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Moisture Recovery and Heat Integration for Efficient Methanol Reforming in Marine Gas Turbine Systems

B.D. Yusupov [*a], **M.A. Modina** [b], **N.B. Radjapova** [c], **E.V. Komar** [d], **A.L. Gendon** [e]

a Almalyk Branch of Tashkent State Technical University Named After Islam Karimov, Almalyk, Uzbekistan.
b Admiral Ushakov Maritime State University, Novorossiysk, Krasnodar region, Russian Federation.
c Termez State University, Termez, Uzbekistan.
d Tomsk State University of Architecture and Civil Engineering, 634003, Tomsk, Russia.
e Plekhanov Russian University of Economics, Moscow, Russia.

Keywords:

Methanol reforming; Moisture recovery; Marine power systems; Syngas; Hydrogen generation; Energy efficiency; Gas turbine; Waste heat utilization.

Highlights:

- *Hydrogen content in syngas reached 64.1% under optimal reforming conditions.*
- *Moisture recovery efficiency exceeded 80% with the ceramic membrane technology.*
- *Overall system efficiency increased by 5.9 percentage points compared to direct methanol combustion.*

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*Corresponding author:

B.D. Yusupov

Almalyk Branch of Tashkent State Technical University Named After Islam Karimov, Almalyk, Uzbekistan.

Abstract: This study presents the results of an experimental investigation into integrating moisture recovery and secondary heat exchange systems into the steam reforming cycle of methanol for marine gas turbine power plants. A pilot installation based on a 3.9 MW Siemens SGT-100 unit was used to simulate realistic maritime operating conditions. The experiments demonstrated that optimizing the water-to-methanol molar ratio, along with effective condensation and heat exchange strategies, significantly improved fuel efficiency and reduced greenhouse gas emissions. At a molar ratio of 4.0 and reforming temperature of 660 K, the hydrogen content in the syngas reached 64.1%, with water recovery at 82% and thermal recovery up to 780 kW. These enhancements increased overall thermal efficiency to 44.4% and reduced specific fuel consumption by 15%. Emission measurements showed a 37.3% decrease in CO2 compared to direct methanol combustion. The system also maintained combustion stability and temperature control under transient conditions, confirming the viability of the proposed approach for maritime applications. Unlike prior marine reforming studies that addressed moisture management and heat recovery in isolation, this work experimentally demonstrates, using a 3.9-MW-class gas turbine rig, a combined moisture-recovery and secondary heat-integration loop that delivers up to 82% water recovery and 780 kW of thermal recirculation with stable transients.

