without providing the substance to stand behind it. As time has passed, the public has begun to ask whether these new governmental policies are genuine concerns or just pretty words. Greenpeace recently released a paper describing the effects of chlorine based products in the environment and challenged Australian government bodies to ban these products as has been done in many countries in Europe.

One of the products recommended by Greenpeace for banning is Polyvinyl Chloride (PVC). PVC pipe makes up a large part of the drainage and sewer pipe market, but may not be as environmentally sensitive as other pipe products such as clay pipe. If politicians and regulators are truly concerned about providing the best possible sustainable environment for their constituents, then it seems that the most environmentally sensitive products that still meet the other goals of the government agencies should be recommended

The goal of this paper is to start to provide some facts about the environmental sensitivity of PVC and Clay pipe, without getting into any emotional name calling. The assumptions, discharge levels and other data have been found in texts at the University and Public Libraries in Sydney and from manufacturer's data sheets. Hopefully the methods used for the calculations are explained well enough that they can be reproduced by the reader.

This analysis of the environmental impacts of PVC versus Clay pipe includes only an introductory look at the by products of the manufacture of PVC pipe and clay pipe. There may be other factors that can be analysed that will give a more complete picture of the environmental sensitivity. Many of these impacts occur predominantly in the industrialised nations of Asia, America and Europe the mining of raw materials (petroleum and salt), production of basic ingredients (chlorine and hydrocarbons) for PVC and production of Vinyl chloride monomer (VCM) is done overseas. Only the production of PVC from VCM and the extrusion of the pipe itself is done in Australia. It is felt, though, that analysis of the overall impact is the best way to compare these two materials.

2.0 Governmental Authorities and Corporations - Environmental Statements

This section outlines a few of the environmental statements and goals that have been made by governmental authorities and corporations in an effort to show their environmental sensitivity.

2.1 Councils

Blacktown, Sutherland and Baulkham Hills Councils are three of the largest in population, representing approximately 16 % of Sydney's Metropolitan population and are the most likely areas to grow in the next twenty years.

The Introduction to Blacktown Council's State of the Environment Report for 1 July 1993 to 31 December 1993 notes:

> *Blacktown council's aim is to provide a safe, clean and healthy environment. This is achieved by promoting the protection and enhancement of the environment and maintaining compatibility with the built environment.*

Page 13 of Baulkham Hills Council's 1995 Strategic Plan covers Environmental Protection, The Council's Strategic Goal is:

> *To protect and enhance the Shire 'natural environment.*

Sutherland Shire Council's report (December 1993), Sutherland Shire Your Future, outlines goals for environmental protection (pages 19, 20, 21):

> *The Shire is waterways and beaches will be safe for recreational use and will support viable aquatic ecosystem.*
>
> *The Shire will be a place where activities do not add significantly to air pollution*
>
> *The Shire will be a place where activities do not lead to land contamination and soil erosion.*

It is implied in these statements that the local environment is the major concern of the Council. When comparing clay and PVC pipe the majority of the environmental impact is in the location of production. For that reason Councils in the Sydney area may have only an intellectual concern for environmental impacts in other parts of the world.

2.2 McDonalds

McDonalds is one of many large corporations that sees the public relations value of being seen as an environmentally sensitive citizen. They have produced a small brochure entitled “McDonald and the Environment.” The summary to the brochure is as follows:

> *We at McDonald’s care about the people and communities we serve and the environment in which we live and we will continue to pursue the most environmentally sound operating practices and procedures possible to protect the global environment on which we all depend*

This is by far the most sweeping statement and indicates the importance that McDonald’s places on the environment. They have shown by previous actions that they are willing to spend money to be seen as environmentally friendly so it makes sense that this concern could continue into their selection of building materials for their sites.

2.3 International Standards Organisation - Draft Standard 14000 - Environmental Management Systems

There has been a move in recent years in Australia to change the way that environmental law is administered. The method, by which the EPA or Council acts as “policeman” in an effort to catch polluters may be receding and a new program where environmental plans are submitted to the environmental regulators, may be becoming more prevalent. These new environmental plans will follow the guide of ISO 14000 as adapted by Standards Australia. The use of environmental management systems take in a huge scope so a complete summary is not warranted here, but two of the “Key Principles” in the executive summary are pertinent to the careful selection of products for a business enterprise using ISO 14000

- Develop management and employee commitment to the protection of the environment, with clear assignment of accountability and responsibility.

- Encourage environmental strategic planning throughout the product or process life cycle.

The first indicates that there should be a commitment to the protection of the environment, not just compliance with the local laws and statutes. The second encourages a big picture look at the environment with a long term time frame implied. It can be derived from these two key principles that activities such as product selection should take into account the products t impact on the environment over the long term.

2.4 Sydney Olympic Bid

In it’s effort to win the right to host the year 2000 Olympics the Sydney Olympic Organising Committee prepared an Environmental Policy which includes a wide range of goals for the Olympic facilities. One of these goals is that PVC products would not be used in the construction of the facilities.

