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Sea Water Desalination Using Waste Heat: A Desalination System for Small and Medium Ships Using Exhaust Heat of the Engine

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Abstract: Marine engine-generated waste heat presents a great potential for efficient desalination. In this research, the investigators explore a desalination system that uses the exhaust gas of a marine engine to convert seawater into fresh water. The configuration includes a heat exchanger that transfers the exhaust heat to a thermal desalination unit, where seawater is vaporized and condensed into freshwater. By tapping into waste heat, this system not only cuts down on fuel consumption but also lessens environmental impact and boosts the availability of fresh water onboard. This makes it a perfect fit for fishing vessels, cargo ships, and offshore platforms. The study emphasizes the design, efficiency, and economic viability of merging desalination with marine engines, presenting a sustainable approach to producing fresh water at sea.
Keywords: seawater, desalination, marine engines, condenser, heat exchanger, waste heat, environment friendly.

I. INTRODUCTION

Freshwater shortage is a major challenge for marine operations, particularly for fishing boats, cargo ships, and offshore platforms that are at sea for extended periods. Conventional desalination methods, such as reverse osmosis (RO) and thermal distillation, generally require a great deal of energy, which can increase fuel consumption and operating costs. Interestingly, marine engines produce a substantial amount of exhaust gas and cooling system waste heat, much of which is left unused. The project is geared mainly towards small ships that are not equipped with fresh water generators. Prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow. This project deals with the design, feasibility study and performance analysis of waste heat recovery-based desalination system which uses thermal energy from marine engine exhaust and jacket cooling water for desalting seawater. The proposed system yields fresh water directly by integration of a heat exchanger with thermal distillation process without need of any external energy in form fuel to drive the process. Incorporation of this technology with marine propulsion system not only improves sustainability, reduces emissions but also helps to enhance self-sufficiency on board ships/vessels working in remote deep sea maritime route.

II. METHOD OF MATERIAL

Methods to design, develop and evaluate the desalination system using waste heat of marine engine and the material selection for enhancing performance and durability have been discussed in this chapter.

A. System Design & Heat Recovery Integration

1) *Waste Heat Source Analysis:* Check the temperature of exhaust gases and cooling water from a ship's engine. Figure out how much heat could be used for making seawater drinkable.
2) *Heat Exchanger Design:* Create a heat exchanger for exhaust gases that transfers heat to seawater. Design a cooler/condenser for heat exchanging in preheating seawater before evaporation. Optimization of the recovery of heat and some thermal efficiency calculations need to be performed.
3) *Desalination Process Selection:* Analyze multi-effect distillation (MED) and multi-stage flash (MSF) processes for superior energy efficiency. Optimize the Evaporation and Condensation chambers for maximum yield of fresh water.

B. System Construction & Materials Selection

1) *Fabrication of Heat Exchange :* Erecting constructions with high thermal characteristics in the material will service heat transmission.
2) *Desalination Unit Assembly:* Integrate the evaporation chamber, condenser, marine freshwater tank and clean marine tank. Use a high-speed seawater pump where continuous operation is being carried out.
3) *Integration with Marine Engine:* Connect the heat exchangers to engine exhaust and cooling system. Make sure you've got good insulation to keep heat from escaping.

C. Performance Testing & Evaluation

1) *Heat Transfer Efficiency Measurement:* Use temperature sensors to keep an eye on how heat moves from the engine to the seawater. Let's see how the predicted heat recovery efficiency compares to the actual efficiency obtained.
2) *Freshwater Output Measurement:* Measure how much fresh water is being made each day, in liters per hour.Check the water quality to see how well the salt is being removed.
3) *Scaling & Fouling Analysis:* Keep an eye on the pipes and heat exchangers for any signs of scaling buildup.Try out various anti-sealant chemicals and self-cleaning features.

D. Material Section

1) *Heat Exchanger Materials:* Stainless Steel (316L) is known for its excellent corrosion resistance and high durability. Titanium is the top choice for use in seawater, as it stops scaling and corrosion. Copper-Nickel Alloy: This blend boasts fantastic heat transfer capabilities and a decent ability to withstand corrosion.
2) *Pipes & Valves*: For a seawater intake pipe, you can use either PVC or HDPE (High-Density Polyethylene).

III. SYSTEM DESIGN AND ARCHITECTURE

The useful waste heat from marine engines for desalination systems consists of various components, whose design is geared toward capturing thermal energy for freshwater production. The systems have thermal desalination methods and heat exchangers in common. These methods are based on desalting using waste heat from the exhaust gases and cooling water of the engine.

