

Hazardous Waste

**Resource recovery of household
batteries, photographic materials and
used motor oil. existing practices**



Urban Solid Waste Series 4 Working Paper

editors:

Inge Lardinois

Arnold van de Klundert

June 1995

This publication is part of the WAREN project which has been carried out by WASTE Consultants. The research for this publication received financing from the Netherlands Ministry for Development Cooperation. Citation is encouraged. Short excerpts may be translated and/or reproduced without prior permission, at the condition that the source is indicated. For translation and/or reproduction as a whole, WASTE Consultants should be notified in advance. Responsibility for the contents and opinions expressed rests solely with the authors. This publication does not constitute an endorsement by the Netherlands Ministry for Development Cooperation. Whilst every care has been taken to ensure the accuracy of the information provided in this publication, neither the authors nor the consultants can be held responsible for any damage resulting from application of described techniques. Any liability in this respect is excluded.

CONTENTS

CONTENTS	1
PREFACE	4
INTRODUCTION	6
THE SCOPE OF THE REPORT	7
CHAPTER 1 HAZARDOUS WASTE MANAGEMENT	9
1.1 What are hazardous wastes	9
1.2 Types and quantities	10
1.3 Hazardous waste management in industrialized countries	11
1.4 Hazardous waste management in economically less developed countries	12
1.5 Legislation and enforcement	13
CHAPTER 2 INFORMAL RESOURCE RECOVERY	15
2.1 The informal sector	15
2.2 Small enterprises and hazardous waste generation	16
2.3 Economics of the informal resource recovery sector	17
CHAPTER 3 THE RECOVERY OF HOUSEHOLD BATTERIES	20
3.1 The functioning of household batteries	20
3.2 Types of batteries	21
3.3 Battery recycling in Cairo	22
3.4 Battery recycling in Calcutta	23
3.5 Economics of household battery recycling	23
CHAPTER 4 SILVER RECOVERY FROM USED PHOTOGRAPHIC MATERIALS	29
4.1 The photographic process	29
4.2 Silver recovery techniques from solutions	30
4.2.1 Metallic replacement	30
4.2.2 Electrolytic recovery	32
4.2.3 Advantages and disadvantages	32
4.3 Silver recovery techniques from scrap film and paper	33
4.3.1 The burning method.....	33
4.3.2 The chemical method.....	34

4.4	Silver recovery in economically less developed countries	34
4.5	Silver recovery in Manila, the Philippines.....	35
4.5.1	Sources of photographic waste materials and markets of products.....	35
4.5.2	Recovery process and equipment	35
4.6	Economics of silver recycling	37
CHAPTER 5 RECOVERY OF USED MOTOR OIL		39
5.1	The composition and sources of used motor oil	39
5.2	Recovery processes.....	40
5.2.1	Reprocessing.....	40
5.2.2	Re-refining	41
5.2.3	Controlled burning.....	41
5.2.4	Other direct reuse practices	42
5.3	Recovery of used oil in economically less developed countries.....	42
5.3.1	Manila	42
5.3.2	Cairo.....	43
5.3.3	Calcutta	44
5.3.4	Accra.....	44
5.3.5	Nairobi	45
5.4	Economics of motor oil recovery	46
CHAPTER 6 HEALTH AND ENVIRONMENT		49
6.1	Working definitions	49
6.2	The possible effects of waste materials.....	51
6.2.1	Photographic materials	51
6.2.2	Household batteries	52
6.2.3	Used motor oil	52
6.3	Safety measures	54
6.3.1	The occupational health strategy	54
6.3.2	Safety measures when recovering photographic materials.....	56
6.3.3	Safety measures when processing used household batteries	56
6.3.4	Safety measures when recovering used motor oil	56
6.4	Limitations within small enterprises	56
CHAPTER 7 CONCLUSIONS		58
7.1	Household batteries.....	58
7.2	Photographic materials.....	59
7.3	Used motor oil.....	59
7.4	The main points summarized.....	60
7.5	Call for more information	61
APPENDIX 1 AVERAGE EXCHANGE RATES IN SELECTED COUNTRIES.....		63

APPENDIX 2 THE MOST COMMON BATTERY SIZES (IEC DESIGNATIONS). 64

**APPENDIX 3 ADDRESSES OF THE CONSULTANTS INVOLVED IN THE
WAREN PROJECT 65**

REFERENCES 67

PREFACE

A few years ago the Undugu Society of Kenya (USK), a non-governmental organization (NGO) working in the low-income areas of Nairobi, met with community members in the Kitui neighbourhood to discuss the opportunities they saw to improve their living conditions. Their major concern was employment, and the question was raised whether an income could be created from the uncollected waste lying around the city and industrial areas. Lacking the necessary knowledge and experience, USK asked WASTE Consultants to assist in setting up waste recovery activities. This was the starting point for the so-called WAREN project (WAsTe REcycling in Nairobi).

Rather than 'reinvent the wheel' and try to develop recycling activities, WASTE Consultants decided to involve local consultants from five other cities where recovery efforts are better developed than in Nairobi. General terms of reference were drafted to guide the research in these cities, adjusted to suit specific local conditions. The consultants investigated the technologies used, the products made and the markets covered by micro-entrepreneurs who recover urban solid waste materials in Cairo (Egypt), Bamako (Mali), Accra (Ghana), Manila (the Philippines) and Calcutta (India). In Nairobi a similar research was done to inventorize the current state of recycling and to identify new implementation opportunities. Each research lasted four to five months and took place in 1991 and 1992.

Ten major materials were identified: rubber, plastics, motor oil, cooking oil, tin cans, photographic materials, broken glass, bone and horn, household batteries and organic waste. Only in Bamako the Terms of Reference for the Malian consultant were adapted and the materials described in his report were not included in the research. Attention was also paid to issues such as the size of workforce and type of labour within enterprises, skills, and import regulations affecting recycling. These issues form the context within which resource recovery may form the basis of viable enterprises, and determine the extent to which recycling activities can be introduced in other cities. On the basis of these researches, the present report on household batteries, photographic materials and used motor oil has been written.

This publication will not be the final product, however. New experience is continually being gained, new technologies are being developed and innovative solutions are being found. We would therefore greatly appreciate hearing of the experiences of readers, so that the information can be updated and be made available to a wider audience. Comments on this report would also be highly welcome.

Many colleagues and friends contributed to the preparation of the WAREN project. We are grateful to the more than hundred individuals and organizations who provided us with addresses, ideas and supporting literature at the start of the project. The publications could not have been written without the contributions of experts from EQI (Cairo), AUC (Cairo), AB&P (Accra), GERAD (Bamako), CAPS (Manila), Ptr Services (Calcutta) and USK (Nairobi) who conducted the research in the six cities over a period of some months doing the painstaking work of visiting and interviewing micro-entrepreneurs, trying to obtain government documents and visiting dumpsites in order to get a glimpse of what technically and commercially is being done by thousands of people in this field of work.

We would also like to acknowledge the people in the recycling sector for describing their activities and sharing their experiences.

This working paper also made use of the following reports written by students during their practical training with WASTE Consultants:

- *Silver recovery from photographic materials: a first exploration into the literature* (in Dutch) by Guus Haveman, 1988.
- *Recycling of used batteries (part 1 and part 2)* by Marieke van Vliet, 1991.
- *Recycling of used oil* by Alfons van Zwol, 1992.
- *Environment and safety in the processing of hazardous waste (used motor oil, household batteries and photographic materials)* by Ronald van der Meer, 1994.

Research data as such do not make a report. Hanns-André Pitot (environmental consultant) carried out the missions in the beginning of the project to discuss the set-up of the research in the selected cities. Assistance with the analysis and interpretation of the financial data was provided by Lex Hemelaar (environmental economist, WASTE Consultants). Also, Ruud van der Laar (occupational hygienist) offered his valuable knowledge and time to read the manuscript. He made many useful comments in particular on the strategy to be followed to improve working conditions. Anne-Lies Risseeuw (WASTE Consultants) took care of the language corrections.

Finally, we would like to thank the Ministry of International Cooperation (DGIS) of the Netherlands for financing the research and this series of publications.

Inge Lardinois (environmental engineer)
Arnold van de Klundert (project leader)
WASTE Consultants

Gouda, June 1995

INTRODUCTION

Since the publication of the famous book *Work from Waste* (Jon Vogler, 1981), there has been silence in the field of small-scale resource recovery. In the meanwhile, however, the scale of resource recovery in certain economically less developed countries has increased at an impressive rate. These experiences are worthwhile to be documented and disseminated to other interested parties.

This report is the fourth in a series on Urban Solid Waste Recovery, which attempts to document the experiences of small-scale recycling activities in a number of cities around the world. The first book in this series was published in 1993 and dealt specifically with organic or biodegradable waste. The second and third publications *Plastic Waste* and *Rubber Waste* describe the products made, the markets covered and the technologies used for waste recycling.

Recycling presents an opportunity to transform (sometimes harmful) waste materials into valuable resources and as such has many benefits. In economically less developed countries waste recycling is usually taking place in the so-called informal sector. It needs no clarification that little effort is put into good working conditions and environmentally sound working methods. Working in this vulnerable environment, an important question is whether small enterprises are able and willing to improve working conditions and diminish environmental pollution.

The recovery of solid urban waste certainly has the potential to contribute to solutions of problems such as unemployment and insufficient waste removal. However, existing problems need to be faced and solutions should be sought. Small enterprises also recycle materials such as household batteries, photographic materials and motor oil, which may pose a threat for the workers' health as well as for the environment. In this report an attempt is made to describe the practice and problems of the recycling of used motor oil, household batteries and photographic materials.

THE SCOPE OF THE REPORT

Hazardous Waste is different from its predecessors in that it does not primarily aim at stimulating the growth of the number of enterprises active in the field, because of possible pollution and bad working conditions. But since rarely any information is available on the prevailing practices in small enterprises recycling household batteries, photographic materials and motor oil nor are they taken into account in any hazardous waste management policy, it seemed worthwhile to document the experiences as they have been documented in the reports of the consultants involved in the WAREN project.

The report is intended primarily for intermediate organizations who support small entrepreneurs to improve their businesses. It is also intended for institutions that are concerned about the potential threat of waste to human health as one of the many environmental problems in fast-growing cities, and who try to promote solutions. Policy and decision makers in government institutions or municipal departments, may also benefit from the experiences described here. Hopefully, it may convince them of the need to come up with adequate solutions.

This report is not intended to provide a complete overview of all technical and economic options for hazardous waste recycling; it is primarily focused on the actual state of waste recycling in small enterprises, as documented in the researches of the WAREN project. Some examples are given to enrich the report.

Although the amount and quality of the collected data on these materials were limited in comparison to plastic and rubber recycling, it was considered useful to publish these data as a working paper as a means to focus attention on existing practices and to call for more information from the field.

Special attention is paid to occupational health and environmental aspects of waste recycling. Although during the research no specific attention was paid to this subject, it proved to be of major importance as one of the factors impeding the expansion of this kind of activities. Therefore, a (theoretical) approach is given on how existing conditions may be improved.

Chapter 1 gives a general introduction to hazardous waste management both in economically developing and in industrialized countries. Chapter 2 gives an impression of the informal environment in which small enterprises are thriving. Also, economic reasons for their existence are given as well as the financial format used to analyze their profitability and vulnerability with respect to fluctuations in the market. The technical possibilities of the recovery of household batteries, photographic materials and used motor oil are described respectively in the Chapters 3-5. Available examples from the WAREN researches as well as economic data are also given in each chapter. Chapter 6 deals with environmental and health aspects and gives some guidelines as to how to improve working conditions. Last but not least, some general conclusions are drawn in Chapter 7.

Appendix 1 lists the exchange rates, on which the cost calculations have been based. Note, however, that the calculations in this report have been taken from real life situations and adapted. The prices that are mentioned, are meant to give an indication only.

Appendix 2 shows various battery sizes as mentioned in Chapter 3.

Appendix 3 lists the addresses of the consultants involved in the WAREN project. They may also be able to refer the reader to local project experience and experiments.

CHAPTER 1 HAZARDOUS WASTE MANAGEMENT

This report deals specifically with the recovery of household batteries, photographic materials and motor oil, which can be classified as hazardous or chemical waste. This chapter looks at hazardous waste management in general in order to put the subject into a broader perspective. Also, it gives an overview of recent developments and problems in economically developing countries as well as in industrialized countries.

Section 1.1 and Section 1.2 deal with the nature and size of hazardous waste problems. Major differences exist between hazardous waste management in industrialized and economically less developed countries, which will be clarified in the Sections 1.3 and 1.4. Because of the importance of legislation and law enforcement, Section 1.5 will deal with this subject.

1.1 What are hazardous wastes

Many definitions exist of 'hazardous waste', varying from very broad to very specific ones. The following definition of hazardous wastes was prepared under UNEP auspices by the Ad Hoc Working Group of Experts on the Environmentally Sound Management of Hazardous Wastes in December 1985 (Batstone et al, 1989):

- Hazardous waste is such as it is legally defined by the State in which it is generated, disposed of or transported by.
- The reason is their chemical reactivity, or environmental or human hazardousness (toxicity, explosiveness, corrosiveness).
- Waste can effectuate this hazard solely or in combination with other substances.
- Radio-active waste as well as domestic refuse are not to be considered as hazardous waste since most countries control and manage these materials in a separate organizational framework.

Thus defined, hazardous wastes may occur in the form of solids, liquids, gases, sludge, containerized gases or contaminated containers, and can originate from a wide range of industrial, commercial and agricultural activities (Batstone et al, 1989).

From the definition and the exclusions (note that radio-active waste and domestic refuse are not included because of logistical reasons, although they may be toxic) mentioned above, it can already be concluded that the term 'hazardous' and the typology of hazardous wastes is subject to a continuing debate. It is clear that 'hazardous' does not necessarily refer to the nature of the material. Also, the amount of waste materials which are considered to be hazardous have evolved over time, as new toxicological and other data have become available on the health effects of various wastes. In many developing countries there is no legal definition of hazardous wastes. Consequently, the use of the term 'hazardous waste' is inevitably open to the user's interpretation (Benavides, 1992). Although not completely fitting into the definition given by Batstone, in this report, household batteries, photographic materials and used motor oil are summarized under the heading of hazardous materials, because of the potential harm they may cause to the workers and to the environment, and the care with which they need to be treated.

Effects depend primarily on the dose of the hazardous substance, which is defined as concentration x the duration of exposure time. Depending on the quantity and the exposure time even relatively harmless materials may pose certain health hazardous effects. For example, hydrochloric acid (HCl) in itself is not an unfamiliar nor a necessarily damaging product (our stomach uses it to digest food), but large concentrations of it in the air are noxious for the respiratory system.

1.2 Types and quantities

A wide range of industrial, commercial, agricultural and domestic activities generate hazardous wastes. Different waste classification systems are being used. However, an explanation of these systems is beyond the scope of this report. Table 1-1 illustrates some examples of hazardous wastes and shows their widespread distribution.

Table 1-1: Some illustrative examples of hazardous wastes.

Source: Batstone et al, 1989.

Sector	Source	Hazardous waste
Commerce & Agriculture	Vehicle servicing Airports Dry cleaning Electrical transformers Hospitals Farms / Municipal parks	Waste oils Oils, hydraulic fluids etc. Halogenated solvents Polychlorinated Bipheryls (PCBs) Pathogenic / infectious wastes Unused pesticides, 'empty' containers
Small-scale industry	Metal treating (electro-plating, etching, anodizing, galvanizing) Photo finishing Textile processing Printing Leather tanning	Acids, heavy metals Solvents, acids, silver Cadmium, mineral acids Solvents, inks and dyes Solvents, chromium
Large-scale industry	Bauxite processing Oil refining (Petrochemical manufacture) Chemical / pharmaceutical manufacture Chlorine production	Red muds Spent catalysts Oily wastes Tarry residues, solvent Mercury

Obtaining reliable information on the quantities and types of hazardous wastes produced by any country is very difficult. International comparisons are almost impossible because of the differences in classification and definition of hazardous wastes from country to country (Batstone et al, 1989). Hazardous wastes are produced by all countries,

irrespective of their state of development (Wilson and Balkau, 1990). However, generated waste quantities may differ quite a lot between the various countries, depending among other things on the number and type of industrial activities taking place.