3.0 By products discharged to the Environment in production and use of PVC and Clay Pipe

In order to accurately compare the two types of pipe, the weights of a similar length of pipe had to be compared. The comparison is made by assuming that 30 metres of 300mm diameter sewer pipe made of each material is to be used. In the production of the 30 metres of Clay pipe (about 2300 kg) the by products in the Clay column are produced. In the production of the 30 metres of PVC pipe (about 405 kg) the by products in the PVC column are produced.

Tables 3. 1, 3.2 and 3.3 give a comparison of most of the significant by products of production and use of Clay pipe with most of the significant by products of PVC pipe. Assumptions and methods of calculation are shown in Appendix A.

3.1 Manufacturing Steps

The production of PVC pipe is basically a seven step process.

1) Salt is either mined or produced by evaporation and transported to the plant

2) Petroleum is pumped from the ground and transported to the plant

3) Chlorine is produced from salt (NaC1).

4) Acetylene or ethylene is produced from the refinement of petroleum.

5) Vinyl Chloride Monomer is produced from Chlorine and either acetylene or ethylene

6) Poly Vinyl Chloride is made from vinyl chloride monomer

7) PVC pipe is made from raw PVC.

The production of Clay pipe is basically a three step process.

1) Clay is extracted from the ground and transported to the plant.

2) The clay is crushed and formed into pipe.

3) The pipe is fired in a kiln

3.2 Energy, Water and Land

Table 3.1 shows some of the general environmental impacts that do not necessarily indicate pollution, but give a feeling for the impact on resources needed for the production of Clay and PVC pipe. Even in the area of clay and sand extraction, PVC pipe requires more due to the additional requirement for bedding.

Table 3.1 - Energy, Water and Land Clay Pipe - PVC Sewer Pipe comparison for 30 metre lengths of 300 mm diameter			
Item	Clay	PVC	% PVC/Clay
Energy Requirement expressed as Energy Equivalent (GJ)	6.9	23.1	335
Water used in production (Litres)	230	2920	1270
Wastewater generated in manufacturing (Litres)	0	1420	+
Bedding used in installation (tonnes)	5.0	11.5	230
Clay and Sand” Extraction required (tonnes)	7.3	11.5	158
PVC Waste to municipal disposal in manufacturing (kg)	0	21.5	+
Clay Waste to municipal disposal in manufacturing (kg)	0	0	0

+ indicates a positive impact for Clay but no percentage can be listed because that would require dividing by zero.

3.3 Air Pollutants

Table 3.2 shows the air pollutants associated with production of PVC and Clay pipe- Most of the air pollutants listed for PVC are from the petroleum refining and energy production required for raw materials, VCM and PVC manufacture.

Table 3.2 - Air Pollutants Clay Pipe - PVC Sewer Pipe comparison for 30 metre lengths of 300 mm diameter			
Item	Clay	PVC	PVC % greater
Total Fluorine Compounds in air (grams)	28	0	•
Particulates in air (grams)	78	256	328
Carbon Monoxide in air (grams)	354	431	122
Oxides of Nitrogen in air (grams)	51	1229	2410
Sulphur Dioxide in air (grams)	129	2415	1872
Sulphur Trioxide and sulphuric acid in air (grams)	55	0	•
Chlorinated organics to air (grams)	0	68.4	+
Hydrocarbons to air (grams)	0	4260	+
Total	695	8659	1246
Greenhouse Gases as equivalent CO (kg)	597	1220	204

+ indicates a positive impact for Clay but no percentage can be listed because that would require dividing by zero.

• indicates a negative impact for Clay but no percentage can be listed because that would require dividing by zero.

3.4 Toxics

The PVC industry as with many chemical industries produces toxic by products. These are usually controlled to the levels specified by the governments under which they operate so that there are acceptable impacts on the environment. Occasionally there are spills and accidents which are usually treated as the type of infrequent occurrence that must be expected in a modern production facility The list below does not describe all of the toxics but it probably covers the major ones.

Table 3.3 - Toxics Clay Pipe - PVC Sewer Pipe comparison for 30 metre lengths of 300 mm diameter			
Item	Clay	PVC	PVC % greater
Mercury to environment (grams)	0	0.58	+
Mercury to Landfill (grams)	0	3.8	+
Absorbable halogenated compounds (AOX) in wastewater (grams)	0	6.1	+
Phenolics in wastewater (grams)	0	2	+
Chlorinated organics to air (grams)	0	68.4	+
1,2 Dichloromethane to Environment (grams)	0	0.462	+
Viny! Chloride Monomer, to Environment (grams)	0	9.96	+

+ indicates a positive impact for Clay but no percentage can be listed because that would require dividing by zero.

