ENVIRONMENTAL BENEFITS OF USING PARABOLIC TROUGH IN SOLAR THERMAL POWER PLANTS

PARASCHIV SPIRU, PARASCHIV SIMONA LIZICA

"Dunarea de Jos" University of Galati, ROMANIA

Abstract
Concentrating solar power (CSP) to generate bulk electricity is one of the technologies best suited to helping to mitigate climate change in an affordable way, as well as reducing the consumption of fossil fuels. Life-cycle assessment of the emissions produced, together with the land surface impacts of CSP systems, shows that they are ideally suited to the task of reducing greenhouse gases and other pollutants, without creating other environmental risks or contamination. Each square meter of CSP concentrator surface, for example, is enough to avoid annual emissions of 200 to 300 kilograms (kg) of carbon dioxide, depending on its configuration. Most of the CSP solar field materials can be recycled and used again for further plants.

Keywords: parabolic trough, environmental benefits, greenhouse gases, climate change, solar thermal plant, emissions reductions, solar power,

1. WHY SOLAR THERMAL POWER PLANTS?

One of the most controversial public debates of the last decade has addressed the effects of energy-related emissions on the environment. Serious and widespread recognition and alarm have centered on air quality and, in a more global context, the greenhouse effect and the destruction of the protective ozone layer of the earth's atmosphere from CO2 and other gases.

Air quality is primarily affected by SO2 and NOX emissions, which cause acid rain and smog. A focal point of the debate has been future energy supply strategies, including the use of environmentally benign energy conversion technologies. Key issues have been the future role of nuclear energy and the strong public desire to rapidly introduce renewable energy technologies on a large scale to ensure sustainable energy growth without harmful societal impacts.

The promise of renewable energy to play a major role in the solution of the environmental crisis has elements of both reality and myth. Renewable technologies such as solar power and wind energy are synonymous with the desire for an environmentally responsible energy supply. Nevertheless, at present solar and wind contribute only marginally to the world's electricity production.

Whereas photovoltaic power generation is often viewed by the public as the emerging solar technology, it is in fact other renewables - notably wind energy, biomass and parabolic trough solar thermal power plants - which produce far more power today.

More than 70% of the present production of the world's electricity produced directly by solar radiation is generated by solar trough plants in the California Mojave desert. The promise of renewable energy to solve the environmental crisis has elements of both myth and reality - we argue that solar trough plants have the potential to regionally displace significant fossil-fired power generation.

2. THE EVOLUTION AND DIMENSION OF GLOBAL ENERGY DEMAND

As a result of the public concern about energy-related emissions, it is generally acknowledged that a key objective of global energy policies should be a significant reduction of emissions, specifically of the greenhouse gas CO2. Note, in particular, the creation of the important Global Environment Facility (GEF) at the United Nations Conference on Energy and Development (UNCED) in Rio de Janeiro in 1992 with the goal of supporting the implementation of energy efficiency measures and renewable energy technologies. In addition, the World Bank has proposed a “Solar Initiative” to support the initial market entry of renewables. In actuality, however, global trends are contrary to the goal of emissions reductions, with data showing an increasing level of CO2 emissions driven by a strong growing demand in primary energy. The World Energy Outlook of the International Energy Agency (IEA) gives an insightful picture of energy growth expectations over the next 1-1/2 decades.

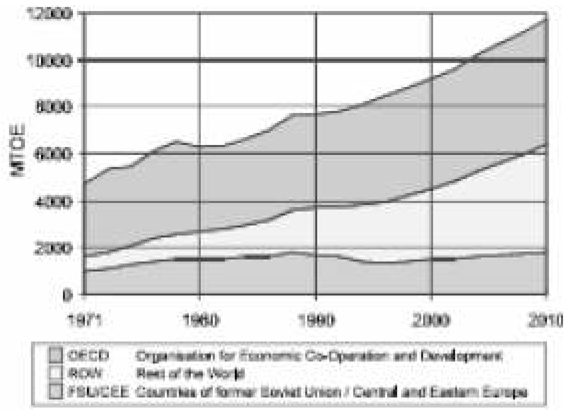

Fig. 1 World Total Primary Energy Demand Evolution (in Million Tons of Oil Equivalent - MTOE)

