



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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Table of Contents Low Capacity Thermal Power Plant Study Guide

1. Understanding the eBook Low Capacity Thermal Power Plant Study Guide
 - The Rise of Digital Reading Low Capacity Thermal Power Plant Study Guide
 - Advantages of eBooks Over Traditional Books
2. Identifying Low Capacity Thermal Power Plant Study Guide
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Low Capacity Thermal Power Plant Study Guide
 - User-Friendly Interface
4. Exploring eBook Recommendations from Low Capacity Thermal Power Plant Study Guide
 - Personalized Recommendations
 - Low Capacity Thermal Power Plant Study Guide User Reviews and Ratings

- Low Capacity Thermal Power Plant Study Guide and Bestseller Lists
- 5. Accessing Low Capacity Thermal Power Plant Study Guide Free and Paid eBooks
 - Low Capacity Thermal Power Plant Study Guide Public Domain eBooks
 - Low Capacity Thermal Power Plant Study Guide eBook Subscription Services
 - Low Capacity Thermal Power Plant Study Guide Budget-Friendly Options
- 6. Navigating Low Capacity Thermal Power Plant Study Guide eBook Formats
 - ePub, PDF, MOBI, and More
 - Low Capacity Thermal Power Plant Study Guide Compatibility with Devices
 - Low Capacity Thermal Power Plant Study Guide Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Low Capacity Thermal Power Plant Study Guide
 - Highlighting and Note-Taking Low Capacity Thermal Power Plant Study Guide
 - Interactive Elements Low Capacity Thermal Power Plant Study Guide
- 8. Staying Engaged with Low Capacity Thermal Power Plant Study Guide
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Low Capacity Thermal Power Plant Study Guide
- 9. Balancing eBooks and Physical Books Low Capacity Thermal Power Plant Study Guide
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Low Capacity Thermal Power Plant Study Guide
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Low Capacity Thermal Power Plant Study Guide
 - Setting Reading Goals Low Capacity Thermal Power Plant Study Guide
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Low Capacity Thermal Power Plant Study Guide
 - Fact-Checking eBook Content of Low Capacity Thermal Power Plant Study Guide
 - Distinguishing Credible Sources

13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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