1) System Components
2) Marine Engine (Heat Source): At a rate of 810°C to 1050°C, aluminum dross that appears on furnace linings in the casting process is later processed to reclaim clean aluminum metal.
3) Heat Exchanger (Waste Heat Recovery Unit): Exhaust Gas Heat Exchanger: Grasps exhaust gas and conveys heat to the desalination front. As for this design; cooling water on the ship is recycled by passing through a heat exchanger, and instead of power being used on the heater, the ship uses heat from the engine to warm up the seawater, and this exchanger could be run in heat recovery mode.
4) Seawater Intake and Pre-Treatment: Seawater is drawn into the system and filtered to remove large impurities before entering the desalination process
5) Freshwater Condenser & Collection Tank: The steam from the desalination process is condensed into fresh water. Stored in a tank for onboard use (drinking, cleaning, engine cooling).
6) Brine Disposal Unit: Concentrated saltwater (brine) is safely discharged back into the sea following environmental regulations.

A. System Architecture & Workflow

1) Seawater Intake & Preheating

Seawater enters through a filter and is preheated using the engine cooling water heat exchanger.

2) Heat Absorption from Exhaust Gas

The preheated seawater enters the exhaust gas heat exchanger, where it absorbs more heat.

3) Thermal Desalination (MED/MSF Process)

Heated seawater enters the evaporation chambers, where it turns into steam in multiple stages.
Steam is condensed into freshwater, while the remaining brine is removed.

4) Freshwater Collection & Storage
The condensed steam is collected in a tank for use onboard.

5) Brine Discharge
The leftover concentrated saltwater (brine) is expelled back into the sea.
Density of seawater: ~1025 kg/m³
Total energy needed:
A) Sensible heat to raise temperature to boiling

Q_1 = m c \Delta T
Q_1 = (10 \times 1.025) \times 3.9 \tims (100 - 25)]
Q_1 = 10.25 \times 3.9 \times 75 = 2997 kJ

2. Latent heat to convert to steam
Q_2 = m L
Q_2 = (10 \times 1.025) \times 2260]
Q_2 = 10.25 \times 2260 = 23185 kJ
Total energy required:
Q_{\text{total}} = Q_1 + Q_2 = 2997 + 23185 = 26182 kJ

B) Energy Available from Cummins 6.7L Marine Engine Exhaust
A Cummins 6.7L marine diesel engine typically produces around 300 HP (223 kW) at full load.
Diesel engine efficiency: ~40% (typical)
Energy lost as exhaust heat: ~30% of total fuel energy
Fuel consumption: ~0.2 kg/kWh
Diesel fuel heating value: ~42,500 kJ/kg
Power output at full load = 223 kW
Power input (fuel energy) = 223 kW / 0.4 = 557.5 kW
Exhaust heat available = 30% × 557.5 kW = 167.3 kW

C)Time Calculation
\text{Time} = \frac{\text{Energy required}}{\text{Power available}}
t = \frac{26182 \text{ kJ}}{167.3 \text{ kW}}]
t = \frac{26182}{167.3} \approx 156.5 \text{ seconds} \approx 2.6 \text{ minutes}

IV. RESULT

Under ideal conditions, the exhaust gases of a Cummins 6.7L marine engine at full load could boil 10 liters of seawater in about 2.6 minutes. However, actual heat transfer efficiency to seawater will be lower due to heat losses, so in practice, it could take longer (likely 5-10 minutes depending on heat exchanger design and efficiency

V. CONCLUSION

Utilizing waste heat from the engine exhaust for seawater desalination on small ships is a practical and energy-efficient solution. Based on calculations, the exhaust gases from a Cummins 6.7L marine engine can provide sufficient energy to boil 10 liters of seawater in about 5–10 minutes, depending on heat exchanger efficiency.

A. Key Takeaways

1) High Energy Availability – Around 30% of the engine's fuel energy is lost as exhaust heat, which can be harnessed for desalination.
2) Sustainable & Cost-Effective – No additional fuel consumption is required, reducing operational costs.

3) Compact & Feasible for Small Ships – A simple heat exchanger and condensation system can produce fresh water without significantly increasing engine load.
4) Production Capacity – With a properly designed system, a small ship running for several hours could produce tens to hundreds of liters of freshwater daily, enough for crew consumption and basic needs.
5) Efficiency Factors – The actual freshwater yield depends on:

Heat exchanger design
Heat transfer efficiency

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METHODOLOGY

Using waste heat for seawater desalination is an energy-efficient and sustainable approach that integrates thermal desalination processes with industrial or power plant waste heat. Here's a clear outline of the methodology for such a system:

1. Identify the Waste Heat Source

- Source types: Power plants (nuclear, fossil-fuel, solar thermal), industrial processes (steel, cement, refineries), or engine exhaust (marine engines, gas turbines).
- Parameters to assess:
  - Temperature of waste heat (low-grade: <100°C, medium-grade: 100–400°C)
  - Availability (continuous or intermittent)
  - Flow rate and heat capacity

2. Select a Suitable Desalination Technology

Waste heat is best utilized in thermal desalination processes, especially those compatible with low to medium temperature heat. Key technologies include:

3. Heat Integration Design

- Heat Exchanger Design:
  - Transfer waste heat to the seawater feed using plate or shell-and-tube heat exchangers.
  - Avoid scaling and corrosion from seawater by choosing proper materials (e.g., titanium, corrosion-resistant alloys).
- Energy Recovery:
  - Implement heat recovery stages to increase thermal efficiency (e.g., reuse latent heat from condensation).
- Thermal Storage (optional):
  - Use phase-change materials or hot water tanks to buffer heat fluctuations.