The following data are given only to indicate the respective orders of magnitude of the hazardous waste production in different countries (Batstone et al, 1989). In 1985, it was estimated that for a number of western European countries, hazardous waste production was approximately 5,000 tonnes per billion \$ of gross domestic production (GDP). The figure for the USA is approximately 75,000 tonnes; the figure for the USA is higher because certain high volume waste streams (sludge, waste water) are included in the calculations. On the basis of very limited data, it was assumed that waste production in the USSR could be estimated at 10,000 tonnes per billion \$ GDP, that in other countries with mature industry at 5,000 tonnes, in newly industrialized countries at 2,000 tonnes and in developing countries at 1,000 tonnes. The total generation of hazardous waste is 100 kilo per person per year for highly industrialized countries with a strong chemical sector, whereas this figure for the OECD (Organization for Economic Cooperation and Development) countries with predominantly agricultural economies is 6 kilo.

1.3 Hazardous waste management in industrialized countries

The history of hazardous waste controls in industrialized countries stretches back barely 25 - 30 years (Wilson and Balkau, 1990). Japan was one of the first countries to introduce comprehensive hazardous waste controls, following the Minamata incident in the late 1960s, in which many people died from eating fish that was contaminated with mercury which had been discharged into the sea (Batstone et al, 1989).

Nowadays, in industrialized countries, the risk of hazardous wastes in water, soil and air is fairly well understood and adequate laws have been enforced. The general public is well informed about the dangers of hazardous waste. It is realized that waste production should be minimized and that waste must be stored or incinerated in such a way that the least possible damage is done to the environment.

In a number of industrialized countries, considerable progress has been made over the last 15 years in hazardous waste management. Naturally, progress varies from country to country, but in some places the system consists of (Batstone et al, 1989):

- Effective legislation
- Effective systems to control waste transport
- Licences for the operators of hazardous waste treatment and disposal facilities
- Availability of well engineered and well managed facilities for hazardous waste treatment, such as incineration, and controlled landfill
- Establishment of good waste collection and transfer systems

The different political and legal systems of the various European countries have resulted in the application of different strategies. Some countries emphasize the establishment of treatment facilities, others are more interventional on waste minimization. Transboundary movement to neighbouring countries is common. In all countries, properly enforced water

pollution and waste disposal legislation, backed by a good technical and services infrastructure, has enabled countries to make good progress (Wilson and Balkau, 1990)

The other side of the coin is that hazardous waste treatment has become an expensive activity. A good control apparatus is needed to see if no one (person or company) tries to get rid of waste materials in a cheap, illegal way that is harmful to the environment, either by dumping on sites that are not equipped for hazardous waste, exporting to countries with no strict environmental policy (often economically developing countries) or by mixing the materials with other waste products.

Proper control of the generation of hazardous waste costs money, but the experience that has been gained in a number of developed countries suggests that cleaning up the 'sins of the past' is much more expensive in the long term. In the United States, for example, a cleaning up operation of improperly managed waste materials has been estimated to cost 10-100 times as much as when they would have been disposed of immediately after generation (Batstone et al, 1989). At a best guess, remediating the United States' hazardous waste legacy will cost \$ 750 billion (Russell et al, 1992).

Although a lot of improvements have been made, hazardous waste management remains a permanent area of concern. Almost all countries still see a need to improve the enforcement of and compliance with the regulations that are in place.

1.4 Hazardous waste management in economically less developed countries

Hazardous waste management in economically less developed countries differs much from that in industrialized countries and it poses special problems. Until recently, hazardous wastes have rarely been a political issue, although there is evidence that hazardous wastes have been causing problems in these countries. Developing countries may focus on other very real and seemingly more urgent problems and do not see hazardous waste disposal as a pressing need and immediate political goal. The general public being unaware of the dangers of hazardous waste, as a consequence, does not exert any pressure on the politicians. Recently, however, environmental groups were established in some developing countries trying to raise public awareness and persuade the authorities to develop legislation and enforce it.

In many countries open dumpsites predominate, and in the absence of controls, hazardous wastes continue to find their way into such sites. Waste pickers may live and work among the wastes. Many dumps are already causing water pollution; often there are no special measures such as a non-percolating soil and run-off water catch that prevent contaminated water from seeping into the ground or flowing away.

The incineration of hazardous waste often takes place in ovens from which the unfiltered exhaust fumes are released directly into the air. Quite often financing is not available for the construction of adequate waste treatment facilities, and there is a lack of trained personnel to operate waste treatment systems (Skinner, 1993). Financial problems, such as restrictions on foreign exchange and limited access to hard currencies, make it difficult to finance treatment facilities (Batstone et al, 1989).

Companies from industrialized countries come to economically less developed countries in order to escape their severe national environmental legislations and take no or less notion of environmental effects caused by their presence. Also, there have been a number of proposals to ship hazardous waste into economically less developed countries for treatment and disposal. Many early legislative arrangements have made exemptions and special provisions for recovery and recycling activities (Baker, 1993). Although export of hazardous waste is legally prohibited in several countries, export is taking place, because industries claim their waste to for recovery.

Despite all these problems, many countries have undertaken some steps to develop hazardous waste management systems. In Malaysia, for example, hazardous waste management has been under investigation for about 10 years. A set of national hazardous waste regulations were introduced in May 1989. Current efforts are focusing on the selection of sites for centralized landfill and treatment facilities (Goh, 1990). A rather different approach has been followed in Thailand (Lohwongwatana, 1990). At an early stage, attention was primarily focused on effluents produced by the metal finishing and textile dyeing industries. The Thai government provided a centralized treatment facility for these wastes as a pilot project, and contracted out the operation of the plant to the private sector. However, no governing regulations on hazardous waste control have yet been put into place.

1.5 Legislation and enforcement

In order to handle the waste problem satisfactorily, legislation and control play a crucial role. Private enterprises, large and small, will usually not take measures on a voluntary basis, since their main interest is profit maximization. Hazardous waste treatment costs money and it is rather difficult to express the benefits in relation to money. The many illegal hazardous waste dumping acts clearly demonstrate this problem, which also still exist in industrialized countries, despite extensive legislation and control.

The effectiveness of legislation will depend in part upon the commitment to enforce the measures - possibly in the face of economic difficulties - and on the existence of an established infrastructure to make compliance possible. Major elements of such an infrastructure include (Baker, 1993):

- Education of the public
- Strategic decisions about facility ownership (public/private)
- Market structure - direction of wastes or some degree of free competition
- Market knowledge - leading to structured systems of waste facilities, or entrepreneurial initiatives
- Waste management facilities of various types, including recovery (if appropriate)
- Transportation infrastructure
- Availability of utilities
- Educational and technical training
- A system of enforcement, regulation and control to apply impartially on all concerned

In economically less developed countries, legislation is usually not as comprehensive as in the industrialized world. In Kenya, for example, the more than 50 pieces of legislation covering environmental aspects are characterized by fragmentation, duplication and sometimes conflicts of interest when it comes to their implementation by different ministries and departments (Undugu Society of Kenya, 1991). The legislation is inadequate on environmental protection, has a weak institutional framework on environmental initiatives and programmes, lacks environmental quality standards (especially the ones covering air pollution) and cannot integrate principles of environmental management into development planning.

An important international initiative (sponsored by the United Nations Environment Programme, UNEP) is the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Baker, 1993). Some principal elements include:

- A desire to minimize transboundary movements - particularly to less developed countries
- Recycling and a minimization of waste generation where possible
- Acknowledgement of the limited capacities of less developed countries
- The importance of technology transfer and technical support
- The need to observe principles of environmentally sound management

CHAPTER 2 INFORMAL RESOURCE RECOVERY

In economically less developed countries many small reprocessing enterprises thrive within the so-called informal sector, although no strict boundaries can be drawn between this and the formal sector. Section 2.1 gives a general description of the informal sector and the circumstances under which such small enterprises operate. Until recently, government authorities and researchers have paid very little attention to the contribution of small enterprises to hazardous waste generation (see Section 2.2). Section 2.3 describes some economic aspects of resource recovery in general.

2.1 The informal sector

The characteristics of urbanization in economically less developed countries are often quite different from those prevalent in the industrialized countries. An important characteristic of urban areas is the prevalence of informal activities that are carried out alongside those of the formal sector. One of the main reasons for the existence of the informal sector is the lack of formal employment opportunities for a large proportion of the urban and suburban populations. For many of the urban poor in these countries, waste recovery often represents a basic strategy for survival.

There is a wide variety of definitions of the concept of the 'informal sector', but not one is generally accepted. Following the International Labour Office (ILO), in this report the term 'informal sector' is used to refer to small-scale units with some of the following characteristics (ILO, 1991):

- They produce and distribute a wide range of goods and services.
- They consist largely of independent, self-employed producers, sometimes employing family labour and/or a few hired workers or apprentices.
- They operate with very little capital.
- They utilize low levels of skills and technology.
- They generally earn very low and irregular incomes.
- They are usually unregistered and unrecorded in official statistics.
- They have little or no access to organized markets, credit institutions, formal education and training institutions.
- They are not recognized, supported nor regulated by governments.
- They are almost invariably beyond the pale of social protection, labour legislation and protective measures in the workplace.
- They are generally unorganized and often operate beyond the scope of action of trade unions and employers' organizations.

These are of course generalizations; it should be recognized that the informal sector manifests itself in many different ways. Production or manufacturing facilities are determined largely by their context, i.e. the country in which they actually operate. However, the characteristics of the informal sector listed above are relevant for recycling activities, including the ones described in this report.

2.2 Small enterprises and hazardous waste generation

In most literature on hazardous waste management hardly any attention is paid to small enterprises. And, according to Benavides (1992), also the literature on environmental aspects of small enterprises is very limited. Little is known, in quantitative terms, on the environmental impact produced by hazardous waste from these enterprises. Virtually no specific information exists on the recycling sector.

In terms of pollution load, many of the small enterprises are not major waste producers, as compared to the larger industries (Benavides, 1992). According to Kent (1991), it is difficult to accurately assess the overall impact of small enterprises on the environment because of the complexity of the question, the diversity of their activities, and the lack of data.

Kent (1991) uses three parameters to assess the impact of small enterprises on the environment:

- The type of economic activities performed
- The productivity (level of output) of small enterprises
- The level of pollution per unit of output of small enterprises versus large ones

With respect to the third parameter, three analytical factors can be used to show that small enterprises contribute more to environmental degradation per unit output than large firms. First, technical inefficiency in production through the operation of obsolete equipment which is less efficient and generates larger proportions of wastes per unit of output, including air emissions. Second, abatement measures per unit of production are more expensive in small enterprises than in larger firms. Finally, governments tend to direct control measures towards the larger firms, leaving the smaller ones out, under the assumption that their contribution is much smaller (Benavides, 1992).

Although it is difficult to draw general conclusions, it appears that in Asia (Kent, 1991):

- Most small enterprises are not involved in activities with high environmental impact.
- The small enterprises that are involved in activities that have an environmental impact are usually not the major polluters in their industrial category, because they account for only a small percentage of total output.
- Analytical and limited empirical evidence suggests that small enterprises pollute more per unit of output than larger firms operating in the same sector.
- Industry, including small-scale firms, is not directly responsible for the bulk of urban air pollution (motorized vehicles are) nor for the bulk of organic water pollution (which consists mainly of household wastes).

•
Sometimes it is found that some small enterprises produce relatively little waste, because they reuse part of their waste in order to save on foreign currency. This is the case in Zimbabwe with some chemical industries (Benavides, 1992).

At a local level, small industries may have a serious impact on the environment. This is especially true when industries are located in residential areas. Toxic fumes may have an impact on the family and immediate neighbours and people in the near vicinity,

particularly children, may come into contact with solid waste. Lack of awareness of any possible danger seems to be one of the major reasons.

The role of small waste recycling enterprises is disputable. On the one hand they reprocess waste materials even the hazardous ones, but on the other hand they also create new waste, thereby polluting the direct surroundings, and causing hazards to their employees.

So far, government authorities have paid little attention to environmental aspects of small enterprises, often operating within the informal sector, because in many countries they are not officially recognized. Hardly any tailor-made waste management policies exist for the small-scale industry. Also, it is generally felt, that small enterprises do not play a very significant role in generating hazardous wastes. For instance, urban authorities in Zimbabwe believe that the contribution of the various categories of industry to the total hazardous waste production is on average as follows (Benavides, 1992):

- - small-scale 8%
- - medium-scale 20%
- - large-scale 72%

2.3 Economics of the informal resource recovery sector

The waste recovery sector in developing countries has the potential to provide a valuable service to society as a whole. In many cities the municipal refuse collection and disposal services are woefully inadequate, particularly in low-income areas, where waste accumulates in the streets and poses risks to the public health. Improved recovery processes could reduce the amounts of waste materials that have to be collected and disposed of by the municipal service, and thus the costs of municipal waste management. Also, the reduction of the volume of waste accumulated in the street is likely to result in a reduction of the risk this poses to public health.

The scale and type of resource recovery in economically less developed countries differs very much from this sector in industrialized countries. For some waste materials, e.g. plastics, the recovery sector is larger in terms of the number of enterprises and persons involved than in industrialized countries. In economically less developed countries, the recycling of household batteries is carried out with simple tools, while in industrialized countries mostly expensive, capital-intensive technology is used.

Some of the characteristics of the market in which recycling enterprises in less developed countries operate are listed below:

- Resource recovery in economically less developed countries is dominated by informal sector entrepreneurs. A large number of traders and reprocessors have managed to set up feasible businesses that generate reasonable or high profits, for example in silver recovery.
- One of the prime factors that determine the feasibility of waste recovery is the price of the virgin material. The price of the recovered material is equal to the price of the virgin material less a reduction for a difference in quality. Therefore, fluctuations in

the price of the virgin material have a direct impact on the price of the recovered material. This makes the waste recovery sector very dependent on developments on the world market for the virgin material.

- Virgin materials often have to be imported, are therefore relatively expensive and consume foreign currency. The use of recovered waste materials as raw material inputs relieve this financial burden for the enterprises concerned as well as for the economy as a whole.
- Labour costs in economically developing countries are low. Also, because of high unemployment rates, there is very little opportunity for income generation in the formal sector. Therefore, the informal waste sector provides employment for many people, although it is often the last resort in their daily struggle for survival. That means that the commonly labour-intensive processes of recovery of waste materials, such as collecting, washing and sorting waste, are soon financially feasible. The dark side of this is that incomes are usually minimal, and working conditions often appalling.
- Products made of, or which include recycled components generally have a lower quality than products made exclusively of virgin material. However, the market for the low-cost consumer items made of non-virgin materials is extensive. First of all, because there are large numbers of low-income consumers, who cannot afford the higher priced virgin-made products. Secondly, because the quality standards required by this group of customers can be met by the products made of recycled materials.
- There are few or no regulations or quality standards for recycled products. In the industrialized countries, such inferior quality products may not pass standard quality tests, but in less industrialized countries they are tolerated.

The financial aspects of waste recovery activities appear to be scarcely documented. However, this report contains a limited number of case-studies of small waste recovery enterprises regarding household batteries, photographic materials and used motor oil. These enterprises are analyzed on their profitability and how vulnerable they are with respect to fluctuations in the market. For this purpose the following format is used:

Profit and Loss Statement

Gross sales price of the product or service	
<u>Sales commission to traders</u>	-
Net sales price of the product or service	
<u>Purchase price of the waste material</u>	-
<i>Product margin</i>	
<u>Cost price of other material inputs</u>	-
<i>Value added</i>	
<u>Costs of labour</u>	-
<i>Gross profit margin</i>	
<u>Cost of depreciation (based on investments) and rent</u>	-
<i>Net profit margin (before interest)</i>	
<u>Costs of interest</u>	-
<i>Net profit margin (after interest)</i>	

A number of financial/economic ratios can be derived from the Profit and Loss Statement. In this report, two ratios are used in the analysis, namely:

1. Return on investment ratio =
 $\text{net profit margin} / \text{investment amount} * 100\%$

What eventually remains after all the costs are deducted is the net profit. The return on investment ratio relates this profit to the money invested in the activity, and is therefore the most suitable indicator to assess the degree of profitability. The percentage could be compared with the rentability of other investment possibilities in order to assess whether investing in alternative economic activities should get a higher priority.

