SOLAR ENERGY, POWER GENERATION AND DESALINATION SYSTEMS

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Contents

Summary

This chapter initially examines the interaction between energy related problems and the role of renewables in helping to reduce the impact of those problems. These are analyzed

in terms of the energy demand and on the factors affecting it, then energy generated environmental problems are investigated in view of sustainable development. This is followed by an examination of the water demand and consumption, the relation of water and energy, the energy related to desalination and how renewables can be used to reduce associated risks. As the chapter deals with power generation and desalination, the high-temperature solar collectors that can be employed in these systems are presented which include the parabolic trough, Fresnel, parabolic dish reflector and heliostat field collectors. Subsequently, power generation and industrial process heat systems are presented which include the high-temperature collector systems as well as solar ponds, which are low temperature systems. In industrial process heat systems the basic concepts are presented as well as the solar industrial steam generation systems. The final section of this chapter presents the direct and indirect desalination systems. The direct systems refer to desalination units that collect the solar energy and produce fresh water in one piece of equipment whereas in the indirect systems two such sub-systems are employed, one for solar energy collection and one for desalination. The desalination systems presented under the indirect systems include the multi-stage flash process, the multiple-effect distillation process, the vapor compression process, reverse osmosis and electrodialysis. The first three belong to the vapor or phase change processes whereas the last two belong to the membrane processes. In all cases the way renewables can be used to power the desalination systems are indicated.

1. Global Energy Problems and the Role of Renewables

In this section the global problems related to the use of energy are presented. In particular the energy demand, the environmental problems related to energy and its effect on sustainable development are presented as well as an analysis of water demand and its relation to energy consumption, desalination and energy consumption, and the role of renewables in both power and desalination systems.

1.1. Energy Demand

In 2010 the world daily oil consumption has reached an all time high record of 87.4 million barrels and despite the environmental problems related to energy use, this is expected to increase further in the next years. There are a number of factors which are significant in the estimation of the future level of the energy consumption and production. The main factors are related to the population growth, fuel prices, consumer tastes and technological developments. Furthermore, governmental policies concerning energy and developments in the world energy markets will be the key factors that will determine the future level and pattern of energy production and consumption.

In the mid 1980's, 25% of the world population consumed 70% of the total energy supply, while the remaining 75% of the population were consuming the rest 30%. If the whole earth population has the same consumption per inhabitant, similar to the one that the Organization for Economic Co-operation and Development (OECD) member countries have on average, it would result in an increase from the mid 1980's world energy demand of 10 TW to about 30 TW. An expected increase in the population from 4.7 billion in mid 1980's to 8.2 billion in 2020 would even raise the figure to 50 TW or more.

The world total primary energy demand increased from 19,345 GTOE in 2002 to 11,235 GTOE in 2007, which represents an average annual increase of about 2%. A Ton of Oil Equivalent (TOE) is equal to 41.868 GJ. In more recent years however the average worldwide growth was higher and from 2001 to 2004 reached 3.7%, while the increase from 2003 to 2004 was 4.3%. The main reason for the rapid rate growth is due to the energy consumption in Pacific Asia which recorded an average increase from 2001 to 2004 of 8.6%.

The major sectors of the economy spending the majority of primary energy sources include electricity generation, transportation, domestic heating and cooling, and industrial. The International Energy Agency (IEA) data reveal that the electricity demand almost tripled from 1971 to 2002. This is due to the fact that electricity is a very "convenient" form of energy to transport and use. The relative share of primary energy for electrical power production in the world increased from about 20% in 1971 to about 30% in 2002 and this is due to the fact that electricity is becoming the preferred form of energy for most applications.

Due to the high increases in China and India, worldwide energy consumption would continue to increase at rates between 3% - 5% for at least the next few years. It is believed however that such high rates of increase cannot continue for many years. This is because even at a 2% increase per year, the primary energy demand of 2002 would double by 2037 and triple by 2057. Therefore, with such high energy demand expected in the next 50 years, fuelled also by the world population explosion, it is important to look at all available strategies to satisfy the future demand, especially for electricity and transportation.