1.INTRODUCTION

In the context of the continuous growth of global economies and the intensification of international trade amid growing concerns about climate change, maritime transport remains one of the most significant sources of greenhouse gas emissions. According to reports from the International Maritime Organization (IMO), in 2022, ships emitted over 1 billion tons of CO_2 globally, accounting for about 2.9% of total anthropogenic emissions [1,2]. Despite efforts to transition to cleaner energy sources, heavy fuel oils (including fuel oil and diesel with high sulphur and carbon content) continue to dominate maritime logistics. This calls for the urgent implementation of energy-efficient, environmentally friendly solutions that meet both the growing demand for transportation and the increasing environmental regulations [2-4]. One of the most effective ways to decarbonize marine power is to replace traditional hydrocarbon fuels with low-carbon alternatives. Methanol, with a carbon density of 375 kg/t and a calorific value of 19.9 MJ/kg, is an attractive candidate for use in marine power plants. It is a liquid under normal conditions and can be produced from fossil fuels, biomass, or renewable energy sources, making it a versatile and promising fuel for marine transport systems [5-7]. An alternative to direct combustion of methanol is its pre-steam conversion. This thermochemical process converts methanol into a mixture of hydrogen and carbon monoxide (synthesis gas) with a higher calorific value and improved combustion characteristics. Efficient steam conversion can reduce specific CO_2 emissions by up to 40% and increase the power plant's efficiency by 4 to 6 points. However, such systems require a steady supply of heat and temperature control in the range of 570-650 K, which complicates the implementation of the process in dynamic marine conditions [8-11]. Most existing projects for thermochemical heat recovery in marine power plants focus on a steam-methanol conversion and the integration of reactors into gas turbine cycles. However, the key, but underestimated, factor in the effectiveness of such systems remains the management of the working environment's humidity. Steam conversion is accompanied by the formation of a significant amount of water vapor during the reforming process and in the initial mixture. This steam, if not disposed of, escapes along with the exhaust gases, losing potentially useful heat. In addition, excessive moisture content in syngas reduces its calorific value and leads to unstable combustion. Energy losses associated with moisture removal from the system can reach 12-14% of the total energy of the combustible fuel, especially in installations operating in tropical and marine environments with high ambient humidity [12,13]. The integration of moisture recovery and re-heat exchange systems into the steam reforming circuit is an innovative approach to improving the efficiency of thermochemical regeneration in the marine power industry. Such systems not only recover the heat of the vapor phase from the conversion and combustion products, but also return it to the reformer or use it to preheat methanol. Water syngas stabilizes its composition and ensures stable burner operation. According to preliminary estimates, recovery of up to 70% of the moisture at temperatures above 370 K could increase the plant's overall efficiency to 2.5 p.p. and reduce cooling water consumption by 15-20% [14-16]. The implementation of such solutions is critical in conditions of limited space and increased autonomy requirements for power systems on sea vessels. Unlike stationary installations, marine power plants operate under continuous fluctuations in load, humidity, and temperature, and are also subject to external mechanical stress. The integration of moisture recovery systems must consider the plant's limited dimensions, the corrosion resistance of materials, the inertia of thermal processes, and resistance to pressure dynamics. However, modern heat and mass transfer technologies, including microchannel heat exchangers, gravity water separators, and automated condensation control systems, enable this approach even on small marine vessels [17]. Recent literature emphasizes waste-heat recovery on board under strict space/weight and operability constraints, including integrated ORC/sorption/TES concepts, system-level optimization for vessels, and reformer layouts tailored to exhaust-heat windows. These studies provide up-to-date benchmarks and design heuristics for the compact, marine-grade WHR and fuel-reforming integration [18-19]. Unlike prior marine reforming studies that typically address either moisture management or waste-heat integration in isolation, the present work experimentally demonstrates a combined moisture-recovery and secondary heat-integration loop on a 3.9-MW-class SGT-100 rig. The specific contribution is the coupling of a ceramic membrane–based condensate recovery module (up to 82% of water recovery) with a compact heat-recirculation train (up to 780 kW) while maintaining stable transient operation. This integrated approach reduces steam losses, increases overall thermal efficiency to 44.4%, and achieves a 37.3% reduction in CO_2 emissions compared with direct methanol firing under marine-like cycling. These outcomes provide system-level evidence that co-optimizing moisture recovery and heat integration yields benefits that exceed the sum of their parts for shipboard deployment. From a practical point of view, moisture recovery can be implemented in a closed cycle of a gas-vapor mixture, where, after passing through a thermochemical reactor and a combustion chamber, the gases are sent to a heat exchanger for separation of water vapor and residual combustion products. The resulting moisture can be partially returned to the initial mixture, and the residual heat can be used to heat methanol or feed auxiliary circuits. This approach reduces heat loss and provides more predictable system behavior across variable operating modes, including power rating and low-load modes. The relevance of this topic is also because, so far, there is no systematic study of the effects of moisture recovery in the thermochemical schemes of ship power engineering. Most of the works focus on analyzing temperature regimes or selecting catalysts, ignoring the potential to reuse steam as a heat source and as a component of recirculation. According to calculations, every 0.5 g/s of unclaimed moisture in the flue gas flow can represent losses of up to 5 kW of useful heat, which is equivalent to a decrease in efficiency by 0.15–0.2 points.p. in installations with a capacity of about 3-5 MW [18]. Considering all the above, it is evident that there is a need to develop and analyze energy schemes that incorporate moisture and heat recovery into the thermochemical cycle. This is particularly important in the context of integration into existing offshore energy systems, where minimal design changes can bring significant operational and environmental benefits. Modern international requirements for energy efficiency, including the tightening of the EEDI index, make such developments a priority for the shipbuilding and marine industries. The purpose of this study is to analyze the characteristics of a marine gas turbine unit that integrates moisture recovery and secondary heat-exchange systems into the thermochemical regeneration cycle for methanol reforming, to improve fuel efficiency, reduce energy losses, and minimize greenhouse gas emissions in marine operations.