2. Net profit ratio =
 $\text{net profit margin} / \text{sales price} * 100\%$

The net profit ratio assesses the vulnerability of the profit with respect to sales price fluctuations. The smaller the ratio, the higher the vulnerability. This is obvious because, in that case, a small decrease in the sales price can result in a losing business.

CHAPTER 3 THE RECOVERY OF HOUSEHOLD BATTERIES

Besides the purpose for which household batteries are originally meant, they are reused for a number of other, sometimes rather striking purposes. The Woodabe, a nomadic people living in the Sahara, use batteries to paint their lips black. In the Philippines, people strip the batteries down, rinse the contents with water and sieve the resulting mixture. The residue is used as a pesticide as well as an ointment to heal wounds. Batteries are also thrown into pit latrines to drive away the smell. Fisher women in the Pacific use them to sink their lines and nets, or take the carbon from batteries to dye the patterns black when weaving floor mats.

Household batteries are also being recovered to generate an income, whereby in particular the zinc is sold. In Section 3.3 and Section 3.4, two cases of household battery recycling are described, as encountered in Cairo and Calcutta. In the other cities researched in the WAREN project, household battery recycling as a commercial activity was not encountered. Section 3.5 gives some economic data of the described recycling activities. But first general information is given about batteries. Section 3.1 describes the functioning of household batteries and Section 3.2 comments on the different types of batteries.

3.1 The functioning of household batteries

In a battery, chemical energy is converted into electricity. The various chemical substances in the battery react with each other under release of energy. A battery consists of two electrodes which are immersed in a solution, called the electrolyte. The electrodes are made of different metals, but also carbon can be used. The principle of a battery is based on the relative ability of two metals to dissolve when placed in an acid solution.

In general, the process taking place in a battery is as follows: The electrode made of the material that has the greatest ability to dissolve, sends positive ions into the acid solution and acquires a negative charge. The other electrode will also send positive ions into the solution, but to a lesser extent, so there is a potential difference between the two electrodes. If the two electrodes of the battery are connected with each other, for example through a wire, the charge flows from the electrode with the greatest solubility to the other electrode. The first electrode can now send more ions into the solution. The other electrode uses the electrons of the charge to precipitate the ions of the electrode material out of the electrolyte. This electrode material has the lowest ability to dissolve. This process will continue until one or the other electrode of the battery is used up.

Almost all modern non-rechargeable batteries are referred to as 'dry cells'. This term implies that the aqueous electrolyte phase has been immobilised, i.e. by the use of gelling agents.

Figure 3-1 shows the inside of a zinc-carbon battery.

The electrode made of zinc, is a cylindrical container in which the other electrode is placed, separated by a special kind of paper or plastic. This second electrode is a compressed mixture of manganese dioxide, immersed in electrolyte and placed in the middle of the battery. The carbon current collector is placed in the manganese dioxide. The case of the battery is a construction of an extra iron sheet on the zinc sheet and a tin bottom.

A zinc-carbon battery contains mercury, like most batteries, though this is not essentially needed. A small quantity of mercury salt added to the electrolyte makes the zinc surface become amalgamated. This avoids undesirable reactions on the electrode and influences the morphology of the zinc, producing a smoother surface and reducing corrosion. Also small quantities of other metals (such as lead and cadmium) prevent the formation of local couples.

3.3 Battery recycling in Cairo¹

In principle all types of dry batteries usually found in household waste can be collected and recycled with the exception of button cells which are difficult to obtain in large quantities. The batteries are dismantled and sorted into the following four main components:

- Zinc shields or covers
- Carbon pins crowned with brass covers
- Carbon powder
- Other secondary materials like paper, acids, and chemicals

Not all components are reused: the recycler may dispose of the carbon powder and other secondary material.

Recovering zinc from waste materials, as carried out in Cairo, is a simple, manual process. First, the zinc is removed from the batteries using a sharp knife. The batteries are cleaned with (diluted) caustic soda (sodium hydroxide). The recovered zinc is mostly washed with water and sold to workshops. The workshops, foundries and smelteries melt the zinc in a small crucible and pour it into moulds to make zinc pellets, used in iron and steel galvanizing workshops. Zinc is also melted in brass foundries where copper and zinc are melted together to produce household appliances, such as handles, frames, figurines, etc. Remoulding zinc usually requires one skilled labourer and one assistant, one crucible with a capacity of 1 to 5 kilograms, a furnace, and ten moulds (50 grams to 1 kilogram capacity).

Carbon pins are reused in two different ways.

The first method is employed in plants and workshops which produce household batteries and prefer to re-use old carbon pins as spare parts or production components. Since no operational modifications need to be made in these cases, the pins are simply cleaned and the brass covers polished before they are used in the production of new batteries. Secondly, the carbon pins are used as heating components.

¹ This section is entirely based on the WAREN research by EQI.

3.4 Battery recycling in Calcutta²

Of all the cities involved in the research, Calcutta seems to be the place where most battery recycling activities take place. House wives sell household batteries to middlemen who sell bulk quantities to the reprocessors. During reprocessing, four battery components are recovered as secondary materials:

1. Zinc, by cutting open the case. The zinc sheet of the container is separated and sold to the zinc melting industry. After melting, the zinc is used by local smithy shops as coating for buckets, soldering, etc. and some of the containers are reused by tiny scale dry cell manufacturing units.
2. Carbon. The carbon electrodes are separated, with or without metal caps. Most of this carbon is used by local small-scale battery units, which use them in manufacturing dry cell batteries.
3. Metallic outer shell. Some of the batteries have a metallic outer shell, whilst others have paper wrappers over zinc containers. The metallic shells are sold as metal scrap.
4. Chemicals. The chemicals consist of the depolariser paste and the active materials. The depolariser contains manganese dioxide and powdered graphite. One kilo of depolariser paste can be retrieved by breaking up 300-350 pieces of standard dry cell batteries.
The rest of the active material, comprising ammonium chloride jelly, mercuric chloride, zinc oxide, with shoot and other organic matters (all non-separable) are used by the cast iron foundries for moulds. About 250 grams of the active material are available by breaking up 300-350 pieces of standard dry cell batteries.

During the survey a number of small indigenous dry cell manufacturers were encountered. They often reuse zinc containers and used up chemicals, particularly the depolariser material, piling them with fresh ingredients. New paper wrappings and plastic are used to give their product a good appearance. Most of these batteries are marketed in villages and are used for operating small transistors, radios, etc. These dry cells have poor operating characteristics and a poor shelf life.

3.5 Economics of household battery recycling

From the research done as part of the WAREN project, it became clear that in Bamako, Accra, Nairobi and Manila, the recycling of household batteries has not been encountered. CAPS in Manila argued that the reason for the absence of any recycling activities in this

² This section is entirely based on the WAREN research by Ptr Services

field is the economic inviability of such activities due to the price of zinc, which is much lower than the prices of other non-ferrous metals such as copper and aluminium. For instance, one kilogram of zinc (virgin material) costs \$1.50 in the Philippines (1991). However, the price of one kilogram of zinc battery cases will be much lower, due to additional processing and a lower level of quality. Suppose that this price is one quarter of the price of virgin zinc or \$0.38 per kilogram. The average weight of a battery is 85 grams of which 17% is zinc. Furthermore, the local minimum wage rate is \$4.30 per day and a working day has nine hours.

From these data it can be computed that it takes 5.9 kilograms of household batteries to recover one kilogram of zinc. Further on, approximately 67 kilograms of batteries would have to be reprocessed just to cover the costs of one labourer. This is a work load of 785 pieces per day or more than 1.5 battery per minute for dismantling. This is a high standard when dismantling is done completely manually. Moreover, this standard needs to be raised, in order to recoup the costs of collection and other processing costs.

The conclusion from this rough calculation is that, in Manila, the process of dismantling batteries is a marginal economic activity. Therefore, activities further down in the recycling chain, like processing into recycled zinc or re-use, are not fed by inputs. The price of virgin zinc is the main determinant in the feasibility of this process.

In Cairo, only a very limited number of people are involved in the battery recycling industry (EQI, 1991). According to the report of EQI, the same factors are valid as in the case of Manila. Indeed, the low price of waste zinc as a raw material compared to other non-ferrous metals is an important reason. Zinc sells at \$ 100 per tonne, whereas aluminium sells at \$ 500 per tonne and copper at \$ 1500 per tonne, although they require the same amount of effort for extraction as zinc does.

As in Manila, another factor determining the inviability of this activity in Cairo is of a logistical nature. In order to extract one tonne of batteries, 1,000 tonnes of waste material would have to be collected (EQI, 1991). Furthermore, one tonne of batteries produces only about 50 kilograms of zinc covers or casings, which makes the job of battery collection and zinc extraction very tedious.

Thus, most battery recyclers are engaged in other forms of recovery as well, such as aluminium recycling. The limited amount of household batteries available, the low market value of the raw materials derived from used batteries, in addition to the considerable physical labour involved, make it difficult to sustain a recycling business relying solely on the revenue obtained from the recycling of batteries.

A survey in Calcutta collected some data with respect to revenues generated by household battery recycling (Ptr Services, 1992). The following table was based on those data.

Table 3-1: Quantity and revenue of waste materials recovered from 1000 household batteries in Calcutta, 1991 (prices in US \$).

Waste material	Quantity	Unit	Price per unit	Revenue
Zinc	15	kilo	0.42	6.23
Carbon	1	1000 pieces	0.01	0.01
Depolariser	2.86	kilo	0.25	0.71
Active material	0.71	kilo	0.08	0.06
Total				7.01

The table shows that every 1000 batteries handled generates a sales revenue of \$ 7. The major constituent is zinc whose market price ranges between \$ 0.33 and 0.50 per kilogram. This is about 25% of the market value of virgin zinc, which is almost \$ 2 per kilogram (Ptr Services, 1992).

Also the survey revealed that housewives sell household batteries to middlemen at a price of \$ 0.05 per k, which approximates \$ 4.25 per 1000 pieces (the average weight is 85 grams for one battery). So, the product margin for battery recycling is \$ 2.75 or about 40% of the sales revenue. This margin is available for covering the costs of collection and dismantling. The survey does not give information about these costs. The example of Cairo discussed above, indicated that the labour costs are relatively too high to make dismantling a profitable activity. However, this may not be the case in Calcutta, as wage rates are substantially lower in India compared to Egypt (World Bank, 1994).

Further down the recycling chain, a number of dry battery manufacturing units exist in and around Calcutta. The majority of them are small cottage industries having manufacturing capacities between 2,000-10,000 pieces per day. These units do not solely use recycled materials as inputs. Most raw materials and chemicals are obtained from the market. The only input being 100% recycled, is the carbon rod. Only in a limited number of cases encountered during the research the depolariser material (manganese dioxide, graphite) was reused.

The following table is derived from a case study which describes the financial costs and benefits of a unit manufacturing 2000 pieces of dry cell batteries (type R 20-1050) per day in a 10 hours' shift (Ptr Services, 1992).

Table 3-2: Profit and loss statement of a manufacturing unit for household batteries which uses secondary materials, Calcutta, 1991.

	US\$/100 pieces	US\$/mth	Description
Gross sales price	15.00	7,800	Household batteries
Sales commission	5.00	2,600	For retailers
<i>Net sales price</i>	10.00	5,200	
Purchase price recycled material	5.00	2,600	Paper, zinc, metal, carbon rods
<i>Product margin</i>	5.00	2,600	
Cost of other material inputs	3.18	1,654	chemicals (manganese oxide, zinc oxide, ammonium chloride)
<i>Value added</i>	1.82	946	
Costs of labour	0.38	198	5 labourers (\$1.16/day, 1 supervisor (\$1.8/day)
<i>Gross profit margin</i>	1.44	748	
Depreciation and rent	0.04	20	Total investment \$275, life time 5 years; rent is \$3/mth
<i>Net profit margin</i>	1.40	729	Before interest

The table suggests that batteries can be sold at a price of \$ 15 per 100 pieces. Batteries which solely use virgin materials are sold at \$ 30 per 100 pieces, i.e. twice as much. The price difference accounts for the difference in quality.

It can be computed that the cost price is \$ 13.60 (\$ 15.00 - \$ 1.40), and a profit (before interest) is gained of \$ 1,40. This is approximately 10% of the sales price, which is a rather small profit margin. The whole process is therefore vulnerable to price fluctuations in the sales market. However, the return on investment is very high. One month generates a profit which is almost three times the total investment of \$ 275 for a period of five years. However, interest payments are very high and, according to the survey, consume as much as half of the profit.



Picture 1 and 2 Dismantling of household batteries in Cairo, Egypt.





Picture 3 Making new batteries out of old components, Calcutta, India.

CHAPTER 4 SILVER RECOVERY FROM USED PHOTOGRAPHIC MATERIALS

Recovering silver from different photographic waste materials (solutions, scrap film and paper) requires different techniques. To fully understand the different possibilities, this chapter starts with an explanation of the photographic process and the function of silver in that respect. In the Sections 4.2 and 4.3, the various recovery techniques for respectively solutions and scrap film and paper will be described.³ Section 4.4 will give some information on silver recovery in economically less developed countries. Only from Manila more elaborated information is available, which can be read in Section 4.5. Economic data are given in Section 4.6.

4.1 The photographic process

Black and white negative film is a thin sheet of transparent plastic covered, on one or both sides, with emulsion, a layer of insoluble, light-sensitive silver halide (usually silver bromide, silver chloride, silver iodide or a combination of these). Light absorbed during exposure converts some of the silver halide into a developable form. The film is 'developed' by treatment with an alkaline solution of an organic reducing agent, usually hydroquinone, which is called the developer. The silver that has been exposed to light, is then converted into metallic silver, forming the final image in black-and-white products.

The process is completed by fixing which is done in a solution containing a thiosulphate compound. In the fixing bath, the unexposed silver halide reacts with the thiosulphate to form a soluble silver thiosulphate complex, which is removed from the emulsion in the fixing bath and in the succeeding wash. The remaining photographic negative is thus darkest (i.e. it contains the most silver) where the most light has fallen. A positive print can be made by exposing print paper, likewise coated with silver halide emulsion, to light that has passed through the negative and developing and fixing in the same way. Much of the silver (up to 80 percent) that was originally contained in the emulsion of the new, unexposed film is wasted in the process of developing, fixing and printing.

The development of colour films, although a far more complex process, occurs basically in the same way except that a dye must be formed at the sites of the developed silver. The silver in the emulsion, having completed its role in image formation, is then unwanted since it will obstruct the light, hiding the colour of the dyes. The metallic silver, deposited in the developing process, is washed away, this time in a bleaching solution or bleach-fix, whereby all of the silver is removed from the film. Therefore, scrap processed colour film has no silver value. With colour films, the amount of silver in the fixing bath will amount to almost 100 percent.

³ *The first three sections are mainly based on information leaflets and booklets from Kodak (see References). Other literature references are mentioned in the text.*

After the photographic process, silver can be found in the fixer or the bleach-fix and in the wash water following the fixing bath. Although the silver concentration in the wash water is generally quite low, the recovery of silver may be very important when a large volume is treated.

Photographic solutions and scrap film and paper can be obtained from a number of sources, such as photographic shops, chemists, television and film studios, government laboratories, universities, etc. Other important sources of used photographic materials are X-ray plates from hospitals and clinics. Although they may look different, they have the same emulsion as photographic films. These plates may be quite big and large numbers may be available.

4.2 Silver recovery techniques from solutions

For any of the solutions, i.e. fixers, bleach-fixers or wash waters to be treated, the techniques involved are generally quite similar. The two basic methods for recovering silver from photographic solutions are metallic replacement and electrolytic plating. For wash water, four basic treatment methods are used: metallic replacement, ion exchange, reverse osmosis, and chemical precipitation. In this case, an electrolytic recovery cell is not practical (among other things, because of the low silver concentration). In this section, the basics of metallic replacement and electrolytic plating will be described. More information about these and the aforementioned other processes can be obtained from the large number of useful brochures from photographic companies, such as Kodak and Agfa.

4.2.1 Metallic replacement

Metallic replacement is based on the principle that when an active metal, such as iron, zinc or aluminium comes into contact with a solution containing a less active metal such as silver, it will replace the silver in the solution, whereby the silver becomes solid metal.

