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A THERMODYNAMIC APPROACH TO THE KINETICS OF ENVIRONMENTAL POLLUTION

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Abstract: Environmental pollution is a social issue initiated by the people and they themselves are the victims. Both the physical and chemical aspects are linked to thermodynamic processes and a thermodynamic approach is very much relevant in environmental issues. The smaller the energy consumed the smaller is the pollution and the environmental impact. The energy that is spontaneously dissipated into the surroundings causes to a large increase in entropy or disorder of the environment. This energy may mechanically or chemically affect particles of the environment, though the organisms are unable to absorb the energy beyond certain specified spectral ranges. Furthermore, excess energy dissipated in any process becomes a pollutant as it affects the equilibrium of various material particles in the surroundings. Since environment also has an intrinsic value in relation to human beings, there emerges a moral obligation to protect the environment.

Keywords: Anthropocentricism, Entropy, Environmental Pollution, Equilibrium, Laws of Thermodynamics, Technological Optimism, Thermodynamics.

1. Introduction

Deterioration of environment is actually an unavoidable consequence of the human life. To some extent nature has the

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capacity to regenerate and restore its original state. When deterioration exceeds a limit, the environment is polluted. Environmental pollution may be defined as the addition of any substance or of energy (heat or sound) to the environment at a rate faster than at which the environment can accommodate it by absorbing, dispersing or breaking it down and that would harm humans and other organisms.[1] The pollution became enormous with the growth of technology especially with the changes caused in industrial machinery with the era of petroleum and related products. In spite of the steps taken by many nations and conscientization by many activists to protect the environment a harmonious shift in the equilibrium of the nature is yet to be achieved.

Environmental pollution is really a social issue. Knowingly or unknowingly its origin is human interference with the nature and eventually pollution affects negatively the life and wellbeing of humankind. Pollution may not be an outcome of deliberate intention to pollute the nature. But human vested interests and selfish desires nurtured by ignorance and quest for short term comforts pave way for pollution. The pollution is not pertaining to the properties of matter and energy and hence the problem and solution is not in the purview of pure Physics. The problem is related to our attitude and hence the solution also should come from our attitude. There are scientific, legal, political and social dimensions regarding environmental issues.

Environmental Studies is inherently multi-disciplinary.[2] For example, consider the topic effect of climate on air pollution; investigation on this requires knowledge of meteorology, thermodynamics, geography, mathematical modelling, etc. The interconnections are many.[3] Whatever be your field of study you will find some role for it in environmental studies, after all we all

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[1]Narayanan, *Environmental Pollution: Principles, Analysis and Control,* Bangalore: CBS Publishers and Distributors, 2011.

[2]Joseph Benny, *Environmental Studies*, New Delhi: Tata McGrawhill, 2010, 8.

[3]S. P. Misra and Pandey, *Essential Environmental Studies*, New Delhi: Ane Books, 2010.

live in the same planet and environment is everybody's concern. A study of the existence and behaviour of living and non-living components of environment requires inputs from Physics, Chemistry, Biology, Geology, etc. Human behaviour and management of human societies are covered by Sociology, Psychology, Economics, Political Science, etc. Of course, there are many other areas like computer science, statistics and mathematics, meteorology and oceanography which form part of environmental studies. There are local, national and international legislations in matters concerned with environment management. Agreements regarding common problems faced by two or more nations are under the purview of international laws.

Physics is the branch of science which deals with matter and energy and the Universe, as we know, consists of matter and energy. Any event is a matter-energy interaction. Matter and energy are inter-convertible. They are the two different forms of one and the same entity. Matter is the material that makes up our physical and biological environments. We are composed of matter. Energy, in a sense, is the ability to do work. The applications of Physics are very much relevant in environmental issues. From energy conservation issues in the development of energy saving materials to the challenge of disposal and storage of waste, the physical sciences are intrinsically involved.

From a very strict point of view of Physics, there is no pollution or pollutant or waste; because whatever that exists is matter and energy. However when certain physical changes affect the survival of living organisms we would consider it as pollution. Anything if placed out of context may become a pollutant. Practically it could be assumed when the equilibrium of a system is disturbed, it becomes pollution. Physical, chemical and biological factors that disturb the environment may be termed as pollution and the factors or substances, which cause deterioration, the pollutants. They may be in the form of solid particles, liquid droplets, gases or in a combination thereof. Environmental degradation is due to contaminants and pollutants arising out of transfer processes of matter and energy.[4]

2. Thermodynamics and Its Features

Thermodynamics, though it is generally considered as a part of Physics, is crucial, because it embraces physical, chemical, and biological energies. A system achieves thermodynamic equilibrium only when the three equilibriums – mechanical, thermal and chemical – are satisfied. Thermodynamics sets restrictions on any process where exchange of energy or matter occurs.