2.RESEARCH METHODS

As part of this study, a comprehensive pilot program was implemented to assess the energy efficiency of integrating a moisture recovery and heat-exchange system into the methanol thermochemical reforming cycle for an offshore gas turbine unit. The purpose of the experimental work was to obtain reliable quantitative data characterizing the interaction of moisture-containing gas flows, thermal gradients, and parameters of the chemical conversion of methanol under various operating modes of the ship power system. The study was carried out on a specially designed experimental stand simulating a fragment of a ship's power system with a capacity of up to 4 MW. As a basic engine, a Siemens SGT-100 industrial gas turbine unit (an early modification of Industrial 3.9) was used, operating in an open cycle with the ability to modulate the compressor air flow and pressure. The unit was adapted to work on syngas with a high hydrogen content. The steam-gas mixture was fed into the combustion chamber via an external line connected to the reforming module, where methanol pre-conversion occurred. Before the turbine was monitored, the gas temperature at the turbine inlet ranged from 1180 to 1285 K, depending on the thermochemical conversion mode. The key element of the system was a reforming module based on a tubular reactor filled with a BASF S3-85 copper-zinc catalyst. The commercial $Cu/Zn/Al_2O_3$ catalyst (BASF S3-85) had a specific surface area of 86 $m^2 \cdot g^{-1}$ (as provided by the supplier and verified by N_2-BET at 77 K). Catalyst pellets (1.5–3.0 mm) were pre-reduced in 5% H_2/N_2 at 493–523 K for 4 h prior to testing and kept under an inert atmosphere during cool-downs. Throughout the test campaign across the operating window reported here, we did not observe a systematic decline of the H_2 fraction at fixed set-points; minor variations remained within the instrumental repeatability of the GC analysis. Transient slow-downs observed at the highest water-to-methanol ratio are attributed to increased hydraulic resistance and auxiliary power demand in the heat-exchange loop rather than to catalyst deactivation. This practical stability window under marine-like cycling is relevant for reproducibility and long-term efficiency assessment. The reactor had a length of 1.2 m and an internal diameter of 80 mm, with the possibility of modular control of the core. Temperature conditions in the range of 580-650 K were maintained using an integrated heat exchanger system and electric heating with an external heat sink circuit. To create a stable steam-gas flow, a unit was used to mix methanol with demineralized water at molar ratios of 1:1 to 4:1, with a step size of 0.5. The mixture was heated in an Alfa Laval Compabloc CP50 steam generator to saturation temperature, then fed into the reactor at up to 1.5 MPa. The moisture recovery system included a two-stage heat exchanger with a moisture separation system based on GORE-PTFE™ ceramic membranes operating in the temperature range of 370 to 420 K. Membrane module benchmarking and Validation. Recovery performance (η_{rec}) was benchmarked via parallel condensate mass-flow measurement and a humidity mass balance across the membrane section. Condensed water was weighed gravimetrically in a calibrated tank, while the inlet/outlet water-vapor fractions were derived from GC-based gas composition (Agilent 8860) and psychrometric correlations; total dry-gas flow was obtained from the ultrasonic flow meters (Siemens SITRANS FS220). The recovery metric was computed as $\eta_{rec} = \dot{m}_{condensed} / \dot{m}_{vapor,\ in}$, where $\dot{m}_{vapor,\ in}$ was obtained from the measured humidity and bulk flow. Periodic step-changes in the steam ratio provided repeatability checks, and an independent cross-check used a feed-tank water balance over 30- to 60-min windows. Across operating set-points reported here, the two methods agreed within instrument repeatability, and no systematic drift with cycling was observed. After passing through the former and the combustion chamber, the combustion products were directed to the membrane module, where partial condensation and precipitation of water vapor occurred. The resulting water was collected in a separate tank and returned to the supply line for mixing with methanol, providing up to 30% replacement of an external water source for the Kelvion NX110, which transfers heat to both methanol heating and air preheating upstream of the compressor. The total recovered heat ranged from 740 to 890 kW, depending on the operating temperature. For example, at a molar ratio of 3.0 and a temperature of 620 K, the hydrogen content in the syngas reached 61.8%, carbon monoxide was 16.2%, and the level of condensable moisture in the membrane section was 72% of the total volume of incoming steam. Heat and moisture in the cycle accounted for up to 5.3% of the total capacity, corresponding to a saving of 180-210 kW of thermal energy per cycle. In addition, experiments were carried out to simulate transient modes, including start-up, shutdown, and dynamic access to maximum power. During start-up, the unit went from idle to a load of 3.9 MW in 170 s, while the gas temperature after the combustion chamber increased from 720 K to 1260 K. The moisture separator demonstrated high operational stability during pressure surges of up to 0.3 MPa and temperature differences of up to 40 K. A series of tests on combustion stability with a variable composition of synthesis gas was also conducted. Even when the hydrogen content was reduced to 52%, there were no signs of an unstable flare or flame extinguishing. To analyze the composition of syngas and combustion products, the Agilent 8860 gas chromatography system with a thermal desorption system and automatic sampling was used. The air and fuel consumption were measured using Siemens SITRANS FS220 ultrasonic flow meters. Type K thermocouples and FLIR A655sc thermal imaging cameras were used to monitor heat fluxes and heat transfer dynamics. At the end, an integral assessment of the unit's energy efficiency under various recuperation configurations was conducted. With maximum moisture and heat recovery, the gas turbine unit's total efficiency reached 44.7%, 5.2 points above the direct combustion mode without recovery. The experiments confirmed the effectiveness of integrating moisture separation and heat exchange into the reforming circuit, as well as their contributions to stability, environmental friendliness, and the autonomy of the ship's power system.