The operation of a metallic replacement unit or cartridge is simple. Silver-containing solution flows in at one side, makes contact with the filler material, and flows out at the other side as can be seen in Figure 4-1, which shows a design of the Kodak Chemical Recovery Cartridge. No motors, pumps, or electrical hookups are required, only simple hose attachments. A bypass loop provides a passage for the solution in case plugging occurs inside the cartridge. The silver precipitates at the bottom of the cartridge.

The construction of a home-made unit is very simple. The process can be carried out as a batch operation by placing steel wool in a bucket, covering it with the used fixer solution, and stirring for ten minutes (Vogler, 1981). The mixture is left for 24 hours for the reaction to take place, then the solution is tested to see whether any silver remains. If the solution is clear of any silver, the liquid is carefully poured off to leave a sludge of silver which can be put into shallow pans and dried in the sun or in an oven. It is then packed in plastic containers and sent to a refinery for silver extraction.

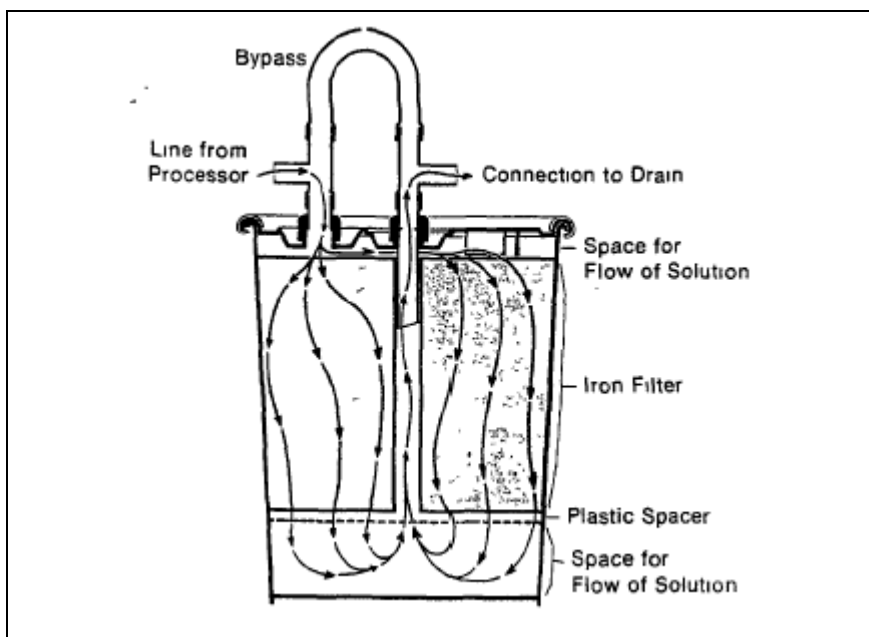


Figure 4-1: Solution flow through the Kodak Chemical Recovery Cartridge.

Source: Kodak, 1979b.

Silver recovery by metallic replacement is often carried out using commercially available cartridges, such as the Kodak Chemical Recovery Cartridges consisting of a plastic bucket or metal barrel containing steel wool. The price of these cartridges ranges between \$ 30 and \$ 50. There are a few cartridges which can be recharged with filler material by the user, but most cartridges are factory-sealed and must be replaced each time they are exhausted. Cartridges work best when a relatively continuous flow of fixer solution passes through them. If, for example, a cartridge were used just once a week, the filler material would oxidize, making it unable to react with the silver. Metallic replacement cartridges should be monitored regularly to determine when the cartridge is exhausted. This can be easily done using test papers, which are paper strips impregnated with a chemical substance that changes colour depending on the amount of silver present in the solution. Also, a bright copper coin can be dipped into the solution for a few moments. If it comes out silvered, the solution still contains silver (Vogler, 1981). If exhausted, the solution cannot be re-used for photographic work as it now contains metal impurities.

The efficiency of silver recovery will depend on how well designed and managed the recovery system is. A well designed system includes a proper choice of equipment for the applied process and a correct installation. System management takes into consideration proper maintenance of the fixer or bleach-fix and cartridge conditions. For example, when using steel wool, the acidity (pH) of the solution is an important factor. If the fixer is too alkaline, the reaction will be slowed down, whereas, if the fixer is too acid, the iron will dissolve too rapidly. Either condition can result in a loss of recovery efficiency. Fortunately, most fixers or bleach-fixers are within the pH range for a good utilization of steel wool. The pH range of the fixer should be between 4.0 and 6.5. Flow rate is a factor as well, and as a compromise between rate and capacity, a pH of 5.0 to 5.5 is recommended.

Techniques used for recovering silver from fixing baths using metallic exchange cartridges can also be applied to bleach-fix solutions. Unlike fixers, however, these methods permit reuse of the bleach-fix after it has been treated with metallic replacement cartridges with steel wool filler.

4.2.2 *Electrolytic recovery*

Electrolytic units are more complex than the metallic replacement cartridges both in design and operation. Therefore, they are generally more expensive than the metallic replacement cartridge, ranging in price from \$ 150 to more than \$ 15,000. A large variety of electrolytic cells, differing considerably in capacity and controls, are available, but their basic operation is much the same. In principle, with basic knowledge on electrolysis, also this process can be carried out with a home-made unit (Vogler, 1981).

In the electrolytic method of silver recovery, silver is removed from fixing baths by passing a controlled, direct electrical current between two electrodes (a cathode and a anode) which are suspended in the fixer solution. Silver is deposited on the cathode in the form of nearly pure metallic silver. The cathodes are removed periodically and the plated silver can be stripped off.

The electrolytic plating method of recovery is the only method which makes reuse of the fixer solution possible, because, unlike metallic replacement, the electrolytic plating method does not significantly alter the chemical composition of the fixer. The chemical changes can be minimized by maintaining the proper replenishment rates.

4.2.3 *Advantages and disadvantages*

The specific advantages and disadvantages with each method of silver recovery are listed below.

Metallic replacement	Electrolytic recovery
Initial capital expenditure is approximately \$ 30 to \$ 50.	Capital expenditure can run \$ 50 to \$ 15,000.
Installation is easy, requiring only a simple plumbing connection.	Electrical as well as plumbing connections are required.
Yields a silver sludge that varies in silver content, resulting in higher transportation and refining costs.	Yields silver with a high degree of purity.
Can reduce silver concentration to less than 1 mg/L in a single pass.	A reduction in silver concentration to 500 mg/L in a single pass may be the best that can be achieved.

Metallic replacement

Does not permit reuse of fixer.

Requires little monitoring and uses simple analytical procedures.

Can be used for recovery of silver from wash water.

Can be used with regenerated bleach-fix systems.

Cannot be used in a continuous circulating system.

Electrolytic recovery

Permits reuse of fixer for some processes.

Requires frequent monitoring for maximum efficiency.

Is not suitable for silver recovery from wash water.

Not all equipment is suitable for use in bleach-fix regeneration.

When incorporated with a continuous circulating system more silver is available for recovery. Less silver is carried into the following wash.

4.3 Silver recovery techniques from scrap film and paper

Silver can also be recovered from scrap black-and-white film and paper. The silver value can be substantial and recovery may be worthwhile if the amount of scrap film and paper is available in sufficient quantities. Silver recovery from solid waste materials is more difficult than from solutions. There is no method available that parallels the simple methods used in reclaiming silver from solutions.

Once the scrap is collected, two basic methods are used by commercial recovery specialists to separate silver from it. The most common method is to burn the film or paper to leave silver-rich ash from which the silver can be recovered. The other, more complex technique is to remove the silver from the waste material by wet chemical treatment and then to recover the silver from the liquid.

4.3.1 The burning method

The major constituents of scrap film and paper are the base and emulsion materials, which are organic materials primarily composed of carbon, hydrogen, and oxygen. Roughly less than 5 percent of the waste material is silver. Burning leaves ash 10 to 20 times richer in silver than the original material. Once it has been reduced to silver-rich ashes, the waste can be sent to a refiner. Good equipment should be used, otherwise the process can result in the loss of a large amount of silver.

The film is chopped in a shredder, or even by hand, and is burnt. For a complete burning of the waste, the proper amount of oxygen needs to be introduced. The normal practice in incinerator design is to use excess air to keep the temperature low. This excess air also

makes sure that an excess of oxygen is present throughout the procedure, thus avoiding the possibility of an explosion or blowback from the sudden addition of oxygen to partially burnt gases. Also, when too much material is loaded at once, the incomplete combustion that occurs can result in a dense black smoke which creates the hazard of an oxygen deficient atmosphere in the combustion chamber.

Another problem to be avoided is the loss of silver-bearing ash disappearing up the chimney. This can be done by maintaining the proper burning conditions, by minimizing turbulence in the burning bed, and by using effective smoke cleaning devices, such as metal rods charged with static electricity so that ash clings to them. Kodak estimates capital investment of an incinerator suitable for silver recovery from photographic scrap to be \$ 200 to \$ 300 per pound per hour of capacity, exclusive of receiving and staging areas for incoming wastes.

4.3.2 The chemical method

Many chemical treatments have been used and proposed. They are often used in cases where the intention is to salvage the base material for reuse. The principal treatments used involve degrading the emulsion layer and the bond between the emulsion and the base without excessive damage to the base material. The most gentle chemical method is the use of proteolytic enzymes in a warm solution. An enzyme is a substance that will eat the gelatine that holds the silver grains, thus releasing them from the film or paper. The temperature range is usually 49°C to 54°C and should be carefully controlled since a temperature that is too high will destroy the enzymes while a temperature that is too low will increase the reaction time needlessly.

In each of these chemical methods, an effective removal of the emulsion is important for the most efficient silver recovery. Once the emulsion, along with the silver, is removed from the base the silver may be recovered by settling, centrifuging, filtering, or a combination of these techniques.

4.4 Silver recovery in economically less developed countries

Not much information is available about the recycling of photographic materials, including silver recovery, in economically less developed countries. One could conclude that silver recovery hardly takes place, only CAPS has described one example of silver recovery in Manila. However, a complicating factor is the secretive circumstances under which silver recovery seems to take place. Although some collectors of photographic materials were traced, it was not possible to collect any field data. For example, in Calcutta (Ptr Services, 1992), several owners of photo laboratories are known to preserve the processed chemicals in glass jars. Buyers visit them periodically to collect the fluid. Sometimes the buyers bring their own chemical reagents and take away the coagulation after decanting the water content. Also in Nairobi, there seem to be traders who collect x-ray plates from a hospital, but they could not be located (Undugu Society of Kenya, 1992).

In Accra (AB&P, 1992), none of the companies visited, varying from photo amateur clubs, photo laboratories, film and broadcasting industries, are engaged in the recycling business. One entrepreneur is known to recover silver from black and white photographic wastes by electrolysis. Apparently silver recovery can provide an income, but all traders are sensitive to protect `their' process and sources.

4.5 Silver recovery in Manila, the Philippines¹

More elaborate information on silver recovery was obtained by CAPS in Manila. In Section 4.5.2 an example is given from a small-scale silver recovery unit based on electrolysis. Firstly, more information is given about the sources of photographic materials.

4.5.1 Sources of photographic waste materials and markets of products

Three major sources of photographic waste can be distinguished. The first source are medical facilities, including dental care units. Hospitals and clinics have their own facilities to develop X-rays. The fixer solution (approximately 20 litres) usually gets saturated with silver bromide after around 200 X-ray films have been processed. These are collected in plastic containers and sold to buyers who recover the silver. The used films are soaked in a chemical compound (nitric acid solution 3%) to remove the silver bromide. The suspended solution is then processed in the same way as the fixer.

The second source are commercial establishments who develop black and white camera films. This branch seems to diminish, because the majority of films being used are now colour ones. The fixers for black and white film are processed in the same way as the fixers in the X-ray films.

The third source are industrial establishments. They are usually large construction companies which have expertise in the iron/steel line. X-ray is used to determine whether there are fractures in the steel structures. The process is the same as the X-ray films from medical sources.

The buyers of these recyclables are usually the recyclers themselves, who process the waste materials into silver. The silver is used to make jewellery of pure silver such as rings, earrings, book markers, tie clips, bracelets, etc. It is furthermore used to strengthen the alloy of gold and silver: adding silver makes the alloy harder.

Besides silver, the cleaned used film material can be sold as well. The cleaned used X-ray films are reused in the flower industry. The films are rinsed to remove the chemicals and then sold to flower shops, who use the films as packaging material.

4.5.2 Recovery process and equipment

To determine the silver content of the solution, a test paper (sold by Kodak Philippines Inc.) is used. The paper is dark yellow and when it reacts to silver it turns from light brown to very dark brown depending on the silver content. Together with the test paper a chart is included, which contains the various shades of brown and the corresponding grammes per litre of silver.

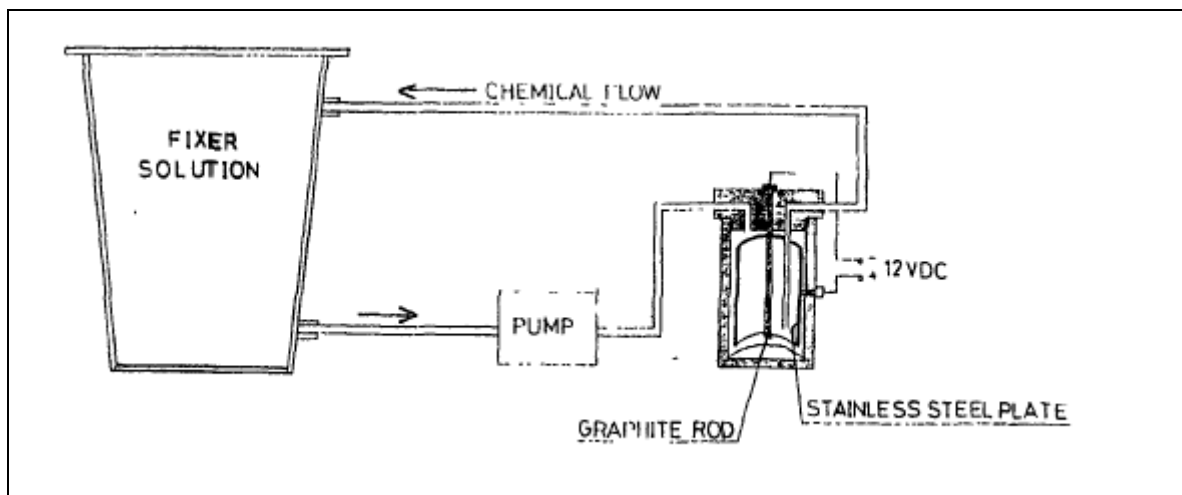


Figure 4-2: Operation diagram of silver recovery by electrolysis.

Source: Design by CAPS, 1994.

The solution is placed in a big plastic container which has two valves: the outflow is located in the lower portion and the inflow located in the upper portion. Figure 4-2 gives an overview of the system. A 1/4 hp (horsepower) chemical pump sucks the solution and delivers it to a smaller plastic container (30.5 cm high and 12.5 cm wide). The solution circulates inside this plastic container and then goes back to the big plastic container.

Inside the small container, electrolysis gives the solution an electrical charge. The small container has two electrical terminals. One is made of graphite rod attached to its cover and the other is made of a bolt and nut located at the side of the container. These are connected to a DC (Direct Current) voltage regulator with 110 volts AC (Alternating Current) input and a 12 volts DC output. Its negative pole is connected to the graphite rod while the positive is connected to the bolt and nut. The head of the bolt protrudes inside to make contact with a stainless steel plate wrap around the inside of the small container. When the device is switched on, electrolysis occurs, whereby the silver attaches itself to the stainless steel plate inside.

To recover the silver in a 20 litre fixer solution, the device should be operated for approximately 30 hours. To fasten the process, the voltage or the electric conductivity of the fixer solution can be increased by adding yeast which makes the silver particles suspended in the solution to attach themselves faster to the positive pole. In both cases, however, the purity of the silver decreases.

The equipment to extract silver from the fixer can be improvised provided that the recycler knows the basic principles of electrolysis. The same knowledge is required to understand the operation of the equipment shown; however, to operate the equipment, half a day on the job training is sufficient. A complete recovery of silver is measured by the colour

reaction of the test paper. If the colour remains the same, the recovery of silver is complete.

4.6 Economics of silver recycling

As described in previous sections, the recycling of photographic materials is not a transparent business. Consequently, as has been the case with the technical data, it has not been possible to obtain many economic data.

