



AN ULTIMATE SOLUTION TO PHASING OUT FOSSIL FUELS – PART II: AIR-WATER THERMAL POWER PLANTS FOR UTILITY-SCALE POWER PRODUCTION AT LOW TEMPERATURES

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ABSTRACT

This paper introduces a novel air-water thermal power plant working at low temperatures and employing hot water as a heat-supply fluid to produce utility-scale power with high second-law efficiency. The air-water power plant uses both air and water as working fluids and employs a direct-contact mass and heat transfer packing to facilitate latent heat (in terms of vapor) and sensible heat transfer from the hot water to moist air for expansion in a gas turbine to produce power. A cycle analysis indicates that with a heat source temperature of around 100°C, the power plant could achieve a power capacity of more than 300 MW, matching the power capacity of fossil-fuel-based power plants, with a thermal-to-mechanical conversion efficiency above 16%. The power plant could also work in summer involving high temperature/high humidity ambient air by using a chiller to cool the power-plant intake air, the inlet air of the compressor system, or the air in a compressor intercooler. In addition to power production, the power plant could supply hot water for heat or water users. This power plant employs completely clean working fluids of air and water, operates at low temperature and pressure, and can use renewable energy such as solar energy and geothermal energy, as well as heat from other sources including industrial waste heat, to produce utility-scale power with low costs. Combined with hot-water thermal-energy storage systems, the power plant introduced could use renewable energy sources to produce dispatchable power reliably for phasing out most fossil fuels used today and becoming a backbone of national power grids to combat global warming and reduce pollution.

Keywords: Thermal Power Plant, Renewable Energy, Direct-Contact Heat and Mass Transfer, Regenerator Condenser, Chiller Cooling

1. INTRODUCTION

Thermal power plants that could enable the use of the vast amount of thermal energy resources at low or medium temperatures to generate electricity could have a significant impact on the advancement of renewable energy. Cao (2022a) demonstrated the concept of utility-scale underground hot-water storage facilities in conjunction with thermal power plants, which could have the potential to displace more than 80% of the global fossil fuel being used today. However, economic feasibility of the storage systems is very sensitive to their temperature and pressure, and a favorable temperature range was shown to be near or slightly above 100°C, more specifically in the low-mid temperature range between 90 to 150°C. If the water temperature is significantly above this range, the costs of the hot-water storage system could increase exponentially. Also, heat acquisition by the water through solar collectors or geothermal energy favors a lower temperature. As the solar collector temperature is increased, the collector efficiency could decrease from around 80% to below 50%. For a higher temperature above 200°C, concentrating solar collectors may have to be employed, which not only increases the costs of the solar acquisition significantly but also would fail to collect the diffuse component of the solar flux, which is generally 25% to 50% of the total solar flux.

Thermal power plants that could generate power at a lower temperature range are also essential to geothermal power production. According to U.S. DOE Energy Efficiency and Renewable Energy (EERE, 2022), geothermal energy resources below 300°F (149°C) would represent the most common geothermal resource. One of the biggest challenges for geothermal exploration is the significant cost of

drilling deep wells for a higher heat source temperature, which may require extensive drilling at depths of 3,000 to 5,000 m depending on the project geology. As the depth of geothermal drilling increases, the cost of drilling would increase exponentially, which may render the project economically infeasible.

Conventional steam-turbine-based power plants that are commonly used in coal-burning vapor power plants and nuclear power plants may be a candidate for solar and geothermal applications, and steam-turbine power plants have been used to generate power using dry steam from geysers. However, according to EERE, the most common geothermal power applications are flash steam power plants, and their uses are limited to the heat source temperature higher than 360°F (182°C). For this reason, binary-cycle geothermal power plants are being used for heat source temperatures below 200°C. In a binary-cycle-based geothermal power plant, heat from the geothermal liquid is transferred to a second fluid that has a boiling temperature lower than water through a heat exchanger (EERE, 2022). The second fluid, generally isobutane, pentane, or ammonia under highly pressurized conditions, receives heat from the geothermal liquid through vaporization. The vapor generated in the heat exchanger is ducted to an expander to produce power. The exhaust flow of the second fluid out of the expander is condensed through a closed-loop condenser and returns to the geothermal liquid heat exchanger to complete the cycle. Modular systems with unit capacities ranging from 1 to 5 MW are normally used (Salameh, 2014). The high pressure and closed-loop mean that the system may incur high costs. It should be pointed out that isobutane, pentane, and ammonia are all highly hazardous substances. Their uses

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