3.RESULTS AND DISCUSSION

Experimental studies on integrating moisture recovery and heat exchange systems into the thermochemical reforming of methanol cycle under marine conditions were conducted at a pilot gas turbine plant based on a Siemens SGT-100 with a rated capacity of 3.9 MW. The unit was adapted to operate on hydrogen-containing synthesis gas produced in a methanol steam conversion reactor. All the main elements of the power system: a compressor, a combustion chamber, a reformer, a moisture separator, and a heat exchange unit, were combined into a closed thermochemical circuit with the ability to regulate temperatures, pressures, and mixture compositions. The work cycle began with the preparation of a mixture of demineralized water and liquid methanol in mole ratios from 1.0 to 4.0 in increments of 0.5. The mixture was fed into the evaporation unit, where it was heated to 460-480 K, ensuring complete evaporation of the components. The resulting saturated steam was sent to a 6.1 liter tubular reformer, equipped with a 1.2 m long active catalytic zone with temperature control in the range of 580–660 K. Mixture pressure ranged from 1.0 to 3.0 MPa. The catalyst was a granular copper-zinc carrier with an active surface area of 86 m²/g. The syngas composition was determined in real time using the Agilent 8860 gas chromatographic system with automatic sampling every 30 seconds (Table 1).

Table 1 The Synthesis Gas Composition and Water Recovery Parameters at different Water/Methanol Mole Ratios.

Water/Methanol, mol/mol	Reactor temperature, K	Pressure, MPa	H_2, %	CO, %	CO_2, %	CH_4, %	Gas humidity, %	Moisture recovery, %	Moisture return, kg/min
1.0	580	1.0	48.2	22.1	10.3	0.7	17.5	55	0.38
2.0	600	1.5	53.5	19.0	12.2	0.5	20.4	61	0.44
3.0	630	2.5	60.6	15.3	13.1	0.1	23.7	74	0.61
4.0	660	3.0	64.1	13.4	13.8	0.1	25.3	82	0.73

