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THE SCIENTIFIC PRINCIPLES OF ENVIRONMENTAL POLLUTION

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Summary

Environmental pollution is shown to arise through disposing of the waste products of human activities in a way which leads to harmful or offensive consequences. Pollution control measures depend for their success on trapping the waste products before they enter the environment. The recycling of these waste products diminishes pollution, and assists the conservation of global resources.

Introduction

The term 'environmental pollution' is one of the most fequently used but poorly analysed terms in the vocabulary of thinking people in industrialised countries. It describes in the popular mind the insidious and far-reaching effects of the thoughtless application of technology, and by implication brings unnecessary opprobrium on the free enterprise system and on the proper efforts of man to better his material condition. The prevalent view of industry as being responsible for intolerable environmental offences has indeed a firm foundation in fact, but little credit is given to the growing awareness on the part of industry that some of its past practices have been unsound. There is very reason to believe that the pressure of public opinion in the developed countries will result in the technological industries becoming much more careful of their environmental effects, and, in doing so, becoming more efficient.

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Two other factors have also recently entered into the situation. The rapid increase in the cost of fuel oil has made industry much more conscious of its efficiency or lack of it; and the realisation that some minerals may become scarce before the turn of the century has led to concentrated thought on the merits of recycling.

Although developing contries have not experienced environmental pollution on the scale that Western countries and Japan have had to live through, there are other forms of pollution which already concern them. This article is written in the hope that it may in some small measure prevent them from repeating the mistakes of others, and encourage them so to order their affairs that their people will live and thrive in a healthy and congenial environment. It tries to set down some of the scientific characteristics of environmental pollution, and to deduce therefrom some broadly valid principles which are applicable to any of its manifestations.

What is environmental pollution?

There is no agreement as to what the term pollution covers. Clearly we are concerned with the health and happiness of man, and his continued survival. In the narrowest sense, pollutants are substances which clearly affect the physical or mental health of man within his lifespan. Many of these are now clearly recognised: the heavy metals (especially mercury, lead and cadmium), carbon monoxide, sulphur dioxide and nitric oxide are some examples. There is increasing concern about the possibility that pollutants in very low concentration may have subclinical effects, affecting such parameters as mental state, memory, ability to concentrate and social behaviour[1].

However to restrict the term 'pollutant' to those chemically definable substances which have been proved to have a measurable effect on health leads to a definition narrower than many would be prepared to accept. Thus man is not happy to have to breathe air laden with noxious odours, even though they do not harm his health; nor to drink water so heavily chlorinated as to be unpalatable. The term 'pollution' is often used to cover the improper use of land, e.g. for the dumping of harmless industrial waste, or wrecked cars, and failure to dispose tidily of the by-products of mining and quarrrying operations.

Much mose serious, but much more difficult to assess, are the possible long-term genetic effects of pollutants. The teratogenic nature of thalidomide is the most graphic example of the unexpected genetic consequences of ingesting a novel chemical substance. No right-minded person would wish to advocate restricting the development of new drugs to improve man's health; but whether our children's children will thank us for our endeavours is a quite different question. Excessive care is preferable to excessive carelessness.

Quite the best attempt to define 'environmental pollution' is the following[2].

"The word pollution is neither precise in its interpretation nor free from emotive undertones, but in the normally accepted sense it means the deliberate or acci-

dental discharge into the environment of waste products of human activities resulting in harmful or offensive consequences."

Each individual must decide for himself what he considers to be 'harmful' or 'offensive'. The foregoing paragraphs merely indicate the difficulty of delineating the phenomenon, and of achieving consensus on its proper definition.

Imperfect systems

The above definition clearly and rightly associates environmental pollution with 'the waste products of human activities'. It is important to appreciate that no human activity, nor any process devised by man, can ever be perfectly efficient in the sense of providing only what was intended or hoped for. In order to pursue this question further, we will attempt to apply some very elementary systems analysis by defining a *system* as anything which produces a desired product or effect[3]. Thus the typical *imperfect system* may be visualized as in Fig. 1: of course a given system may provide more than one desired product or effect, and more than one unwanted by-product. The Law of Conservation of Mass-Energy requires that the total output (both desired and unwanted) equal the total input. There is therefore no difficulty in principle of measuring the extent to which unwanted by-products are formed: they are defined exactly by the mass-energy balance:

input – desired products/effects = unwanted by-products/effects.

It is now a simple matter to see from what systems the various environmental hazards originate. Table I shows a selection of systems, with their inputs and products/effects both wanted and unwanted. We see that Man himself is a system falling within the above definition, a system whose waste products will result in 'harmful or offensive consequences' even if he indulges in no other activity but living.