3.5 Variation with size of pipe

It should be noted that as the pipe size gets larger the comparative impact of PVC versus clay gets more significant. This is because the weight ratio of the pipes gets closer as the pipe diameters get larger. Table 3.4 summarises the impacts of Energy and Air Pollutants,

Table 3.4
Clay Pipe PVC Sewer Pipe comparison for 30 metre lengths of 150, 300, 375 mm diameter

Item	size	Clay	PVC	PVC % greater
Energy Used in production (GJ)	150	2.7	5.7	111
	300	6.9	23.1	235
	375	9.6	37.6	292
Total Air Pollutants from production (kg)	150	0.27	2.18	707
	300	0.69	8.83	1180
	375	0.96	14	1400

3.6 Limits of Data and Assumptions

If this document or some derivative of it is to be made public and the PVC industry is put under threat, it is certain that they will criticise it and the ideas in it. It is important, therefore, to identify areas where criticism might come, to be ready to argue in a sensible fashion.

The majority of the data reported here about the waste products of PVC manufacture are from one text; *POLYVINYL CHLORIDE - Environmental Aspects of a Common Plastic,* by Walter Totsch and Hans Gaensslen of the Fraunhofer Institute for Systems Technology and Innovation Research, published by Elsevier Applied Science (T&G). Some of the data is backed up in Meyers (1986), but not to the level described in T&G. Critics of this paper could say that I) T&G were biased and reported the very worst case figures. They could also say that 2) production techniques have improved since 1987, when most of the T&G data originates.

My feeling is that neither of these arguments are substantial. T&G is not written in a sniping, critical way, like the Greenpeace paper on Chlorine. It is written in a factual tone without condemning the industry and quotes reports from government agencies like the US EPA, and the Swiss Department of Lands and Environment (it has a German name so I'm not exactly sure of the title) and various German scientific journals. The second criticism is also less than compelling. PVC has been made for about 50 years and the production facilities are huge. Acetylene and chlorine have been made for even longer. If initial improvements could have been made to the chemical processes, I think they would have been made before 1987. Secondly, even if new ideas had been developed it would take a long time to implement them because of the capital requirements of changing such a large scale industry.

4.0 Greenho use gas impacts of production of PVC and Clay Pipe

The greenhouse effect has created considerable concern and controversy over the past decade. There is no argument that the level of Carbon Dioxide (C0 in the earth's atmosphere has increased since the late 1800's from 280 parts per million (ppm) to 350 ppm or that CO_2 holds heat in the atmosphere. Opponents of any governmental efforts against the greenhouse effect say that other factors such as increased cloud or absorption by the oceans will offset the rise in CO_2 levels. Recently, a United Nations report endorsed by hundreds of scientists was published saying that the best information we have to date indicates that the earth will undergo substantial warming in the next 50 years (Time magazine, 25 September 1995). This is the first report by such an eminent organisation stating that the greenhouse effect was indeed a genuine global concern.

The large amounts of energy used in the production of PVC mean that the greenhouse gases generated in it's production, are quite substantial. About 9 times as much greenhouse gas impact is generated with the production of 30 metres of 300mm PVC pipe as with 30 metres of 300mm diameter clay pipe. Table 4.1 shows a comparison of the levels of greenhouse gases and their total impact. The method of calculation is shown in the Appendices.

Table 4.1 -	Comparison of Greenhouse gases generated in the production of 30 metres of 300 mm diameter PVC and Clay sewer pipe			
	Kg gas to air/ 30m length	Multiplier	Kg CO_2 equivalent	Total kg CO_2 equivalent
PVC - CO_2	1145	1	1145	
PVC - N_2O	0.257	290	75	
PVC - Total				1220
Clay - CO_2	593	1	593	
Clay - N_2O	0.014	290	4	
Clay - Total				597
PVC equivalent kg of CO,/ Clay equivalent kg of CO_2				204%

Other waste gases are generated during the production of PVC pipe and Clay pipe. These should also be considered. Vinyl Chloride monomer breaks down in about 2.5 days in the atmosphere, so it is not a significant greenhouse gas Oxides of nitrogen are secondary greenhouse gases because they are ozone precursors (BTCE Report 88, page 138) and ozone is .a greenhouse gas. Carbon monoxide (CO) is a secondary greenhouse gas because it is a precursor to ozone, eventually oxidises to CO and uses up OH radicals which remove methane, a major greenhouse gas.

5.0 Additional comments

5.1 Other pollutants from PVC Manufacturing

T&G indicate, without putting specific statistics to the impacts, that there are a variety of other pollutants that likely result from PVC manufacture. In the integrated oxychlorination stage of VCM manufacture large amounts of chlorinated hydrocarbon residues are created. A list of these residues is included in Table 5.1. In some cases they are treated with chlorine to produce carbon tetrachloride and perchlorethylene. These are solvents that are sold separately. In other cases they are incinerated and the HC is recovered and reused in the process. In any of these industrial processes there are wastes and incomplete chemical conversions. It can be assumed that a level of byproducts similar to the other processes is likely. The details of these losses are not explained in T&G. Table 3.6 in T&G notes 0.169 grams of chlorinated organics per kg of PVC lost to the atmosphere and 0.015 g of absorbable halogenated compounds lost to the water, it can be assumed that the compounds described are those listed in Table 5.1.