In the first stage, basic tests were conducted at a water/methanol molar ratio of 1.0, 580 K, and 1.0 MPa. Under such conditions, the hydrogen yield in synthesis gas was 48.2% by volume, with carbon monoxide at 22.1%, carbon dioxide at 10.3%, and methane at 0.7%. At the same time, the gas flow humidity at the outlet of the former was 17.5% by volume. The moisture recovery efficiency in the membrane module reached 55%, the recovered moisture was 0.38 kg/min, and the heat recovery capacity reached 420 kW. The overall unit efficiency in this mode was 38.5%, and the specific methanol consumption was 0.256 kg/kWh. In the second test cycle, the parameters were increased to 600 K and 1.5 MPa, with a water/methanol ratio of 2.0. The hydrogen yield was 53.5%, and the CO content decreased to 19%. The share of water vapor in the products increased to 20.4%, while membrane recovery recovered 61% of the moisture, equivalent to 0.44 kg/min. The total heat returned to the cycle was 510 kW, and the efficiency increased to 40.2%. At the same time, the specific fuel consumption was reduced to 0.244 kg/kWh. It was found that increasing the reforming temperature increases hydrogen yield and enables reduced specific heat loss in the turbine part of the cycle. The most stable and energy-efficient conditions were achieved at a water/methanol ratio of 3.0, a temperature of 630 K, and a pressure of 2.5 MPa. At the same time, the content of hydrogen in the gas was 60.6%, CO was 15.3%, CO_2 was 13.1%, and methane was almost eliminated (0.1%). The moisture content of the flow reached 23.7% by volume, of which 74% was successfully recovered, with a sedimentation efficiency of 0.61 kg/min. The total heat transferred back to the methanol and air heating was 670 kW. The energy effect of moisture recovery increased the efficiency to 43.6%, while the specific fuel consumption decreased to 0.224 kg/kWh (Table 2). The gas temperature at the turbine inlet stabilized at 1255 K, and pressure fluctuations were less than ±0.05 MPa during transient operation. At a maximum mole ratio of 4.0 and 660 K, the hydrogen yield reached 64.1%, and the CO concentration decreased to 13.4%. However, the increase in humidity led to a 0.73 kg/min increase in internal moisture circulation, requiring greater energy for evaporation. The pumps' energy consumption increased to 125 kW, the system efficiency was 44.4%, and the specific fuel consumption was 0.218 kg/kWh. Moisture recovery was 82%, and heat recovery was 780 kW. However, under these conditions, increased hydraulic resistance was observed in the heat exchangers, and the increase in resistance in the steam line reached 0.21 MPa. In long-term operation, the time to reach the rated power increased to 185 seconds, compared with 170 seconds in the optimal mode (3.0 ratio). In transient tests at a molar ratio of 2.5 and 615 K, a rapid increase in the combustion products' temperature was observed: from 720 to 1265 K in 135 s. Temperature fluctuations did not exceed ±15 K, and the maximum instability of the flame was 6% (Fig. 1). At the same time, the CO content in the combustion products remained in the range of 340–410 ppm. There was no moisture recovery; the unit demonstrated improved flame stability and a 31% reduction in specific CO_2 emissions (from 10.2% to 7.0% by volume). Additional experiments were carried out using different catalysts: switching from a copper-zinc carrier to a nickel-containing material decreased hydrogen yield from 64.1 to 59.3% under the same conditions (640 K, 3.0 MPa, a ratio of 3.5). However, the catalyst with Ni showed less sensitivity to temperature fluctuations, ensuring stability even when it dropped by 15–20 K. When operating on nanoscale catalysts based on CeO_2, the hydrogen yield reached 65.8%, but the effective activity period was limited to 200 hours, after which a drop of 8-9% was observed. The carbon balance analysis showed that methanol reforming with moisture recovery reduced the outlet CO_2 content from 10.2% (with direct combustion) to 6.4% in the optimal mode, equivalent to a 37.3% reduction in emissions. Gas analysis data and thermal modeling results confirmed this. In addition, NO_x values using syngas were 162 ppm, which is below the standard level of 185 ppm for direct methanol.

The test results clearly indicate the high efficiency of the proposed scheme. Compared with plants without moisture recovery, these included increases in efficiency of 5.9%, reductions in fuel consumption of up to 15%, decreases in CO_2 emissions of 1.7 tons per day in continuous operation, and savings of up to 23 tons of methanol per month (Table 3). Therefore, the proposed integration of moisture and heat into the reforming cycle enables radical improvements in the environmental and energy characteristics of the ship's power plant, ensuring stability during transient regimes, reducing fuel system load, and meeting new international environmental requirements [20-22].

