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THERMOCHEMICAL FUEL CONVERSION IN MARINE POWER SYSTEMS: MODELING AND EFFICIENCY ANALYSIS

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Abstract. *This paper presents a comprehensive study on the thermochemical conversion of hydrocarbon fuels using non-catalytic steam reforming for advanced energy systems. The research focuses on evaluating energy gain from fuel processing and explores mathematical modeling as a tool for optimizing thermochemical reactors and integrated marine power systems. Results indicate significant potential for waste heat recovery and improved fuel efficiency through syngas production..*

Key words: *thermochemical conversion, steam reforming, syngas, waste heat recovery, mathematical modeling, marine power systems*

Introduction.

Recent Developments in Thermochemical Conversion. Recent advances have underscored the importance of innovative reactor configurations and catalyst systems for steam reforming in PEMFC and hydrogen production applications [1]. At the same time, new methodologies for waste heat recovery from gas turbines – such as embedded heat exchangers and sCO_2/ORC bottoming cycles – have demonstrated efficiency gains of up to 29% and power increases reaching 49% [2, 3]. Onboard marine systems, including LNG-powered ships and offshore platforms, have been shown to benefit similarly, with hydrogen production from boil-off gas and thermochemical recuperation providing substantial environmental and economic advantages [4, 5, 6, 7].

Main text.

To evaluate the energy efficiency of hydrocarbon fuel thermochemical processing via steam reforming, a combustion heat gain coefficient is proposed [8, 9]. This parameter characterizes the increase in lower heating value (LHV) of the converted fuel products relative to the base fuel. The LHV of the produced syngas components is recalculated per kilogram of input fuel to determine this coefficient.

To identify optimal parameters for non-catalytic steam conversion, the influence of process temperature, operating pressure, and the steam-to-fuel ratio (S/F) on the resulting energy content of syngas was investigated. The proposed efficiency metric provides a quantitative basis for assessing the energetic benefits of thermochemical upgrading.

Regression analysis of the parameter relationships allowed for the identification of effective operational ranges. Specifically, maximum energy gain was observed within the temperature interval of 623–1123 K and pressure range of 0.1–2.0 MPa.

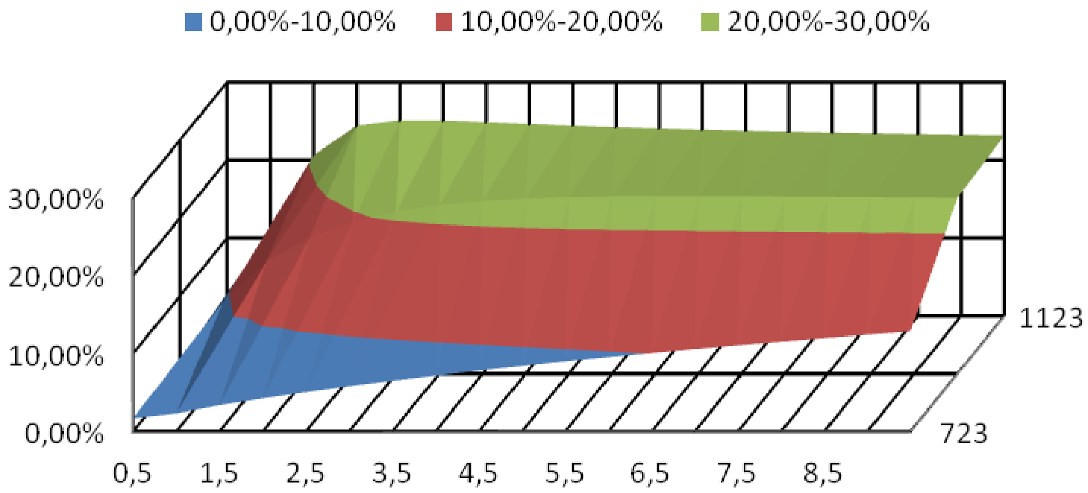

Figure 1 - Parametric dependence of syngas energy characteristics on temperature and steam-to-fuel ratio