The main condition which supports the existence of life is the thermal state of the environment. There is an optimum range of temperature which favours the existence of living organisms as we understand now. The Earth is not heated uniformly by the sun. The thermal state is very much related to the differential heating from the Sun over the Earth's surface. This heating is the main driver for all atmospheric and oceanic circulations or currents. All life is governed by the laws of thermodynamics, which are fundamentally physical laws about energy. There are three fundamental laws: (i) the conservation of energy – energy is always conserved. It is neither created nor destroyed, but may be converted from one to another; (2) the increase in entropy – in any energy conversion, you will end up with less usable energy than you started with and (3) the *zeroth* law – absolute zero of temperature is unattainable.[5] In our discussions we are concerned with the first two laws.

Thermodynamics can be said as the science of energy transfer and its effects on properties of matter. A thermodynamic system is defined as a quantity of matter or a region in space chosen for study. The region outside the system is called surroundings. The real or imaginary surface that separates the system from its surroundings is called boundary. Any system with its surroundings constitute an unclosed system which

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[4]Narayanan, *Environmental Pollution*, 6.

[5]Keller Edward and Daniel B. Botkin, *Essential Environmental Science*, Delhi: Wiley, 2008, 70.

consists of fixed amount of mass, which is actually the working substance usually a gas or liquid enclosed in a cylinder and no mass may cross the system boundary but energy in the form of heat and work may cross the boundary. This mass or working substance is the medium through which the conversion of heat energy into mechanical energy occurs. The closed system with its boundaries may move. Examples of closed systems are sealed tanks and piston cylinder devices without valves. In a sense, the universe also can be considered as an example of closed system.

The ultimate source of energy for all environmental systems is the Sun. The energy that enters the Earth's atmosphere as heat and light is balanced by the energy that is absorbed by the biosphere, plus the amount that leaves the earth's surface as invisible heat radiation.[6] When solar energy strikes the earth, it tends to be degraded into heat energy. Only a small part of this energy gets absorbed by the green plants, and is subsequently transformed into food energy. The food energy then flows through a series of organisms in the ecosystems.

The natural tendency of any system is to maintain its equilibrium. Pollution occurs when the system loses its equilibrium. A system is said to be in thermodynamic equilibrium when it is free from any kind of extra force. The system is in thermal equilibrium when the temperature at all points of the system is the same. Similarly the system should maintain mechanical equilibrium (equality of forces or pressure) and chemical equilibrium (equality of chemical potential). In other words, there should not be any unbalanced force on the system. The conversion of energy from one form to the other can be explained with the first law of thermodynamics.

3. Low Consumption of Energy

Knowledge that energy can be converted from one form to another has led numerous would be inventors over the years to try building machines or devices that would produce more energy than they consumed. A common idea is to use the output

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[6]Kiran *et al*, *Understanding Environment*, London: Sage Publications, 2009, 34.

from a generator to drive a motor and that in turn to drive the generator to keep the cycle going and to yield additional power in the bargain. Unfortunately all such devices have one feature in common: they don't work. When all the inputs and outputs of energy are carefully measured, they are found to be equal. There is neither net gain nor loss in total energy. This observation is now accepted as a fundamental law, the law of conservation of energy, also called first law of thermodynamics.

According to the first law of thermodynamics, $Q_1 = Q_2+W$ where Q_1 is the heat energy originally supplied to the system, W is the work produced and Q_2 is the heat rejected.[7] Thermodynamic concern is efficiency which is given by the W/Q_1.[8] Consider the functioning of an automobile engine for which Q_1 is the heat energy supplied by the ignition of the fuel. This provides the mechanical energy (W) for the vehicle to move. But a portion Q_2 of the Q_1 will be dissipated as heat and sound to the surroundings. Q_2 should be small (for W to be high) from the point of view of efficiency as well as environmental pollution. For environment, the energy Q_1 also is a concern and it should be small as much as possible, because W the energy converted as useful work, also is transformed to some other forms of energy and will not be available for further work. W which is converted as mechanical energy of the vehicle will be dissipated into surroundings as heat energy due to the friction with the atmospheric air. A portion of the W causes wear and tear of the components of the machinery. Thermodynamic efficiency which is the ratio of output to the input doesn't take into account whether the magnitude of input is high or low. The smaller the Q_1 the smaller is the quantity of pollution and environmental impact for any given process. In processes which are designed for specific purpose there may be limitations to reduce energy consumption. Consumption of energy is inherent

[7]M. M. Abbottt and H. G. Van Ness, *Thermodynamics with Its Chemical Applications*, Noida: Tata Mcgrawhill, 2005, 9.