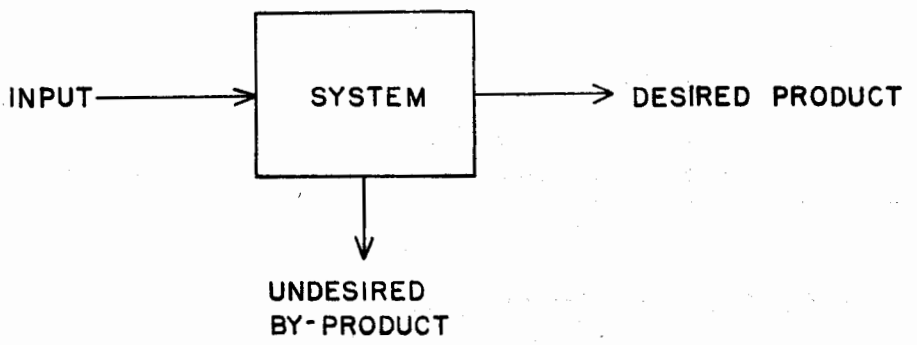

Fig. 1 Imperfect system: unwanted by-products arise through the inefficiency of the system.

Table I
Examples of imperfect systems

System	Input	Desired product	Unwanted by-products
Man	Food, drink, air	Life, energy	Faeces, urine
Food distribution	Canned food	Distributed food	Empty tin
Car	Petrol, oil, air	Kinetic energy	Exhaust gases (NO, CO etc.)
Transportation method	New car	Transportation	Used or wrecked car
Chemical plant	Raw materials	Required product	Gaseous and liquid effluents
Agriculture	Seed, fertiliser etc.	Crop	Excess fertiliser running off into river, lake

We now see that at least in some cases the unwanted products/effects of a system originate with the inefficiency of the system. There are however other cases where the unwanted by-product arises from an impurity or additive in the input, although of course it may undergo physical or chemical transformation on passage through the system. This situation is shown schematically in Fig. 2. There are many examples of this, some of which are mentioned in Table II. Most typically a system uses an impure input, *and* operates at less than perfect efficiency, so that a *typical system* will be as indicated in

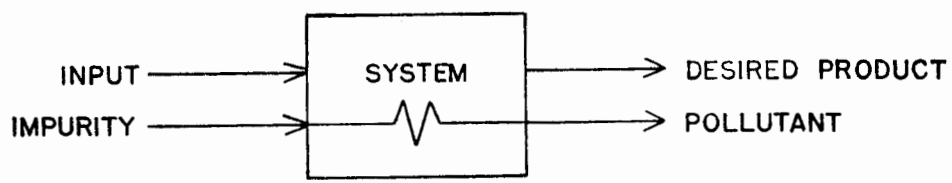

Fig. 2 System in which pollutants arise through an impurity in the input.

Table II
Systems in which unwanted by-products arise from impurity in the input

System	Input	Impurity	Desired product	Unwanted by-product
Power generation	Coal or oil	Sulphur compounds	Power	Sulphur dioxide
Zinc refinery	Zinc ore	Cadmium compounds	Zinc	Cadmium
Car	Petrol etc.	Pb alkyls	Kinetic energy	Lead compounds

Fig. 3. One familiar source of unwanted products is the internal combustion engine. The petrol it uses normally contains a little organic sulphur, as well as lead and phosphorus compounds added deliberately to promote smoother combustion and longer engine life. These give rise respectively to sulphur dioxide, lead compounds whose chemical nature is uncertain, and phosphroric acid in the engine's exhaust gas: but other equally important exhaust constituents are nitric oxide and carbon monoxide, both of which occur because of the imperfection of the combusion.

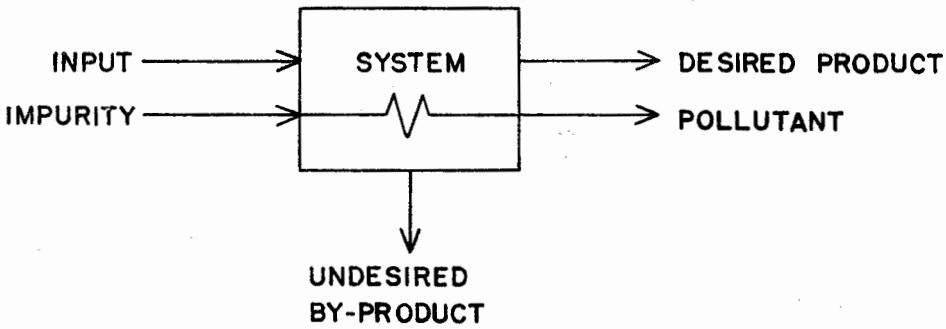

Fig. 3 Typical system operating at less than perfect efficiency and containing an impurity in the input.