Transportation is at 95% oil based. Therefore, the available oil resources and the oil price will influence drastically the future changes in transportation. Possible replacements for oil would be biofuels such as ethanol, methanol, biodiesel and biogas. Additionally, hydrogen can also provide a clean transportation alternative for the future if it can be produced economically and without causing environmental pollution from renewable energy sources.

Natural gas use is already established and this will be used at rapidly increasing rates to make up for the deficit in oil production; however, this also may not last much longer than oil at the expected higher rates of consumption. At the moment, coal is the largest fossil resource available but is also the most problematic due to environmental concerns. Despite this, coal use is expected to continue to grow, especially for power production because of increased use mainly in China, India and Australia. This could create many problems from the environmental point of view, unless advanced clean coal technologies (CCT) with carbon sequestration are not deployed.

1.2. Energy, Environmental Problems and Sustainable Development

Energy is considered as the most significant factor in economic development. After the oil crisis, at the early seventies, the concern was on the cost of energy, during the past two decades however the problems associated with environmental degradation are more apparent. These energy related environmental problems are due to a combination of

several factors such as the increase of the world population and the consequent energy consumption, and the expansion of the industrial activities. Many scientists now realize that the possible solutions to environmental problems would require long-term actions for sustainable development. As part of this, the dependence on renewable energy resources appears to be the most effective solution.

Another parameter to be considered is the world population. By the end of 2011 the world population reached 7 billion and with the current rate of increase it is expected to double by the middle of this century. As economic development will continue to grow, the global demand for energy is expected to increase.

Until recently, only conventional pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulates, and carbon monoxide (CO) were considered in environmental analysis. Recently however, carbon dioxide (CO_2) and hazardous air pollutants, which are toxic chemical substances which are harmful even in small doses, are considered in such analysis. In fact carbon dioxide, which is a greenhouse gas, plays a vital role in global warming, being responsible for about two-thirds of the greenhouse effect as fossil fuel combustion is the most significant contribution to the CO_2 emitted to the atmosphere.

If humans keep degrading the environment, the future of our planet and of the generations to come will be negatively impacted. The three environmental problems that are today well known are:

- **Global climate change:** Greenhouse effect refers to the role of the atmosphere to keep the surface of the earth warm. During the last years however, it is increasingly associated with the contribution of various gases such as CO_2, CH_4, CFCs, halons, N_2O, ozone and peroxyacetylnitrate in rising the earth's temperature. These are produced by the industrial and domestic activities. Increasing atmospheric concentrations of these gases, called greenhouse gasses, increase the amount of heat trapped by decreasing the heat radiated from the earth's surface, so as the surface temperature of the earth is raised. Today there is an agreement among the world's leading climate scientists that global warming is caused mainly by CO_2 and other gases emitted by human activities, such as from fossil fuel combustion, methane emissions and CFC releases.
- **Ozone layer depletion:** The ozone that exists in the stratosphere plays a natural equilibrium-maintaining role for the earth, through absorption of ultraviolet (UV) and infrared radiation. A global environmental problem the planet is facing today is the depletion of the stratospheric ozone layer caused by the emissions of CFCs, halons and NO_x. The depletion of ozone layer can lead to increased levels of damaging UV radiation reaching the ground, causing eye damage to humans and increasing the rates of skin cancer. Energy related activities are directly or indirectly responsible for the emissions which lead to stratospheric ozone depletion. CFCs have the most significant role in ozone layer depletion, mainly used as refrigerants in air conditioning and refrigerating equipment, as well as NO_x emissions produced mainly by fossil fuel combustion.
- **Acid rain:** This is a form of pollution in which NO_x and SO_2 produced by the combustion of fossil fuels are moved over long distances in the atmosphere and

precipitated on the earth as acid rain. Therefore, the solution to the problem of acid rain requires the control of NO_x and SO_2. These kinds of pollutants cause both regional and trans-boundary problems and energy-related activities are the major sources of acid precipitation. As acid precipitation depends on energy consumption, the easiest way to reduce its effect is by reducing energy consumption.