Because of the high price of silver, the recovery from photographic materials could be a profitable activity, even if the volume is small. A favourable aspect is that the difference in quality between recovered silver and the virgin material is small. Therefore, the price of recovered silver approximates the virgin price. Besides the price of silver, the factors that determine the operation of a silver recovery unit are the potential value of the silver-bearing waste, the cost of processing the waste for the recovery of silver, ecological pressures, capital expenditures required, and the know-how and experience required to operate the recovery unit.

One of Kodak's information leaflets states that when the concentration of silver in the fixer is at least 3 grammes per litre (or approximately 1/2 troy ounce⁴ per gallon) and the volume of fixer one uses is 380 litres (100 gallons) per year or more, some economic gain can be expected with silver prices in the range of \$ 12 to \$ 20 per troy ounce. Of course, the cost of recovering and refining the silver have to be deducted from this amount. (Recovering silver from photographic materials)

The only figures available from the WAREN research refer to a case study in Manila. This describes a process which can be carried out in a private home with simple, small-scale equipment (see also Section 4.5.2.). The figures refer to a 24 hours' recycling cycle.

Table 4-1: Profit and loss statement of silver recovery from 20 litres of photographic solutions (fixer) in Manila, 1991. (prices in US \$)

	US\$	Description
Sales revenue silver	28.50	on average 190 grams at \$0.15 per gram
Purchase price fixer	9.26	one 20 litre container
<i>Product margin</i>	19.24	
Cost of other material inputs	2.59	Transportation \$ 1.85, Electricity \$ 0.74
<i>Value added</i>	16.65	
Costs of labour	1.85	
<i>Gross profit margin</i>	14.80	

⁴ Silver is usually measured in troy ounces: 1 troy ounce = 31.1 grammes.

Depreciation	2.06	Total investment \$740, life time 3 years, 10 cycles per month
<i>Net profit margin</i>	12.74	Before interest

The data in Table 4-1 show that the cost price of silver recovery is \$ 15.76 (\$ 28.50 - \$ 12.74) for 190 grams or \$ 0.08 per gram. The silver can be sold at \$ 0.15 per gram, so the profit margin is \$ 0.07 per gram or a high profit ratio of 47%. So the profitability of the process can bear some fluctuations in the sales price. The table also shows that silver recovery generates a profit of more than \$ 12 per cycle. This production capacity would generate a yearly profit of \$ 989 to \$ 2,069, however, interest payments have to be deducted. Still, it means that the capital invested is recouped within approximately one year. This makes silver recovery in Manila a highly profitable business. Even higher profits are possible when the cost of transportation can be reduced by buying the fixer in bulk quantities, e.g. from big establishments such as hospitals.

CHAPTER 5 RECOVERY OF USED MOTOR OIL

Oil is widely used as a lubricator for motor vehicles and other machinery such as hydraulic pumps and motors, compressors and electrical transformers. During its use the oil becomes dirty and contaminated and therefore useless and even harmful. The oil has to be drained off and replaced with clean oil. A completely safe method of disposal does not exist.

Spillage of a bit of oil can be very harmful for the environment. For example, oil sometimes seeps very quickly into deeper layers down to the groundwater, where minute traces of oil may spoil whole reservoirs of drinking water; one litre of oil can make 1000 m³ of water undrinkable.

The recovery of used motor oil is carried out in all cities that were researched during the WAREN project. In some cases, the oil is directly re-used, for example as a termite repellent. Oil is also re-used as a fuel and can be regenerated into new oil by reprocessing or re-refining. The last activity is mostly carried out in large-scale enterprises.

The first section gives an explanation of the composition and sources of used motor oil. Section 5.2 deals in general with the various recovery processes for motor oil and Section 5.3 gives examples of oil recovery as carried out in Manila, Cairo, Calcutta, Accra and Nairobi. Section 5.4 gives some economic data.

5.1 The composition and sources of used motor oil

Used oil, as defined by the Secretariat of the Basel Convention in its so-called Technical Guidelines, is an oil from industrial and non-industrial sources which has been used for lubricating or other purposes and has become unsuitable for its original purpose due to the presence of contaminants or impurities or the loss of original properties (e.g. lubricating oils, hydraulic fluids, metal working fluids, insulating fluids/coolants).

Automotive and industrial oils are composed of an organic base stock which contains thousands of organic constituents. However, for specific applications additives are applied to the base stock to increase the performance and the life of the oil. The most important additives are dispersants and detergents which may form as much as 20 percent of the oil weight. Besides these additives, several other (hazardous) compounds are added to improve the quality of the oil. Consequently, a large variety of different types of oil exist, whereby the composition depends on the specifications which are needed for a particular industry. For example, metal working oils contain several additives to reduce wear on cutting and grinding tools.

Due to physical contamination and chemical reactions occurring during its use, used oil may contain impurities, such as heavy metals. An important contaminant in used oil is lead of which the concentration is higher than in clean oils. This is due to the use of leaded fuel. Also, metals may enter the oil as part of the lubricating package or from external

sources such as the wear of metal parts. Examples of metals that can be found in used oil are zinc, barium, chromium and aluminium.

Used oil may also contain contaminants, such as chlorinated and aromatic hydrocarbons (benzene, toluene and xylene). Also, polychlorinated biphenyls (PCBs) have been detected in used oils (up to 3800 ppm) (Mueller Associates, 1989). PCBs are suspected to be carcinogenic.

Contamination of used oil may also occur by mixing it with other oily fluids or liquid wastes; such contamination may seriously prejudice recovery operations.

Used oils originate from diverse sources. These include petroleum refining operations, small generators (do-it-yourself car and other equipment maintenance), industrial sources, and the rural farming population (Secretariat of the Basel Convention, 1993). Collecting used oil from non-industrial sources and local/small generators is very difficult and requires a well established and efficient infrastructure.

5.2 Recovery processes

Used oils can be recycled or reused in a variety of ways. The first option in the waste management hierarchy is to conserve the original properties of the oil allowing for direct reuse as an oil (regeneration which can be either reprocessing or re-refining). The second option is to recover its heating value by controlled burning.

In the Technical Guidelines, a distinction is made between reprocessing and re-refining. Both processes involve operations which separate and remove contaminants in used oil so that this oil becomes suitable for reuse. Contaminants removed in this process are part of waste streams which must be disposed of in an environmentally sound way.

Apart from economic considerations, oil regenerating technologies depend on the quality of the used oil and in particular on the presence of difficult oil products such as heavy fuel oils. Particularly re-refining processes involve the application of reasonably sophisticated technology, and require care and expertise in their operation (Secretariat of the Basel Convention, 1993).

5.2.1 Reprocessing

In reprocessing relatively simple physical and chemical treatments such as settling, heating, filtration, coagulation and centrifugation are applied to remove the basic contaminants in used oils. The objective is to clean the oil to the extent necessary for less demanding applications. The end product will thus be a partially cleaned fuel oil. These oils are mostly used in industrial applications (Secretariat of the Basel Convention, 1993).

5.2.2 *Re-refining*

The principal product of re-refining is clean oil, which is used primarily as a lubricating oil. Re-refining requires modern techniques which are expensive to operate when all safety and environmental precautions are adhered to. In the re-refining process a continuous feed of used oil is heated and in stages de-watered, and finally by vacuum distillation separated into different grades of distilled oil. These oils may then be hydro-treated to produce a fine clear product. The by-products which have marginal value, include distillation bottoms (used as an asphalt extender or in fuel oil blending) and demetallized filter cakes (used as road base material). The remainder of the materials are residues or waste streams such as acid tar, spent clay, centrifuge sludge and process water that are to be treated and/or disposed (Secretariat of the Basel Convention, 1993).

Re-refining could be seen as one of the preferred methods for the treatment of used oil. It has the beneficial effect of reducing the consumption of virgin oils. However, it is very sensitive to the scale and the economics of the operation.

Several processes are available to produce clean oil. These include (Mueller Associates, 1989):

- Solvent treatment/distillation/hydrotreatment
- Acid clay
- Vacuum distillation/clay polishing
- Chemical cleaning/demetallization/clay polishing

These processes produce basically the same product, but they generate different by-products. In the past acid clay was the most widely used process to re-refine used oil; however, the high costs of mitigating the environmental risks (for example related to the production of acid sludge as a by-product, which contains sulphuric acid, combustibles, lead, organo-metallics, sulphonates and possibly some carcinogenic materials) associated with this process have forced the re-refining industry in most industrialized countries to adopt alternative, relatively clean technologies such as vacuum distillation and solvent treatment (Mueller Associates, 1989).

5.2.3 *Controlled burning*

The inherent high energy content of some used oil streams may encourage their direct use as fuels, without any pretreatment or processing, and without any quality control or product specification. Normally, used oils in order to use them as a fuel need to be subjected to treatments involving some form of settlement to remove for example sludge and suspended matter, heavy metals and carbon. Some simple treatment can substantially improve the quality of the material.

The partial replacement of fuel with used oils is a technique that is widely applied around the world, in particular under controlled conditions in cement kilns. Most oil-fired domestic, commercial, industrial or utility boilers can burn used oils. However, uncontrolled combustion of used oils can lead to serious pollution of all environmental media. Also, possible corrosion of equipment is reported.

5.2.4 *Other direct reuse practices*

Used oils have traditionally been used for purposes other than reprocessing, re-refining and burning; they are used for all kinds of purposes, such as: road oil, raw material in asphalt production, floatation and, secondary lubricant, pesticide carrier, weed killer, livestock oil, all-purpose cleaner, and vehicle undercoating (Secretariat of the Basel Convention, 1993).

For instance, for many years used oil has been applied to gravel roads as dust suppressant. It has been used most commonly in rural areas. While some road oiling is still common in various areas of the world, its popularity has declined over the recent years, one reason being environmental problems. Studies suggest that the potential impact generated by road oiling on public health and environment are severe enough to discourage or prohibit such a practice where and whenever possible.

The environmental effects associated with the other direct end uses listed in this section, vary from one application to another. The nature and extent of environmental risk possibly caused by any given application will depend on the volume of oil used, the operational practices of the companies or individuals involved, and the manner in which the oils are ultimately discharged into the environment. Generally speaking, these practices should be avoided unless it can be demonstrated that environmental risks can be effectively controlled on a site-specific basis.

5.3 **Recovery of used oil in economically less developed countries**

In this section the results are described based on the researches carried out by the consultants involved in the WAREN project.⁵ Although the collection of any data on resource recovery from photographic materials was more difficult, oil recovery businesses are also far from transparent.

5.3.1 *Manila*

In Manila, the petrol stations and industrial users gather the used oil and store it into 200 litre drums. Traders who buy these used motor oils come regularly, either weekly or monthly, depending on the volume of oil. They, in their turn, sell these oils to the local oil companies.

Four local companies are competing for used motor oil. The biggest converts the used motor oil to bunker fuel by reprocessing and adding certain additives. The other three companies re-refine used oil into good-quality oil and either sell it to multinational oil companies or add additives to produce different kinds of motor oil. During the re-refining

⁵ *The sections 5.3.1. to 5.3.5. are entirely based on the WAREN research by respectively CAPS, EQI, Ptr Services, AB & P and Undugu Society of Kenya.*

process, sludge is produced. Formerly, this was disposed of indiscriminately, to the detriment of the environment. However, one of the companies developed a process wherein all of the sludge produced in the process is converted into bunker oil.

A significant portion of the re-refined oil is used for two-stroke engines of motorcycles. This kind of oil is sold in used soft drink bottles all over Metro Manila by small stores, repair shops and auto supply stores. Some unscrupulous sellers are diluting the motor oil. Through carelessness, some buyers get their motor oil contaminated with micro-organisms because it is sold in open bottles. As a result their engines malfunction.

A problem of the three local re-refiners is the supply of used oil. Their re-refineries are operating below 50% of actual capacity, because of the lack of raw materials. The lack of used oil is also attributed to the increasing usage of additives to prolong the life of the oil. Therefore, used oil is also imported for re-refining.

In the Philippines, used oil also has various uses in construction. Firstly, it is used as a protective coating for wooden forms used in concreting. Columns and beams are constructed by using lumber or plywood for forms to hold the fresh concrete in place. To extend the life of these wooden forms, a liberal coating of used oil is applied to protect the wooden forms from the water of the fresh concrete and to facilitate the removal of these wooden forms once the concrete is hardened.

Secondly, used oil is an extender for termite repellent chemicals. The oil is mixed with these chemicals to cover more surface area in the application of termite repellent chemicals. In some low-cost housing, only used motor oil is applied as the sole termite repellent, especially if the sides of a house are all concrete and the wooden portions serve as roof support only.

5.3.2 *Cairo*

The following industries depend on a mixture of used oil and other raw materials as a source of fuel:

- Bakeries buy used motor oil, mix it with black oil, and then use it as a fuel for traditional ovens.
- Asphalt-producing vehicles use a combination of used motor oil, black oil and rubber tire pieces as a fuel.
- In the production of lime from limestone, heat is generated from mixing black oil and used motor oil.
- Despite legal prohibition, several kilns used for the manufacture of red bricks are still in operation. They use motor oil mixed with black oil and coal powder as a fuel to start the firing process by inserting it among the adobe pieces.

The used oil is also re-refined to serve as a lubricant for locally made low-speed machinery (e.g. tile polishing machines and the gear boxes of plastic moulding machines). The first step is to sieve the motor oil with a special cloth to remove solid particles. The oil is then heated to 150°C, whereby the direct heat is being applied to remove the water content. It is then left to cool. Sulphuric acid (92% concentration) is added to warm (40°C) oil to enable it to react with other impurities. At the end of this process, the oil is sieved to

remove the impurities. 'Fuller's earth', a special type of clay, is then added and the oil and clay mixture is heated to 300°C, then left to cool. The mixture is once again sieved to extract any clay residue and other impurities. This is the final step of the re-refining process. The re-refined oil is packed and transported either in four litre plastic containers or 200 litre barrels.

All equipment used to recover used oil is locally manufactured. In the recycling workshop, the oil is screened using a device made of two containers and an agitator. One skilled labourer and an assistant can screen one tonne of oil daily. The heating process is carried out using a heating system, which includes a fuel oil tank, an oil burner, connecting pipes, an electric air blower, and an oven built of thermal bricks. The system requires one skilled operator, one semi-skilled assistant, and two labourers to operate the oil tank. The operation of mixing oil with 'Fuller's earth' is done by one skilled labourer. Mixed with white lead powder and zinc oxide, re-refined oil serves as 'painter's putty' (paste) which is used to fill in gaps and cracks in walls.

5.3.3 Calcutta

In Calcutta, used motor oil as available from automobiles, trucks and buses, is put to a number of uses:

- Rust prevention on the undercarriages of cars and lorries
- Fuel oil
- Anti-termites for cheaper wooden door frames, window frames and roof structures

A substantial quantity of used oil in Calcutta goes through a re-refining process for which there are only two large-scale units in the outskirts of Calcutta. Small-scale units recovering used motor oil, by any of the conventional processes like settling and filtration have not been detected. It was not possible to get an idea of the re-refining process followed by the two units as it is done with the help of foreign technology and equipments which the owners keep as a closely guarded secret.

5.3.4 Accra

Until recently waste oil spills in garages and filling stations and to a larger extent in drainage systems were common features. The waste materials were a nuisance to the garages and filling stations since they could not easily be disposed of. Recently, however, the garages and filling stations found buyers and a limited number of outlets to a safe disposal of the waste materials.

The intermediary collectors go from one filling station to the other to collect the used oil. The oil is delivered to the industries in Accra where it undergoes limited reprocessing, which includes:

- Filtration of the used oil to remove metal particles and dust during handling.
- Pre-heating the used oil to 80/90°C to reduce its viscosity.
- Pumping the oil through injectors and final ignition as a boiler fuel oil.

Also, the mining companies use limited amounts of used oil as cheap substitutes for residual oil in small-scale steam generation applications. Some small-scale industries depending on residual oil for firing boilers and other heating systems are gradually switching to used oil as a substitute.

Some companies collect some of the used oil and use them sometimes directly for:

- Heat generation/direct heating
- Boiler heating oil for steam generation in factories
- Wood priming/preservation

In smaller filling stations, the used oil is still burned in open drums at the outskirts of the filling station. There is currently no small-scale industry engaged in mass collection and recovery of the used oil.