Table 5.1 - Byproducts of integrated oxychlorination (from T&G Table 3.5)			
Low Boilers		High Boilers	
Chlorinated organic compound	kg/tonne of VCM	Chlorinated organic compound	Kg/tonne of VCM
Chloroform	6.8	1, 1,2-trichloroethane	3.2
EDC	2.5	EDC	0.7
Carbon Tetrachloride	1.4	Cis – 1,3 - dichlorobutene	0.7
Chlorobutadiene	1.2	Trans- 1,3- dichlorobutene	0.6
1, 1 - dichloroethane	0.9	1,1,2,2-tetrachloroethane	1.4
Other	2.2	Other	2.4

It should be stressed that the figures in Table 6. 1 are byproducts prior to treatment.

Other toxic agents such as heavy metals are sometimes added to PVC to give it different properties. If these are added to the waste stream in any significant amounts they would add to the pollutional characteristics of the production processes.

5.2 Gluing agents are used in joining PVC pipe. These solvent and gluing materials are probably toxic. The “plastic’ odour from them is certainly strong.

5.3 More frequent remo val - The expected life of a clay pipe is 100 years. The expected life of a PVC pipe is 50 years (by the PVC manufacturers estimate). Theoretically this means that for each time that a clay pipe is used two PVC pipes must be used. Two PVC pipes must be safely disposed of for each one clay pipe. Two excavations, two lots of bedding, rehabilitation of the surface either by replanting or repairing the concrete or road pavement must be done two times to one, etc.

An argument may be made that land uses change and therefore the drainage or sewer requirements would change more frequently than 100 years so the two to one ratio is not appropriate. In response, 1) The calculations could be done for 1.5:1, to show those impacts, as well; and 2) There are many examples of sensitive situations where the cost of having to excavate due to the end of the pipes life is far greater than the probability that excavation will be required due to changing land uses. Examples include pipes underneath building foundations, within areas containing sensitive flora and fauna such as council reserves national parks and near busy city streets or main roads where blocking off the road causes traffic delays and inconvenience to large numbers of people.

5.4 Environmental impacts of water flowing through PVC Pipe v. Clay Pipe

As PVC pipe breaks down vinyl chloride is released. Vinyl chloride is toxic and carcinogenic, but it is also a gas at room temperature (Boiling point -13°C). Some vinyl chloride goes into the water that passes through but it is eventually released to the air. The environmental impacts of VCM released into water from flow through pipes are considered very minor.

5.5 Environmental impacts of PVC v. Clay in the waste stream

Landfill - Vinyl chloride gas escapes as the PVC breaks down. It breaks down in the atmosphere in about 2.5 days so this is not considered a substantial concern.

Incineration - When PVC and other chlorinated hydrocarbons are burned dioxins are formed. Dioxins are the most toxic materials ever tested. Many countries incinerate their wastes and the generation of dioxins in the waste gases from incineration may be one of the reasons that PVCs have been banned and phased out in these countries. Five council areas in Sydney currently incinerate their wastes at the Waverley Woollahra Incinerator in South Sydney. The incinerator has reached about the end of it's useful life and there is debate currently going on about whether a new one should be built. Part of that debate centres on the release of dioxins. The plastics industry says that dioxins from PVC incineration is not an issue and say they have reports proving it. The green groups and other people opposed to incineration don't accept these reports.

The logic of the reports does not really make sense. If you burn chlorinated organics at high temperature you get dioxins. PVC is a chlorinated organic. If more PVC appears in the waste stream it seems that there would be more dioxins. On the plastics industry side, the levels are very low and highly variable so there probably is no firm statistical link between more PVC and more dioxin. Still this seems more hocus pocus than reassuring scientific research.

5.6 Banning of PVC in other countries

The Greenpeace Document, The Chlorine Crisis, lists several countries with PVC bans and phase outs (page 34). One strong reason is probably safety in building materials. When a building catches fire, the temperatures are often such that the PVC will not ignite rather it will smoulder. When it smoulders Hydrochloric acid and other toxic gases are formed which can be deadly. The Beverley Hills Supper Club fire killed 161 people in 1977, most as a direct result of the gases from the decomposition of PVC building materials (page 36, Greenpeace). The plastics industry has responded to claims that the PVC insulation was responsible for the fire by quoting the Fire Marshall's report which listed several causes only one of which might have been the gases from the PVC insulation. It says that the report quoted by Greenpeace was written by someone hired by a competing insulation material.