The dimension of the energy need, specifically for the developing world and the emerging southeast and east Asian markets, emphasizes the critical importance of tackling the greenhouse effect. By 2010, the world will be consuming 48% more energy than in 1991 (Figure 1-1). The increase in energy use forecast for the rest of the world is expected to be even more pronounced than in the OECD. In these countries, particularly in China and the dynamic economies of East Asia, the average annual growth in energy use during this period could be more than 4% per year. (Figure 1-2)

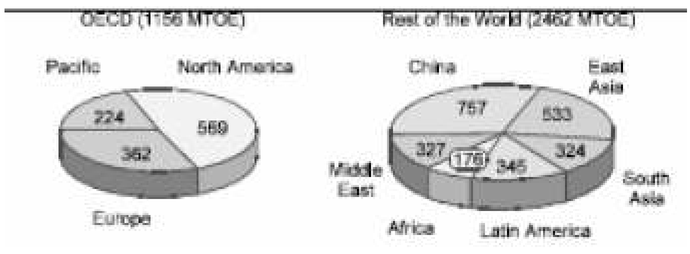

Fig. 2 Incremental Primary Energy Demand 1991-2010 (in Million Tons of Oil Equivalent)

Electricity is the most rapidly growing form of end-use energy with an increase of about 70% at the end of the time horizon. In many countries, the growth of electricity will keep pace with or exceed GDP growth. Figure 1-3 shows electricity demand growth by fuel category.

Fossil fuel based generation capacity will grow faster than power generation from nuclear and hydro in the OECD countries due to limited expansion possibilities, specifically caused by permitting problems for nuclear and a saturation in the development of hydro electric power. In the rest of the world, incremental electricity demand will be mainly met by fossil fuels.

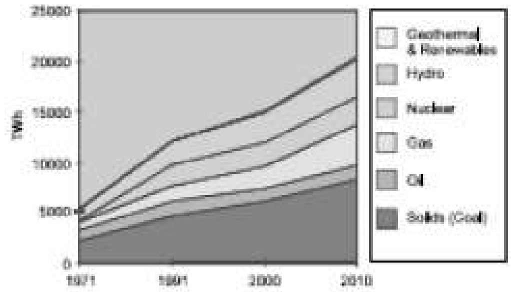

Fig. 3 World Electricity Demand Evolution by Type of Fuel

The modern development of renewable and specifically solar energy technologies in the 1970's began as a result of the finite availability of fossil fuels, specifically crude oil and natural gas. Today's global energy economy will continue to rely predominantly on fossil fuels through the first decades of the next millennium.
Under static conditions of increase in demand and production, fluid hydro-carbon reserves of oil and gas will be exhausted in 4 and 6-1/2 decades, respectively, at today's depletion rate and price level (Fig. 4).

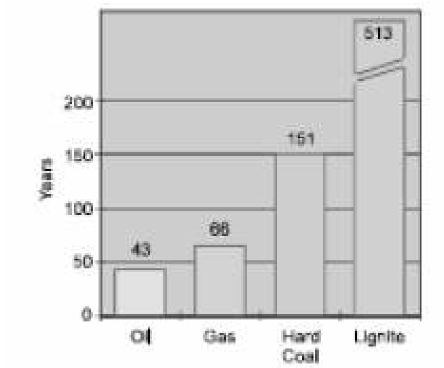

Fig. 4 Range of Global Reserves of Fossil Fuels at Current Depletion Rates

These reserves can be prolonged when using so-called unconventional primary resources like shale oil, oil tar and bituminous oil reserves.
The other huge fossil reserve, coal, will last about 200 years or so but its use contributes to the greenhouse effect. Specific CO2 emissions for coal are 30 to 80% higher than for oil or gas, respectively. One strategy proposed to reduce these emission levels is coal gasification, with the gas being used in efficient combined cycles. However, gasification does not alleviate the specific CO2 emissions issue, and the use of gasified coal in combined cycles is less effective by about 10 percentage points than the use of natural gas. Hence coal is expected to play a less dominant role in a future environmentally-driven energy supply scenario.
In such a scenario, coal will regain dominance if oil and gas supplies become scarce and renewables have not gained extensive use. Once the liquid fossil fuels are exhausted coal liquefaction might become of strategic importance. With rising price for fossil fuels over the next 1-2 decades, renewable technologies will become increasingly competitive.