5.3.5 *Nairobi*

Used oil from private sources, industrial sources (small-scale as well as large-scale) and institutions is either dumped or used locally for wood treatment where possible. This is due to a lack of an efficient collection system and the little amount of used oil generated at these sites. The largest source of used oil are the servicing garages and petrol stations. They have an organized used oil collection system and market.

The oil is reused for wood preservation and boundary marking.

The largest buyer of this oil is the oil refinery at the outskirts of Nairobi which has a monopoly over the waste market. The company uses German technology, and produces all types of lubricants and break-fluid. The costs of the plant were \$ 240,000. The refinery started in 1982 and handles 55% of used motor oil in Nairobi. Two lorries are used for oil collection, each with a capacity of 22 drums of 200 litres each. Certain routes are followed on a weekly basis. Oil is purchased from institutions, service stations and garages, and transportation firms. The purchase price per 200 litre drum is \$ 7. Previously, they used to buy 30 drums of oil per month at \$ 4 each, from a tyre-producer. However, this was discontinued due to rubber impurities.

One of the major problems for the refinery is dealing with the used oil residue. This can be a very expensive undertaking. The refinery has tried to set up a plant that would use the residue for free in a cement factory. However, this activity was unsuccessful due to the fact that it was impossible to heat up the residue to the required temperature. There was also the problem of the clogging of the firing jets.

Re-refined motor oil is currently sold as virgin oil. It is apparent that customers have no information on the fact that it is obtained from used oil. A few garages and individuals did not recommend the use of this oil. Allegations were made that the oil was lighter than required and can cause engine problems.

5.4 Economics of motor oil recovery

The feasibility of the recovery of used motor oil is very much determined by, firstly, the price of oil on the world market and, secondly, the (implicit or explicit) local price subsidies. For example, before the oil crisis started in Egypt in the early seventies, oil companies operating locally, as well as petrol stations and users of motor oil, had a problem in disposing of their used motor oil on the market (EQI, 1991). Because of the low price of fuel, used motor oil had no market value. During the Arab-Israel war in 1973, prices of petroleum products dramatically increased and that created a market for the recovery of used motor oil. Figure 5-1 illustrates the increase in the price of used oil in Egypt between 1973 and 1991.

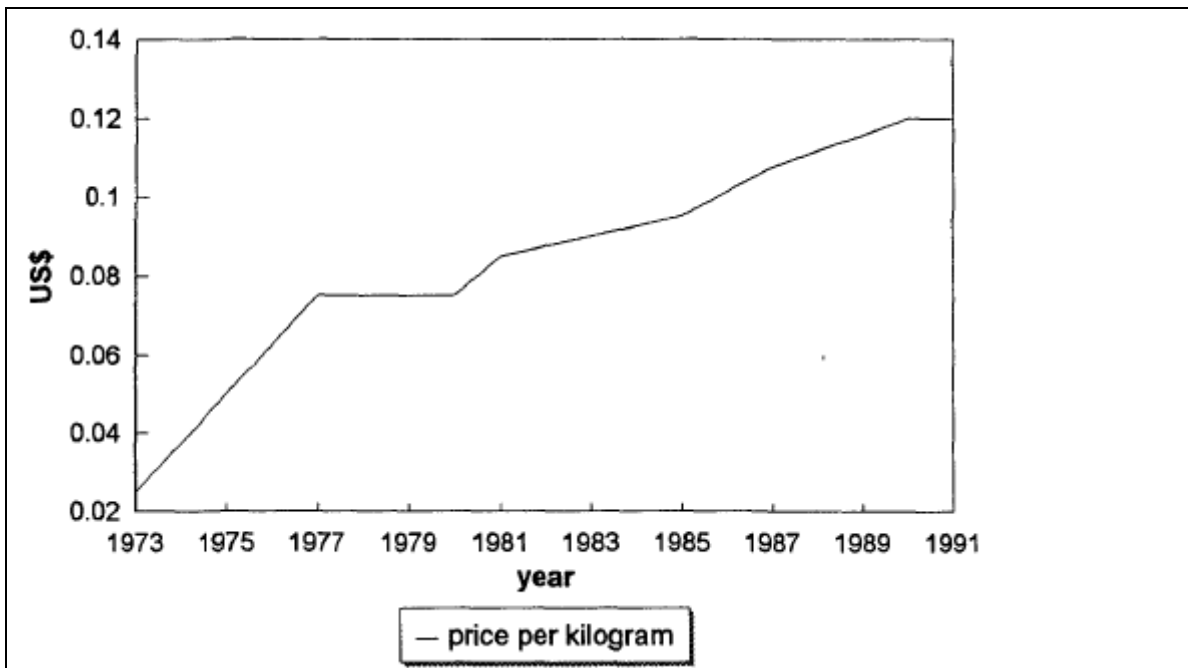


Figure 5-1: Price trends for used motor oil in Egypt (1973-1991).

Source: EQI, 1991.

In 1994, the market for recycled oil in Cairo was small, but the market for the direct use of used motor oil was still significant. However, both markets are under pressure. Firstly, because first class lubricants and paints become more popular and, secondly, because of the prohibition of red brick production in adobe ovens (whereby used motor oil was used to facilitate the firing process).

In the Philippines, the government lowered the sales price of bunker fuel from \$ 0.19 to 0.14 per litre in 1991, which has reduced the attractiveness of motor oil recovery (CAPS, 1992). The 1994 sales price of used motor oil is about \$ 0.12 per litre. This means that the savings in fuel costs by using used motor oil instead of virgin oil dropped from \$ 0.07 to 0.02, or from 37% to 15% respectively. However, the saving is still considerable, particularly for firms that consume large quantities of bunker fuel to run their operations.

Data on the costs of converting used motor oil into bunker fuel are not available for Manila. CAPS reasoned that the production of re-refined oil from used motor oil will increase, although the profitability of the process will remain the same. They envisaged

that the re-refiners will be able to compete with the large-scale companies for used motor oil, because the latter's process will become less profitable.

Table 5-1: Profit and loss statement of re-refining 1 tonne or 1,111 litres of used oil in Cairo, 1991 (prices in US \$).

	US\$	Description
Gross sales revenue re-refined oil	310.0	1,111 litres of used oil results in 1,000 litres of re-refined oil (input/output ratio = 0.9) at \$ 0.31 per litre
Purchase price	125.0	1 tonne or 1,111 litre of used oil
Product margin	185.0	
Additives	35.0	
Value added	150.0	
Cost of labour	30.0	3 skilled (operating screening device, heating system and mixing with Fuller's earth) at \$ 19; 2 semi-skilled assistants at \$ 6; 2 unskilled (operating the oil tank) at \$ 5
Cost of transportation	2.5	
Gross profit margin	117.5	
Cost of depreciation	1.0	total investment \$1,650 comprising a screening device \$150, a heating device \$1,500; life time of 1,650 tonne
Net profit margin	116.5	before interest

Table 5-1 shows that the sales price of re-refined oil is \$ 0.31 per litre. This is 50 to 70% of the price of the virgin product of \$ 0.45 per litre. However, both prices are subject to considerable fluctuations of the oil price on the world market. The net profit (before interest) is \$ 116.5 per 1,000 of re-refined oil, which implies a cost price of \$ 193.5 per 1000 litres (\$ 310 - \$ 116.5).

Assuming that the production level is 200 tonnes of used oil yearly (daily capacity is 1 tonne), the annual profit before interest is \$ 23,300. Although the trade commission for retailers and the interest still have to be deducted, the profit level is quite high in relation to the investment of \$ 1,650. Also, the net profit ratio is almost 40% ($116.50/310 * 100\%$) which means that the profit level can bear a fair drop in the sales price. The conclusion is that the re-refining of used oil is certainly not a marginal business in Cairo.

Data from Calcutta for the year 1991 show that used oil is stored in 30,000 litre tankers and purchased by recyclers at a price of approximately \$ 5,000, i.e. \$ 0.17 per litre. After re-refining, the oil is sold at a price of approximately \$ 11,700,-, i.e. \$ 0.39 per litre, which is 45% of the virgin price of \$ 0.87 per litre. Thus the product margin is \$ 0.22 per litre, which is 56% of the sales price. Cost data for Cairo in Table 5-1 indicate that this seems to be a fair margin.

Finally, data from Ghana for the year 1992, refer to the collection process of used oil. In Accra, intermediary collectors go from one filling station to the other and collect the oil at

a fee of around \$ 0.07 per litre. Subsequently, the used oil is delivered to the industries in Accra at a price of about \$ 0.22 per litre. The virgin price of refined oil is approximately \$ 1.80 per litre. The data do not give information on sales prices for recycled oil. But suppose that, like in Cairo and Calcutta, the price of re-refined used oil is about 50% of the virgin price, this would approximately be \$ 0.90 per litre in Accra. In that case, the product margin would be \$ 0.68 per litre or 76%. This is considerable higher than in Cairo and Calcutta, both in relative and in absolute terms.

CHAPTER 6 HEALTH AND ENVIRONMENT

Although the recovery of waste materials has numerous benefits including environmental ones, the recycling methods themselves may pose health hazards to the workers and cause environmental pollution in the immediate surroundings of the recycling unit. Urban solid waste may contain large quantities of pathogenic micro-organisms. Waste can also attract rats, and the diseases they carry, such as plague, endemic typhus and rat-bite fever. Flies and other insects are also responsible for the transmission of pathogens. These are problems which occur mainly during the collection and sorting of mixed waste materials.

Household batteries, photographic materials and used oil contain hazardous substances, such as metals, acids and organic solvents, and recycling these materials may cause additional health problems. Exposure may occur during collecting, sorting and processing waste materials, maintenance of machines and cleaning the working area. In this chapter, a (theoretical) attempt is made to assess the health and environmental effects of recovery activities of these materials. The first section contains some general information on how hazardous materials may affect human health and the environment. Section 6.2 examines the potential effects of the waste materials that are described in this publication. Also, a (theoretical) strategy for improvement and some safety measures are given. The last section analyzes the possibilities and limitations that recycling enterprises generally face.

Working conditions not only involve the exposure to hazardous substances. Factors such as noise, lighting, vibration, safety and work area climate are of equal importance. However, these will not be dealt with in this report.

It is difficult to draw a line between occupational and environmental health for the described activities. The reason is that the small enterprises are usually located within or around the house, thus, the family, and to a lesser extent, the neighbours are exposed to hazards arising from the work that is done (Benavides, 1992).

6.1 Working definitions

In working environments, different factors exist that can be responsible for harmful effects on human health. Factors that can have psychological, physical, biological and chemical effects can be distinguished. For now, only the chemical aggravating factors are discussed.

One of the definitions of toxic substances is: 'All chemical products that have the ability of being a hazard to human health or cause a nuisance after contact or intake by humans' (DGA/Arbeidsinspectie, 1992). Exposure to toxic or hazardous substances can take place in the following ways (DGA/Arbeidsinspectie, 1992):

Lungs: The lungs can easily inhale substances and transport them to the bloodstream. Once in the blood, these substances can reach any part of the body. Some substances may directly affect the lung tissue, others may only be taken up by the lungs and have their effect elsewhere in the body.

Skin and eyes: Some substances (fluids, substances and agents) can enter the human body through the skin and get into the bloodstream. Fluids, such as alkalies and acids, in the eye may cause intense pain.

Gastrointestinal tract: This form of exposure takes place when toxic substances are swallowed. The risk of this exposure depends on the hygiene measures taken. Smoking, eating and drinking in the working place, unhygienic behaviour and insufficient sanitation increase the chance of accidental intake. Heavy metals can easily be taken up this way.

The human body has a considerable capacity to purify dangerous substances. It is primarily the liver and kidneys that do this work, but if the body is exposed to a chemical over a longer period of time, the natural defence system can no longer render it harmless. The substance is then stored in the body and can cause various medical problems. Lead and cadmium are examples of such substances. It takes a long time for the body to break down lead and, in the case of cadmium, there is no breakdown at all (Joint Industrial Safety Council, 1987).

Health effects are determined by the dose resulting from the multiplication of concentration and time of exposure. Two extremes are short-term high-level exposure and long-term low-level exposure. In the first case the effects are seen very fast after exposure, while in the other case effects often can only be seen after many years. Furthermore, the health effects between these two extremes are generally different. Many substances can have both long and short-term effects. For example, alcohol has short-term effects on the nervous system (i.e. coordination/motorial problems), while long-term effects may include liver disorders.

Toxic substances can be distinguished into five groups (DGA\Arbeidsinspectie, 1992):

1. Oxygen replacing gases
The damaging effect of oxygen replacing gases lies in the fact that a shortage of oxygen may result, which can lead to unconsciousness and even death. Carbon monoxide is an example of such a gas.
2. Irritating substances
Irritating substances have an acute effect on the skin, lungs or mucous membranes of the respiratory tract and eyes. Most of the irritation will disappear gradually.
3. System-toxic substances
System-toxic substances have various effects on the functioning of organs such as lungs, liver, stomach, intestines, kidneys and heart; the circulation or production of the blood, or the nervous system. Substances that affect the unborn child also belong to this group.
4. Allergens
Allergens cause an allergic reaction of the skin or respiratory system. The intensity of the reaction or whether there will be any allergic reaction at all, differs from person to person. With people who are hypersensitive to a certain element, the smallest concentration of this element will give an allergic reaction.
5. Carcinogenic substances
Carcinogenic substances may cause cancer. Every exposure, no matter how short, means a risk, although a shorter exposure means a smaller risk. They are also called genotoxic because they damage the genetic material unrepairably.

Pregnant women, asthma patients, diabetics, people with metabolic problems and children who carry out heavy work form a group that have a higher risk to suffer from the health aggravating factors mentioned above (DGA\Arbeidsinspectie, 1992).

It is important to realize that exposure to a combination of toxic substances, as may occur in the handling of waste materials, may have a more serious as well as a less serious health impact.

6.2 The possible effects of waste materials

This section describes the possible health risks of handling the waste materials discussed in this report.

6.2.1 Photographic materials

There are five photographic waste materials: developer, fixer, washing water, waste film and waste paper. In particular the solutions, which can be acids, alkalis and organic solvents may have aggressive reactions. The developer is an alkaline fluid (pH 10) and the fixer is acid (pH 4.5).

Acids and alkalis are corrosive substances which can damage the skin and eyes on contact. Even short-term exposure can cause serious burns.

Various occupational skin diseases may result from contact of the skin with hazardous chemicals. Occupational contact dermatitis (or eczema) accounts for the great majority of these diseases. Two types can be distinguished:

- Irritant eczema (non-allergic)
- Allergic contact eczema

Irritant eczema is a skin disease produced by prolonged contact with certain chemicals, such as solvents and corrosive (alkali and acid) substances. After a time the skin dries out, becomes tender and cracks.

Allergic contact eczema is a delayed type of skin disease caused by a newly acquired high sensitivity to (very small quantities) of a chemical. Symptoms are irritation and swelling of the skin, with subsequent drying and flaking.

Particularly the developer may cause allergic contact eczema. Solvents have the ability to dissolve other substances and thus, they can also affect the mucous membranes and the skin.

The inhalation of vapours from acids and alkalis may damage the respiratory tract and lungs. Solvents may cause dizziness, headaches, tiredness, reduced comprehension and prolonged reaction times after short-term exposure (Joint Industry Safety Council, 1987).

In the Netherlands it is not allowed to dump photographic waste solutions in the sewerage system, because of their toxicity. The law explicitly forbids dilution with water used to lower the concentration of the chemical substance.

Also, scrap film and paper are seen as chemical waste and should be treated accordingly (Kodak, 1990a).

6.2.2 *Household batteries*

A battery contains metals. As long as the battery remains closed, it is not very contaminating for the environment. Once the battery is cut open or starts to leak by itself, the contamination starts. The contents of batteries depend on the type of battery. The most important contaminants per type of battery are:

- Zinc-carbon: ammonium chloride or zinc chloride electrolyte, zinc, mercury, lead and cadmium
- Alkaline-manganese: potassium hydroxide electrolyte, zinc powder
- Mercury-oxide: potassium zincate electrolyte, mercury, zinc powder
- Silver-oxide: potassium zincate electrolyte, silver, zinc powder
- Zinc-air: ammonium chloride electrolyte, zinc powder
- Lithium: lithium
- Nickel-cadmium: potassium hydroxide electrolyte, cadmium, nickel

Cutting the batteries into pieces as described in the Sections 3.3 and 3.4 causes dust, which consists of carbon and which may also contain the contaminants mentioned above. Inhaled dust accumulates in the lungs and causes a tissue reaction. This lung disease is called pneumoconiosis which is still the most common incapacitating occupational disease. The chemical composition of the substance is of great importance. Particles of some metal or metal alloys can damage the body's internal organs. Some examples are lead, cadmium and mercury.