The First Law of Environmental Pollution

The definition quoted above states in effect that environmental pollution occurs when the discharge (either deliberate or accidental) into the environment of the unwanted by-products of systems leads to harmful or offensive consequences. There are several implications of this to explore. First, the unwanted by-product is not automatically a pollutant. There are many systems producing unwanted by-products whose discharge into the environment has no undesirable effects whatever. Some systems produce both harmful and harmless unwanted by-products. The internal combustion engine can again be taken as an example: amongst the constituents of its exhaust are water vapour, nitrogen and carbon dioxide, all of which occur normally in air.

Secondly, if the unwanted by-products are harmful or offensive, they will not lead to environmental pollution provided they are treated in such a way as to render them harmless or inoffensive. This of course is frequently done; the internal combustion engine may again be cited as the example. The use of catalytic afterburners, now required by law in the United States, effects the reaction of nitric oxide with carbon monoxide and other reductants, and the oxidation of the excess reductants, so that the exhaust gas only contains trace quantities of pollutants.

From the environmental resource point of view, it is most preferable to put the "unwanted" by-products to some use; in other words, to use them as the input into a second

system from which some desired product or effect may result. As an example, let us consider domestic refuse, which in industrialised countries consists mainly of metal, glass, plastics and other organic material. After separating the metal and glass, the organic fraction may be (a) composted, (b) burnt to produce heat or (c) converted into a fuel oil. The main problem is that such processes are relatively expensive when compared with the classic procedure of dumping in refuse pits: indeed in Great Britain most of the domestic refuse is still disposed of in this way.

From the foregoing considerations we are led to a statement of the First Law of Environmental Pollution, which may be expressed in the following way:

> *Environmental pollution results when the unwanted by -products of any system are disposed of in such a way as to lead to harmful or offensive consequences.*

The Second Law of Environmental Pollution

Unfortunately these harmful or offensive consequences may happen to people quite a long distance from the source of the pollutants; in some cases damage to vegetation by sulphur dioxide has been claimed to occur some hundreds of miles from the power stations emitting it. The well-known tendency for progressive dilution to occur spontaneously, in keeping with the Second Law of Thermodynamics, enables us to write down the Second Law of Environmental Pollution in the following way:

> *Any pollutant on emission to any phase of the biosphere will tend to become diluted in that phase to the greatest possible extent, and will simultaneously interact with and appear in other phases.*

The most common sequence of events is from the atmosphere through rain to the land and hence to rivers and lakes. So for example sulphur dioxide emitted from power stations seems to react with traces of ammonia in the atmosphere to give ammonium sulphate which is dissolved by rain. Fortunately in this case the product is not only harmless but is positively useful as a fertiliser. However insecticides such as DDT migrate very effectively through the biosphere, and traces have even been detected in the Antarctic.

It is perhaps the heavy metals which give greatest cause for concern, since once emitted into the biosphere there is no way in which they can be recovered. It is fundamental to the treatment of unwanted by-products that *the more dilute the pollutant, the more difficult and costly its treatment.* It is obviously true of gaseous pollutants that once they have escaped into the atmosphere, only natural processes can lead to their removal. However at the point of discharge it may be possible to do something, as indeed can be done with vehicle exhaust. The same is also true of liquid effluents. A solution of a mercury salt at 10^{-3} M is readily treated to give quantitative removal of mercury, but at a thousand times greater dilution the problem is extremely difficult. This principle could be exemplified in many other ways, but the conclusion is always the same: *a pollutant must be treated before its discharge into the environment or not at all.*

Conclusions

From this analysis of the way in which pollution arises, we may distil the following general principles for its recognition, analysis and control.

1 Identify the system whose unwanted by-product is responsible for the trouble.

2 Enquire whether it arises from the imperfect operation of the system: if so, endeavour to improve its efficiency.

3 If it arises from an impurity in the input to the system, seek to remove it before it enters the system.

4 If neither of these procedures is technically or economically feasible, try to catch the potential pollutant at its point of entry into the environment. All safe disposal procedures depend on attaching another system to the first, so that the unwanted by-product does not enter the environment in an uncontrolled manner.

Finally it is important to remember that pollutants are always a form of waste. Common sense dictates that every effort should be made either to prevent its formation, or to use the waste for some useful purpose. In this way the control of environmental pollution is seen to be closely linked with the recycling of valuable commodities and hence connected with the conservation of global resources.

References

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บทคัดย่อ

อาจแสดงให้เห็นว่า ความสกปรกในสิ่งแวดล้อมเกิดขึ้นจากการทิ้งของเสียที่เกิดจากกิจกรรมของมนุษย์ ด้วยวิธีซึ่งทำให้เกิดผลลัพธ์ที่เป็นอันตราย หรือน่ารังเกียจ ความสำเร็จของมาตรการควบคุมขึ้นอยู่กับการดักของเสียก่อนที่จะเข้าสู่สิ่งแวดล้อม การหมุนเวียนนำของเสียกลับมาใช้ใหม่ทำให้ความสกปรกลดลง และช่วยอนุรักษ์ทรัพยากรของโลก