2. SOLAR ENERGY SYSTEMS
2.1 THE SOLAR RESOURCE

Of the sun's rays, which pass through the earth's atmosphere to the ground, a portion is scattered by particles or clouds. The intensity of solar radiation outside the atmosphere is about 1.3 kW/m². Even though only a fraction of this actually hits the earth's surface, the magnitude of the energy from this source is enormous. Consider, for example, that utilizing only 1% of the earth's deserts and applying a conversion efficiency of 15% to produce electric energy would develop more electricity than is currently produced worldwide by fossil fuels. This is not practical given the need to distribute the electricity to users around the world, but it does highlight the magnitude of this resource. Solar radiation is abundant ¾ solar power stations built on the equivalent of only 1% of semi-arid or arid lands could in theory supply the world electricity needs.

Technically speaking global radiation, which includes all radiation energy incident on surface, is comprised of a diffuse (scattered) component and a direct normal component (the part coming undisturbed directly from the sun). Fig. 5 illustrates the definitions of Global, Diffuse and Direct Normal Radiation (DNR).

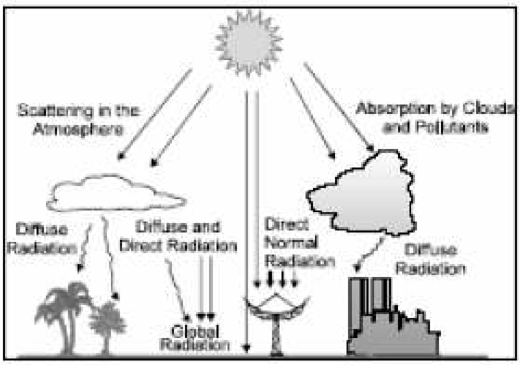

Fig. 5 Direct Normal, Diffuse and Global Radiation

Because the sun is an intermittent resource, its energy is not available throughout the day and seasonally with the same intensity. The angle of the sun's rays relative to the earth's surface changes during the day and with the seasons. The sun is low in the sky in winter, which results in a lower energy flux and causes air temperatures to drop. In summer, the sun is overhead and the energy flux is high. Radiation levels are affected by both weather conditions and the length of the path traveled by rays through the atmosphere.

2.2. PARABOLIC TROUGHS

Parabolic troughs consist of long parallel rows of identical concentrator modules – typically glass mirrors - that are curved in only one dimension, forming troughs. Tracking the sun from east to west while rotating on a north-south axis, the trough focuses the sun's energy on a pipe located along it's focal line (Fig. 6). Troughs can also rotate on an east-west axis but such systems normally yield less annual energy; however, the output tends to be seasonally more uniform. A heat transfer fluid, typically oil at temperatures up to 400°C, is circulated through the pipes and then pumped to a central power block area, where it passes through a heat exchanger. The oil's heat is then passed to a working fluid, such as water or steam, which is used in turn to drive a conventional turbine generator. Several commercial units with sizes up to 80 MWe were put into operation with peak net electric efficiencies of 23%.