[8]Robert F. Mueller, *Thermodynamics of Environmental Degradation*, Washington, D.C.: Annual Meeting of the American Geophysical Union, 1971.

with technology. However, designing of projects with low energy consumption are not totally a hopeless subject. An obvious conclusion, though we are unable to think of, is that environment would benefit from the absence of technology. Consumption in the strict sense is impossible in the processes related to energy and hence a clarification is necessary.

4. Only Conversion; No Consumption

One should be aware of the fact that we do not and of course we cannot consume matter or energy. Both, matter and energy are conserved in any process. We just transform it from one form to the other. However, apparently there is consumption of energy. Otherwise no one can be asked to pay electricity bill or water bill. Since we make use of the energy in one particular form, it will not be available for further use in the same form, though actually there is conservation. Thermodynamics shows how to set balances for the conservation of mass and energy. Though not consuming, when we make use of matter and energy, their quality or usefulness is degraded. The degraded matter or energy may be restored to their initial conditions, but at the expense of some external energy source. From the first law of thermodynamics it is clear that total amount of energy in the universe does not change. This means that it is impossible to extract more energy from any system than the amount of energy that originally entered the system.

The Universe itself can be considered as thermodynamic system. We may consider a thermodynamic universe as an evolving non-equilibrium isolated system, comprising the Sun, the Earth, and background space. Though there has been exploitation of the environment right from the beginning of the human history, it was always a very direct one. The end-users, human beings, directly or indirectly exploit the environment in various ways. In the early stages it was non-deliberative and without the aid of any technology for their survival. Later, human creativity helped to develop machines that greatly increased the rate of exploiting natural resources and providing manufactured goods. The end-users appear to be an information consumer, since matter and energy are conserved. In TV broadcasting, though it is not a thermodynamic subject, there is no consumption of energy. But we 'consume' the TV signals or information. The transmitted signals from the stations, though they are packets of energy, cannot be made use in any way other than the detection at the receiver. We retrieve the signals using antenna and boost the signal by supplying additional energy.

According to the law of conservation of energy, in any physical or chemical change, energy is neither created nor destroyed but merely changed from one form to another. Here is a basic question that arises from the law: If the total energy is always conserved, if it remains constant then why can't we just recycle the energy inside our bodies and why can't it be recycled in ecosystems? For this to be possible, the system should be a closed one such as a biological perpetual motion machine. It could continue indefinitely without an input of any new material or energy. The law of entropy tells us that this is impossible. The second law of thermodynamics addresses how energy changes in form. It is a sad reality of our universe that energy always changes from a more useful, more highly organized form to a less useful, disorganized form. When an automobile engine works, the energy stored in the fuel is released for its functioning and dissipated to the surroundings in different forms and it cannot be gained back to the fuel or to any storage device. This means that energy cannot be completely recycled to its original state of organized high quality usefulness. Whenever useful work is done, heat is released to the environment and the energy in that heat can never be completely recycled. The amount of usable energy gets less and less.

The net flow of energy through an ecosystem, then, is a one way flow, from source of usable energy to a place where heat can be released. An ecosystem must lie between a source of usable energy and a sink for degraded energy. The ecosystem can be viewed as an intermediate system between energy source and the energy sink. The energy source, ecosystem and energy sink together form thermodynamic system.

An ecosystem is the simplest entity that can sustain life. At its most basic, an ecosystem consists of several species and a medium of air or water or both. The ecosystem must sustain two processes, the cycling of chemical elements and the flow of energy. Ecosystems are real and important. It is often difficult, however, to define the limits of a system or to pinpoint all the interactions that take place because natural ecosystems, for example, a pond or a forest, are not isolated ones. They are connected to other ecosystems like paddy fields or mountains. But when we manage or domesticate individuals or populations, we separate them from their ecosystems. Then we must replace the ecosystem functions of energy flow and chemical cycling with our own efforts. This is what happens in a zoo, where we must provide food and remove the wastes for individuals separated from their natural environments.

5. Excess Energy and Pollution

From the first law of thermodynamics, it is clear that every time energy is transformed from one state to another, there is a loss in the amount of energy that was available to be converted into work. When the magnitude of the loss increases efficiency decreases. This loss of energy is entropy, given by Q_2/Q_1, which is an outcome of the second law of thermodynamics. It is postulated that the total entropy in the world is constantly increasing. As entropy increases, the amount of available usable energy decreases. Entropy brings a balance in creation. When there is creation of new states, there is dissolution of other states to create balance. There is no danger in it as it is an inherent part of any natural process.