6.0 Toxicity of byproducts of production of PVC and Clay Pipe

Toxicity of Vinyl Chloride

In 1974 three people died of a rare Liver cancer after working in a PVC factory in Louisville, Kentucky. This incident promoted the start of studies to determine the toxicity of Vinyl chloride. Vinyl chloride emissions and workplace concentrations are now regulated by the United States government. Limits have been set for food, air and water.

Alcohol beverages:	2.1 mg/kg
vinegar:	9.4 mg/kg
edible oils:	0.05 - 14.8 mg/kg
butter:	0.05 mg/kg
water, highest avg:	10 µg/L
Workplace air:	1 ppm

LD much greater than 0.00 1g/kg, Vinyl chloride is a gas at room temperature (page 3537 Clayton and Clayton, 1981)

Phenol
LD_{50} mouse = 0.3 g/kg
Man = 1 gram may be lethal

Mercury
LD_{50} rat oral = 0.2 g/kg (HgC1)

EDC, Ethylene Dich loride, 1,2 Dich loroethane
LD_{50} rat = 0.7 g/kg single oral dose (page 3491 Clayton and Clayton, 1981)

Chlorofor m
LD_{50} rat = 2.0 g/kg single oral dose (page 3462 Clayton and Clayton, 1981)

Carbon Tetrach loride
LD_{50} rat = 2.8 g/kg single oral dose, LI) mice = 12.8 g/kg single oral dose (page 3462 Clayton and Clayton, 1981)

Chlorobutadiene
LD_{50} rat = 0.25 g/kg single oral dose, LD mice = 0.26 g/kg single oral dose (page 3577 Clayton and Clayton, 1981)

1,1-dischloroethane
LD_{50} rat = 0.725 g/kg single oral dose (page 3488 Clayton and Clayton, 1981)

1,1,2-trichioroethane
LD_{50} rat = 0.2 g/kg single oral dose (page 3510 Clayton and Clayton, 1981)

1,1,2,2-tetrachloroethane
LD_{50} dog = 0.7 g/kg single oral dose (page 3513 Clayton and Clayton, 1981)

Air Pollutants

Table 6.1 shows the safe workplace concentrations for the air pollutants generated in the manufacture of clay and PVC pipe.

Table 6.1 Toxicity levels for Air Pollutants resulting from clay and PVC pipe manufacture

Substance	TWA (mg/m^3)	STEL (mg/m^3)
CO	57	458
SO_2	5.2	13
NO_2	5.6	9.4
NO	31	NL
$CC1_4$ - Carbon tetrachloride	31	NL
VCM	13	NL
EDC - Ethylene Dichloride	40	N
Chloroform	49	NL

National Occupational Health and Safety Commission, October 1991.
NL - Not Listed.

TWA - Time weighted Average is the term used to express the exposure standards for airborne contaminants over an eight-hour working day, for a five-day working week. STEL - Short Term Exposure Limits is the term used to express the exposure standards for airborne contaminants averaged over a 15 minute period.

Clay

The clay used to make clay pipes has no toxicity to humans, animals, fish, plants or other organisms. Sediments from clay mining, transport and manufacture can have some damaging effects

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Appendix A

A.1 Pipe Characteri stics
Weight of Clay Pipe - Vitrified Clay Pipeline Systems - Technical Manual, Punchbowl Pipes Pty Ltd, page 12
Weight and lengths of PVC pipe - phone call Arthur Cayser at Vinidex Tubemakers

Table A. 1 Weight and Length of PVC and Clay Pipes.

Diameter(mm)	kg/6m length PVC Sewer	Kg/30m PVC Sewer	kg/1.5m length Clay	Kg/30m Clay	PVC/ Clay
100	9.8	49	NA	NA	-
150	20	100	45	900	0.11
225	50	250	80	1600.	0.16
300	81	405	115	2300	0.18
375	132	660	160	3200	0.21
450	NA	NA	230	4600	-

A.2 Energy

53 Gigajoules/tonne of PVC plus 4 GJ/tonne for pipe extrusion, page 99 of G&T
3 GJ/tonne of clay is from energy usage for bricks in T Sinclair (1987), Summary, page (vi),
9.9 GJ/thousand bricks in a tunnel kiln, I brick weighs 4kg so 99/4. 2.5 GJ/tonne. M Flack says pipes can't be packed as tight as bricks so might lose a little efficiency Limits to comparison:
Energy figures are for 1987, PVC industry may say they have gotten more efficient

A.3 Water

PVC I Chlorine production - Production of chlorine by amalgam process uses 1650 litres process water/tonne of Cl and 100,000 litres of cooling water (T&G, pagel3, Table 2.7). Assume 0.8% cooling water lost. 2450 L/tonne Cl x 0.5677tonne CI/tonne PVC = 1390 L/t PVC.
Production of chlorine by diaphragm process uses 4300 litres process water/tonne of Cl and 290,000 litres of cooling water.(T&G, pagel3, Table 2.7). Assume 08% cooling water lost.
4300 L + 2320 L = 6620 L/tonne Cl x 0.5677tonne CI/tonne PVC = 3760 L/t PVC. T&G, page 8, Table 2.3 shows about 69.2% of chlorine production by amalgam and similar water usage processes and 30.8% by diaphragm. (0.692 x 1390) + (0.308 x 3760) = 2120 L/tonne of PVC in the chlorine production process.