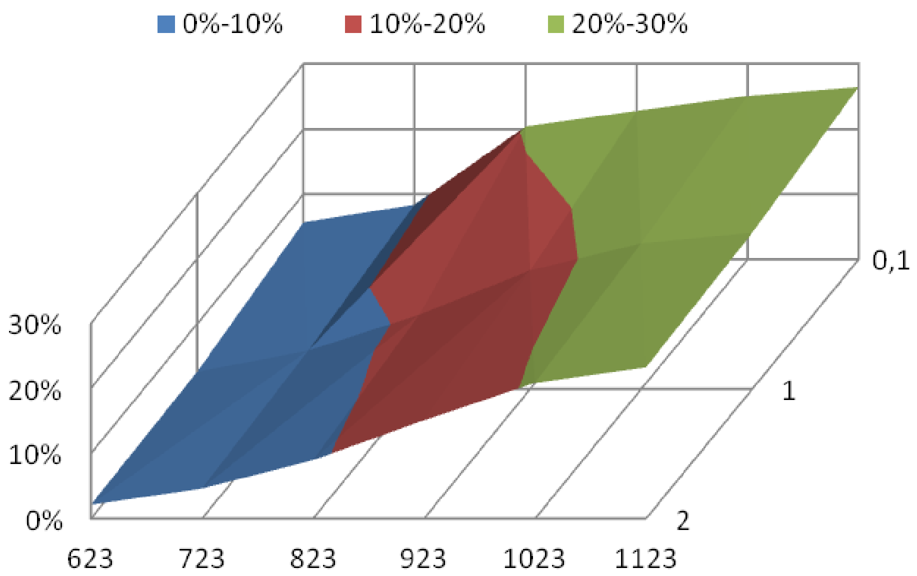

Figure 2 - Example of regression-based modeling results for reforming efficiency under varying pressures and temperatures

Parametric studies demonstrated that the optimal steam-to-fuel ratio varies with temperature, and the maximum combustion heat gain is achieved under specific combinations of process parameters. Graphical representation of the results illustrates these dependencies.

A thermodynamic model of the reactor was developed to simulate the conversion process. The reactor was treated as a system governed by non-catalytic gas-phase reactions at predefined operating conditions. The output composition was determined based on known input streams by applying Gibbs free energy minimization principles.

The obtained results confirm the feasibility of targeted control over the reforming process to enhance energy recovery from waste heat in shipboard power systems.

Further Development: Mathematical Modeling and System Optimization.

As part of advancing thermochemical energy recovery, increasing attention is being paid to mathematical modeling as a tool for quantitative analysis and optimization of power system performance. One of the most promising directions involves using the thermal potential of exhaust gases to drive steam reforming of complex hydrocarbon mixtures.

Numerical studies have shown that the exhaust gas temperatures of modern gas turbine engines are sufficient to initiate reforming reactions of heavy hydrocarbons, including components of associated petroleum gas. This provides the basis for broader utilization of such gas as an alternative fuel in marine power systems.

In the development of combined diesel-gas turbine power plants with thermochemical heat recovery [10], an integrated thermal model was constructed. The system layout includes compressors, combustion chambers, water and syngas feed units, steam generators, dehydrators, and high-/low-pressure reformers. The modeling of the reactor is based on equilibrium thermodynamics, utilizing Gibbs free energy minimization to determine the composition of conversion products. The energy balance of the reactor is used to estimate the required heat input from exhaust gas streams.

The system configuration accounts for the functional interdependencies of its components, enabling identification of operating conditions that maximize secondary energy utilization. As a result, mathematical modeling proves to be a critical approach for selecting efficient configurations of next-generation marine power systems.

Summary and conclusions.

The study confirms the potential of thermochemical fuel conversion to significantly improve the efficiency of marine energy systems by recovering waste heat. The integration of mathematical modeling supports the identification of optimal process parameters and system configurations. These insights open pathways to more flexible, low-carbon, and energy-resilient propulsion solutions for high-tech maritime applications.

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