The first attempt to address the environmental problems humanity is facing and to address the challenges of achieving worldwide sustainable development was the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, in June 1992. From this meeting it was concluded that the goal of sustainable development cannot be realized without major changes in the world's energy system. Therefore, *Agenda 21,* which was the most important outcome of this meeting and which was adopted by UNCED, called for "new policies or programs, as appropriate, to increase the contribution of environmentally safe and sound and cost-effective energy systems, particularly new and renewable ones, through less polluting and more efficient energy production, transmission, distribution, and use." Agenda 21, which is also called the Rio declaration on environment and development, was adopted by 178 governments. The Agenda is in fact a comprehensive plan of action that needs to be taken globally, nationally and locally by organizations of the United Nations System, Governments, and Major Groups in every area in which human impacts on the environment. Sustainable development is a serious policy concept and can be considered as development which must not carry the seeds of destruction because such development is unsustainable.

Today, one of the main factors that can help to achieve sustainable development is energy and the requirement for a supply of energy that is fully sustainable. To achieve sustainable development within a society it is required to secure a sustainable supply of energy and achieve an effective and efficient utilization of energy resources. It is obvious that in the long term such a supply should be readily available at reasonable cost, be sustainable and able to be utilized for all the required tasks without requiring major infrastructure development and causing negative societal impacts. Such capabilities are offered by most renewable sources of energy and this is why these are closely connected to sustainable development.

1.3. Water Demand and Consumption

Water is the most important element together with the sun to sustain life on earth. The provision of clean water is becoming an important problem for many places of the world. As its name implies, in arid areas, potable water is very scarce and as it can easily be understood, the establishment of a human habitat in these areas strongly depends on the way fresh or clear water can be provided. Humanity has been dependent on rivers, lakes and underground water for the clean water requirements in domestic life, agriculture and industry. During the last decades however, the worldwide population explosion on one hand and the rapid industrial growth on the other resulted in a large escalation for clean water demand, mainly for use in the production of adequate quantities of food to satisfy the increased population. In addition to this there is also the problem of pollution of rivers and lakes by industrial wastes and the large amounts of sewage discharged, again due to the increased population. Actually, on a global scale, man-made pollution of natural

sources of water is becoming the largest cause for clean water shortage. Another problem is that of uneven distribution as for example, countries like Canada which have a tenth of the world's surface fresh water are inhabited by less than 1% of the world population.

The distribution of the water resource is also a major issue with about 70% spent by agriculture, about 20% by the industry and only about 10% is used in households. Water conservation measures are nowadays considered for many applications. One of the most effective examples is drip irrigation, developed in the early 1960's, using perforated plastic pipes to deliver the water to crop roots which uses 30-70% less water than traditional methods and results in an increase in crop yield. Despite its advantages until today this system is used in less than 1% of the irrigated land. This is due to the heavy subsidization to irrigation water applied in many places on the earth, and as a result farmers have no incentive to invest in drip systems or other water saving methods.

1.4. Water and Energy

The importance of supplying clean potable water can hardly be overstressed. Water is an abundantly available resource on earth, covering three-fourths of the planet's surface. About 97% of the earth's water however is salt water in the oceans and only 3% is clean water, which supply most of human and animal needs. This is contained mainly in the poles as ice, ground water, lakes and rivers. Nearly 70% from this tiny 3% of the world's clean water is frozen in glaciers, permanent snow cover, ice and permafrost. Moreover, about thirty percent of all fresh water is underground, most of it in deep, hard-to-reach aquifers. Lakes and rivers altogether contain just a little more than 0.25% of all fresh water.

Water and energy are two inseparable commodities. The history of mankind proves that water and civilization are two entities which are highly related. It is a well known fact that all great civilizations were developed and flourished near sources of fresh clean water. Historical records prove the importance of water in the preservation of life and development of the civilization. The most typical example of this influence is the Nile River in Egypt which provided water for irrigation and mud full of nutrients to raise crops. Ancient Egyptian engineers were able to master the river water and Egypt, as a major agricultural nation at the time, became the main wheat exporting country in the whole Mediterranean Basin.