Table A.2 - Water usage in chlorine production process						
	process per t C1		process per t PVC	make up per t Cl		make up per t PVC
diaphragm	1650	0.5677	937	800	0.5677	454
amalgam	4300	0.5677	2441	2320	0.5677	1317
diaphragm %production		69.2	648			314
amalgam % production		30.8	752			406
Total Litres /t of PVC			1400			720

PVC/hydrocarbons and chlori ne to VCM - Most VCM production is earned out in ethylene and chlorine to VCM plants (T&G, page 22). 144 L of output feed water and 293,500 L of cooling water, steam and boiler feed is needed (T&G page 23, Table 2 14) Assume 0.008 x 293,500 = 3350 L/tonne of VCM which is essentially equal to a tonne of PVC. A less used method is acetylene and HCI. Only 100,000 L of cooling water is needed. Assume 800 L is used up Assume the ratio of uses is 80% for ethylene and 20% for acetylene

Table A.3 - Water usage in VCM production process						
	process per t Cl		process per t PVC	make up per t C1		make up per t PVC
ethylene	144	1	144	2350	1	2350
acetylene	0	1	0	800	1	800
diaphragm %production		80	115			1880•
amalgam % production		20	0			160
Total Litres / t of PVC			115			2040

PVC I VCM to PVC - Meyers (page 2.8-9) lists 3000 litres/tonne of PVC wastewater in the VCM to PVC manufacturing process: Meyers (page2 1, Table 2.8-4) lists consumption of 2000 litres of deionised water, 120 m of cooling water and 900kg of steam. Assuming that 0.8% of the cooling water and steam were lost during the production (Most industrial processes reuse cooling water), that would equal about 2000 L + 960 L = 2960 L of waste water, so it about balances.

Table A.4 - Summary of water usage in PVC pipe manufacturing processes			
Process	Wastewater	Makeup water	Total
Chlorine	1400	720	2120
Acetylene/Ethylene	0	0	0
VCM	115	2040	2155
PVC	2000	1000	3000
Pipe extrusion	0	0	0
Total	3515	3760	7275

There may be some wastewater from the ethylene, acetylene and PVC pipe extrusion processes but none was listed in T&G

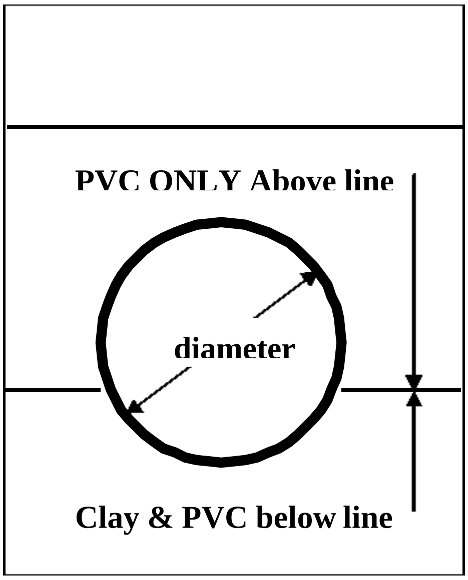
Clay - M Flack says they add 10% water to extrude the clay It all goes off to the atmosphere as clean H during firing in the kiln.

A.4 Waste PVC
Figure 5.1, page 64, T&G

A.5 Bedding

Table A.5 Bedding quantities		
pipe diam	pipe Len	30
300	PVC	Clay
top cover	150	0
outside diam	335	356
bottom layer	75	75
side width	150	150
block area	0.356	0.166
Backfill/m	0.268	0.116
m^3 / complen	8.025	3,487
tonne/ m	1.44	1.44
tonne/ complen	11.56	5.02
PVC/clay	230%	

PVCvC1ay-G.Mw /pa



A.6 Waste Mercury
PVC - Table 3.1, page 34, T&G
0.28 g/tonne to air and 0.02 W tonic to water = 030 g/t

0.3 x 92,800 t PVC/year = 27.8 kg/year

A.7 Water emissions AOX, Phenolics
Table 3.6, page 41, T&G

A.8 Atmospheric emissions, Particulates, CO, NOx , SO_2, C1 Organic s, Hydrocarbons
PVC - Table 3.6, page 41, T&G
Waste Chlorinated organics: 169 g/tonne PVC. to air and 15 g/tonne AOX= 184 g/t
184 g/t x 92,800 t/year= 17075 kg = 17 tonnes
Clay - Using the data from the stack testing by Aerkem, 26 July 1995, gives the following table