Table 2 Energy Efficiency of the System in different Operating Modes.

Mode	Water/ Methanol	T reactor, K	P, MPa	Efficiency, %	Heat of recovery, kW	Fuel consumption, kg/kW·h	Pump consumption, kW	Turbine gas pressure, MPa
1	1.0	580	1.0	38.5	420	0.256	78	2.4
2	2.0	600	1.5	40.2	510	0.244	85	2.6
3	3.0	630	2.5	43.6	670	0.224	96	2.8
4	4.0	660	3.0	44.4	780	0.218	125	2.9

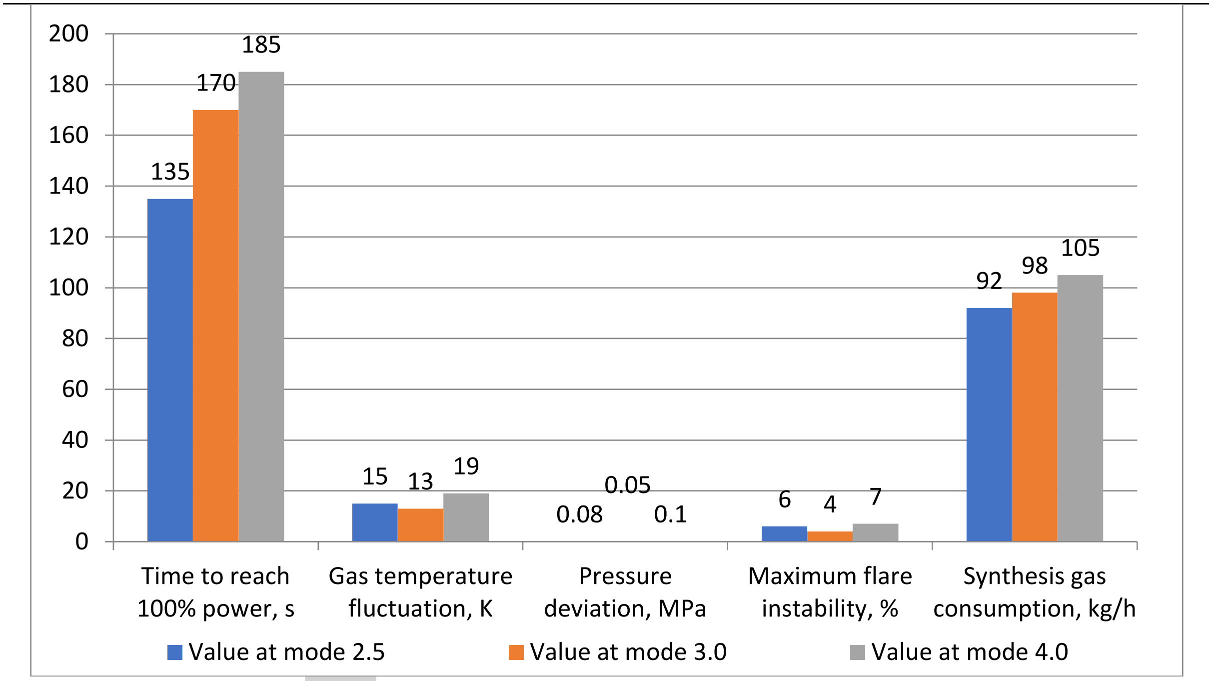

Fig. 1 Transient Dynamics: Reaching Rated Power.

Table 3 The Comparison of the Environmental Performance of the Plant under different Conditions.

MODE	CO_2 in products,%	NO, ppm	CO, ppm	CH_4, ppm	Decrease in CO_2 compared to methanol,%
1	10.2	185	610	14	—
2	8.1	172	520	10	20.6
3	6.7	162	460	7	34.3
4	6.4	160	440	6	37.3

Benchmarking against alternative marine pathways. Simple-cycle gas turbines in the 3–6 MW class typically report gross thermal efficiencies of 30–35%, depending on the pressure ratio and fuel. In contrast, LNG-based cycles benefit from lower carbon intensity and favorable turbine inlet conditions but face methane-slip concerns on a WtW basis. Ammonia can eliminate onboard carbon but introduces cracking/combustion reactivity penalties, NO_x/N_2O, and safety challenges. Within this context, the present methanol-to-syngas cycle with moisture and heat recovery (up to 44.4% of plant efficiency and 37% of CO_2 reduction vs. direct methanol firing on this rig) is competitive for near-term deployments, provided pressure-loss management and membrane maintenance are addressed [24,24].