Environmental concern is the energy that is spontaneously dissipated into the surroundings and therefore corresponds to a large increase in entropy or disorder of the environment. This energy leads to a chaotic scenario in the distribution of various types of particles in the environment and breakage of chemical bonds in materials. The dissipated energy cannot be gathered or focused to some point for a useful work. Organisms on the other hand require energy of certain definite types in certain spectral ranges. Furthermore they have adapted to absorb the energy required for them mostly from sunlight. Though not always by human purposeful interventions, natural materials acquire energy in excess of what they would possess. In this way, practically, any material may become a pollutant. This could be illustrated with a simple example though not a thermodynamic one. Water and soil in natural areas are not pollutants. Due to deforestation, the top-soil as well as the sub-soil becomes disturbed. When the surface is depleted of leaves, the energy of the falling water will not be dissipated easily, and the particles of the top-soil absorb this energy. This make them move and they transfer the energy to other particles and finally result in soil erosion, landslide, etc.

The principle that underlies the loss of heat is the principle of increasing entropy. Entropy refers to the degree of disorder: Increasing entropy means increasing disorder. The principle is that without energy inputs, everything goes in one direction only: toward increasing entropy. This principle of ever increasing entropy is most readily apparent in the fact that all human made things tend to deteriorate. The conversion of energy and the loss of heat are both aspects of increasing entropy. Heat energy is the result of random vibrational motion of atoms and molecules. Thus it is the lowest form of energy and its flow to cooler surroundings is a way for that disorder to spread. Therefore the second law of thermodynamics is nowadays more generally stated as: a system will go spontaneously in one direction only – toward increasing entropy. Thermodynamic concern is not only the energy which is not available for further use but the matter which becomes waste and remains useless.

6. Technological Optimism

Technological optimists think that technology can solve all the issues related to environment.[9] For example the shortage of food can be rectified by increasing the productivity of agricultural

[9]Andreu D. Basiago, "The Limits of Technological Optimism," *The Environmentalist* 14 (1994), 17-22.

land. Improved seeds, fertilizers and irrigation methods shall contribute much to the productivity. If the environmental quality is threatened by pollution more effective pollution control devices can be invented. Though the claims are apparently convincing, technology has limitations. Technology by nature results in environmental pollution and hence technological solutions also may have certain side effects. In many cases it is just a matter of avoiding local effects by moving from one place to another. Dumping the waste materials to some location is not actually pollution control. Certain cases where recycling is done, there are possibilities of forming poisonous gases or similar pollutants.

Technological solutions are mostly like stop gap arrangements. This is obvious with the issue of waste generated as a part of industrial process. The waste in any process is equal to the amount of natural resources used. This equivalence can be explained with the first law of thermodynamics and law of conservation of mass and energy. In order to reduce the waste, one possible solution is to reduce production. All the matter used will turn as waste at one or other stage. So it is commendable if the products are designed as naturally degradable or decaying. The question remaining is whether the waste is fit for recycling.[10] If recycling or decaying is impossible the waste remains as matter which is not available for any further action and will be a liability for the future. Most of the plastic utensils and electronic equipments will gradually fall into this category. Technology seems helpless in proposing a radical solution for disposing the plastic as well as electronic waste.

Here the concern is not whether technology can fix problems of climate change or similar issues by finding ways to pull carbon out of the atmosphere or develop non-polluting energy sources. The question is about how well technology can compensate for the loss of various natural goods and services by

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[10]Miller and Spoolman, *Introduction to Environmental Science*, New Delhi: Cenage Learning India Private Limited, 2009, 46.

supplying alternative artificial replacements.[11] If the optimists are right, then the future people's interests will not be harmed by our present activities. But such an expectation seems baseless in the context of the already noted problems in our environment.

Climate change is likely to be the defining environmental problem of the twenty first century. Increasing scientific evidences suggest that the impacts of warming will be more serious and will occur sooner than had previously been believed and several studies have suggested that temperature stabilisation at or below 2^{0}C above pre-industrial temperatures is an essential requirement.[12] Warming above this level would likely cause large areas of Greenland ice sheet to melt, the West Antartic ice sheet at substantial risk and widespread disruption of global ecosystems. 0.8^{0}C warming has already been realized and the world is close to a threshold level of climate change that could be considered dangerous. There is no technological solution for this problem as any technology in this regard in industry would generate the gases which contribute to global warming.