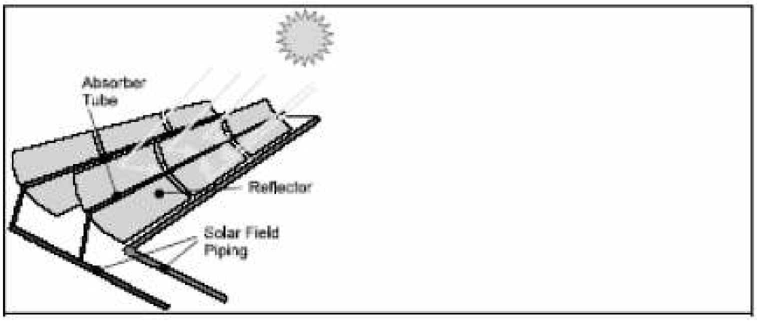

Fig. 6 Trough Principle

Parabolic trough solar fields can supply steam to power plant systems, essentially fulfilling the role of a solar boiler in contrast to fossil fuel-fired boilers. The nature of the intermittent solar energy source is such that the maximum full load operating hours to be expected is about 2,400 hours annually. For this reason it makes good technical and economic sense to choose a power plant configuration that can run on fossil fuel for many additional hours in the year. Plants with the capability to run on solar energy and/or fossil fuel - are called hybrid plants and the main fuel used is solar radiation. Fig. 7 shows a schematic diagram of a typical plant configuration.

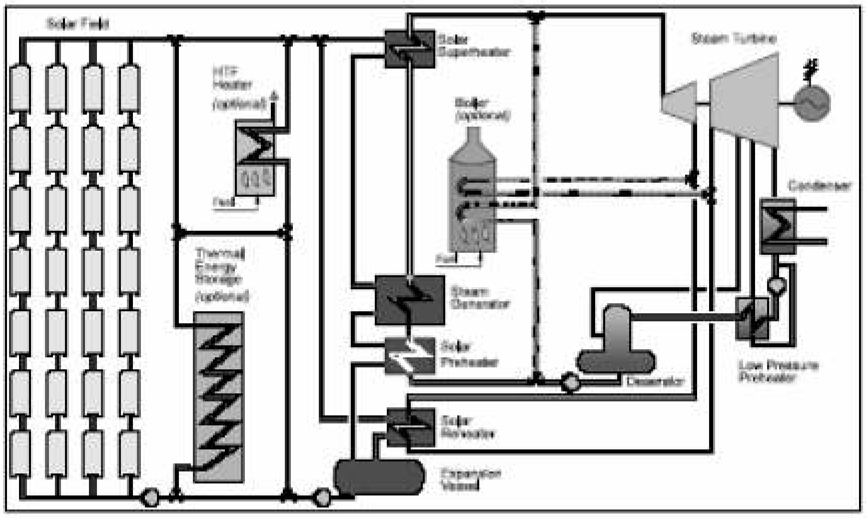

Fig. 7 Integrated Solar/Rankine Cycle System

The solar field is comprised of parallel rows of Solar Collector Assemblies (SCAs). SCAs supply thermal energy to produce steam to drive a steam turbine/generator. The collectors are single-axis tracking and aligned on a north-south line, thus tracking the sun from east to west. An individual sun sensor device controls the position and tracking of each SCA. All of the SCAs are controlled by a main process computer. In a parabolic trough solar field of current design heat is transported to the power block via an intermediate loop using a synthetic oil (biphenyl-diphenyl oxide) for the Heat Transfer Fluid (HTF). The HTF passes through a heat exchanger system to generate, superheat, and reheat the steam entirely with solar energy in the solar operating mode. Superheated steam generated by the heat-transfer fluid is then fed to a conventional steam turbine. Spent steam is condensed into water, which returns to the heat exchangers, where it reverts back to steam. After passing through the heat exchangers, the cooled heat-transfer fluid circulates once again through the solar field, thus repeating the process. The remainder of the plant equipment is conventional. A supplementary gas-fired boiler or heat transfer fluid heater is also available (both shown as options in Figure 5-1) to allow hybrid operation (solar and natural gas) on cloudy days or evenings. The conventional power block uses feedwater heaters to increase cycle efficiency for the inlet steam pressure and temperature conditions that are generated by the solar field. Auxiliary services include water pumping, treatment and storage, natural gas transmission, and electric interconnection and transmission.

3. PROJECT DEVELOPMENT

During the project RO/2005/PL95183/S “EUROPEAN ENGINEERS IN RENEWABLE ENERGY” as a beneficiary I developed together with JESUS MORENO SOSA ingeniero industrial from “Ayesa” a spreadsheet simulation model which allow users to design a solar field with parabolic trough collectors using a synthetic oil (HTF) in charge to feed a power plant operating with Rankine cycle. The model has been developed in Microsoft Excel® spreadsheet program. The spreadsheet is used for data input and output. One of the advantages to this approach is that users do not require special software to use the program.