6.2.3 *Used motor oil*

During its use, motor oil gets contaminated. Wear and tear of the motor brings metals into the oil. Pressure and heat can change the chemical structure of the oil. Dust and fluid (water, fuel) can creep into the oil circuit. Used oil can thus contain hazardous substances (see also Table 6-1) that are no original constituents of motor oil and their environmental effects are different and more severe than the ones cause by crude oil.

Table 6-1: Contaminants of potential concern in used oils.

Organic contaminants	Probable source	Approximate concentration, µg/l
Aromatic hydrocarbons Polynuclear (PNA) Benzopyrene Pyrene	Petroleum base stock	360-62000 1670-33000
Monoaromatics Alkyl benzenes Methalenes	Petroleum base stock	900000 440000
Chlorinated hydrocarbons Trichloroethanes Trichloroethylenes Perchloroethylene	May be formed chemically during use of contaminated oil	18-1800 18-2600 3-1300
Metals Barium Zinc Aluminium Chromium Lead	Additive package Engine or metal wear Contamination from leaded gasoline	60-690* 630-2500* 4-40* 5-24* 3700-14000*

* All concentrations for metals are in mg/kilo (ppm).

Source: McCabe, 1989.

Used motor oil is a rather toxic product (Vazquez-Duhalt, 1988). It contains polynuclear aromatic hydrocarbons (PAH) and high levels of heavy metals. PAH, such as benzo(a)pyrene, are well known for their high carcinogenicity. Considerable quantities of heavy metals, such as lead (Pb), zinc (Zn) and chromium (Cr) are contained in used oil; these metals may be highly toxic to organisms. Other toxic constituents which are found in used oil are: PCBs (polychlorinated biphenyls), phenol, naphthalene and toluene.

The contaminants in the oil are very toxic and carcinogenic. By means of inhalation, ingestion or skin contact, used motor oil can induce lipid pneumonia, lipid granuloma in the lung, eczematous dermatitis, contact dermatitis, folliculitis, oil acne, lipid granumola and melanosis in humans. Finally, used motor oil can induce cancer principally in the form of squamouscell cancer of the skin, scrotal cancer, bladder cancer and lung cancer.

As already mentioned in the introduction, motor oil can easily be spilled on the ground, and this oil can be transferred rapidly to aquatic environments by rain and runoff waters. Also, roads oiled with used oil for dust control can be an important source of water contamination. Used oil provokes a change in the microbial communities and decreases the primary production of phytoplankton. The damage to crustaceans, mollusca and fish caused by hydrocarbon pollution can also be very considerable. It has been found that used motor oil is one of the most important mutagenic agents in the aquatic environment. The presence of used motor oil in the soil inhibits plant development and the metal content in the surviving plants is increased.

The burning of used oil may also cause problems, especially when burning is carried out in inadequate installations. Exhaust gas from the combustion of used oil contains high levels of heavy metals. Also, large amounts of toxic gases, such as SO₂, NO_x and HCl, can be emitted.

Most re-refining processes generate two types of waste streams: sludge, such as dehydration sludge, acid sludge and solvent sludge, and spent clay. These waste streams should be adequately treated and disposed of. From a properly operated re-refinery system only very small amounts of exhaustion fume will be emitted.

6.3 Safety measures

This section describes a general approach, the so-called occupational health strategy (prescribed by the Labour Inspectorate in the Netherlands), that can be followed when trying to diminish health effects and pollution, and applied in recovery activities. Additional specific safety measures for the various waste materials are also given.

6.3.1 The occupational health strategy

Whatever it is that a company does or produces that causes the health risks, the strategy to deal with these risks is the same. Four steps or levels, can be distinguished (DGA\Arbeidsinspectie, 1992):

1. Measures at the source of contamination

Measures at the source of contamination have the highest priority. They may consist of:

- Replacing a certain substance with another material that involves a lower risk for human health
- Cleaner technology
- The application of alternative production methods or processes
- A change in the technical construction of the production process
- A change in working methods
- An adjustment of the lay-out of the working place
- The application of service and cleaning programmes

The raw materials of the recyclers are waste materials. They themselves have not much influence on their composition. At this level only the production methods can be improved. Examples of possible options are:

- A change in the technical part of the production process, such as closed processes instead of open ones.
- A change in working methods, for example, an adjustment of the working place i.e. hanging wet sheets around the dust source to prevent the spreading of dust.

2. Ventilation

Ventilation measures are only possible when the exposure takes place through air. In which case local exhaustion, supported by room ventilation is the first option.

If during the process, toxic fumes or dust are formed, an exhaustion method should be applied. This equipment can be too expensive for the entrepreneurs. A solution may be to have at least two open windows so natural ventilation can take place. Perhaps the work can even be done out in the open air. In that case, one must be extra careful not to spill waste oil.

3. Separation of the workers and the source of contamination

The goal of separation is to minimize the number of people that undergo exposure, reduce the exposure time by making technical provisions that separate the worker from the source of exposure. Measures at this level often have an organizational character, such as, spreading the work over different rooms, shifting from work regularly and spreading the work over a longer time.

The most dust or fume producing processing steps should take place in a separate room, or outside. If there is more than one worker, they could take turns at the dust prone tasks to spread the dose over more than one person.

4. Personal protection

The measures to be taken at the first three levels can be too expensive or impractical, and therefore measures at the fourth level need to be taken. Gloves should be used in processing the three waste materials. If it is not possible to process the oil or the photographic materials in a closed circuit and separate them from the workers, it is recommended to wear mouth caps. The type of mouth caps to be used depends upon the type of materials (gases, coarse or fine dust) used in the recycling activity. Still better would be professional respiratory protection but the filters need to be changed regularly, which makes it an expensive protection method. Skin contact with any of the three waste materials is unwanted. Therefore protective clothing, as with mouth caps depending on the type of materials (i.e. acid fluents, solvents) used, must be worn. These clothes should remain on the working place and not be taken home. If the working place is situated in a private home, the clothes should be kept in a separate room. If any job involves a risk of splashing oil or photographic materials, such as with filling tanks and manual mixing, protection for the eyes and mouth is necessary too.

To protect the environment, additional measures can be taken. Any material that has leaked during the process, should be collected to prevent it from seeping into the ground. The waste products that are left over after processing, are chemical waste and should be treated as such. This means they should be dumped at a special site or incinerated in an oven that is equipped for chemical waste. Unfortunately these facilities are not always available. In that case, the waste should be stored until the facilities are present or dumped at a site with the least risk to human, animal and vegetable life. Although this is by no means a satisfying solution.

6.3.2 Safety measures when recovering photographic materials

During the processing of used photographic materials, skin contact should be avoided. Short incidental skin contact is not very damaging, but repeated and enduring skin contact may result in skin diseases. The processing circuit should be a closed one, as far as possible. This means that the use of open reservoirs, storage tanks or processing apparatus should be avoided so that poisonous, caustic fumes cannot escape. Where no closed circuit is possible, firstly local exhaustion and secondly respiratory protection is a possibility. To protect the eyes against fumes or fluid drops, a face screen or goggles are a solution. Exposure to almost all vapours can be prevented if the fluid temperature is kept below 50°C.

6.3.3 Safety measures when processing used household batteries

The risk for exposure to metals in batteries is especially high when they are stripped down manually. It is important to keep the hands clean and make sure that as little dust as possible is inhaled. Working clothes should be left at the working place after work to prevent spreading any contaminants at home. When the batteries are stored for a longer period, there is a risk that, through chemical reactions, hydrogen gas is formed. This can cause serious explosions.

6.3.4 Safety measures when recovering used motor oil

The process with which oil is recycled should be as closed as possible. To keep the formation of vapours at a minimum, the oil should be kept at low temperatures. If the oil must be heated, one should realize that the oil may emit toxic fumes, so exhaustion, ventilation and respiratory protection are recommended. To prevent aggravating effects on the skin, gloves must be used whenever there is a risk of skin contact with oil.

6.4 Limitations within small enterprises

In most industrialized countries high standards for working conditions exist. In the Netherlands, the allowed concentrations of toxic substances in the working place are among the lowest in the world. Companies must sometimes make big investments to adhere to those standards. It will not always be possible for companies in less industrially developed countries to reach the same standards without damaging their competitive positions or even endangering the continuity of their company. This is even more applicable to the small entrepreneurs in the low-income areas of cities in economically less developed countries.

Entrepreneurs and employees are often not aware of the risks they run. There is little or no environmental consciousness.

The entrepreneurs' first concern is a short-term one: to make a living. Relatively high investments that pay only in the long run or only improve working conditions and do not

create extra profits, cannot easily be made by the informal micro-entrepreneurs. Another problem in small companies is the shortage of manpower and time. Also, small industries may have space limitations, therefore, having difficulties in installing treatment systems.

Most of the entrepreneurs involved in recovery activities operate illegally. This means that it is difficult to reach them with education nor, if environmental or labour legislation does exist, is it possible for the government to check these companies. Despite these limitations, it is important to try to improve working conditions and minimize environmental pollution.

CHAPTER 7 CONCLUSIONS

As became clear during the writing of this report, hardly any research has been carried out on working conditions and environmental pollution generated within small recycling enterprises. This is certainly true for the waste materials described here, but it can also be said about the recycling of more common materials, such as waste plastics.

As can be concluded from Chapter 1 and 2, within national hazardous waste management plans hardly any attention is being paid to small enterprises. Under the auspices of the Urban Management Programme, case studies have been carried out in several countries (Peru, Zimbabwe and Mexico) to assess the magnitude of hazardous waste generation within small enterprises in comparison to large-scale enterprises. It was concluded that large-scale enterprises generate most problems and that national policy plans thus should focus on these enterprises. Although this might be true from a national government point of view, it certainly does not solve the problems for the workers in small enterprises.

7.1 Household batteries

Whether the recovery of household batteries takes place, is very much determined by the local and international economic situation. Due to among other things the low zinc price on the world market, household battery recycling is hardly taking place in the Philippines nor in Egypt. In India, however, quite a number of enterprises are active in this field, although these enterprises usually do not depend only on waste materials. However, the case from Calcutta clearly shows that the financial vulnerability is high.

However, the fact that battery recovery is taking place, is a sign of ingenuity and creativity of the persons involved. Despite the problems, these people succeed in recovery, while in industrialized countries, battery recycling is still being developed. In the Netherlands, collected used batteries are stored in large silos awaiting future treatment or export to the United States.

Besides financial constraints, environmental and health problems can be raised. Under present circumstances the working conditions (especially men and children are involved) are not very encouraging. Also, the performance of batteries made from waste materials is limited and the pollution caused by the recovery in the direct surroundings is considerable.

Because of these problems, it is doubtful whether manual recovery as it is currently taking place in small enterprises should be implemented on a larger scale. However, before drawing conclusions more research should be carried out with respect to:

- the exact problems in terms of occupational health and environmental pollution
- the magnitude of environmental health problems in relation to the living environment within the neighbourhood and around the house
- the way people involved in recycling activities perceive the problems themselves.

Sometimes government authorities forbid or try to discourage these activities without offering any alternatives, thereby depriving people from their income. A crucial question is whether improvements can be made that fit within the financial limitations and profit margins of these enterprises and which are acceptable to the persons involved.

Summarized, it can be concluded that the manual recovery of household batteries, as encountered in India, is not an attractive business, neither from a financial point of view nor from an environmental health viewpoint.

7.2 Photographic materials

Data on the recovery of silver from used photographic materials are limited. It is known that photographic materials are being collected for this purpose and thus it can be concluded that recovery of silver can be a profitable activity, encouraged by the high price of (recycled) silver. However, it was difficult to collect data on the techniques used and the profits realized and thus the income generated, due to the secretive circumstances under which these entrepreneurs operate. In none of the cities it was possible to trace enterprises where the recovery is actually taking place. It should be stressed that the secretiveness of this sector is not specific for economically less developed countries; also in industrialized countries it is extremely difficult to get access to technical and financial information.

Because of the relatively simple techniques that can be used and the potential profitability, the recovery of silver seems to be the most promising activity of the recycling of waste materials described in this publication. Its potential could even be higher in the future, when environmental laws become more stringent and drainage of photographic materials in the sewerage system is forbidden.

Tourism in less developed countries is still growing, and so does the photographic industry. Feasible recycling businesses could be set up. Small entrepreneurs could possibly benefit, but to confirm this more research on technical and economic data is needed.

7.3 Used motor oil

From the waste materials described in this publication, the recovery (in its diverse forms) of used motor oil is probably the most widespread activity; it has been identified in all researched cities and the cases examined suggest that it is a profitable business.

Reuse of motor oil, such as its use as a termite-repellant, is taking place on a large scale, not so much out of financial motivations, but because of perceived advantages of its use. In most cases, environmental impacts of direct reuse are overlooked, possibly because of lack of awareness.

Used oil is also used as fuel not only in large-scale industries, but also in small enterprises. The use of used motor oil can reduce operating costs considerably, simply because it is cheaper. However, because of environmental problems caused by oil combustion, its use in certain operations is in some cases forbidden, e.g. in Egypt.

Reprocessing and especially re-refining processes are out of scope for small entrepreneurs. Technologies are too complicated and investments are too high. These processes require a lot of knowledge and safety measures. Small-scale recovery cannot guarantee a constant and good oil-quality either. Another limiting factor for informal sector entrepreneurs is the monopoly the large-scale used oil processors have, regarding both the market price and the technology.

An activity which could involve small entrepreneurs is the collection of used motor oil from garages and petrol stations. Possible drawbacks for these entrepreneurs may be the need for tankers to transport the oil, safety measures to be followed carefully and the geographical spread of used oil generators.

Because of the serious environmental problems, caused by uncontrolled processing and dumping of used oil, effective legislation and enforcement is needed. The complexity of this issue is demonstrated in industrialized countries, where, despite of extensive legislation and control, illegal dumping and export of used oil, is still taking place.

7.4 The main points summarized

The starting point for the WAREN research were two different problems: on the one hand unemployment and on the other hand large amounts of waste materials lying uncollected in the streets. For the three waste materials discussed in this report it can be concluded that income and employment generation should not be the most important objective. Starting point should be concern about the existing practices and handling of waste materials within these enterprises.

However, further research on existing practices needs to take place to assess the problems exactly and the possible improvements. There is insufficient information about practices taking place in enterprises that recover silver from photographic materials. The recovery of household batteries raises concern especially about the working conditions, mainly for men and children who are involved in this business. For the recycling of motor oil concern is not so much about the working conditions of personnel involved, but about the tremendous possible pollution, which spillage and careless recovery of motor oil may cause. Future research activities should take existing practices in enterprises, but also the problems with generation, recovery and disposal of these materials in general as a starting point. Also, activities should focus on improvements of the existing practices that can be applied on the development of alternative recovery, treatment or disposal options.

The possibilities for the improvement of working conditions and the environment of micro-entrepreneurs in low-income areas in developing countries seem to be limited because of the lack of finance and legislation, but these need to be assessed further. Sometimes simple and low-cost measures can be taken that result in considerable

improvements. Probably awareness of the employees has to be raised on the hazards of the work.

Ironically, lack of governmental interference, possibly a major reason behind this thriving recycling trade, at the same time works against the labourers, i.e. innovations are not being stimulated and there are no welfare schemes for these people. A few NGOs have tried to organize some kind of support for the waste pickers and recyclers, but these labourers have yet to be noticed by authorities and welfare organizations. Also, local governments should provide facilities to dispose of (hazardous) waste in a safe way, so the micro-entrepreneurs need no longer release this waste in the open. This will improve the quality of the environment and decrease the risk of polluting drinking water.

The problems described above also call for a broader approach in the sense of poverty alleviation. Survival strategies are the driving force behind informal recycling operations, where health and environmental considerations are not seen as a priority. Besides, people buy the products because they have a good price/quality ratio, and (logically) effects on public health and environment are not considered. It is also important to realize that these small industries tend to be located in the poorer urban areas, where basic sanitary facilities are deficient and environmental health problems are the most severe.