4. Water Treatment System Design

- Pre-treatment: Filtration, chlorination, and anti-scaling agents to protect the desalination units.
- Post-treatment: Remineralization, pH adjustment, and disinfection (UV or chlorination) to make water potable.

5. Integration and Control System
- Monitor temperature, flow, salinity, and pressure.
- Use automation systems (PLCs/SCADA) to adjust for variable waste heat inputs and optimize efficiency.

6. Environmental and Economic Analysis
- Brine disposal: Manage concentrated brine safely—dilution, deep-well injection, or evaporation ponds.
- Energy efficiency: Calculate GOR (Gained Output Ratio) or specific energy consumption (kWh/m^3).
- Economic feasibility: Analyze CapEx, OpEx, and ROI compared to conventional desalination

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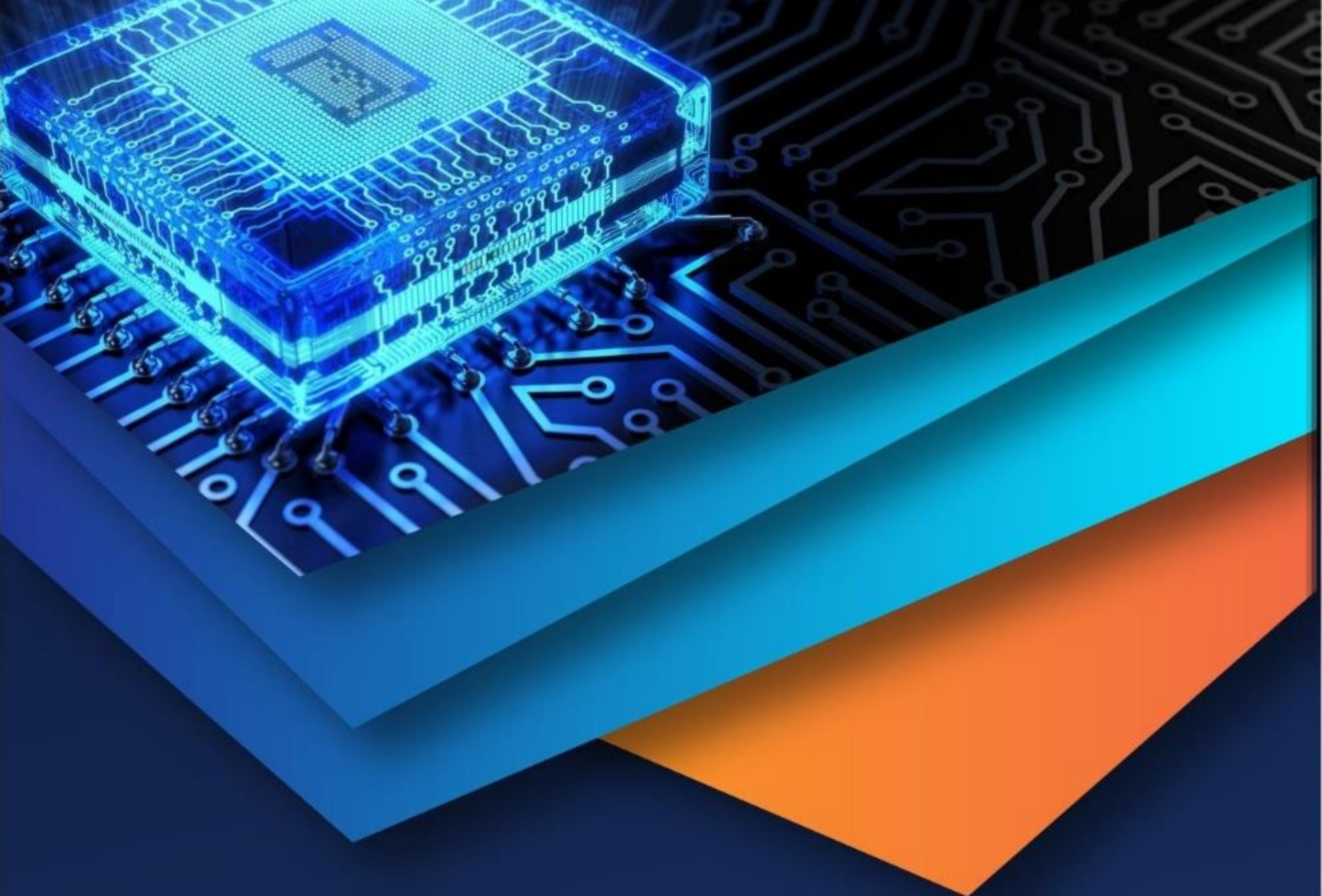

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