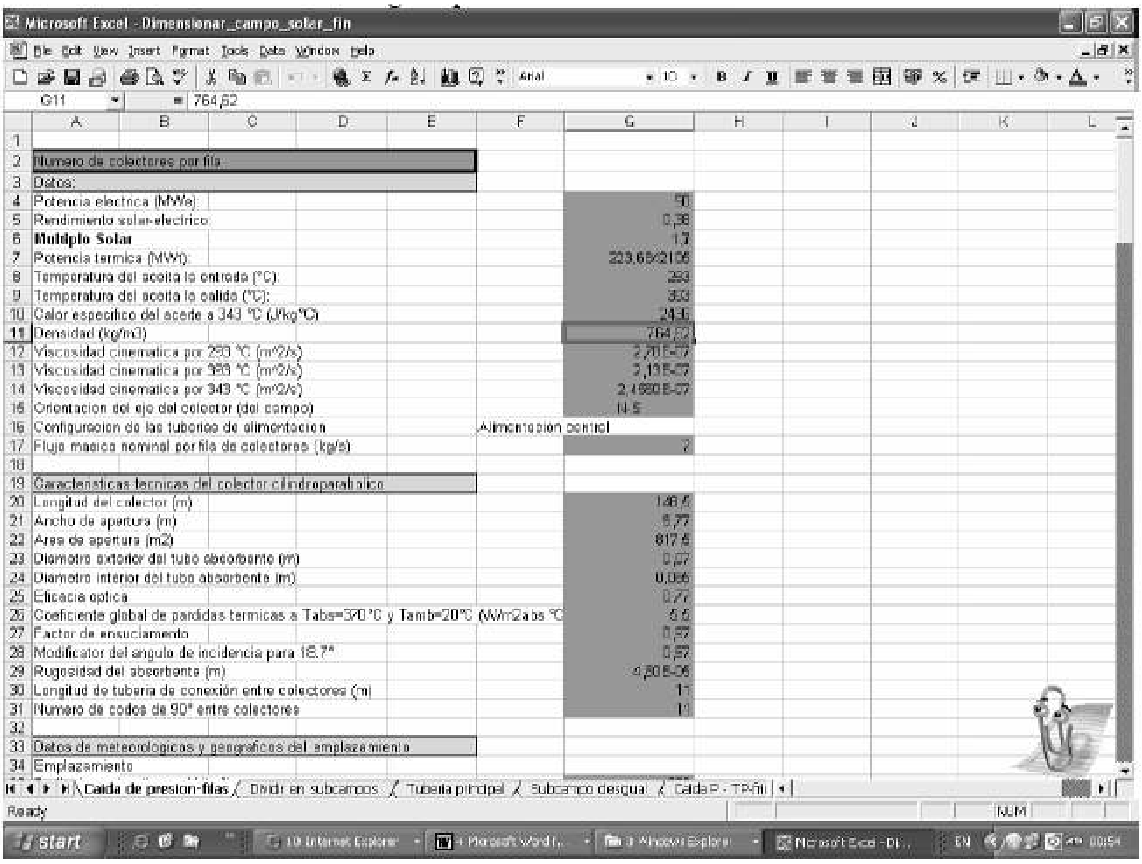

Fig. 8 Spreadsheet simulation model

4. CONCLUSION

Solar thermal power plants will reduce dependency on fossil fuels and, thus, avoid the risk of drastic electricity costs escalation in future. Hybrid solar-fossil fueled CSP plants, making use of special finance schemes at favorable sites, can already deliver competitively priced electricity. Basically, solar thermal power plants compete with conventional, grid-connected fossil fuel-fired power stations – in particular, modern, natural-gas-fired combined cycle plants in mid-load or base-load operation mode. However, a mixture of factors, including reform of the electricity sector, rising demand for ‘green power’, and the possibility of gaining carbon credits from pollution-free power generation as well as direct support schemes –e.g. feed-in laws or renewable portfolio standards for renewable power in some countries – are all increasing the economic viability of such projects.

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