It appears to be very difficult to translate the waste management strategies employed by industrialized countries directly to economically less developed countries where there is usually lower public/industry awareness and a lack of resources, legislation and trained staff. Many differences exist, for example transport network inadequacies may mean that national solutions are not feasible in some countries, which requires a greater emphasis on local or regional solutions. This reinforces the need for small-scale solutions. Another difference is the fact that in economically less developed countries a large number of people are involved in informal waste recovery (e.g. picking and sorting at dumpsites, recycling of waste materials). Especially because of the health risks these persons face, a different focus on the existing problems is needed. This concern also forms the reason for this report.

More support from donor agencies, local governments and non-governmental organizations is needed and justified. Waste collectors and recyclers contribute positively to the environment and the local economy in terms of employment and income. Next to that, there should be a public concern about the circumstances in which the people in this sector live and work.

7.5 Call for more information

This working paper describes the results from the WAREN research. More research in this area is definitely needed, and the focus needs to be broadened regarding the following subjects:

- Income generation
- Working conditions
- Environmental pollution
- Quality of products

- Innovative techniques
- Organization of employees
- Government support
- Poverty alleviation
- Financial appraisal of small enterprises

However, before initiating more research on the recovery of waste materials discussed in this report, non-governmental organizations, municipalities, consultant agencies, universities and other research institutes are called to react upon issues described in this working paper and the subjects above. More information is needed on:

- The scale and the type of problems of (hazardous) waste recycling
- Involvement in supporting recyclers
- Improvement of existing practices
- Information on successful approaches

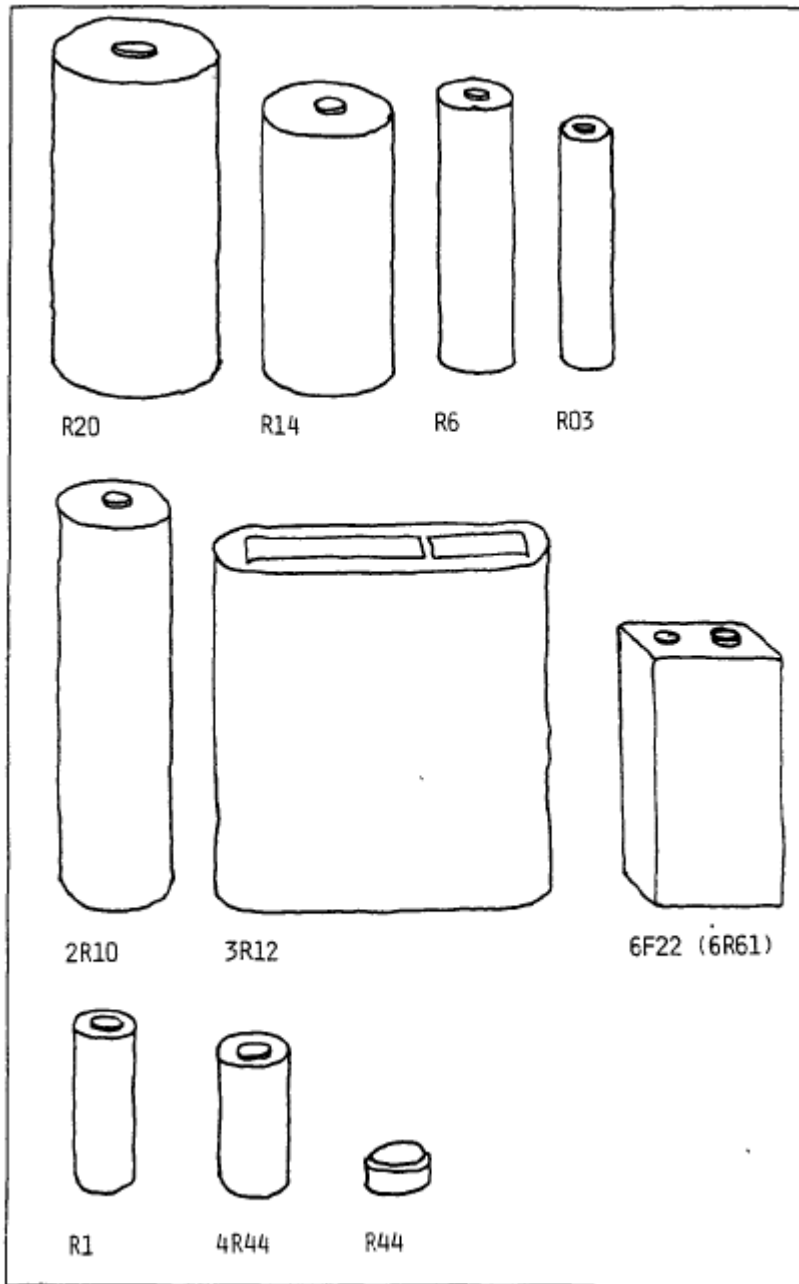
Comments and experiences from readers are most welcome.

APPENDIX 1 AVERAGE EXCHANGE RATES IN SELECTED COUNTRIES

1991/1992 (period during which WAREN research was carried out):

The Philippines	\$ 1 = 30 Pesos (P)
Egypt	\$ 1 = 2 Egyptian Pounds (LE)
Ghana	\$ 1 = 450 Cedis (C)
Kenya	\$ 1 = 25 Kenyan Shillings (Ksh)
India	\$ 1 = 30 Rupees (Rp)
Mali	\$ 1 = 300 Francs (CFA)

APPENDIX 2 THE MOST COMMON BATTERY SIZES (IEC DESIGNATIONS)



Source: Lindqvist, T. and K. Christiansen. *Collection and sorting of used batteries.*

TEM, University of Lund, Sjobo, Sweden, 1990.

APPENDIX 3 ADDRESSES OF THE CONSULTANTS INVOLVED IN THE WAREN PROJECT

American University in Cairo
Department of Engineering
113 Sharia Kasr El Aini
P.O. Box 2511, Cairo, Egypt
Contact person: Dr Salah El-Haggar
Tel: +20 (2) 354 29 64, ext. 5309/5455
Fax: +20 (2) 355 75 65

Asafo-Boakye and Partners
P.O. Box 7186, Accra North, Ghana
Contact persons: Mr E.A. Kuma, Mr James Gordon
Tel: +233 (21) 77 30 78 / 77 30 81 / 77 30 93
Fax: +233 (21) 77 30 94

CAPS (Center for Advanced Philippine Studies)
Room 8, Maya Building
678 EDSA, Cubao 1102,
Quezon City, Metro Manila, The Philippines
Contact person: Mr Dan Lapid
Tel: +63 (2) 912 36 08
Fax: +63 (2) 912 34 79

Environmental Quality International (EQI)
7th floor, 3 B Bahgat Ali Street
Zamalek, Cairo, Egypt
Contact person: Mr Mounir Bushra Mina
Tel: +20 (2) 340 86 28 / 340 00 52 / 340 82 84
Fax: +20 (2) 341 33 31

GERAD/IMRAD
Boîte Postale 1988, Bamako, Mali
Contact person: Mr Bakary Diakité
Tel/fax: +223 22 59 99

Ptr Services
Consulting Engineers
15 Ganesh Chandra Avenue, 2nd floor
Calcutta 700 013, India
Contact person: Mr R. K. Banerjee

Tel: +91 (33) 26 26 90

Undugu Society of Kenya

Landhies Road

P.O. Box 40417, Nairobi, Kenya

Contact persons: Mr Aloys Opiyo, Mr Kuria Gathuru

Tel. +254 (2) 55 22 11

Fax: +254 (2) 54 58 88

REFERENCES

AB & P. *Product-market-technology combination of waste materials recycling in Accra, Ghana*. WAREN project. WASTE Consultants, the Netherlands, 1992.

Associated Industrial Consultants. *Final report on case study on hazardous waste and emissions from small-scale manufacturing in India*. UNCHS, Nairobi, 1992.

Baker, L. Unpublished papers used for 'Intensive course on appropriate technology for hazardous waste management in economically developing countries'. ISWA, Istanbul, 28-30 June 1993.

Batrec. Inauguration of the battery recycling plant in Wimmis, Switzerland. October 27, 1992.

Batstone, R., J.E. Smith, Jr., and D. Wilson (eds.). *The safe disposal of hazardous wastes; the special needs and problems of developing countries*. Vol. I, II & III. World Bank Technical Paper No. 93. Washington D.C., The World Bank, 1989.

Benavides, L. *Hazardous waste management for small-scale and cottage industries in developing countries: Overview Paper*. Prepared for Expert Group Meeting on Local Management of Hazardous Wastes from Small-scale and Cottage Industries. UMP, Mexico City and Leon, October 27-29, 1992.

Bro, P. Batteries and the environment. In: Sequeira (ed.), *Environmental Oriented Electrochemistry*, 1994.

Bromley, R. (ed), *Planning for small enterprises in Third World Cities*. Centre for Development Studies, University College of Swansea, UK, and Regional Planning Program, State University of New York at Albany, USA. Pergamon Press, Oxford, 1985.

CAPS. *Recycling activities in Metro Manila*. WAREN project. WASTE Consultants, the Netherlands, 1992.

Copius Peereboom, J.W. and L. Reijnders. *Hoe gevaarlijk zijn milieugevaarlijke stoffen?* Second edition. Boom Meppel, Amsterdam, 1989.

Curi, K. (ed.). *Hazardous waste management in economically developing countries*. Turkish National Committee on Solid Wastes & ISWA, Istanbul, 1993.

DGA/Arbeidsinspectie. *Arbo informatie systeem toxische stoffen, basisbundel, overheidsbeleid, wetgeving richtlijnen tips*. NIA, Amsterdam, 1992.

EQI. *The recycling of solid waste in Cairo, Egypt*. WAREN project. WASTE Consultants, the Netherlands, 1991.

Frings, U. and J. Porst. Waste oil recycling. In: *GATE*, No.3, 1989.

- Goh, K.S. Developing hazardous waste programmes in Malaysia. In: *Waste Management & Research*, Vol.8, No.2, April 1990.
- Haveman, G. *De recycling van zilver uit fotochemicaliën. De chemische processen en de mogelijke opbrengsten; een eerste verkenning door de literatuur en handel*. WASTE Consultants, Gouda, 1988.
- Hewstone, R.K. Health, safety and environmental aspects of used crankcase lubricating oils. In: *The Science of the Total Environment*, Vol. 156, No. 3, 1994.
- ILO. *The Dilemma of the Informal Sector*. Report of the Director-General (Part 1), ILO, Switzerland, 1991.
- Joint Industrial Safety Council. *Safety - Health and Working Conditions. Training manual*. JISC in co-operation with the International Labour Office in Geneva, Stockholm, 1987.
- Kent, L. *The relationship between small enterprises and environmental degradation in the developing world (with emphasis on Asia)*. Prepared for USAID, 1991.
- Kodak. *Silver recovery with the Kodak chemical recovery cartridge, type P*. Eastman Kodak Company, USA, 1979.
- Kodak. *Recovering silver from photographic materials*. Eastman Kodak Company, USA, 1979.
- Kodak. *Fotografie en het milieu*. Kodak Nederland BV, the Netherlands, 1990.(a)
- Kodak. *Veilig omgaan met fotografische chemicaliën*. Kodak Nederland BV, the Netherlands, 1990.(b)
- Koppert, P. et al. *Stimuleren van milieu-innovatie; preventie van afval en emissies in het midden- en kleinbedrijf*. Erasmus Studiecentrum voor Milieukunde, Erasmus Universiteit, Rotterdam, 1992.
- Lardinois, I. and A. van de Klundert. Batteries: an environmental hazard. In: *Health Alert*, No. 135, 1992.
- Lindhqvist, T. and K. Christiansen. *Collection and sorting of used batteries*. TEM, University of Lund, Sjöbo, Sweden, 1990.
- Lohwongwatana et al. Industrial hazardous waste treatment facilities in Thailand. In: *Waste Management & Research*, Vol. 8, No.2, April 1990.
- Makarim, N. Hazardous waste management in Indonesia. In: *Waste Management & Research*, Vol.8, No.2, April 1990.

Maltezou, S.P., A.K. Biswas and H. Sutter (eds.). *Hazardous waste management*. Selected papers from an International Expert Workshop convened by UNIDO in Vienna, 22nd - 26th June 1987. Tycooly Publishing, London, 1989.

Instituut voor het Midden- en Kleinbedrijf Nederland. *Milieuzorg in het midden- en kleinbedrijf*. Amsterdam, 1992.

Meer, van der R. *Environment and safety in the processing of hazardous waste*. WASTE Consultants, Gouda, 1994.

Mendoza Marquez, H. *Case study on hazardous waste and emissions from small-scale and cottage tanneries in urban areas in Mexico*. Urban Management Programme, UNCHS, Mexico City, 1992.

Mubvami, T. *Hazardous waste management for small-scale manufacturing and cottage industries in urban areas in Zimbabwe*. Final draft, 1992.

Mueller Associates, Inc. Waste Oil. *Reclaiming technology, utilization and disposal*. Noyes Data Corporation, New Jersey, USA, 1989.

Nieuwenhuis, J.W. and J.H. de Zeeuw. *Informatiedocument afgewerkte olie*. Report no. 738902007. RIVM, Bilthoven, 1990.

Porst, J. *Possibilities of controlled disposal of waste oil for petrol stations and service workshops in Third World countries without regulated waste oil management*. Chemisches Labor und Beratungsbüro. Unpublished paper from GATE.

Ptr Services. *A report on recycling of waste in city of Calcutta*. WAREN project. WASTE Consultants, the Netherlands, 1992.

Ritsema, A. De slag om de recycling van fotochemicaliën. In: *Recycling*, augustus/september 1993.

Röben, B. "We need a waste avoidance programme". In: *GATE*, No.3, 1994.

Rummel-Bulska, I. The Basel Convention: a global approach for the management of hazardous waste. In: Curi (ed.), *Hazardous waste management in economically developing countries*, 1993.

Russell, M. et al. The U.S. Hazardous Waste Legacy. In: *Environment*, Vol. 34, No.6, 1992.

Sadek Eid, M. and S.M. El-Haggar. *Recycling urban solid waste in small-scale industries, Cairo, Egypt*. WAREN- project. WASTE Consultants, The Netherlands, 1992.

Schoenberg, von A. Battery recycling in the Alps. In: *Warmer Bulletin*, No. 31, November 1991.

Secretariat of the Basel Convention. *Draft Technical Guidelines on used oil re-refining or other reuses of previously used oil (R9)*. Revision I, 1993.

Sequeira, C.A.C. (ed.). *Environmental oriented electrochemistry*. Studies in Environmental Science. Elsevier, Amsterdam, 1994.

Skinner, J.H. International progress in hazardous waste management. In: Curi (ed.), *Hazardous waste management in economically developing countries*, 1993.

Undugu Society of Kenya. *Waste recycling in Nairobi, Kenya*. WAREN project. WASTE Consultants, the Netherlands, 1991.

Vazquez-Duhalt, R. Environmental impact of used motor oil. In: *The Science of the Total Environment*, No. 79, 1989.

Villarán, F. et al. *Generación de residuos peligrosos en la Pequeña empresa industrial*, 1991.

Vliet, van M. *Recycling of used batteries (part 1). A survey of the possibilities to sort and process used batteries*. WASTE Consultants, Gouda, 1991.

Vliet, van M. *Recycling of used batteries (part 2). Appropriate technologies for developing countries*. WASTE Consultants, Gouda, 1991.

Vogler, J. *Work from Waste: Recycling wastes to create employment*. Intermediate Technology Publications/Oxfam, UK, 1981.

Wilson, D.C. and Balkau, F. Adapting hazardous waste management to the needs of the developing countries - an overview and guide to action. In: *Waste Management & Research*, Vol.8, No.2, April 1990.

World Bank. *World Development Report 1994*. World Bank, Oxford University Press, New York, 1994.

Yetis, U. and A.T. Atimtay. Utilization of waste oils from environmental perspective. In: Curi (ed.), *Hazardous waste management in economically developing countries*, 1993.

Zwol, van A. *Recycling of used oil. Searching for a usable process*. WASTE Consultants, Gouda, 1992.