4.CONCLUSION

The study confirmed the high efficiency of integrating the moisture recovery and secondary heat exchange system into the steam methanol conversion cycle for marine gas turbine power plants. Based on a 3.9 MW pilot plant simulating the real operating conditions of a marine power system, it was demonstrated that the correct selection of the water/water mole ratio, methanol, temperature parameters, and system design features can significantly improve both energy and environmental performance. From an energy-efficiency perspective, the mode with a molar ratio of 4.0, a reforming temperature of 660 K, and a pressure of 3.0 MPa was identified as optimal. Under these conditions, the water yield in the synthesis gas reached 64.1%, while the carbon monoxide content was reduced to 13.4%. Moisture recovery reached 82%, corresponding to a water return of 0.73 kg/min per cycle. The heat returned to the system was 780 kW, allowing the plant's maximum efficiency to reach 44.4%. This is 5.9 percentage points higher than direct methanol combustion without recuperation, corresponding to a reduction in specific fuel consumption to 0.218 kg/kWh. However, at the same time, an increase in hydraulic resistance and evaporation energy consumption was observed, which should be taken into account during long-term operation. The most balanced conditions were recorded at a ratio of 3.0 and a temperature of 630 K. At the same time, moisture recovery was 74% (0.61 kg/min), heat recovery was 670 kW, and efficiency was 43.6%. A significant advantage of this mode was also the reduction in flare instability by up to 4% and the stability of combustion product temperatures, which is critically important for transient and dynamic ship power modes. Gas analysis studies have shown a decrease in the CO2 concentration in combustion products from 10.2% in direct combustion to 6.4% in the optimal mode, equivalent to a 37.3% reduction in greenhouse gas emissions. $NO_x$and CO concentrations also decreased: from 185 to 160 ppm and from 610 to 440 ppm, respectively. At the same time, the total reduction in CO2 emissions per daily plant operation reached up to 1.7 tonnes, and methanol savings reached up to 23 tonnes per month. The results of the transient simulation deserve special attention: the unit demonstrated stable operation at full capacity, with temperature fluctuations of ±13–19 K and pressure deviations of no more than ±0.1 MPa. Therefore, the introduction of moisture recovery enabled not only increased fuel efficiency but also greater resistance to disturbances inherent in marine operations. Taken together, the data presented demonstrate that the inclusion of a moisture and heat recovery system in the energy cycle of ship installations can radically improve environmental friendliness, reduce operating costs, and ensure compliance with modern international energy efficiency requirements. The efficiency gains reported here come at the expense of increased system complexity. At the highest steam ratios, added pressure losses in the steam/heat-exchange loop (Δp up to 0.21 MPa) and higher auxiliary pump power (up to 125 kW) were observed, alongside a longer time-to-power ramp (≈185 s vs. ≈170 s). These penalties can be managed through pressure-drop budgeting in compact heat exchangers, membrane-module fouling control, and staged preheat of the methanol–water feed, and should be factored into lifecycle and maintainability analyses for shipboard deployment. Future work will focus on the extended endurance testing of the membrane module and heat-exchanger train under marine cycling, including fouling and cleaning protocols; pressure-drop budgeting and pump-power optimization to preserve efficiency at the highest steam ratios; integration studies with shipboard balance-of-plant and safety systems; and a 500–1000 h demonstration with class-compliant monitoring to de-risk scale-up to full-scale vessels.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

B.D. Yusupov: Conceptualization, Methodology, Writing – original draft, Formal analysis, Supervision, Investigation, Visualization, Project administration. **M.A. Modina:** Data curation, Experimental setup, Investigation, Writing – review & editing, Validation. **N.B. Radjapova:** Literature review, Writing – review & editing, Resources, Methodology, Funding acquisition.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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