Energy is as important as water for the development of good standards of life as it is the source that powers all human activities. Water is also by itself a power generating force in the form of hydraulic power. The first attempts to harness hydraulic power are reported more than 2 millennia ago and the energy gained was mainly used to grind grain.

1.5. Desalination and Energy

The only practically inexhaustible source of water is the oceans, which however have high salinity. Generally, a way that was always thought would be probable to tackle the water-shortage problem is with desalination of this water, meaning the process required to remove salt from seawater or brine water.

World Health Organization (WHO), specified that the permissible limit of salinity in water is 500 parts per million (ppm) but for some special cases up to 1000 ppm can be accepted. Most of the water quantities available on earth have salinity of about 10,000 ppm in the form of total dissolved salts, and this water is called brine water, whereas seawater has salinity in the range of 35,000–45,000 ppm. Excess brackishness of consumed water except from the problem of taste, causes stomach problems and laxative effects. The function of any desalination system is to purify or clean saline water and provide fresh water with total dissolved solids within the permissible limit of 500 ppm or less. This is achieved with several desalination methods that will be described later in this chapter.

All manmade desalination processes require large quantities of energy to achieve separation of salts from seawater. This factor is very important as it is a repeated cost, which very few of the water-problematic areas of the world can afford. One exception is the countries of the Middle East, which because of their oil income, have the necessary money to invest in desalination equipment and the oil as the energy input to run these systems. In many other areas of the world the governments have neither the cash nor the oil resources to develop in a similar manner. The installed capacity of desalinated water systems in year 2010 is about 60 million m^3/day. Due to the continuing problems of climate change this is expected to increase significantly in the next decades. The increase of desalinated water supply will unavoidably create a series of problems, the most significant of which are the increased energy consumption and environmental pollution caused by the use of fossil fuels which creates a chain reaction as this is the reason why more desalinated water is required. It has been estimated that the production of 60 million m^3/day requires about 495 million tons of oil per year. Therefore, due to the environmental problems related to the use of fossil fuels, it is questionable whether we could afford to burn fuel on the scale needed to provide everyone with fresh water even if oil was much more widely available. As was seen above, if desalination is accomplished by conventional technology, then it will require substantial quantities of fossil fuels. Thus, apart from satisfying the additional energy demand, environmental pollution would be a major concern and sources of energy that are not polluting will have to be employed. Fortunately, there are many parts of the world that suffer from water shortage problems but have abundant renewable sources of energy that can be used to operate desalination processes.

In principle, solar desalination is the process applied in nature to produce rain, which remains the main source of fresh water supply worldwide. In this process, solar radiation falling on the surface of the sea is absorbed and converted into heat which causes evaporation of the water. The vapor thus created rises above the surface of the water and is moved by winds. When this vapor is cooled down to its dew point, condensation occurs and fresh water precipitates as rain. In fact, all available man-made distillation systems are copies to a small-scale of this natural process.

It is a well recognized fact that desalination is one of the main ways to produce fresh water to meet the demand. Renewable energy systems which produce useful energy from sources that are inexhaustible and freely available in nature, are friendly to the environment, and they do not produce any harmful effluents. Therefore, fresh water production using desalination technologies driven by renewable energy systems are

considered to be a possible solution to the water shortage problem at remote areas which are characterized by lack of potable water and conventional energy sources or electricity grid.

Today, several renewable energy desalination pilot plants have been installed worldwide and the majority of them have been operated successfully for many years. All of them are custom designed for the specific location and harness solar, wind or geothermal energy to produce fresh water.

Although at the moment renewable energy powered desalination systems cannot compete with conventional systems with respect to the cost of water produced, are likely to become more widely feasible solutions in the near future by considering the increased cost of fuel as its reserves are depleted and of course the environmental problems related to its use should never be underestimated.

This chapter presents a description of the industrially matured methods used for seawater desalination. The chapter is also focused on the use of renewable energy systems in desalination.

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Biographical Sketch

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