Table A.6 Air Pollution Calculations for Clay Pipe from Aerkem monitoring data.

	g/m^3	m^3/min	Min/day	grams/day	tonnes clay /day	grams/ton
NOx	0.009	510	1440	6610	300	22
SO_2	0.023	510	1440	16891	300	56
Particulates	0.014	510	1440	10282	300	34
CO	0.063	510	1440	46267	300	154
SO_3	0.0096	510	1440	7050	300	24
Total Fluorine Compounds	0.005	510	1440	3525	300	12

Table Al Comparative Impact of Clay and PVC Air Pollutants				
	g/tonne PVC	g/complen PVC	g / tonne Clay	g / comlen Clay
NO_x	3034	1229	22	51
N_2O	634	257	6.2	14.3
SO_2	5962	2415	56	129
Particulates	631	256	34	78
CO	1063	431	154	354
SO_3	0	0	24	55
Total Fluorine Compounds	0	0	12	28
HC	10519	4260	0	0
Total	21843	8848	308.2	709.3
PVC comp Len / clay comp len		1247%	t PVC pipe/year	92800
tonnes air pollutants from PVC		2027		

A.9 1,2 Dichloromethane (EDC - Ethylene Dich loride)

PVC - section 3.3 (1st of two) page 35, 36 T&G lists "Actual EDC emissions will be between 10 and 30 t per annum." Assuming 15 tonnes of EDC and 13,200,000 tonnes of PVC (1987, page 5 T&G):
(15,000,000 grams EDC) /(13,200,000 tonnes PVC) = 1.14 grams EDC/tonne PVC

A.10 Vinyl Chloride Monomer

PVC - second section 3.3 page 36-38, T&G notes 20 - 30 t/a (say 24 t/a) during manufacture of VCM, <5 t/a (say it/a) in processing and 300 t/a in stripping. Use a total of 325 t/a.
Assuming 13,200,000 t PVC/a:
(325,000,000 grams VCM) / (13,200,000 tonnes PVC) = 24.6 grams VCM/tonne PVC

From Meyers (page 2.8-9,10), 3000 litres of water per tonne of PVC made from VCM monomer (this process only), VCM residue = C 10 ppm (say 8 mgIL):
3000 L/tonne PVC x 8 mg VCM/L = 24 grams VCMltonne of PVC, very similar to levels reported in T&G
Meyers (page 2.8-li) also lists emissions from hot air of drying equipment, <20 mg/m3, but no air volumes are listed. Page 2.9-7 and 9 list the same figures for a slightly different process.

A.11 Origin of Pollutants

The byproducts going to the environment from the production of PVC have two primary origins. First, is the generation of the large amounts of energy needed to produce the PVC and second is the catalysts and other chemicals that result from the chemical processes needed to produce the chlorine, ethylene, acetylene, VCM and PVC. Table A.8 shows the division of the two categories. This table is presented so that it is clear that there are not just pollutants from the burning of fossil fuels for energy.

Table A.S - Categories of pollutants from the Manufacture of PVC	
Energy Related Pollutants	Chemical Process Related Pollutants
Particulates	PVC
Oxides of Nitrogen	VCM
Sulphur Dioxide	Mercury
Hydrocarbons	Absorbable halogenated compounds
Carbon Monoxide	Phenolics
	Chlorinated Organics
	1,2 Dichloromethane (EDC)

Appendix B - Greenhouse Gas Calculations and Assumpt ions

B.1 kg of Carbon per unit of Energy

World power consumption in 1987 over 8 Terawatts (TW) = 8 x 10^9 kw-years; which produced 5 Gigatonnes of carbon as CO_2
U.S. Dept of Energy Prediction for the year 2025 = 27 TW, 21 TW of which will be fossil fuels. This is predicted to produce 13.6 Gigatonnes (Gt) of carbon as CO_2 (page 119, section 5.2 Carbon Dioxide and the Greenhouse Effect, Henry and Heinke, 1989).

13.6 Gt/21TW=0.648 Gt of Carbon/TW

1TW-yr =10^9kW-yr

10^9 kW-yr x 24 hrs/day x 365.25 days/year = 8.76 x 10^{12} kW-hr
(8.76 x 10^{12} kW-hr) \ (278 kW-hr per GigaJoule) = 3.15 x 10^{10} Gj

(0.648 x 10^9 tonnes of Carbon) / 3.15 x 10^{10} GJ = 0.0206 tonnes of Carbon / GJ
=20.6kgCarbon/GJ

This estimate is based on the energy provided to the PVC industry being typical of a mix of fossil fuel energy sources as it generally is in industrialised nations. If all the energy were provided by coal the kg Carbon / GJ would be greater. If significant parts were hydro electric or nuclear power the kg Carbon / GJ would be less, since these energy sources do not contribute CO_2 to the atmosphere.