7. Moral Obligation

Environment may be defined as everything that is not me. It is the natural world in which people, animals and plants live. The study of environment is confined to the system of interacting living and non-living components. The philosophical question involves the moral question: why is it morally wrong to pollute and to destroy the environment? If that is wrong, is it simply because a sustainable environment is essential to human wellbeing? Or is such behaviour also wrong because the natural environment and its denizens have certain values in their own

[11]Brennan Andrew and Lo, *Understanding Environmental Philosophy*, Durham: Acumen Publishing Ltd., 2010.

[12] Frances C Moore, "Climate Changes and Air Pollution: Exploring the Synergies and Potential for Mitigation in Industrializing Countries" in Linda Goldstein, ed., *Environmental Pollution Control*, Oakville: Apple Academics, 2010, 73-84.

right which ought to be respected and protected?[13] The distinction between instrumental value and intrinsic value is of central importance in answering these questions. Instrumental value is the value that the things have in virtue of being a means or instrument to service some other ends. Intrinsic value in the sense of non-instrumental value is the value that things have as ends in themselves, that is in their own right and regardless of whether they are useful as means to other ends. As an example a herb may have instrumental value because it provides the ingredients for some medicine. It may have an instrumental value as an aesthetic object for human observers. But the plant also has some value in itself, as it contains life, independently of its prospects for furthering some ends such as human health or the pleasure from aesthetic experience, it has intrinsic value. The intrinsically valuable is good as an end in itself. So it is commonly agreed that something's possession of intrinsic value generates a moral duty on the part of moral agents to protect it, or at least to refrain from damaging it. It is not because of the fact that environment is essential for the existence of the human being. Rather than a necessity, we must see that we are integrated to the environment. We are not complete in ourselves. The environment also has a role in moulding our personality. At the same time speaking about the environment is meaningless if there are no humans. So without humans the environment also is not complete in itself. There is mutuality between the environment and the human beings. From a Christian religious point of view human beings are created in the image and likeness of God. Anthropocentricism views human beings as the centre of ethical concern and the environment is seen as a useful resource. Non-anthropocentrism does not place human beings above or below other beings and it attaches intrinsic value to the human beings as well as non-humans. Ignoring the contrivance between the two views, it is obvious that humans have intrinsic value. If human beings have an intrinsic value, there is no doubt

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[13]Brennan Andrew and Lo, *Understanding Environmental Philosophy*, Durham: Acumen Publishing Ltd., 2010.

the environment or ecosystem where they are an integral part, also must have an intrinsic value. So we have moral obligation to protect our environment. The intrinsic value of the non-humans is relative to that of humans as values are human centred.

8. Conclusion

It could be said that the advent of heat engines resulted in industrial revolution and it contributed much to the human progress. Heat engines have the potential to generate huge amount of work. The engines are powered by oil, gas or nuclear fuels. In spite of the contribution to the industrial revolution, mostly in material aspects, the engines caused very much to the pollution of the environment as they are fuelled by oil, gas or nuclear material. The impact of such fuels may not be confined to the particular region or township where the engine is operated. The effects of these activities spread in a global scale. Here one possibility is to continue with the present technological advancements and try to combat the issues when arise, according to the technological solutions itself. Today's solution may be a part of tomorrow's problem. The other one is to go back to the nature, minimise industrial production and try for products which are more eco-friendly. In the present scenario choosing the latter is environmentally justifiable, because technological solutions are prone to further problems. When a new project is implemented a comprehensive resource expenditure survey and analysis are essential. This should cover all the aspects of the project. This should take into account of the output product as well as the wear and tear of the various components. This kind of an approach is applicable to the pollution control programmes also. Since the dissipated energy may spread widely, provision for harmless dissipation of energy could be worked out and implemented.

To conclude, it could be said that the following steps would reduce pollution (i) limiting of industrial production. When production is limited, naturally consumption of energy would be reduced. The industrial production as whole cannot be stopped. But there need a re-thinking on chemical fertilizers, cosmetics etc. This could be realized only when the society becomes convinced of the evils of consumerism. (ii) Development of low power consumption technology like LED lamps reduce pollution. (iii) Design of naturally degradable or re-usable products as that jute or paper instead of plastic bags. Recycling of certain plastics and polymers may not be successful. But ceramic and glass based utensils could be recycled. (iv) social awareness. Since we are endowed with free will, it is our own convictions and attitude that matters in all the three steps mentioned before. Whatever be the technology and policy we adopt, finally the results depend on our free will.