B.2 kg of Carbon as CO to the atmosphere per tonne of PVC pipe produced

57 GJ / tonne of PVC pipe produced (T&G, page 45 Table 4. 1) includes the total energy content of the raw materials and the energy requirement of electrolysis, pumps, process heat, etc.
57 GJ / tonne of PVC pipe x 20.6 kg Carbon / GJ = 1174 kg carbon

1 tonne of PVC contains considerable carbon that has been included in this estimate of total energy use. Chemical formula for VCM = C_2H_3C1. The ratios are the same for PVC. Molecular weight C: 2 x 12 = 24, H: 3 x 1 = 3, Cl 1 x 35.45 = 35.45 Total = 62.45 g/mole Ratio of Carbon = 24 / 62.45 = 0.384
so 384 kg of carbon / tonne of PVC produced add 5% for waste PVC and other chemicals that are used in production but do not go to CO_2 in the process. 384 x 1.05 = 403 kg C Total C to atmosphere 1174 - 403 = 77 1kg C/tonne of PVC
771 kg Cx (44/12) = 2827 kg CO_2 / per tonne of PVC

This analysis assumes that the PVC stays in the ground or is disposed of to landfill not incinerated at the end of it's useful life, If it was incinerated the carbon in the PVC molecules would be broken into CO and disposed to the atmosphere.

B.3 kg of Carbon per unit of Energy Generated by Burning of Natur al Gas

Aerkem Pty Ltd report to M Flack dated July 26, 1995. Carbon dioxide 0.8% and 510 m^3/min.
510 m^3 x 1440 min/day x 7 days/week = 5,140,000 m^3 of air/wk
340 ppm natural air is CO_2 340/1,000,000 = 0.00034 = 0.034%
0.8% - 0.034% = 0.766%. 5,140,000 m^3 of air/wk x 0.00766 = 39,370 m^3 of CO_2/wk
The ideal gas law says that 22.4 litres holds a mole of any gas at 0°C and 1 atmosphere (101.3 kN/m2).(page 13, Brescia, Arents, et al 1975)
(39,370 m^3 of CO_2/wk x 1000 L/m^3)/22.4 L/mole = 1,756,000 moles of CO_2/week
(1,756,000 moles of CO_2/week x 44 grams/mole of CO_2) / 1,000 grams/kg = 77,260 kg/week
77,260 kg of CO_2/week / 300 tonnes of clay pipe/week = 258 kg CO_2 of clay pipe

1.0 x 10^{16} cubic feet of natural gas = 2.94 x 10^{15} kw-hr of electricity (page 462, Manahan, 1984)
The ideal gas law says that 22.4 litres holds a mole of any gas at 0°C and 1 atmosphere (101.3 kN/m2). Natural gas is mostly methane and there are 16 grams per mole of methane ((C=) 12g + (4H=) 4g = 16g) (page 13, Brescia, Arents, et al 1975)
16g/22.4 litres = 0.714 grams of methane/L of natural gas
0.714 g or methane/L x 12/16 = 0.536 g Carbon / Litre of natural gas

1.0 x 10^{16} ft^3 natural gas x (28.3 Litres / ft^3) = 2.83 x10^{17} Litres of natural gas
0.536 g Carbon / Lx (2.83 x 10^{17} Litres of natural gas) = 1.516 x 10^{17} g Carbon
= i.516x 10^{14} kg of Carbon
2.94 x 10^{15} kW-hr/(278 kW-hr/GJ) 1.058 x 10^{13} GJ

so if:
1.0 x 10^{16} ft^3 natural gas = 1.5 16 x 10^{14} kg of Carbon
and
2.94 x 10^{15} kW-hr = 1.058 x 10^{13} GJ
then
1.516 x 10^{14} kg of Carbon = l,058x 10^{13} GJ → 14.3 kg of Carbon/ GJ of natural gas energy

B.4 kg of Carbon as CO to the atmosphere per tonne of Clay pipe produced

14.3 kg C/GJ x 3 GJ / tonne of Clay pipe =42.9kg C / tonne of Clay Pipe
42.9 kg C x (44/12) = 157 kg CO_2 of Clay Pipe

Appendix C -Relative Toxicities

Relative Toxicity of Australian Snake Venom, LD_{50}

C. 1 Relative Toxicities of Australian Snake Venom and dioxin		
	grams/kg	Micrograms /kg = g/kg x 10^6
Red-bellied black snake	0.0025 g/kg	2500
King Brown	0.0024 g/kg	2400
Common Brown Snake	0.00005 g/kg	50
Copperhead snake	0.0005 g/kg	500
Dioxin - male guinea pig		0.6
Dioxin - female guinea pig		2.1
Dioxin male Rat		22
Dioxin female Rat		45 to 200
Hamster male and female		3000

Dioxin figures from Scientific American, February 1986, volume 254, Number 2, Page 25, Dioxin by Fred H. Tschirley